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ANIMALS OF THE CLOUD FOREST: ISOTOPIC VARIATION OF ARCHAEOLOGICAL  
FAUNAL REMAINS FROM KUELAP, PERU

by

SAMANTHA MARIE MICHELL  
B.S. Idaho State University, 2014

A thesis submitted in partial fulfillment of the requirements  
for the degree of Master of Arts  
in the Department of Anthropology  
in the College of Sciences  
at the University of Central Florida  
Orlando, Florida

Summer Term  
2018

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## ABSTRACT

Stable isotopic analyses of faunal remains are used as a proxy for reconstructing the ancient Chachapoya dietary environment of the northeastern highlands in Peru. Archaeologists have excavated animal remains from refuse piles at the monumental center of Kuelap (AD 900-1535). This archaeological site is located at 3000 meters above sea level (m.a.s.l.), where C<sub>3</sub> plants dominate the region. The study presented here is one of the few in the Central Andes that uses faunal remains to develop local isotopic baselines, reconstruct resource exploitation, and provide insight into dietary variation. Bone collagen stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotopes are used to investigate animal diets of nine local fauna (Camelidae, Cervidae, Caviidae, Chinchillidae, Cuniculidae, Leporidae, Felidae, Canidae, and Aves). Different taxonomic families were evaluated to explore the range of isotopic variation within and between these animals. Stable carbon and nitrogen isotopic values of both the wild and domesticated Kuelap faunal samples suggest a diet of both C<sub>3</sub> and C<sub>4</sub> plant foods. Significant dietary differences were identified between domesticated and wild animals (specifically camelid and cervid), suggesting ecological differences or strategic provisioning from possible domestic C<sub>4</sub> crops (maize) by humans. The domesticated camelids displayed a large isotopic variation similar to other highland archaeological studies in Peru, with an average  $\delta^{13}\text{C}$  value of  $-14.13\text{‰}$  and a standard deviation of 2.96. The cervids displayed lower variation than the camelids and had an average carbon value of  $-19.13\text{‰}$  with a standard deviation of 2.38. These are the first faunal isotopic data for the eastern montane region of Chachapoyas and serve as an essential baseline in the evaluation of human subsistence strategies and animal management strategies in the northern Peruvian highlands.

“Some people talk to animals. Not many listen though. That’s the problem.”  
Winnie-the-Pooh (A.A. Milne)

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## CHAPTER ONE: INTRODUCTION

The "animal connection," or human–interaction, has been hypothesized as an important diagnostic behavior of humans that links tool making, symbolic action, language, and domestication for adaptive purposes (deFrance, 2009; Shipman, 2010:519). Through hunting, animal domestication, and animal husbandry, humans dramatically altered their social lives and economic well-being. These dramatic lifestyle changes were the result of the establishment of new settlement strategies that took advantage of these relationships with animals. Subsistence strategies, along with the preparation, consumption, and disposal of food, reflect ecological resources used in dietary practices and human–animal interactions.

The Chachapoyas region of Peru provides an excellent area for investigating human–animal interaction due to its wide range of environments. This range encompasses wet and dry tropical forests, high grasslands, and mountainous scrub regions, giving the past Chachapoya people the potential to interact with a large variety of plants and animals (Brush, 1977; Church & von Hagen, 2008; Guengerich, 2015; Schjellerup, 1997). This study includes the use of isotopic analysis of remains from nine different faunal species as a proxy for reconstructing the ancient Chachapoya dietary landscape of the northeastern highlands in Peru. Excavations of structures at the monumental center of Kuelap (AD 900-1535) have taken place, yet there is little previous research focused on the faunal remains at this or other archaeological sites in the region (Toyne, 2015a; 2015b). Animal diets are modeled using stable isotope analysis to obtain  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from bone collagen of various local fauna to investigate the range of isotopic variation within and between animals with different expected dietary regimes. The faunal isotope ratios fall into distinctive isotopic niches, allowing for the creation of a model to estimate the dietary

resource landscape (or “food-scape”) of the local region. Differences in isotopic compositions, which reflect diet, between domesticated and wild animals (specifically camelid and cervid) will be investigated to explore human–animal interactions. These are the first isotopic data for the eastern montane region and serve as an essential baseline in the evaluation of isotopes, human subsistence strategies, and animal domestication.

### Purpose of Research

The purpose of this thesis is to explore the past lives of people and animals at Kuelap, Peru. This is accomplished through the bioarchaeological analysis of animal remains using stable isotope methods and analysis. The goal of this study is to produce more knowledge about life at Kuelap and to provide a more detailed perspective on the humans and animals that once thrived in the Chachapoyas region. Since ancient humans exploited and managed wild and domesticated animals, animal diet can be reconstructed, the local baseline isotopic variation of the region can be reconstructed, as well as an understanding of the resources that were available to humans and animals. Stable isotope values are a close representation of diet and provide data that can be used to make inferences regarding dietary regimes, feeding relationships, and food web structure (Laymen, Araugo, Boucek, Hammerschlag-Peyer, Harrison, Jud, Matich, Rosenblatt, Vaudo, Yeager, Post, & Bearhop, 2012). Along with understanding relationships among species, animals can be used as a proxy for human diet and environmental reconstruction.

### Bioarchaeological Approaches

Bioarchaeology is a subfield of biological anthropology that aims to explain human behavior within an evolutionary and biocultural framework through the study of ancient human, animal, and plant remains (Martin, Harrod, & Pérez, 2013). Bioarchaeologists utilize human

remains to reconstruct cultural and environmental variables by making hypotheses about behavior that can be verified or denied by quantitative and qualitative datasets generated from during analyses of the remains. Bioarchaeology often integrates a variety of scientific methods from other fields of science to obtain information about the human remains (such as age, sex, stature, disease, and trauma) as well as the context of the remains (such as population density, environment, ecology, food sources, and social structures) (Martin et al., 2013). Since humans are animals, this project aims to use bioarchaeological approaches to explain human and animal behaviors in the past through ancient faunal remains.

### Stable Isotope Analysis in Bioarchaeology

For this thesis, stable isotope analysis will be used to analyze faunal remains from Kuelap, Peru. Bioarchaeologists have used stable isotope studies to investigate past diets since the 1970's (Katzenberg, 2008). By using stable isotope analysis of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) from archaeological faunal remains, researchers can gain better resolution of the dietary and subsistence patterns that existed in the past.

Isotopic analysis of archaeological faunal material can provide perspectives on local ecological conditions such as trophic dynamics, habitat preferences, and biogeology while also providing a quantifiable baseline with which to interpret human dietary patterns (Szpak, Orchard, & Gröcke, 2009). Food web models involve analyzing the relative position of a species in an isotopic space, or niche, to create a graphic illustration of the relationships between carbon and nitrogen isotopic variables (Laymen et al., 2012). By understanding their place on two isotopic axes (carbon and nitrogen), the variation in isotope values within species, across species, and between wild and domesticated species can be investigated using the food web model. The

archaeological and modern samples selected were animals that were resources of the Chachapoya people according to ethnographic and archaeological sources. Isotopic insights on various foods (especially major resources) can lead to more accurate interpretations of effects of diet on health, demography, and migration in future stable isotope analyses (Katzenberg, 2008).

### Zooarchaeological Approaches

The use of faunal remains in bioarchaeological isotopic research has provided archaeologists with a unique framework with which to interpret isotopic values to better understand natural variation, dietary regimes, and human–animal interactions across a region. Brewer (1992:230) discussed a shift in zooarchaeological research, with culture history goals, such as “establishing the antiquity” of humans, being replaced by subsistence and environmental reconstruction goals, to investigate temporal and spatial relationships between species. Archaeologists began using theoretical approaches that involve zooarchaeological material in the 1940’s to evaluate human–animal interactions of past peoples and to better understand the broader patterns in environmental and social contexts in a region (Birch, 2013; Brewer, 1992; deFrance, 2009; Martin et al., 2013). Zooarchaeology has often used qualitative and quantitative osteological methods to investigate the cultural and socioeconomic roles of animals, but also the broader ecological and cultural structures operating in the past. Basic zooarchaeological approaches such as taxonomic identification, osteological element identification, and descriptions of the faunal sample in its archaeological context are necessary for supporting and interpreting any stable isotope data (Ben-David & Flaherty, 2012; Birch, 2013; Brewer, 1992; deFrance, 2009; O’Connor, 2000; Shipman, 2010).



Deposited refuse piles can provide information about the human–animal interactions by allowing researchers to investigate what species of plants and animals potentially were used for human consumption. By understanding the isotopic variation of domestic refuse, we can start to better understand and use stable isotope analysis to make inferences about diet and subsistence strategies. Management of domesticated animals can be influenced by social, economic, and political factors; all major anthropological topics investigated by archaeologists. Urban bone assemblages provide archaeologists with an opportunity to investigate the relationships between the community and its neighboring regions, other parts of the community, the surrounding ecosystem, and where/how occupants deposited refuse (Ben-David & Flaherty, 2012; Birch, 2013; Peterson & Fry, 1987; O'Connor, 2000; Shipman, 2010). Faunal material from Kuelap provide an opportunity to explore the diet of the animals of importance to the Chachapoya people from a single site community where very limited research (archaeological and isotopic) has been performed.

### The Sample

A total of 81 archaeological and modern animal bones, derived from domestic refuses at Kuelap, were analyzed to reconstruct the isotopic variation of the region (Table 1). Out of the 81 total samples, 74 are archaeological. Chronologically, these samples range from AD 900-1535. The chronology of the site is based on C<sup>14</sup> dating from previous excavations and allow for a general and preliminary examination of the animal samples (Narváez, 2013). There are seven modern samples included in the analysis for comparison.

*Table 1. Summary of nine taxonomic faunal families sampled from Kuelap.*

<b>Family</b>	<b>Common Name</b>	<b>Number of Specimens</b>
Camelidae	Llama or Alpaca	43 (including 1 modern)
Cervidae	Deer	10
Caviidae	Guinea Pig	19 (including 5 modern)
Chinchillidae	Viscacha	1
Cuniculidae	Paca (montane)	1
Leporidae	Rabbit	1
Felidae	Puma	1
Canidae	Dog or Fox	2
Aves (family unknown)	Bird (small)	3 (including 1 modern)
		Total = 81

Standard methods for sample preparation, collagen extraction, and analysis were conducted (Longin, 1971). Samples were sent to the University of Florida’s Light Stable Isotope Mass Spectrometry lab in the Department of Geological Sciences where stable isotope analysis was conducted for both carbon and nitrogen using the collagen residue. During analysis, standards were analyzed alongside the Kuelap samples to ensure the precision of the instrument. Duplicates of the samples were also analyzed to ensure the accuracy in the preparation methods discussed above.

A variety of analytical methods were executed on the dataset, including both descriptive and inferential analyses. The basic statistics (average, maximum, minimum, range, and standard deviation) of each taxonomic family was explored before statistical differences between major animal groups were evaluated (using normality and non-parametric tests).

## Research Questions and Hypotheses

The research on animal–human interactions and isotopic studies in the Chachapoyas region is currently limited yet needed to build baselines and understand the isotopic variation in the ancient Andes. This study aims to develop the isotopic variation of animals in the Chachapoyas and Central Andean region, as well as answer the following research questions and hypotheses:

- What is the isotopic variation of the faunal remains found at Kuelap?
  - What is the degree of carbon and nitrogen isotopic variation in bone collagen between and within species?
  - Do the isotopic values discriminate enough to create a food web?
- Do stable isotopes reveal evidence for human–animal interactions or types of animal management strategies that took place at Kuelap?
  - Are there significant differences between domesticated and non-domesticated species?
- How does the overall isotopic variation of the faunal remains at Kuelap compare to other zoo-isotopic studies in the Andes?

In order to explain these questions, I have generated hypotheses about the wild and domesticated animals and their isotopic values (Table 2).

*Table 2. Hypotheses table to evaluate the isotopic variation of wild and domesticated animals.*

<b>Null Hypothesis</b>	<b>Alternative Hypothesis</b>
<b>If the wild and domesticated animals are living in the same region and consuming the same food, then they should have a low range of isotopic variation.</b>	If the animals are living in the same regions, but fall into distinct ecological niches, then they will have a higher variation of isotopic results.
	If the animals' isotopic values fall into distinct ecological niche expectations, then a food web (dietary baseline) can be created for Kuelap.
<b>If the wild and domesticated animals consume the same plant material, they should have similar isotopic values.</b>	If animals are interacting with humans, then there could be a dietary influence that is reflected in the isotopic values.

## Chapter Summary

The topic of this thesis is an exploration of the isotopic variation of the Central Andean region by utilizing faunal remains at the Chachapoya site of Kuelap. This chapter includes an introduction of the area of study, the gaps in the research that support the need for this study, and the approaches and methods that will be used to reach the goals of the overall project. In Chapter Two, I will explore the archaeological and ethnohistoric background of Kuelap and the greater Chachapoyas region, as well as the human relationship with animals. In this chapter, I also review basic stable isotope theory and its role in building food web structures. The isotopic landscape of the region and past zoo-isotopic studies will also be addressed. In Chapter Three I discuss the isotopic methods utilized. Chapter Four presents the results of the isotopic analysis. In the fifth chapter, I discuss the isotopic data by the taxonomic family, as well as compare wild and domesticated large-bodied herbivores. I will also compare the Kuelap dataset with two other faunal isotope studies in Peru. In my conclusion and final chapter, I summarize a new perspective on the isotopic landscape of the region. Since this is the first zoo-isotopic study in

the region, I will conclude with a review of the isotopic variation and possible human–animal interactions discovered in this thesis as well as the study limitations and future directions.

## **CHAPTER TWO: LITERATURE REVIEW**

The first half of this chapter focuses on the central Andean region/environment, as well as the current archaeological knowledge and investigations of Chachapoya society. Background information is provided for wild and domesticated animals and their relationships with people in the past. The natural ecology and food regimes of these animals will be discussed and the site of Kuelap, the focus of this zooarchaeological analysis, will be introduced. In the second half of this chapter, a review of stable isotopes theory is presented, including how they can be used in archaeological studies to interpret diet and isotopic variation in the past. Food web structures can provide a model for these archaeological studies. Past Andean bioarchaeological studies will be reviewed to establish the current understanding of the isotopic variation and regional subsistence strategies of the people and animals.

### **The Andes**

#### **Geography and Geology**

The South American Andean mountain range runs along the western border of the continent (Figure 1). The Andes are described as generally lower in the northern region and higher in the central and southern regions (Malpass, 2016; Oncken, Chong, Franz, Giese, Götze, Ramos, Strecker, & Wigger, 2006). The central Andes is made up of alpine areas, plateaus, highland lakes, and U-shaped valleys with an average elevation of 4000 m.a.s.l. (Garziona, Hoke, Libarkin, Withers, MacFadden, Eiler, Ghosh, & Mulch, 2008).



*Figure 1. Map of South America with Andes mountain range shaded in yellow (modern border of Peru and stars indicating the location of modern day Lima and the archaeological site of Kuelap). (Source: Jaime Rogers, ESRI World Imagery Clarity/GADM).*

The extreme changes in geography create significant biodiversity and varying climates in the ecosystems of this region (Hoorn, Wesselingh, Steege, Bermudez, Mora, Sevink, Sanmartín, Sanchez-Meseguer, Anderson, Figueiredo, Jaramillo, Riff, Negri, Hooghiemstra, Lundberg, Stadler, Särkinen, & Antonell, 2010). The local geographies of the Andes are varied due to changes in climatological conditions caused by altitude, seasonality, and El Niño events (Clark, Malhi, New, Hilton, West, Gröck, Bryant, & Ascough, 2013). The climate of the highland Central Andes generally has two seasons, wet and dry. The wet season occurs from December to February, and the dry season from May to September (Malpass, 2016). Compared to the coastal Andes, the highlands have decreased temperatures at night and increased annual precipitation on the oriental (eastern) slope.

### Ecological Zones

There are many types of environmental zones in the Andes. Three major ecological zones on the eastern slopes of the Andean Eastern Cordillera in northern Peru include the grassland *puna* located at 4000 m.a.s.l., the high-altitude grass and mixed forest of the *jalca* is found between 3000-4000 m.a.s.l. the temperate tropical montane cloud forest *kichwa* at a lower altitude between 3000-2000 m.a.s.l., and the tropical pre-montane forested *yunga* below 1800 m.a.s.l. (Brush, 1977; Pulgar Vidal, 1972; Schjellerup, 2005; Young, 1993; 1999; 2009). The Andean people utilized these different environments by situating their villages in locations where they could take advantage of the distinct resources predominating in each of these environmental zones. By adjusting to the different ecological zones of the Andes, the ancient people of this environment created cultural systems that took advantage of the plants and animals that were well adapted to particular altitudes. For example, Brush (1977) found that the Andean people



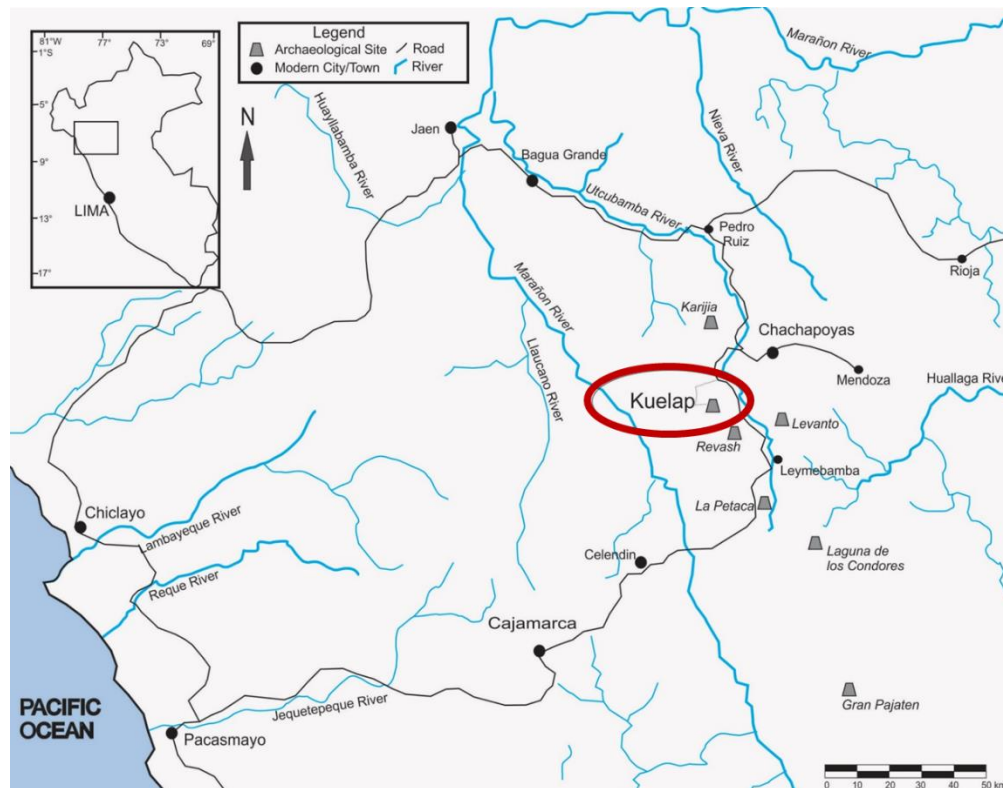
near Uchumarca in the eastern montane would grow potatoes and tubers in fields in the lower portion of the *puna* (>3000 m.a.s.l.), while also using this zone to pasture their herds of Camelids (llamas and alpacas). Meanwhile, fruits and other low-altitude plants would be planted and harvested in the *yunga* zone.

## Chachapoya Society

### Location and Environment

The Chachapoya site of interest for this thesis is located in a cloud forest juncture that forms at the Northeastern Peruvian Andes and upper Amazon basin (Figure 2). Archaeologists have defined the Chachapoyas region as a 1500 km<sup>2</sup> area between the Marañón and Huayallaga rivers in the eastern slopes of the Andean Cordillera Oriental of Peru (Church & von Hagen, 2008; Toyne, 2015b:31). Deep U-shaped valleys, grasslands, and steep slopes rising to 4000 m.a.s.l. dominate this region in the Central Andes (Brush, 1977; Church & von Hagen, 2008; Garzzone et al., 2008). Guengerich (2015:367) discusses how, due to its location on the eastern Andean Cordillera, the Chachapoyas region is caught between two bodies of scholarship based on the geographical intermediary position; the Andes and the Amazon.

This location in northern Peru receives substantial precipitation from the Amazonian plains climatological systems (Johnson, 1976). This climate and the variation in altitude in the Central Andes create various micro-climates in the Chachapoyas region, ranging from dry tropical forests, high grasslands, and mountainous humid forests (Schjellerup, 1997). As Brush (1977:17) discusses, due to the steep environmental gradient, local communities in a mountainous region like the Central Andes would be presented with “a wide range of micro-climates and vegetation belts”.



*Figure 2. Map showing the Chachapoyas region in Peru with major archaeological sites including Kuelap (circled). Adapted from Toyne, 2015a: Figure 1.*

### Chachapoya Culture

There is archaeological evidence dating back 10,000 years ago indicating early occupation of the Chachapoyas region. Most investigated archaeological sites in this area, however, date to later periods (Church & von Hagen, 2008). Large structures and communities with similar architectural and iconographic traits have been excavated and dated back to the Middle Horizon period (AD 800), supporting a long-term occupation in the northern Peruvian Andes had occurred at these sites and region until the 16<sup>th</sup>-century Spanish colonization (Church & von Hagen 2008; Guengerich, 2014).

At its peak during the Late Intermediate Period (AD 900 to 1470), the Chachapoya culture was a pre-Columbian society likely made up of over 300,000 individuals (Church, 1994; 2006; Church & von Hagen, 2008; Muscutt, 1998; Schjellerup, 1997). The Chachapoya were thought to be socially organized in kinship-based groups that were based in local communities but would unite as allies (Church & von Hagen, 2008; Muscutt 1998). There is debate over whether the past people identified with a centralized power, saw themselves as single people, or were organized in nucleated hierarchical population clusters (Church & von Hagen, 2008; Narváez, 1987; Schjellerup, 1997).

Before the Spanish arrived, the Chachapoya saw an invasion and influx of Inka around AD 1470 (during the Late Horizon), who came to the region due to its strategic location and resources in the intermontane north-south corridor that connects the Andes and Amazon (Church, 1994; 2006; Church & von Hagen, 2008; Muscutt, 1998; Schjellerup, 1997; Toyne, Church, Coronado, & Morales 2017). The Chachapoya people would have been situated where Amazonian resources such as tropical medicines, gold, and bird feathers would have been utilized, as well as Andean resources such as cultivated plants, wild, and domesticated animals (Toyne et al., 2017). This strategic location in the Upper Marañon River valley would have provided the Chachapoya people with an opportunity to act as a cultural crossroad for trade, movement, and interaction networks across the Central Andes, Northern Andes, and Western Amazonia (Church & von Hagen, 2008:910-911; Schjellerup, 1997).

### Subsistence Strategies

Living above 2500 meters, the people of the Chachapoya culture had subsistence strategies that were heavily dependent on cultivated plants that do well in the *yunga*, *kichwa*, and

*quechua* zones (Guengerich, 2015; Schjellerup, 2005). The Chachapoya people were largely dependent on high elevations plants (including tropical grasses, quinoa, potatoes, tubers, squashes, and fruits) as well as low altitude crops (such as maize, beans, and squashes) (Church, 2006; Muscutt, 1998). Due to the variety of ecological zones (Figure 3), subsistence inventories would include fruit and cultigens that do well in tropical areas, cereals that do well in temperate climates, and tubers that do well in cool climates (Brush, 1977). Archaeological evidence for these plants has been found at various Chachapoya sites (Bonavia, 1968; Church, 1994; Guengerich, 2014; Gonzales & Toyne 2014; Koschmieder, 2012; Narváez, 2013; Vasquez, Rosales, & Kent 1997). Koschmieder (2012) and Guengerich (2014) both discuss the phytolith and macrobotanical analyses of archaeological materials that took place in the Chachapoyas region and provides paleobotanical evidence of maize (*Zae mays*) consumption by the ancient Chachapoya people. Along with domestic crops, the Chachapoya culture relied on hunting wild animals (such as rodents, deer, birds, and fish) and domesticated camelids, guinea pigs, and possibly dogs in their subsistence strategies (Church & von Hagen, 2008).

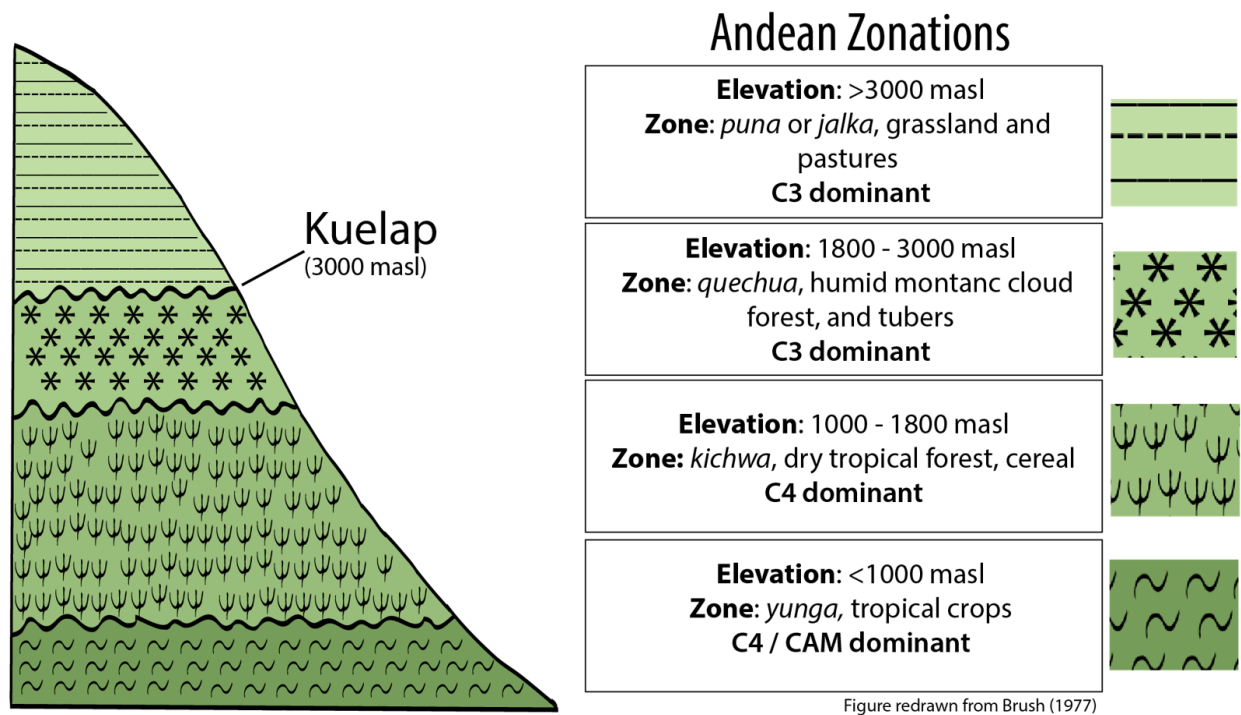


Figure 3. Illustration of the ecological zones in the Central Andean region with Kuelap's relative location marked by a red star. (Courtesy of Jaime Rogers: redrawn figure after Brush 1977: Map 2).

### Animals in the Chachapoyas Region

The Chachapoya culture utilized many animals as food, economic, and ritual resources from the local environment of the Andean and Amazonian regions (Church & von Hagen, 2008; Guengerich, 2015). Animal remains that have been recovered in Chachapoya archaeological record include camelids, deer, guinea pigs, rodents (*viscacha*, *paca*, and rabbit), mountain and jungle cats, dogs, various birds, caiman, tapir, bear, snakes, and freshwater fish (Guengerich, 2014; Koschmieder, 2012; Narváez, 2013; Vasquez et al., 1997). With the Chachapoya culture utilizing both hunting and domestication in their subsistence strategies (as discussed above), these food sources then ultimately end up in kitchen middens, urban trash heaps, or as funerary

offerings. Little direct zooarchaeological research has been conducted on animals in the Chachapoyas region to date. That said, this thesis focuses on the zooarchaeological remains excavated from Kuelap, located in the center of the Chachapoyas region. The rest of this chapter will identify and briefly discuss the taxonomic families that make up the sample material of this project. For this thesis, archaeological remains were identified only to the family name, since many of the samples were collected from fragmented, partial, or commingled remains and species could not be determined. The animal habitat, ecology, food habits, social behaviors, predators, and human acquisition patterns will be reviewed to better comprehend the isotopic variation produced by the faunal collagen samples.

#### Camelidae (Llama or alpaca)

In the Camelidae family, two genera are native to South America; the *Lama* and the *Vicugna*. Each of these ungulates has wild and domesticated variants. From the *Lama* genus, there is *Lama guanicoe* (the wild guanaco) and *Lama glama* (the domesticated llama in Figure 4A). From the *Vicugna* genus, there is *Vicugna* (the wild vicuña) and *Vicugna pacos* (the domesticated alpaca in Figure 4B). Archaeologically, it is often difficult to specify which species is represented in the sample due to their similar morphology. Llamas are the largest of the four species described above and are more facially prognathic than the alpaca. If the cranium is not available for sample identification, the size of the postcranial remains can help distinguish between llama and alpaca bones at archaeological sites but require complete skeletal elements and have large range of overlap.



A)



B)

*Figure 4. A) Photograph of modern llamas (Lama glama) living at Kuelap. B) Photograph of modern Chachapoya alpaca (Vicugna pacos).*

Camelids have unique pedal physiology that allows them to traverse easily across rocks and slopes, making them well adapted to the steep terrain of the highlands of the Andes. These ungulates are the largest native mammal herbivores in the Andes (Bonavia, 2008:11). Camelids are not ruminants (although similar) and have a longer colon than other animals, which allows these animals to have greater digestive efficiency and survive with much less water than other mammals, making them “arid land specialists” (Bonavia, 2008:19; Moore, 2016).

Camelids graze and browse on a large variety of forage, such as grasses and legumes (Bonavia, 2008; Franklin, 2011). Wild species of camelids prefer to eat wild foods like grasses, rushes, and sedges (Cajal, 1989). On the other hand, domesticated Camelids are known to be generalists, and can eat many types of forage (Grant, 2017; Gundermann, 1984; Yacobaccio, 2001). Domesticated camelids are often foddered or have their mobility restricted by humans, which in turn influences their diet. Bonavia (2008) discusses how the domesticated llama are better adapted to diets of low-quality fodder, such as grass and grains commonly found in the arid regions of the Andes.

Camelids are social animals that prefer to live in large herds but are often quite territorial. They also are prey to an ambush predator, the puma, which is the only native predator in the Andes that can kill adult camelids (Perrig, Donadio, Middleton, & Pauli, 2017; Walker & Novaro, 2009). These factors support the idea that camelids in the Chachapoya region would have preferred to live in large open fields or pastures (often in the highland *puna* ecological zone) where there is room to eat in peace and keep an eye on their surroundings.

As discussed by Bonavia (2008), the camelid family was the source of the subsistence economy for hunter-gatherers in early hunting societies and then later for more complex agricultural societies. Camelid utilization began in the Central Andes around 5500 BC with the



first domestic forms appearing between 2500 and 1750 BC (Bonavia, 2008; Wheeler, Pires-Ferreira, & Kaulicke, 1976).

Domestication was an intimate human–animal interaction, with camelid pastoralism being central to the expansive complex societies of South America and the Andean prehistoric economy (Moore, 2016; Wheeler, 1984). For this thesis, llamas and alpacas will be the focus due to their anthropogenic origins and the large sample size available. Llamas were raised as beasts of burden, while alpaca more typically for its wool (Bonavia 2008:22). Previous research suggests the Andean people domesticated camelids not only for their food and wool, but so they could broaden their network of Andean interaction through caravans and trade (Church, 2006:9; Church & von Hagen, 2008; Gil, Ugan, Otaola, Neme, Giardina, & Menéndez, 2016; Goepfert, 2010; 2012; Mengoni, 2008; Szpak, Millaire, White, & Longstaffe, 2014; Yacobaccio & Vilá, 2013). Material culture, such as ceramics and clothing, excavated from archaeological sites in the Andes depict camelids, suggesting the species played an important ideological and economic role across the region including highlands and the coast (Bonavia, 1999; Guengerich, 2015:365).

#### Cervidae (Deer)

Research suggests that there are many deer species that range in the Chachapoyas region; *Hippocamelus antisensis* (taruca, north Andean deer), *Mazama nemorivaga* (Amazonian brown brocket), *Mazama rufina* (Ecuador red brocket), and the *Odocoileus virginianus* (white-tailed deer) (Brokx, 1984; Lizcano & Alvarez, 2016; Roe & Rees, 1976; Rossi & Duarte, 2016). The white-tailed deer is the most only deer species identified at Kuelap and included in this thesis sample material. These species have broad habitats ranging in elevations 2500 to 4500 m.a.s.l. on the eastern montane of the Andes in Peru.

Cervidae, or deer, are undomesticated medium-sized herbivores that digest plants through rumination (Brokx, 1984; Gallina & Arevalo, 2016; Smith, 1991). These grazing and browsing mammals feed on legumes, leaves, twigs, grasses, fungi, flowers, and the occasional fruits (Emmons, 1990; Emmons & Feer, 1997). Deer are opportunistic foragers and can be successful in a variety of different ecological systems (Brokx, 1984).

Cervids live in matriarchal herds with males interacting in overlapping territories. Deer use many different types of vocalization to communicate with one another (Atkeson, Marchinton, & Miller, 1988). These communications include warning one another from predators, looking after their young, asserting dominance, or mating practices. Deer are prey to many predators and are hunted by felids, canids, and humans for food. However, deer are very agile and can run quickly, change directions, and jump high. While not much is known about the preferred ecological habitat of the cervids in the Chachapoyas region, the dense cloud forest would provide an ecological zone with plenty of resources for the deer to consume as well as coverage from predators including human hunters.

#### Caviidae (Guinea pig)

Caviidae are a family of rodents native to South America. There are three species of guinea pigs found in the Chachapoyas region; *Cavia tschudii* (the wild montane guinea pig), *Cavia aperea* (the Brazilian guinea pig – lowland and uncommon), and *Cavia porcellus* (domestic guinea pig). *C. porcellus* is the smaller and domesticated descendant of the montane guinea pig and is now only found in captivity (Weir, 1974). These animals are widely distributed across South America and can tolerate a vast range of temperatures and elevations. Wild guinea

pigs are found in habitats ranging from high-altitude meadows to wet tropical floodplains but prefer to live near water by savanna or grasslands (Morales, 1995).

Caviids (guinea pigs) are known to be strict herbivores. In the wild, caviids live in small groups and graze on plant material like leaves, roots, tubers, fruits, and flowers (Asher, Oliviera, & Sachser, 2004; Wagner & Manning, 1976). Raised within households and dependent on humans for food, domesticated guinea pigs would generally subsist on alfalfa, grasses, and occasionally kitchen vegetable scraps (National Research Council, 1991; Morales, 1995; Weir, 1974).

Caviids are very social animals that live in close contact in small groups or pairs. It has been found that guinea pigs prefer to live in low population densities, with no more than ten individuals in a group (often composed of all female and offspring with one male) (Sacher, 1998; Terril & Clemons, 1998:7) These groups use many kinds of noises and vocalizations to communicate about danger, injury, food, or their location (Terril & Clemons, 1998).

While natural predation is not as large of an issue for domesticated caviids, wild caviids are prey to many animals such as felids, canids, and large birds (Cassini, 1991; Cassini & Galantem, 1992; Morales, 1995). Wild caviids prefer to seek shelter in burrows or crevices where it is harder for predators to see them. Humans are also a predator of wild guinea pigs; hunting, capturing and consuming caviids as a supplemental food source (Muscutt, 1998).

The guinea pig has long been a vital food source to the people of the Andes as early as 5000 BC and is also widely involved in social, economic, religious, and medical practices in different parts of the Andes (Morales, 1995). These animals were originally domesticated for their meat and supplemented human diets with a rapidly reproducing high protein and low fat (Muscutt, 1998).

### Chinchillidae (Viscacha)

From the Chinchillidae family, the rodent species *Lagidium pervanum* (also known as the northern viscacha) is native to the Peruvian highlands. Another possible species of viscacha in the area could be the *Lagidium ahuacaenses* (nearly extinct). Currently, there is only one known population of *L. ahuacaenses*, which was found in southern Ecuador (Ledesma, Werner, Spotorno, & Albuja, 2009).

The northern viscacha is a medium-sized rodent and herbivore that eats a variety of plant material like grasses, roots, lichens, moss, and seeds (Pearson, 1948; Werner, Ledesma, & Hidalgo, 2006). Viscachas prefer altitudes between 3000 to 5000 m.a.s.l. in the neotropic region. The viscacha habitat is dry and rocky terrain and they choose to find shelter in rock crevices near water. Chinchillidae live in big colonies of small family units (2 to 5 individuals in a burrow) and are rarely territorial or aggressive (Pearson, 1948). These animals do not venture far from their rock shelters and can jump high and hide quickly from danger. Viscachas' main predator is the Felidae and Canidae families, which will be discussed (Pearson, 1948: 349). Humans are also a predator of these animals; archaeological contexts indicate that these creatures were hunted and eaten as a supplement to human dietary regimes. The fur of viscacha was also a commodity obtained through hunting and would be used with other animal fiber to create yarn (Pearson, 1948: 372).

### Cuniculidae (Mountain Paca)

In the rodent family Cuniculidae, *Cuniculus taczanowskii* (the mountain paca) is a large burrow-dwelling rodent that inhabits the high Andean montane forest regions between 2000 and 3500 m.a.s.l. (Eisenberg & Redford, 2000; Rios-Uzeda, Wallace, & Vargas, 2004). Mountain

pacas are nocturnal animals that spend the day in burrows that can go underground up to several meters deep (Rios-Uzeda et al., 2004). The mountain paca is an opportunistic frugivore that prefers to eat fruits, nuts, and seeds but will also eat grains, leaves and insects (Emmons & Feer, 1997).

Mountain pacas typically live alone, but in dens nearby their monogamous mates. Due to their larger body size, mountain pacas stay near their dens to prevent making too much noise and being noticed by predators (primarily from the Felidae and Canidae families). While the archaeological record does represent some Cuniculidae species present at domestic sites, they were not likely a primary dietary source for humans (Toyne, 2018 personal communication).

#### Leporidae (Rabbit)

In northeastern Peru, *Sylvilagus brasiliensis* (the Brazilian/forest cottontail) is the dominate Leporidae species. Also known as the tapeti, these medium-sized rabbits occupy a large range of elevations but generally live in moist forested areas (Mares, Ojeda, Barqueq, 1989). These animals do not burrow but will dig into the surface of the ground to create their grass nests.

Leporidae are exclusively herbivorous. Tapeti, or rabbits, are foragers that are especially fond of young leaves that are tender and full of protein, shrubs, or grasses (Emmons & Feer, 1997). There is little research on the social behavior of the *S. brasiliensis*, but other Leporidae species have been seen to be polygynous (Eisenberg & Redford, 2000; Nowak, 1999). Cottontail rabbits are nocturnal solitary animals that are fast, agile, and good at hiding from predators (Emmons & Feer, 1997). Predators include felids, canids, and humans (Calouro, 2000).

Rabbits are an important source of protein for many animals in the region. Humans hunt this game species to supplement their diet and to collect their pelts. Leporidae has also been known to go near human settlements because they are attracted to salt and urine (Eisenberg & Redford, 2000).

### Felidae (Puma)

Out of all the animals in the Central Andes, the most highly specialized for killing and meat-eating come from the felid family (Emmons, 1990). There are at least seven cat species that range between the neotropical rainforest and the Andean mountains in northern Peru, although the most well known in the region is the puma (Emmons & Feer, 1997). The species of Felidae in the region around Chachapoyas can include *Leopardus colocola* (pampas cat), *Leopardus pardalis* (ocelot), *Leopardus wiedii* (margay), *Leopardus tigrinus* (oncilla, northern tiger cat), *Leopardus jacobitus* (Andean mountain cat), *Panthera onca* (Jaguar), and the large-bodied *Puma concolor* (puma, cougar, mountain lion) (Nielsen, Thompson, Kelly, & Lopez-Gonzalez, 2015).

Felids are generalists who partake in a purely carnivorous diet and will eat any animal they can catch (but they prefer to eat small to mid-sized mammals) (Emmons, 1990; Iriarte, Franklin, Johnson, & Redford, 1990). These cats are territorial and act as a recluse. They are ambush predators, meaning they use the element of surprise as a method for capturing prey. Because of this, felids prefer habitats of dense vegetation and rocky terrain. Their prey most often includes cervids, camelids, canids, leporids, and other large rodents (Busch, 2000). While mostly solitary animals, Felids often share kills and organize into small communities (Emmons,

1990). Pumas are the apex predators of the central Andean region; however, they are sometimes killed by humans for their pelts or for sport.

#### Canidae (Dog or fox)

Another carnivore (but also scavenger) family is the Canidae, which include dogs and foxes. The canids found in the Chachapoyas region are likely one of three species: *Lycalopex culpaeus* (the culpeo or Andean fox), *Speothos venaticus* (the bush or forest dog), and *Atelocynus microtis* (the short-eared zorro/fox). All these wild species prefer distance from humans.

Canids can occupy many types of environments; including woodlands, grasslands, forests, and open areas (Emmons & Feer, 1997). The dogs typically display social organization, cooperation, and strategy by living in packs, while the foxes are typically solitary animals (Souza Pinto, & Dalponte, 2009; Larivière & Pasitschniak-Arts, 1996:6). Canids can travel long distances and run economically to tire and take down their prey. Their diets consist of vertebrates and invertebrates such as frogs, paca, rodents, and reptiles as their prey, but they will consume fruit if their prey is scarce (Emmons, 1990). Dogs and foxes in the Chachapoya region may have been used to supplement the diet through opportunistic hunting, but they are uncommon in the archaeological record and suggest that they were not part of the domestic household in any regular way.

#### Aves (Small birds)

Aves, or birds, were also important animals in the Chachapoyas region, either by supplementing human diet or by providing resources such as feathers. Terrestrial domesticated ducks have been identified in the archaeological record from Kuelap but were not specifically sampled in this thesis (Toyne, 2018 personal communication).

The animals described above provide a basic understanding of the local habitat, eating patterns, and human–animal interactions expected to be held by fauna families in the Chachapoyas region of Peru. To reconstruct the dietary isotopic variation present in the past, the samples must be placed in the context of the basic biology, behavior, and environment influencing the isotopic results.

### The Archaeological Complex of Kuelap

#### Location

Kuelap is a major archaeological site found in the cloud forest highlands of the central Chachapoyas region that dates to approximately AD 600-1535 (Narváez, 1987; 1996; 2009; 2013). The Chachapoya culture occupied the region from AD 600 until AD 1470 when the Inka invaded the region until the Spanish conquest in AD 1535. Kuelap is located at a latitude of -6°25'2.99" South and longitude of -77°55'14.39" West at 3000 m.a.s.l. This 500 by 150 meter domestic and ritual complex was constructed on the top of a 75,000-square meter ridge, following the common hilltop settlement patterns of other Chachapoya sites as seen in Figure 5 (Church, 2006; Guengerich, 2015; Muscutt, 1998; Schjellerup, 2005). Narváez (1987; 1996; 2013) describes Kuelap as a significant Chachapoya occupational site constructed with extensive agricultural terraces on the western flank of a long narrow ridge.

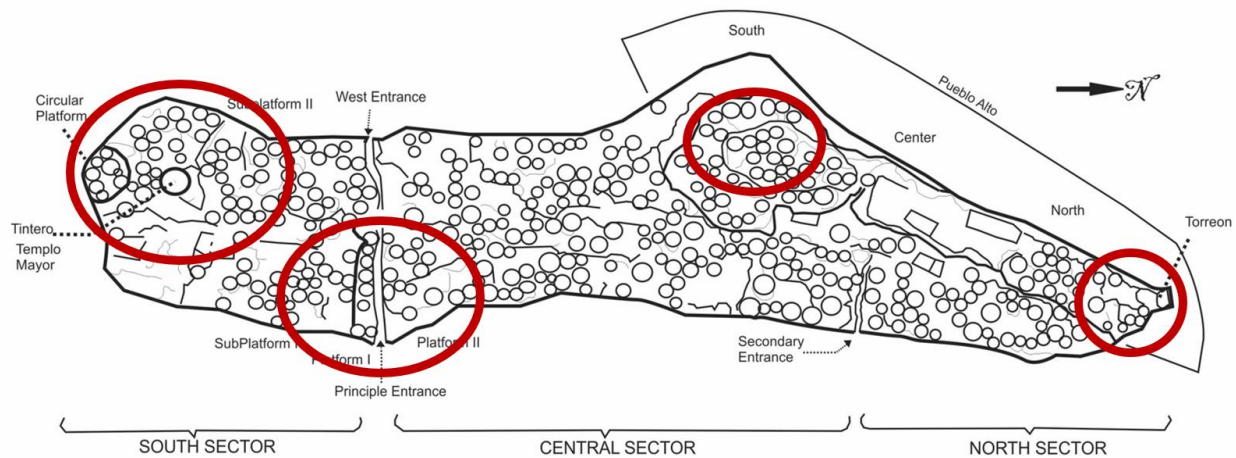




*Figure 5. Aerial view and photographs of the archaeological site of Kuelap (star), showing the hilltop settlement, location in modern day Peru, architectural structures, and entrance (with modern llama). (Source: Jaime Rogers, Samantha Michell, ESRI World Imagery Clarity/GADM)*

## Site Organization

A small selection of archaeological sites, including Kuelap, can be seen in Figure 2. The nature of Kuelap, or its function and role in the past Chachapoya culture, remains somewhat a mystery even though it is among the most massive stone constructions in South America from pre-Columbian times (Guengerich, 2015:365). Kuelap is thought to be of political and religious importance due to the massive perimeter walls, residential structures, and burials that make it unique compared to other Chachapoya settlements (Narváez, 1987; 1996). See Figure 6 for a plan map of the archaeological site's layout. In Figure 5, a plan map of the excavated site can be viewed to understand the general layout, size, and structures present at Kuelap. The site is contained by 10 to 20-meter-high perimeter retaining wall which creates a platform. This architecture of the platform is made up of large cut limestone bricks joined with mud mortar that encases a rubble fill (Church & von Hagen, 2008:915). There are only three entryways to the site that are narrow and long-walled corridors. On the main platform, archaeologists have identified two different sectors (upper and lower 'pueblos') with over 400 circular residential structures and other buildings.



*Figure 6. Drawing of the archaeological site of Kuelap, showing the general layout of structures, divisions, and entrances. Permission by Toyne, 2015b: Figure 2 (Appendix II).*

There are two building patterns at Kuelap, radial and linear, which suggests social interactions and planning around household groups (Guengerich, 2015; Narváez, 2013). The Pueblo Bajo (or lower sector) contains a unique structure known as the Tintero or Templo Mayor, which is unlike any other structure in the Chachapoyas region (Guengerich, 2015:367; Narváez, 2013). The Tintero contained many exotic materials, leading Narvaez to believe it to be a ritually significant structure. Alternatively, the Pueblo Alto (or upper sector) is separated from the rest of the site by extremely high retaining walls and contains several rectangular structures thought to be constructed later than the rest of the site and are Inka in origin. While its size and structures suggest that Kuelap was an important place in the region, there are limited perspectives from other sites in the area about the Kuelap's role in the Andes. This partial knowledge restricts our understanding of the power structures and social organization in the Chachapoyas region.

## Diet and Animal Remains at Kuelap

There are many archaeological remains found at Kuelap that indicate diet and human-animal interactions in the past. Microscopic starch analysis at Kuelap displays evidence for yucca, beans, maize, and tubers as major food sources for the local residents (Narváez, 2013). Along with these plants, domestic refuse at Kuelap includes many species of animal remains; larger ungulates (camelids and cervids) and small rodents (guinea pigs, viscacha, paca, and rabbit) (Narváez, 2013; Toyne et al., 2017). Platform runs, or stone corrals, excavated from the floors of domestic houses at Kuelap indicate that the people at Kuelap raised guinea pigs as a source of animal protein as well as an economic commodity like many other Andean residents (Morales, 1995; Muscutt, 1998; Narváez, 1996; 2013). This species was living in close contact with humans on a daily basis and makes a valuable proxy along with the remains of other animals towards reconstructing past environments using stable isotope analysis.

## Stable Isotope Theory and Applications

### Basic Theory and Behavior

Isotopes can be used in multiple fields of science, such as paleoclimatology, archaeology, anthropology, forensics, petrology, hydrology, oceanography, planetary science, and ecology (Ambrose, 1993; Fry, 2000; Griffiths, 1998; Sharp, 2017:6). Isotopes provide some of the earliest records of life on earth and allow researchers to investigate how elements cycle throughout the environment. These atomic variants of chemicals, or isotopes, have the same atomic number as their element and are located in the same place on the periodic table. The atomic mass of an isotope of a given element, however, is different due to varying number of

neutrons. Stable isotopes are useful to researchers because they stay in relatively fixed abundances over a large temporal range due to biological, biochemical, chemical, and physical processes (Meier-Augenstein, 2010:5). Studying stable isotope compositions in biological and geological material allow researchers interested in ecosystems to better understand how isotope ratios vary and change.

### Diet Reconstruction

Stable isotope analysis provides archaeologists with an opportunity to reconstruct the diet of past populations of both human and animal species (Ambrose, 1987; DeNiro, 1987; van der Merwe, 1982). Due to variation in the ratios of carbon and nitrogen stable isotopes within ecosystems, the ratios can be analyzed to measure the contribution of different resources to the consumers' diet (DeNiro & Epstein, 1978; 1981). Reconstructing diet is based on the foundational principle that 'you are what you eat' and those food molecules are incorporated into the consumer's body tissue after consumption (Ambrose & Norr, 1993). The ratio between heavier and lighter stable isotopes of  $^{13}\text{C}$ Carbon and  $^{12}\text{C}$ Carbon, and  $^{15}\text{N}$ Nitrogen and  $^{14}\text{N}$ Nitrogen are preserved in organic tissue (such as bone) during tissue construction and can be analyzed to determine food consumption patterns. These analyses are possible because the carbon and nitrogen isotopes compositions of consumer tissues can act as 'proxies' for the types of the food being consumed after trophic level enrichments are considered (Ambrose, 1993; Ambrose & Norr, 1993; Ben-David & Flaherty, 2012; Katzenberg, 2008; Szpak, White, Longstaffe, Millaire, & Vásquez, 2013).

## Animal Tissues

Isotopic studies can utilize any tissue or metabolic product that contains carbon and nitrogen (Ambrose, 1990; 1993). The consumer tissues most commonly analyzed in archaeological isotope studies are bone and teeth. Bone provides a window for many researchers to investigate isotopic compositions and their role in the environment and diet. Bone collagen allows researchers to study a relatively slow remodeling tissue that reflects an average overall time of formation (Ambrose, 1990; 1993; Katzenberg, 2008). Teeth are also used in archaeological studies due to their resistance against decomposition and diagenesis and can preserve both dentin and enamel from a shorter period of formation during early life (Ambrose, 1993; Katzenberg, 2008). Dentin contains an organic component, while enamel is almost completely inorganic in nature. Bone collagen will be utilized in this thesis as sample material.

Collagen is the most abundant organic fraction of skeletal tissue, making up 20-22% of fresh bone by weight (Ambrose, 1993). In archaeological studies, collagen can be preserved for thousands of years and is resistant to diagenetic alterations, so the *in vivo* isotopic composition is thought to be retained (Ambrose, 1991). Another material commonly used in isotopic diet reconstruction comes from the inorganic fraction of bone, or hydroxyapatite, which make up ~70% of bone and ~98% of enamel (Ambrose, 1993). Carbonate ( $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$ ) makes up 2-5% of the bone apatite by weight and comes in the form of structural or absorbed carbonate.

## Carbon

Carbon is metabolized (enters the diet and then skeletal tissue) through the consumption and digestion of plants. Plant tissues obtain carbon through the  $\text{C}_3$ ,  $\text{C}_4$ , or CAM photosynthetic pathways, which causes the fundamental variation in carbon isotope ratios (DeNiro & Epstein,

1978). Plants that utilize the Calvin cycle for photosynthesis, or C<sub>3</sub> plants, produce an average  $\delta^{13}\text{C}$  value of  $-26\text{‰}$ , with a range from  $-19$  to  $-34\text{‰}$ , and have isotopically depleted carbon isotope values due to fractionation (Ambrose, 1993; DeNiro & Hastorf, 1985). C<sub>4</sub> plants use the Hatch-Slack photosynthesis pathway and have an average  $\delta^{13}\text{C}$  value of  $-13\text{‰}$ , with a range from  $-8$  to  $-15\text{‰}$  (DeNiro & Hastorf, 1985). C<sub>4</sub> plants are enriched in carbon-13 because they are more efficient at trapping CO<sub>2</sub>. The third photosynthetic pathway is the Crassulacean acid metabolism (CAM). CAM plants have  $\delta^{13}\text{C}$  values that vary due to environmental conditions, with hot, arid environments exhibiting C<sub>4</sub>-like values and cooler, wetter environments exhibiting C<sub>3</sub>-like values (Ambrose, 1993). This allows researchers to use CAM plants as a type of paleothermometer when reconstructing past environments (Ambrose, 1993; DeNiro & Hastorf, 1985).

Carbon isotope values of collagen, or other animal proteins, reflect the protein component of the diet since amino acids are directly routed from the diet into the tissue (Ambrose, 1993; DeNiro & Epstein, 1978). Fractionation, however, does occur as the amino acids are incorporated into the skeletal tissue, such that the values produced during analysis are not directly reflective of the consumed material. For comparisons of isotopic compositions derived from different sources (plant diet consumed vs collagen tissue), it is important to account for the changes in tissue—diet fractionation ( $\Delta^{13}\text{C}_{\text{collagen-diet}}$ ). Due to the transition from plant material to organic bone, an enrichment of approximately  $+5\text{‰}$  must be considered when looking at the faunal isotopic values to be able to determine the type and relative proportion of dietary protein these animals had in human diets (Ambrose & Norr, 1993; Deniro & Epstein, 1978; van der Merwe & Vogel, 1978). In secondary and mixed consumers, such as carnivores and omnivores, the collagen will reflect the signature of animal proteins in their diet, but ultimately the signature



will be derived from the plants eaten by the primary consumer and no additional fractionation factor is applied (Ambrose, 1993; Finucane, Agurto, & Isbell, 2006).

## Nitrogen

Nitrogen enters the diet through the consumption of plants, which obtain nitrogen from soils or bacteria (Ambrose, 1991; Meier-Augenstein, 2010). Nitrogen isotope ratios in collagen ( $\delta^{15}\text{N}$ ) provide insight in reconstructing diet by discriminating between plant and animal protein sources, terrestrial and marine protein sources, and evaluating trophic levels (Ambrose, 1991; DeNiro & Epstein, 1981; Finucane et al., 2006; Schoeninger, DeNiro, & Tauber, 1983). Terrestrial plants typically have a  $\delta^{15}\text{N}$  range between  $-6$  and  $+6$  ‰ (Meier-Augenstein, 2010:27). Nitrogen isotope ratios of consumers display a 3 to 4 ‰ trophic level enrichment each step up the food chain due to fractionation that occurs between the diet and tissue of consumers (Bocherens & Drucker, 2003; DeNiro & Epstein, 1981; Hedges & Reynard, 2007; Schoeninger & DeNiro, 1984; Schoeninger, 1985). This trophic level fractionation occurs when  $^{15}\text{N}$ -depleted urine is excreted from the body, leaving the isotopically heavy nitrogen in the skeletal tissue (Meier-Augustine, 2010). For comparisons of isotopic compositions derived from different sources (plant diet consumed vs collagen tissue), it is important to account for the changes in tissue—diet fractionation ( $\Delta^{15}\text{N}_{\text{collagen-diet}}$ ). Due to the transition from plant material to organic bone, an enrichment of approximately  $+3$  ‰ enrichment in nitrogen must be considered if comparing the collagen tissue samples to plant isotopic signatures (Hedges & Reynard, 2007).

Studies have found there are two main influences affecting the collagen nitrogen isotope values of human bones; climate and physiology. A negative relationship has been found between plant nitrogen values and precipitation, with moist forests and montane areas producing plants



with depleted nitrogen values (Heaton, 1987). Arid and dry environments have been seen in isotopic studies to produce plants with enriched nitrogen values (Heaton, 1987). Anthropogenic activities such as agriculture also create variation in regional nitrogen values, due to soil disturbance and application of nitrogen rich fertilizers. Ecosystems act in tandem with physiological and metabolic changes in the body (such as nutritional stress, infection, or pregnancy) and have been identified to have a great influence on nitrogen isotope ratios (Ambrose, 1993; Fuller, Fuller, Sage, Harris, O'Connell, & Hedges, 2004). These influences are unknown in animals' nitrogen isotope ratios as no experimental studies have been completed. These factors can influence sample isotopic values and create too large of a variation for trophic levels to be clearly detected.

#### Dietary Studies (Baselines and Food webs)

Stable isotope analysis allows researchers to determine a chemical signature that sheds light on information about the diet, but for interpretations of this signature to be accurate, one must understand the isotopic landscape of the region of interest. This can be done by producing a baseline of bioavailable carbon and nitrogen compositions from local sources such as fauna or plants, especially the species that primary consumers and humans would be consuming and influencing their isotopic signatures.

Casey and Post (2011) discuss how many factors can affect isotopic signatures, creating a need to understand the variation of values at the base of the food web, since they propagate up the food web through the trophic levels of consumers. By taking this variation into account, erroneous interpretations can be avoided, and the more biogenetic isotopic ratio of resources can be observed. Isotopic baselines should be considered for all regions because thorough knowledge

of the range and variation in isotopic compositions of foods that may have been consumed are a necessary step towards understanding diet and local environmental conditions. Baselines from consumed material in different regions/environments become vital for future archaeological studies in order to accurately interpret isotopic data (especially from human tissues) in the region. By using ethnographic sources from other Andean contexts, isotopic variations can be evaluated to help archaeologists understand more about the subsistence strategies with a known variation of likely consumed foods.

### Potential Issues and Causes of Variation

Stable isotope values are “indirect indicators” of feeding pathways (Laymen et al., 2012: 35) and are a product of not only intake and trophic interactions, but of biological and chemical processes during, and after, life (such as metabolism and diagenesis). Metabolism differences during life lead to variable ranges of fractionation of these isotopes as they are stored in biological tissue. This is a possible issue when interpreting stable isotope results because these stressors can alter the isotopic composition of the bone and not reflect the true biogenetic dietary signature.

Many of the taxa in this study have different body sizes and digestive systems, so comparisons between families should be made with these limitations in mind. To prevent inaccurate comparisons in this study, only large-bodied animals (camelid and cervids) with similar diets (herbivores) and larger sample sizes will be statistically compared. Other general comparisons will be made between animals of similar body sizes and dietary habits.

Diagenesis is a process that occurs to skeletal material postmortem and alters the original chemical composition of the tissue by gaining and losing ions to the environment (Ambrose,

1993; Dobberstien, Collins, Craig, Taylor, Penkman, & Ritz-Timme, 2009; Kendall, Eriksen, Kontopoulos, Collins, & Turner-Walker, 2018). By pretreating bone before extracting collagen, pollutants and contaminants often introduced into the tissue composition during diagenesis can be removed. After collagen extraction, carbon weight (%), nitrogen weight (%), and C/N ratios will be evaluated by comparing samples to the expected percentage range for good preservation. Any samples that did not fall into this range were not included in further analyses.

### Isotope Research Summary

Since the 1980's, archaeologists have been using the behavior of stable carbon isotopes during photosynthesis and the behavior of nitrogen isotopes between trophic levels to measure the diet of ancient peoples (Ambrose, 1987, DeNiro, 1987, van der Merwe, 1982). By using stable isotope analysis as a method for reconstructing diet, bioarchaeologists have a quantitative technique that can provide another perspective about life in the past.

### Andean Isotopes

Environmental differences within the Andes lead to interesting studies in stable isotope compositions in Peru. The “marked environmental complexity and diversity” present in the Andes is primarily due to the variation in altitude (Szpak et al., 2013:2), which influences isotopic compositions systematically. Research has shown that foliar  $\delta^{13}\text{C}$  values were positively correlated with altitude and negatively correlated with mean annual precipitation, while foliar  $\delta^{15}\text{N}$  values were negatively correlated with both altitude and mean annual precipitation (Szpak et al., 2013).

Plants that utilize the Calvin Cycle for photosynthesis, or  $\text{C}_3$  plants, are the most predominate plants in the central Andes in the form of legumes, grains (such as quinoa), tubers,

vegetables, and tropical grasses (Cadwallader, Beresford-Jones, Whaley, & O'Connel, 2012; Kellner & Schoeninger, 2008; Wu, Feakins, Martin, Shenkin, Bentley, Blonder, Salinas, Asner, & Malhi, 2017). Only a few cultivated plants in the Andes, such as maize and kiwicha, use the Hatch-Slack photosynthesis pathway due to the high altitude, cold, and wet weather and produce enriched  $\delta^{13}\text{C}$  values of  $\text{C}_4$  plants (Cadwallader et al., 2012; Toyne et al., 2017; Tykot and Staller, 2002). There are, however, several non-domesticated species, such as tropical grasses, that utilize the Hatch-Stack photosynthesis pathway and produce enriched  $\delta^{13}\text{C}$  values as well (Szpak et al., 2013). Since humans in the Andean environment would eat mostly cultivated  $\text{C}_3$  plants, highlands inhabitants' diet typically would have depleted carbon and nitrogen isotopic compositions and exhibit low isotopic variation, unless they were eating maize or kiwicha. Archaeological studies in Northern Peru have also used stable isotopes to investigate the influence of fertilization on nitrogen values and found that this agriculture practice leads to enrichment in nitrogen values in domesticated plants and animals that could affect past and future interpretations of isotopic data (Szpak, Millaire, White, & Longstaffe, 2012a; 2012b).

Most of the isotopic research in Peru has used anthropological models focusing on archaeological remains to study human diet and behavior (Cadwallader et al, 2012; Kellner & Schoeninger, 2008; Samec, Morales, Yacobaccio, 2014; Somerville, Goldstein, Baitzel, Bruwelheide, Dahlstedt, Yzurdiaga, Raubenheimer, Knudson, & Schoeninger, 2015; Toyne et al., 2017; Tung & Knudson, 2018; Turner, Kingston, & Armelagos, 2010). Dietary reconstruction has also been used to investigate gender, life histories, mobility, political differences, and changes in a population (Knudson, Peters, & Gagigao, 2015; Somerville et al., 2015; Turner et al., 2010; Turner, Klaus, Livengood, Brown, Saldaña, & Wester, 2013). Most of

these studies have occurred in Southern Peru due to the preservation of material remains and quantity of archaeological excavations and studies associated with the Inka civilization.

Specifically, in the Chachapoyas region, Toyne and colleagues (2017) have suggested that humans in the Chachapoyas region should have depleted  $C_3$  values, suggesting a plant-based diet of potato and tubers, or a diet consisting of very little animal protein, such as guinea pigs, who were consuming local  $C_3$  grasses. They proposed that maize was not likely a significant food staple at the site of Los Pinchudos, due to the ecological zones which limit production of  $C_4$  plants at high elevations.

#### Andean Zoo-isotopes

Archaeologists working in Peru and the surrounding Central Andean areas have recently started to analyze the isotopes of faunal material to investigate questions of human and animal interactions and behavior. Szpak and fellow researchers (2014; 2015; 2016) focused on using camelid bone, teeth, and hair to better understand the life histories and economic, social, and ritual significance of these animals in ancient coastal Andean culture. Another study located in highland Peru, at the Wari site of Conchopata, investigated human and animal diet patterns to see if there was evidence for maize agriculture and animal management practices during the Middle Horizon period (AD 600-1350) (Finucane et al., 2006). They used stable isotopes analysis to demonstrate the widespread maize consumption by humans and animal (camelids) alike.

In southern Peru, many archaeological studies have been performed to investigate the Inka civilization using some animal isotopic analyses as supplements to the human data. For example, in Knudson, Gardena, & Yaeger's article (2012), camelid enamel and bone were used to understand how changes in a social environment can lead to mobility and diet changes for the

humans and animals living in the region under political integration. In the Southern Cordillera of the Andes (Argentina) other studies utilizing faunal skeletal remains (camelids, rodents, and birds) are much more prevalent due to long-term hunter-gatherer lifestyles in Patagonia and provide excellent comparative examples that explore isotopic variations that have been used to evaluate economic, subsistence, and climatic theories for local regions (Bonomo, Scabuzzo, Politis, & Zucol, 2017; Fernández, Markgraf, Panarello, Alberto, Angiolini, Valencio, & Arrizabalaga, 1991; Fernández, Gil, Ugan, & Neme, 2016; Izeta, Laguens, Marconetto, & Scattolin, 2009; Gil et al., 2016; Kuznar, 1993).

Most of these previous studies focus on camelids and their isotopic variation (Finucane et al., 2006; Knudson et al., 2012; Szpak, 2014; 2015; 2016). A factor leading to low isotopic variation, especially in camelids, comes from ethnographic and ethnohistoric lines of evidence that suggest herding and controlled husbandry was a major influence leading to low amounts of inter- and intra-individual isotopic variability (Szpak et al., 2014:116). Of these studies discussed above, only two were directly focused on creating dietary baseline faunal/plant isotopic data; Finucane et al. (2006) in southern Peru, and Szpak et al. (2013) in northern Peru. Most others focus on the isotopic results of the human samples, and any zooarchaeological samples are supplemented but not individually investigated. Finucane et al. (2006) and Szpak et al. (2013) selected animals and plants that were local and showed evidence of strong anthropogenic ties. These samples build to anthropologists' current understanding and ability to interpret stable isotope results from archaeological sites. Faunal remains provide a unique method for investigating the past environment, resources, and human/animal interactions in the past.

## Stable Isotope Evidence of Animal Management

The animals' isotopic values should reflect the diet of their natural niches; however, if the animal diets are influenced by humans, the isotopic compositions may be more or less variable or change over time. Mayan bioarchaeologists have provided evidence showing how it is possible for wild animals to have isotopically shifted values due to changing diets from interactions with human created agricultural fields (Sharpe, Emery, Inomata, Triadan, Kamenov, & Krigbaum, 2018; White, Pohl, Schwarcz, & Longstaffe, 2004). Since maize is the only C<sub>4</sub> plant in the Mayan region, stable isotope analysis can discriminate animals that were consuming maize (C<sub>4</sub> plants) from those who were not. White et al. (2004) found that wild deer had “semi-domesticated” themselves by grazing/roaming in the agricultural fields and supplementing their diet with corn/maize. Commensal species such as guinea pigs, rodents, etc. may also act as indicators of the resources available in the anthropogenic environment, due to their close interaction and habitation with humans. One of these interactions includes foddering of food, as discussed earlier in the animal review. Foddering is a practice of domestication that would have isotopically shifted values compared to wild animals of the same species.

## Chapter Summary

There has been no previous zooarchaeological stable isotope analysis of Chachapoya material, so for future studies in Chachapoyas, the research in this thesis will provide an isotopic context in which human–animal interactions can be considered. The different animal families included in this thesis will produce a variety of isotopic compositions from which to better understand and reconstruct past diets and food webs in the Central Andes.

In this chapter, the Andean environment and the Chachapoya culture (with focus on Kuelap) were reviewed. Subsistence strategies and human–animal interactions practiced by the Chachapoya people were discussed, along with the basic animal ecology of the specimens included in this thesis. The second half of the chapter focused on a basic description of stable isotope theory and its current use in archaeological studies in the Andes.



## **CHAPTER THREE: MATERIAL AND METHODS**

This chapter is centered on a review of the materials and methods that were utilized during the stable isotope analysis of the Kuelap faunal samples. I will explain the material identification, exportation, and documentation processes. The methods are separated into the pretreatment phase and the mass spectrometer phase. Finally, I identify the statistical analysis that used to evaluate the isotopic results.

### **Sample Material**

Faunal collagen samples were analyzed to evaluate the stable carbon and nitrogen isotope variation present in the region and provide a dietary baseline for Kuelap, Peru. A total of 81 faunal bone samples were selected from domestic refuse sites across Kuelap and represent taxa that have been recognized ethnographically and archaeologically to have been sources of animal protein in the Chachapoyas region or faunal refuse that was present in the local region (Church & von Hagen, 2008; Finucane et al 2006; Guengerich, 2014; Narváez, 2013; Vasquez et al., 1997). These samples date from approximately AD 900-1535 representing the complete occupation of the site. Currently, they cannot be refined chronologically more specifically to consider temporal changes.

Dr. J. Marla Toyne, University of Central Florida, selected 74 archaeological fauna bones excavated from domestic contexts at Kuelap. Nine different taxonomic families were identified by the zooarchaeologist on site during excavations between 2000 and 2012; their family and common names are provided in Table 3. As discussed in Chapter 2, there are many species present in the highlands of northern Peru. There are osteological limitations in the classification of specific species, so for this thesis, families are the most exclusive taxon discrimination

possible. The genus and species suggestions are based on the zooarchaeologist's identification and the natural ranges of the animals found during the literature review where possible.

Camelids, cervids, and caviids make up a majority of the sample. Note that some taxa include multiple individuals while others are only represented by single specimens.

*Table 3. Summary table of faunal samples from Kuelap, Peru: including taxonomic families, common names, and sample sizes.*

<b>Taxonomic Family</b>	<b>Common Name</b>	<b>Number</b>	<b>% of Samples</b>
Camelidae	llama or alpaca	43 (including 1 modern)	53.8
Cervidae	deer	9	11.3
Caviidae	guinea pig	19 (including 5 modern)	23.8
Chinchillidae	viscacha	1	1.3
Cuniculidae	paca (montane)	1	1.3
Leporidae	rabbit	1	1.3
Felidae	puma	1	1.3
Canidae	dog or fox	2	2.5
Aves	bird (small)	3 (including 1 modern)	3.8
		(Total n = 81)	

There are difficulties differentiating between camelid species due to their similar morphology, so the camelid sample (n = 43) is made up of two possible species: *Lama glama* (llama) or *Vicugna pacos* (alpaca). The Cervidae sample (n = 9) are identified as all *Odocoileus virginianus* (the larger bodied white-tailed deer). The 19 archaeological caviid samples and the five modern samples belong to the domestic species, *Cavia porcellus*.

There are two separate wild rodents represented in this thesis sample; one Chinchillidae (the northern viscacha, *Lagidium peruanum*) and one Cuniculidae (the mountain paca, *Cuniculus taczanowskii*). The wild Leporidae (likely the Brazilian/forest cottontail rabbit, *Sylvilagus brasiliensis*) is also included in this thesis to represent the wild small- and medium-bodied herbivores in the Chachapoyas region.

There are two carnivorous families present in the sample: a Felidae and a Canidae. The single felid sample is likely from a puma (*Puma concolor*). While found in a domestic context, it was not likely a food source for the Chachapoya people. There are three archaeological canid samples. They are wild foxes or dogs such as the culpeo (or Andean fox *Lycalopex culpaeus*), the bush/forest dog (*Speothos venaticus*), and the short-eared zorro (*Atelocynus microtis*). There are two archaeological, and one modern, small-bodied birds (*Aves*) also included in the stable isotope analysis.

Dr. Toyne obtained seven local Kuelap modern specimens: one camelid (llama), one small bird, and five domestic guinea pigs. Raised for meat production, or other economic uses, the modern faunal material can help archaeologists increase their sample sizes and understand isotopic variation in the local region (O'Connor, 2000). These modern samples are predicted to provide local isotopic values since they are indigenous to the site. They can be used to model local variation in this ecological zone (~3000 m.a.s.l.), or possible changes over the long term in ecology or animal provisioning strategies.

The sample of the archaeological samples was a combination of bone fragments and complete skeletal elements present (especially in small-bodied animals). The fragmented samples were long bone shaft fragments where it is more challenging to identify species among animals of similar body sizes. Preservation and consumer tissue types (bone elements) were

considered during sample selection. An effort was made to choose similar bone elements when possible to try and account for the differences in isotopic routing (between breakdown and assimilation into different bone tissues) (Layman et al., 2012:7). Even though there is a range of different species, long bones were selected when available, and the cortical bone was isolated over trabecular bone so that similar tissue (in formation and turnover-rates) could be compared. In one case (the modern llama), a handheld Dremel© (model 4000) rotary cutting tool was used to cut a smaller piece of a larger, well-preserved bone.

Overall, the archaeological bone samples display little observable diagenetic changes and appear to be well preserved macroscopically. There was minor discoloration or adhering soil particles from the burial environment that required mechanical and water ultra-sonication and removal during the sample preparation process discussed below. The modern samples were cleaned of all soft tissue (Figure 7C).

Dr. Toyne identified, weighed, and photographed the samples and exported the remains to the University of Central Florida in Orlando, Florida in 2016 following all the necessary protocols and regulations set by the Peruvian Ministerio de Cultura (Permit no. RVM N°037-2017-VMPCIC). Samples were photographed in lab upon arrival. Each sample was photographed at least twice at different views and with a metric scale present. Examples of two archaeological and one modern sample photographs can be seen in Figure 7.



A) Archaeological camelid proximal phalange (Sample ID: K-A29).



B) Archaeological cervid distal metapodial fragment (Sample ID: K-A17).



C) Modern domestic guinea pig scapula and humerus (Sample ID: K-MA4).

*Figure 7. Two faunal archaeological and one modern Kuelap faunal samples before undergoing chemical pretreatment.*

## Methods for Collagen Extraction and Stable Isotope Analysis

There are two general phases in the methodological procedures for this thesis. The first phase includes the pretreatment methods needed to prepare the samples for further analysis. The second phase of the methodology is the analysis using the mass spectrometer. Sample preparation was performed in the Laboratory of Bioarchaeological Science at UCF. General safety considerations for lab work were always applied, including proper personal protective equipment (PPE), standard operating and safety procedures.

The exported samples were given a sample identification number for documentation purposes. Information was organized into a spreadsheet including the sample's identification number, archaeological provenience, and other important contextual and species identification information. A spreadsheet was created to record the dates of each protocol stage of collagen extraction and isotopic analysis preparation so that the processes could be tracked, and any methodological or human error could be detected if isotopic results prove inconsistent. The samples were then evaluated for any abnormalities, such as pathology or large taphonomic damage, and were removed from further analysis if compromised. No samples in this thesis were removed due to visible pathological or taphonomic damage.

Collagen was extracted from the faunal collagen samples following a modified Longin (1971) protocol for bulk tissue analysis. In summary, this extraction method allows researchers to dissolve the mineral portion of the bone, leaving an insoluble collagen residue that is dried and then ran through the mass spectrometer for stable isotope analysis. This method was selected to lessen the influence of diagenesis on (and remove pollutants from) the bone to avoid

compromising the stable isotope composition of the collagen material. This is done by removing the humic and fulvic acids from the sample during pretreatment.

### Sample Preparation and Pretreatment

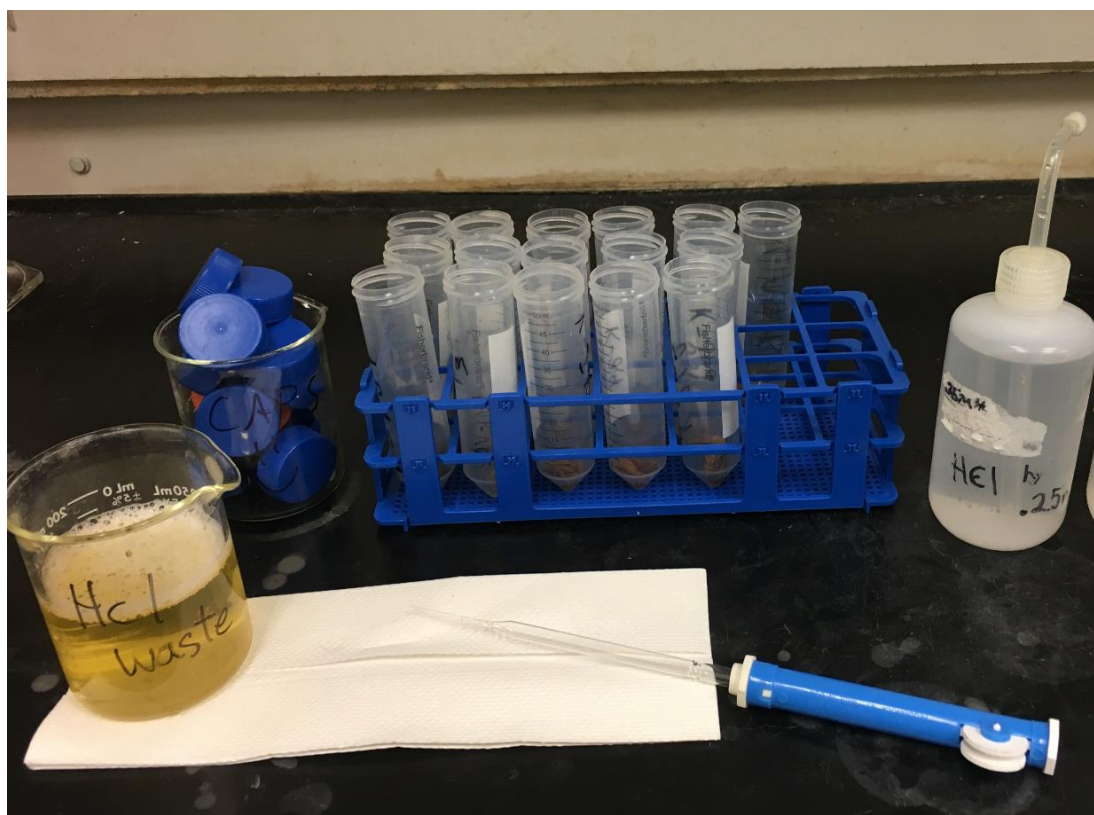
The first step of is the cleaning and mechanical breakdown (grinding) of the sample. A piece of bone between 1.0 and 3.0 grams was isolated from the rest of the exported bone sample by using a hammer, plier, chisel, or mortar and pestle. Any visible foreign material was gently scrubbed away using distilled water and a toothbrush. Once hand-washed, the samples were placed in labeled beakers with enough distilled water to cover the sample entirely. These beakers were then ultrasonicated for five to ten minutes to remove smaller adherent materials from the bone. The water was removed after sonication and the samples were placed in the drying oven at 60°C for 24 hours.

An agate mortar and pestle were used to fracture the samples into large chunks (~5mm<sup>2</sup>). Since demineralization is dependent on surface area, consistent bone fragment sizes are preferred to obtain a better collagen yield from the sample. The weights for the dry bone fragments were recorded on the sample forms before the material was transferred into a labeled plastic 50 ml centrifuge test tube.

Ambrose and Norr (1993) argue that treating samples with methanol/chloroform is an effective method to remove any lipids in the samples, especially in well-preserved bone. Lipid extraction was performed by adding 10 ml of 2:1 chloroform: methanol to the samples (Folch, Lees, & Stanley, 1957). The samples were then gently agitated for 20 minutes before being spun in the centrifuge and the extraction solvent was removed with a pipette. These steps were repeated until no color change was observed in the solution, indicating a lack of lipids still

present in the sample. Once lipids were removed, the samples were dried in the fume hood for 24 hours.

The inorganic portion of the bone was dissolved in weak hydrochloric acid (0.25 M HCl). Over the course of 1 to 8 weeks (depending on sample fragment size, animal, and preservation), 10 ml of 0.25 M HCl was added to the sample test tubes. The acid was removed and refreshed with new acid every other day until the samples became translucent and soft. A photo of this process can be seen in Figure 8. Once the samples were fully demineralized, the acid was removed, and 10 ml of distilled water was added and removed repeatedly until the water solution reached a pH between 2.5 and 3.0.



*Figure 8. A photo of the Kuelap faunal bone during the pretreatment phase of analysis where samples are demineralizing in 0.25M HCl.*



Contaminants in the soil called humic and fulvic acids can influence the isotopic composition of the collagen sample and need to be removed before analysis. These acids are base-soluble and can be easily removed with a short sodium hydroxide (NaOH) treatment (DeNiro & Epstein, 1981; Katzenberg, 1989). After removing the water solution from the end of the demineralization process, 10 ml of 0.1 M NaOH was added to the sample and agitated every few minutes for 20 minutes before being spun in the centrifuge and the solution removed. NaOH was added, removed, and replaced only if there was a visible color change in the solution. The rinse was repeated until a clear solution was obtained. Then, distilled water was added and replaced until the pH of the solution was  $\sim 7 (\pm 1)$ .

After possible contaminants have been removed from the demineralized bone, the extracted collagen was made water-soluble by heating the sample in a weak acid. The water solution was pipetted away, and 10 ml of 0.25M HCl was added to the samples once and removed. After this initial weak acid rinse, 5 ml of distilled water was added to the samples and the pH was checked to make sure the solution ranged between 2.5 and 3.0. The samples were then placed in an oven (at 90°C). After 16 hours, the samples were removed from the oven and spun in the centrifuge so that the remaining collagen solution could be pipetted off and placed in labeled (and pre-weighted) glass dram vials. The uncapped glass dram vials were placed in the oven (at 90°C) until the solution had completely dried, usually around 24 to 36 hours, until all that remains is collagen as a ring of amber/brownish residue at the bottom of the vial.

As discussed in Chapter 2, fresh bone contains between 20 and 25% collagen by weight. By determining the collagen yield of the samples, the percent collagen can act as an indicator for overall preservation. Ambrose (1993) suggests a minimum collagen yield of 1.0% for each sample before further isotopic analysis takes place and Dobberstein and colleagues (2009) state

that isotopic values remain constant until bone collagen yields fall under 1.0% of the total bone mass. The collagen yield is calculated using the following equation:

$$\% \text{ collagen yield} = (\text{vial w/ collagen} - \text{vial w/out collagen}) + (\text{sample dry weight}) \times 100$$

After calculating the collagen yield, the collagen samples were capped in their glass vials.

### Mass Spectrometer Analysis

The isotopic analysis was conducted at the University of Florida in the Light Stable Isotope Mass Spec Lab in the Department of Geological Sciences under the direction of Jason Curtis. The laboratory uses a Thermo-Finnigan Delta<sup>Plus</sup> XL Isotope Ratio Mass Spectrometer (IRMS) interfaced via a ConFlo-III device to a Costech ECS 4010 carbon and nitrogen elemental analyzer in continuous flow mode. Collagen residue samples were removed from their glass dram vials and weighed in small tin capsules, which were placed in the mass spectrometer and combusted, so that the residue would sublime into a gas and travel through the instrument. After combustion, the mass spectrometer separated the gas molecules of different masses by turning collagen into a positively charged beam of ions that run through a curved magnetic field (Ambrose, 1993). The magnet in the mass spectrometer deflected the lighter isotopes more than the heavier ones, which were collected by different electronic detectors at the end of the flight tube. The isotopic  $\delta$  values of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  were calculated from the ratios of the voltages of the major and minor beams of the sample and the standards (Ambrose, 1993). The carbon ( $^{13}\text{C}$  and  $^{12}\text{C}$ ) and nitrogen ( $^{15}\text{N}$  and  $^{14}\text{N}$ ) isotopic compositions of extracted fauna collagen samples are expressed in per mil (‰) as  $\delta$  values:  $\delta = [(R \text{ sample}/R \text{ standard}) - 1] \times 1000$ . The results of these isotopic ratios are compared to the standards Vienna PeeDee Belemnite (VPDB) for carbon and (AIR) for nitrogen.

## Precision and Accuracy of the Isotopic Data

Several steps were taken to ensure that the carbon and nitrogen values produced during stable isotope analysis were accurate and a true representation of the biogenetic collagen of the faunal bones (Ambrose, 1990; Longin, 1971; Meier-Augenstein, 2010). The accuracy of the preparation methodology and calibration/functioning of instrumentation was evaluated by comparing the results of the sample and run duplicates.

A total of 10% of the samples were duplicated and put in separate batches throughout the pretreatment phase to allow for comparison after stable isotope analysis to ensure confidence in the methodological and instrumentation procedures. If the values of the two samples from the same specimen differed greatly (over 1 ‰), then they were not included in further analysis. Analytical precision of the mass spectrometer was checked against laboratory standards (USGS 40 and USGS 41) a total of 11 times to ensure accurate results.

The integrity and preservation of the faunal bone collagen were evaluated by using the collagen yield (%), the carbon and nitrogen content (%weight C and %weight N), and the atomic C/N ratio, as indicators for diagenetic alterations or degradation of the sample quality (Ambrose, 1991; Ambrose & Norr, 1992; Meier-Augenstein, 2010). The material accepted as diagenetically unaltered have C/N ratios ranging between 2.9 and 3.6 (DeNiro, 1985). Atomic C/N ratios of collagen outside this range may not reflect the true diet isotope composition and would be removed from further analysis (Ambrose, 1991). If a sample has low concentrations of carbon and nitrogen (%C and %N below 30% and 10% by mass respectively), they will be excluded from the study, since low concentrations of these elements have been correlated with a diagenetic alteration (Ambrose, 1990). After determining that the data set is reliable, the modern

samples  $\delta^{13}\text{C}$  ratios were adjusted by enriching them +1.5 per mil to account for fossil fuels (Marino & McElroy, 1991).

### Analytical Methods

The statistical analyses consisted of exploratory isotopic data and univariate analysis involving both descriptive and inferential methods. The five quality indicators discussed above, and the two isotopic values, were collected into a spreadsheet along with the sample identification and context information. After evaluating the integrity and preservation of the sample, the focus of the statistical analysis was on the two (carbon and nitrogen) stable isotope values. This dataset allowed for the calculation of averages, standard deviations, ranges, and identification of outliers in the isotope variables from the nine different species represented in the sample. Carbon and nitrogen isotope values were also compared by utilizing biplots to assist in the visualization of the fauna in an isotope space. After the descriptive statistics were evaluated, inferential statistical methods were utilized using SPSS® software. The isotope values were tested separately for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Next, non-parametric tests (Mann-Whitney U) was used to compare the means of stable isotope ratios of the camelid and cervid collagen samples to see if there were any statistically significant differences between the domesticated and wild animals. A confidence interval of 95% (p-value = 0.05) was used. Understanding the spread, or variation, of different families of animals, allows a food web model to be created.

### Chapter Summary

Overall, the methods used in this thesis comprised of two separate preparation and analytical phases. The first phase included the pretreatment and extraction of collagen from the

bone samples. After extraction, the collagen yields were calculated, and the samples were shipped off for mass spectrometer analysis. This analysis produced five variables: carbon and nitrogen stable isotope values ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ), the carbon and nitrogen content (% weight C and % weight N), and the atomic C/N ratio. The next chapter is focused on the results of the statistical analyses.

## CHAPTER FOUR: RESULTS

The results of the stable carbon and nitrogen isotope analyses of faunal bone collagen sampled for this research from the archaeological site of Kuelap are presented in this chapter. Data authenticity and sample preservation parameters are considered. The archaeological and modern stable isotope datasets are analyzed using descriptive statistics; first by overall carbon and nitrogen results, and next by taxon families. The chapter concludes with an analysis of the isotope data according to taxon family groups using non-parametric statistical analysis.

### Data Authenticity

Several steps were taken to ensure that the carbon and nitrogen values produced during stable isotope analysis were accurate and a true representation of the biogenetic collagen of the faunal bones (Ambrose, 1990; Longin, 1971; Meier-Augenstein, 2010). The precision of the mass spectrometry instrumentation was evaluated through multiple runs of known standards. The accuracy of the preparation methodology and calibration/functioning of instrumentation was evaluated by comparing the results of sample and run duplicates.

### Instrument Precision

To provide confidence in the instrumentation used during analysis, the reliability of the mass spectrometer instrumentation was measured by using a known standard during analysis. USGS 40 produced a standard deviation of 0.05 ‰ for  $\delta^{13}\text{C}$  and 0.06 ‰ for  $\delta^{15}\text{N}$  (n = 11). These results suggest consistent and accurate measurements of the isotope composition during analysis and reliability over the two analytical runs.

## Duplicated Samples

During the processing and pretreatment of the faunal samples, ten samples were duplicated. Collagen yields for the ten duplicated samples had an average difference of 1.54%, with a maximum difference of 3.42% and a minimum difference of 0.07%. All duplicates produced consistent collagen percentages above 1.0%, providing assurance in the pretreatment procedures of this study.

Table 4 displays a summary of the differences between a sample and its duplicate in the carbon and nitrogen isotope values of ten samples. Out of the ten, nine samples produced an average difference of 0.08 ‰ for  $\delta^{13}\text{C}$  and 0.26 ‰ for  $\delta^{15}\text{N}$  from the original to the duplicate. Only the sample K-A04 produced a 4.79 ‰ difference in  $\delta^{13}\text{C}$  and a -1.76 ‰ difference in  $\delta^{15}\text{N}$  when comparing the original and duplicate. For this reason, K-A04 is removed from further analysis in this study. A Pearson's Correlation was used to measure reliability between the isotopic values of these duplicates and the correlations are 1.00 for  $\delta^{13}\text{C}$  and 0.91 for  $\delta^{15}\text{N}$ , showing a strong positive correlation between the original and duplicated sample. These results suggest the isotopic values from the analysis are reliable. For this thesis, the first run value of the sample will be used in further analysis.

*Table 4. Summary of calculated accuracy with K-A04 highlighted and later removed. Averages were produced from the differences between the original and duplicate sample for both carbon and nitrogen stable isotope values and can be seen in the bottom two rows of the table.*

Samples Duplicated	Differences in $\delta^{13}\text{C}$	Differences in $\delta^{15}\text{N}$
K-A03	0.03	0.13
K-A04	-4.79	-1.76
K-A12	0.04	0.06
K-A20	-0.07	-0.32
K-A34	0.08	-0.24
K-A42	0.29	-0.46
K-A47	-0.06	0.18
K-A59	0.01	0.10
K-A70	-0.08	-0.64
KLL	0.10	0.15
<b>Average accuracy</b>	<b>0.55</b>	<b>0.41</b>
<b>Average accuracy (after K-A04 removal)</b>	<b>0.08</b>	<b>0.26</b>

### Preservation of Collagen

The integrity and preservation of the faunal collagen were evaluated by means of the collagen yield (%), the carbon and nitrogen content (%weight C and %weight N), and the C/N ratio (Ambrose, 1991; Ambrose & Norr, 1992; Meier-Augenstein, 2010). Table 5 presents the collagen quality indicator averages, ranges, and standard deviations for all the Kuelap samples. For collagen quality indicators of individual samples, see Appendix I. The collagen yields of the sample range from 2.5% to 24.3%. There is one exception, sample K-A05, which has a



calculated collagen yield of 0.99%. However, an observable amount of collagen is present in the vial, and the calculated percent may have been the result of a weight-scale error, so the sample is included in further analysis. All the other samples in the study have collagen yields greater than 1% and indicate good preservation (Ambrose, 1993). The collagen samples have carbon concentrations ranging from 36.6% to 47.5%, which is greater than the 30% regularly accepted in isotopic literature as diagenetically unaltered (Ambrose, 1990). The collagen samples have nitrogen concentrations ranging from 13.3% to 17.3%, which is greater than the acceptable 10%. These values are also used to indicate that diagenesis has not influenced the isotopic compositions of the collagen samples. The faunal materials have acceptable C/N ratios ranging from 3.2 to 3.4 and indicate that the isotopic values reflect the original isotope composition of the animal's diet (Ambrose, 1991). Quality indicators were also evaluated by separate archaeological and modern collections (Table 6). All collagen quality indicators the collagen yield (%), the carbon and nitrogen content (%C and %N), and the C/N ratio (Ambrose, 1993) demonstrate that these archaeological and modern bone samples retain their biogenetic integrity and therefore, are acceptable for further statistical analysis.

*Table 5. Collagen Quality Indicators.*

<b>Kuelap Faunal Collagen</b>				
	<b>%Yield</b>	<b>%C</b>	<b>%N</b>	<b>C/N Ratio</b>
<b>All Animals (n = 80)</b>				
Average	11.63	45.04	16.16	3.23
Maximum	24.31	47.50	17.25	3.42
Minimum	0.99	36.56	13.20	3.16
Range	23.32	10.94	4.05	0.26
Standard Deviation	5.28	1.94	0.77	0.05

*Table 6. Averages of quality indicators from modern and archaeological Kuelap samples.*

Collagen Samples		Quality Indicators			
Collection	Size	%Yield	%C	%N	C/N Ratio
Archaeological	73	11.34	44.86	16.08	3.24
Modern	7	14.60	46.94	17.00	3.20

#### Modern Specimens

Modern samples (n = 7) were included in this thesis as a comparison collection to the archaeological sample (n = 73). The carbon isotopic values ( $\delta^{13}\text{C}$ ) of the five modern juvenile guinea pigs, one bird, and one adult llama samples were corrected (enrich by 1.5 ‰) to account for the recent industrial burning of fossil fuels, which affects modern atmospheric carbon (Marino & McElroy, 1991). The collagen quality indicators of the modern samples are presented in Table 6 with the archaeological collection. These modern values are included in the tables and figures for comparison.

## Stable Isotope Results

### Overall Dataset

Eighty of the 81 samples demonstrate good collagen preservation and accurate stable carbon and nitrogen isotopic values. The archaeological and modern collection and their mean stable carbon and nitrogen isotope values are presented in Table 7.

*Table 7. Averages of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) stable isotope values from modern and archaeological Kuelap samples.*

Collagen Samples		Stable Isotope Values	
Collection	Size	$\delta^{13}\text{C}/\text{‰}$	$\delta^{15}\text{N}/\text{‰}$
Archaeological	73	-15.31	+5.37
Modern	7	-18.36	+5.94

The mean carbon isotopic values, or  $\delta^{13}\text{C}$ , for the entire dataset ( $n = 80$ ) is  $-15.57 \text{ ‰}$  with a standard deviation of  $3.40 \text{ ‰}$  and range from  $-21.17$  to  $-9.94 \text{ ‰}$ . The mean  $\delta^{13}\text{C}$  value for all archaeological specimens ( $n = 73$ ) is  $-15.31 \text{ ‰}$  with a standard deviation of  $3.37 \text{ ‰}$  and range from  $-21.17$  to  $-9.94 \text{ ‰}$ . The mean  $\delta^{13}\text{C}$  values for all modern specimens ( $n = 7$ ) is  $-18.36 \text{ ‰}$  with a standard deviation of  $2.32 \text{ ‰}$  and range from  $-20.71$  to  $-14.24 \text{ ‰}$ .

The mean nitrogen isotopic values, or  $\delta^{15}\text{N}$ , for the entire dataset ( $n = 80$ ) is  $+5.42 \text{ ‰}$  with a standard deviation of  $1.52 \text{ ‰}$  and range from  $+1.97$  to  $+10.66 \text{ ‰}$ . The mean nitrogen isotopic value for the archaeological specimens ( $n = 73$ ) is  $+5.37 \text{ ‰}$  with a standard deviation of  $1.44 \text{ ‰}$  and range from  $+1.97$  to  $+10.05 \text{ ‰}$ . The mean nitrogen isotopic values for all modern specimens ( $n = 7$ ) was  $+5.94 \text{ ‰}$  and range from  $+3.51$  to  $+10.66 \text{ ‰}$  and a standard deviation of  $2.31 \text{ ‰}$ .

Individual faunal isotope values for each sample are presented in Table 8 with their lab sample identification, taxonomic family, and sampled skeletal element. These 80 Kuelap samples will be used to create figures and plots for evaluating the carbon and nitrogen isotopic variation in the Chachapoyas region.

*Table 8. Total sample list with sample identification, taxonomic family, element, carbon and nitrogen stable isotopes.*

Lab ID	Collection	Skeletal Element	$\delta^{13}\text{C}/\text{‰}$	$\delta^{15}\text{N}/\text{‰}$
Camelidae				
K-A01	archaeological	phalange	-12.00	+5.32
K-A02	archaeological	phalange	-12.62	+4.83
K-A03	archaeological	phalange	-14.96	+5.67
K-A07	archaeological	phalange	-16.83	+4.62
K-A08	archaeological	rib	-12.06	+5.40
K-A09	archaeological	cranium	-11.70	+5.85
K-A11	archaeological	rib	-9.94	+4.00
K-A12	archaeological	rib	-13.89	+5.83
K-A16	archaeological	rib	-10.57	+5.37
K-A18	archaeological	radius	-19.11	+4.26
K-A19	archaeological	rib	-14.20	+5.41
K-A21	archaeological	metapodial	-13.70	+4.69
K-A28	archaeological	radius	-20.64	+5.04
K-A29	archaeological	phalange	-11.67	+5.30
K-A30	archaeological	phalange	-12.36	+4.92
K-A31	archaeological	phalange	-14.19	+5.37
K-A34	archaeological	metapodial	-13.41	+4.81
K-A35	archaeological	phalange	-12.64	+4.83
K-A37	archaeological	rib	-14.80	+5.62
K-A38	archaeological	rib	-13.58	+5.53
K-A39	archaeological	rib	-12.57	+4.89
K-A40	archaeological	rib	-12.88	+4.76
K-A42	archaeological	metapodial	-20.19	+5.06
K-A43	archaeological	metapodial	-16.30	+7.29
K-A45	archaeological	phalange	-14.19	+5.69

K-A46	archaeological	metapodial	−21.16	+4.56
K-A50	archaeological	phalange	−11.79	+5.01
K-A52	archaeological	metapodial	−15.84	+6.07
K-A54	archaeological	metapodial	−12.81	+4.17
K-A55	archaeological	metapodial	−14.63	+5.73
K-A56	archaeological	metapodial	−16.31	+5.64
K-A59	archaeological	mandible	−13.71	+4.88
K-A62	archaeological	phalange	−14.34	+5.28
K-A64	archaeological	phalange	−13.46	+6.31
K-A66	archaeological	metapodial	−20.72	+4.67
K-A67	archaeological	phalange	−12.39	+4.20
K-A68	archaeological	metapodial	−10.80	+2.34
K-A69	archaeological	humerus	−18.20	+7.57
K-A70	archaeological	humerus	−14.81	+5.05
K-A71	archaeological	metapodial	−10.52	+4.56
K-A101	archaeological	radius	−10.24	+2.69
K-A103	archaeological	metapodial	−10.72	+4.79
KLL	modern	metapodial	−16.21	+6.85
Cervidae				
K-A06	archaeological	coccyx	−19.08	+7.52
K-A17	archaeological	metapodial	−19.91	+5.71
K-A20	archaeological	tarsal	−13.17	+4.32
K-A27	archaeological	metapodial	−19.67	+3.98
K-A32	archaeological	metapodial	−18.38	+5.62
K-A44	archaeological	humerus	−20.04	+5.58
K-A47	archaeological	metapodial	−19.87	+5.44
K-A65	archaeological	metapodial	−20.87	+4.38
K-A102	archaeological	radius	−21.17	+4.47
Caviidae				
K-A10	archaeological	femur	−16.69	+4.49
K-A13	archaeological	femur/tibia	−17.52	+4.63
K-A14	archaeological	mandible	−11.16	+1.97
K-A15	archaeological	mandible	−10.99	+3.33
K-A22	archaeological	tibia	−16.32	+5.94
K-A23	archaeological	tibia	−16.87	+4.37
K-A24	archaeological	tibia	−15.97	+4.61
K-A25	archaeological	femur	−16.18	+5.16
K-A26	archaeological	humerus	−14.41	+4.86
K-A33	archaeological	mandible	−18.84	+10.05

K-A36	archaeological	femur	−16.00	+5.31
K-A48	archaeological	pelvis	−21.04	+4.32
K-A58	archaeological	femur/tibia	−18.24	+3.57
K-A61	archaeological	pelvis	−19.59	+7.15
MA1	modern	femur	−20.71	+3.51
MA2	modern	femur	−19.10	+5.32
MA3	modern	femur	−18.89	+5.34
MA4	modern	humerus/scapula	−20.35	+4.58
MA5	modern	humerus/scapula	−19.02	+5.32
Chinchillidae (Viscacha)				
K-A41	archaeological	femur	−19.65	+8.36
Cuniculidae (Mountain Paca)				
K-A53	archaeological	femur	−19.66	+8.11
Leporidae (Rabbit)				
K-A05	archaeological	femur	−11.72	+7.35
Felidae (Puma)				
K-A57	archaeological	mandible	−18.49	+7.23
Canidae (Dog or Fox)				
K-A51	archaeological	femur	−11.83	+7.86
K-A60	archaeological	ulna	−11.05	+6.26
Aves (Small birds)				
K-A49	archaeological	humerus	−17.09	+6.46
K-A63	archaeological	metacarpus	−12.45	+9.78
K-A72	modern	humerus/femur	−14.24	+10.66

## Distribution of Isotopic Variation by Taxonomic Family

The nine taxa from Kuelap and their descriptive statistics (mean, maximum value, minimum value, range, and standard deviation) from the carbon isotope analysis are presented in Table 9. The largest portion of the sample ( $n = 42$ ), the archaeological Camelidae (llama/alpaca), have an average  $\delta^{13}\text{C}$  value of  $-14.13\text{ ‰}$  with a range from  $-21.16$  to  $-9.94\text{ ‰}$ . The other large-bodied herbivores presented in the sample ( $n = 9$ ), the Cervidae (or deer), have an average  $\delta^{13}\text{C}$  value of  $-19.13\text{ ‰}$  and range from  $-21.17$  to  $-13.17\text{ ‰}$ .

Almost a quarter of the total sample ( $n = 19$ ) is Caviidae, or domestic guinea pig. Archaeological caviids ( $n = 14$ ) have an average  $\delta^{13}\text{C}$  of  $-16.42\text{ ‰}$  and a range of  $-21.04$  to  $-10.99\text{ ‰}$ , while the five modern samples have a mean  $\delta^{13}\text{C}$  value of  $-19.61\text{ ‰}$  and a smaller range of  $-20.71$  to  $-18.89\text{ ‰}$ . There are three other archaeological small herbivores represented in the sample, but each are represented by only one sample. The Chinchillidae, or viscacha, has a  $\delta^{13}\text{C}$  value of  $-19.65\text{ ‰}$ . This value is almost identical to the montane paca from the Cuniculidae family, which has a  $\delta^{13}\text{C}$  value of  $-19.66\text{ ‰}$ . The last rodent in the sample, the Leporidae (rabbit), was more enriched in carbon-13 than the other rodents and has a  $\delta^{13}\text{C}$  value of  $-11.72\text{ ‰}$ .

The carnivores of this sample are represented by three samples (one felid and two canids). The Felid, or puma, has a  $\delta^{13}\text{C}$  value of  $-18.49\text{ ‰}$ , while the two Canids (foxes or dogs) have enriched carbon with an average  $\delta^{13}\text{C}$  value of  $-11.44\text{ ‰}$  and range from  $-11.83$  to  $-11.05\text{ ‰}$ . Three small birds, two archaeological and one modern, were also included in the analysis. The archaeological aves produced an average  $\delta^{13}\text{C}$  value of  $-14.77\text{ ‰}$  and range from  $-17.09$  to  $-12.45\text{ ‰}$ . The modern aves sample has a  $\delta^{13}\text{C}$  value of  $-14.24\text{ ‰}$ .

Table 9. Descriptive statistics for the  $\delta^{13}\text{C}$  (‰, VPDB) for the nine taxon families (archaeological separate from modern samples).

$\delta^{13}\text{C}$ (‰, VPDB)							
Taxon (n = 80)	Common name	Sample size	Mean	Maximum	Minimum	Range	Standard Deviation
Camelidae	llama/alpaca	42	-14.13	-9.94	-21.16	11.22	2.96
Camelidae (modern)	llama	1	-16.21	-16.21	-16.21	n/a	n/a
Cervidae	deer	9	-19.13	-13.17	-21.17	7.99	2.38
Caviidae	guinea pig	14	-16.42	-10.99	-21.04	10.05	2.83
Caviidae (modern)	guinea pig	5	-19.61	-18.89	-20.71	1.83	0.85
Chinchillidae	viscacha	1	-19.65	-19.65	-19.65	n/a	n/a
Cuniculidae	paca	1	-19.66	-19.66	-19.66	n/a	n/a
Leporidae	rabbit	1	-11.72	-11.72	-11.72	n/a	n/a
Felidae	puma	1	-18.49	-18.49	-18.49	n/a	n/a
Canidae	dog/fox	2	-11.44	-11.05	-11.83	0.78	0.55
Aves	bird (small)	2	-14.77	-12.45	-17.09	4.63	3.28
Aves (modern)	bird (small)	1	-14.24	-14.24	-14.24	n/a	n/a

The nine taxa from Kuelap and the descriptive statistics (mean, maximum, minimum, range, and standard deviation) from the nitrogen isotope analysis are presented in Table 10. The archaeological Camelidae (llama/alpaca) have an average  $\delta^{15}\text{N}$  value of +5.13‰ and range between +2.34 to +7.57 ‰. The cervidae (or deer), have an average  $\delta^{15}\text{N}$  value similar Camelids at +5.22 ‰ with a range of 3.98 ‰. Cervids in this sample range isotopically in nitrogen from +3.98 to +7.52 ‰.

The domesticated Caviidae (guinea pigs) have a mean  $\delta^{15}\text{N}$  value of +4.94 ‰ with a range of 8.08 ‰. Archaeological caviids (n = 14) have an average  $\delta^{15}\text{N}$  of +4.98 ‰ and range from +1.97 to +10.05 ‰, while the five modern samples have a mean  $\delta^{15}\text{N}$  value of +4.82 ‰ and



a smaller range from +3.51 to +5.34 ‰. The rest of the wild rodents have enriched nitrogen values. The Chinchillidae, or viscacha, has a  $\delta^{15}\text{N}$  value of +8.36 ‰. This value is again like the montane paca from the Cuniculidae family, which has a  $\delta^{15}\text{N}$  value of +8.11 ‰. The last rodent in the sample, the Leporidae (rabbit), was slightly depleted in nitrogen compared to the other rodents and has a mean  $\delta^{15}\text{N}$  value of +7.35 ‰.

The felid, or puma, has a low  $\delta^{15}\text{N}$  value of +7.23 ‰, while the canids (foxes or dogs) have an average  $\delta^{15}\text{N}$  value of +7.06 ‰ and range from +6.26 to +7.86 ‰. The three small birds, two archaeological and one modern, produced an average  $\delta^{15}\text{N}$  value of +8.97 ‰ and a range of 4.2 ‰. The archaeological aves have an average  $\delta^{15}\text{N}$  value of +8.12 ‰ and range from +6.46 to +9.78 ‰.

*Table 10. Descriptive statistics for the  $\delta^{15}\text{N}$  (‰, AIR) for the nine taxon families (archaeological separate from modern samples).*

$\delta^{15}\text{N}$ (‰, Air)							
Taxon (n = 80)	Common name	Sample size	Mean	Maximum	Minimum	Range	Standard Deviation
Camelidae	llama/alpaca	42	5.13	7.57	2.34	5.24	0.96
Camelidae (modern)	llama	1	6.85	6.85	6.85	n/a	n/a
Cervidae	deer	9	5.22	7.52	3.98	3.53	1.09
Caviidae	guinea pig	14	4.98	10.05	1.97	8.08	1.89
Caviidae (modern)	guinea pig	5	4.82	5.34	3.51	1.83	0.80
Chinchillidae	viscacha	1	8.36	8.36	8.36	n/a	n/a
Cuniculidae	paca	1	8.11	8.11	8.11	n/a	n/a
Leporidae	rabbit	1	7.35	7.35	7.35	n/a	n/a
Felidae	puma	1	7.23	7.23	7.23	n/a	n/a
Canidae	fox/dog	2	7.06	7.86	6.26	1.60	1.13
Aves	bird (small)	2	8.12	9.78	6.46	3.32	2.34
Aves (modern)	bird (small)	1	10.66	10.66	10.66	n/a	n/a

Figures 9 and 10 are simple scatter plots of the nine taxonomic families and their carbon and nitrogen results. The archaeological and modern samples are plotted together and are represented by circles and stars respectively. In the discussion chapter, these simple scatter plots will be used to compare to plant isotopic ranges, determine outliers, and visualize the variation in within and between species at Kuelap.

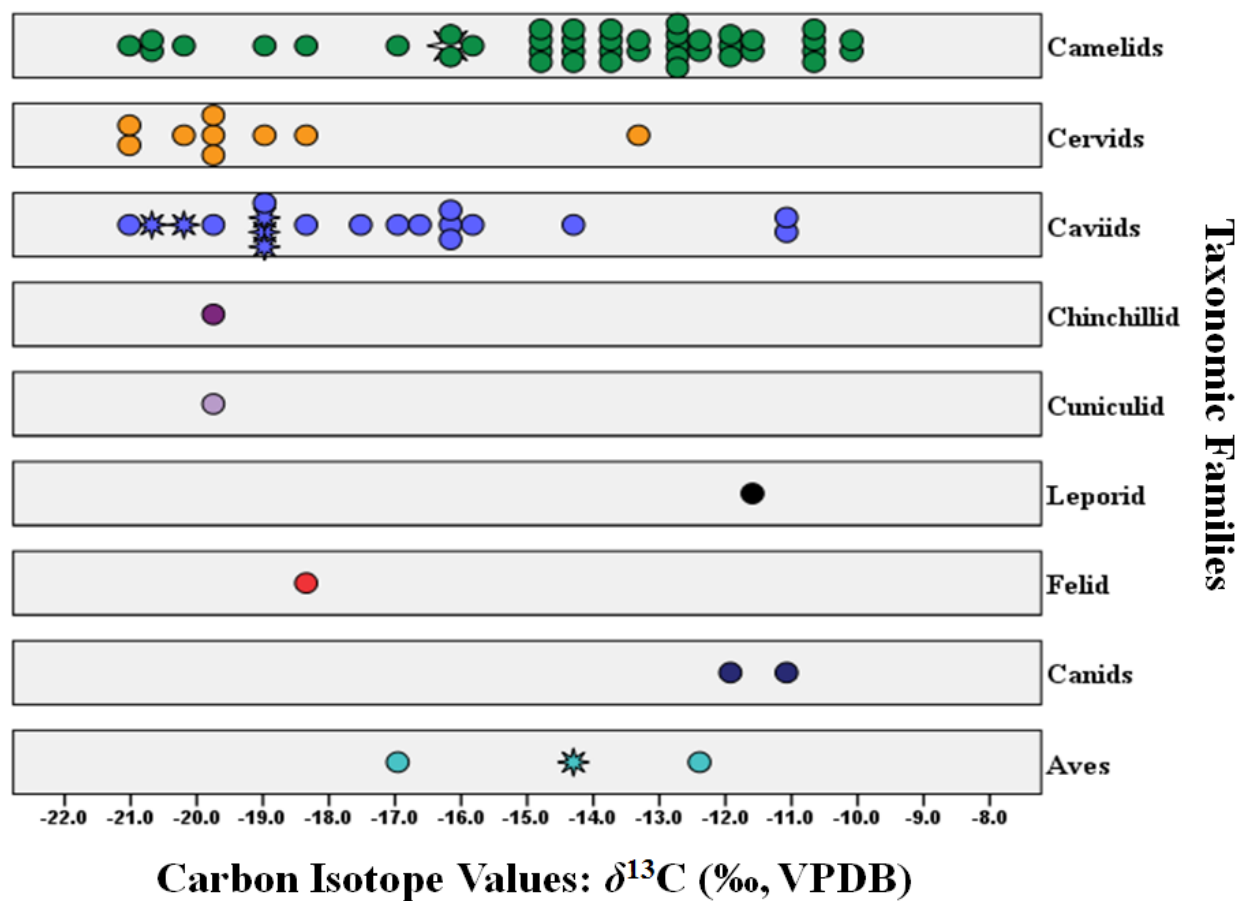


Figure 9. Scatterplot of carbon stable isotope ( $\delta^{13}\text{C}$ , ‰, VPDB) values, separated by taxonomic families, for archaeological (circle) and modern (star) faunal samples from Kuelap.



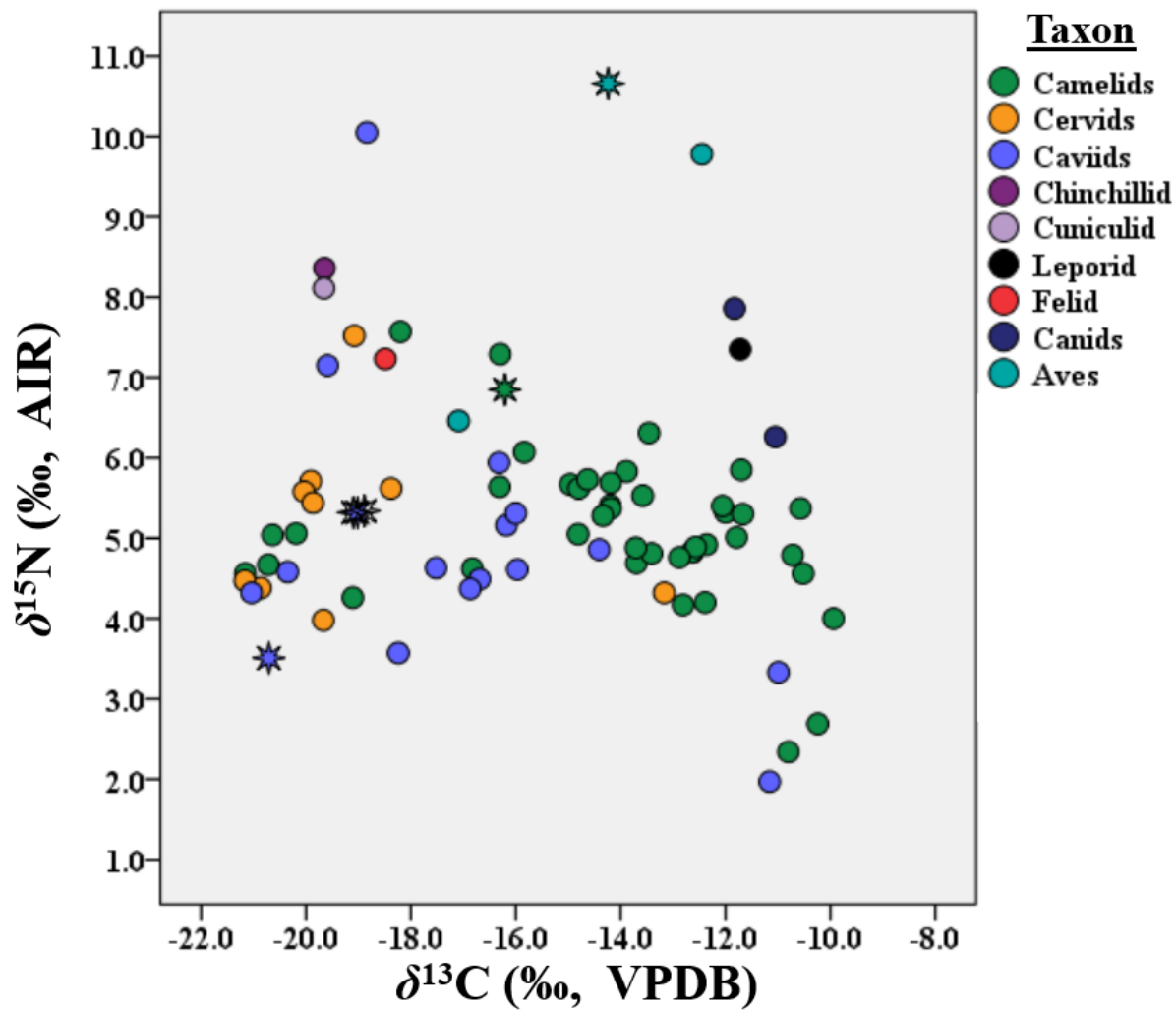


Figure 11. Biplot of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) stable isotope values for individual archaeological (circle) and modern (star) samples from Kuelap.

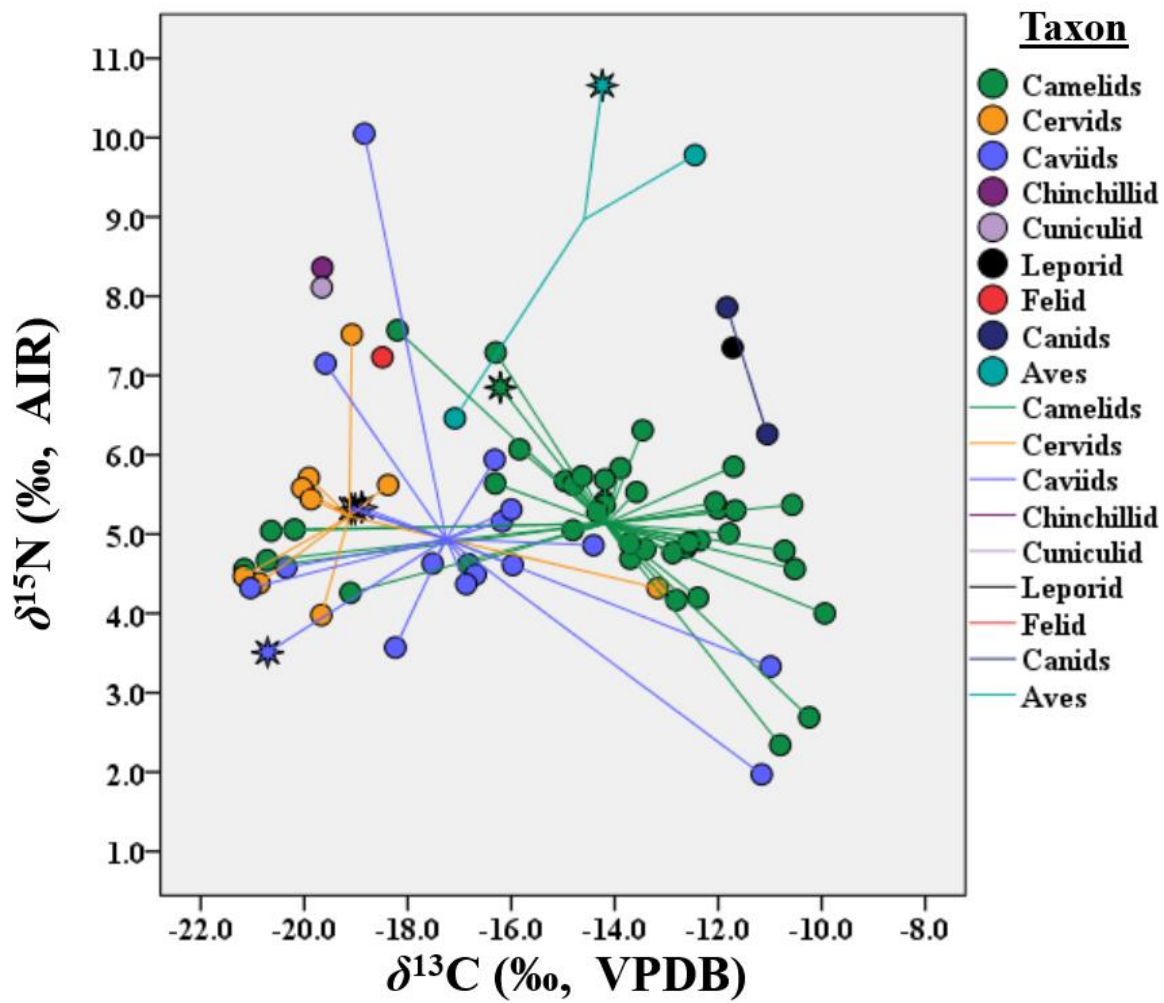


Figure 12. Biplot of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) archaeological (circle) and modern (star) stable isotope values for individual samples from Kuelap, with taxonomic families connecting to their mean value by colored lines.

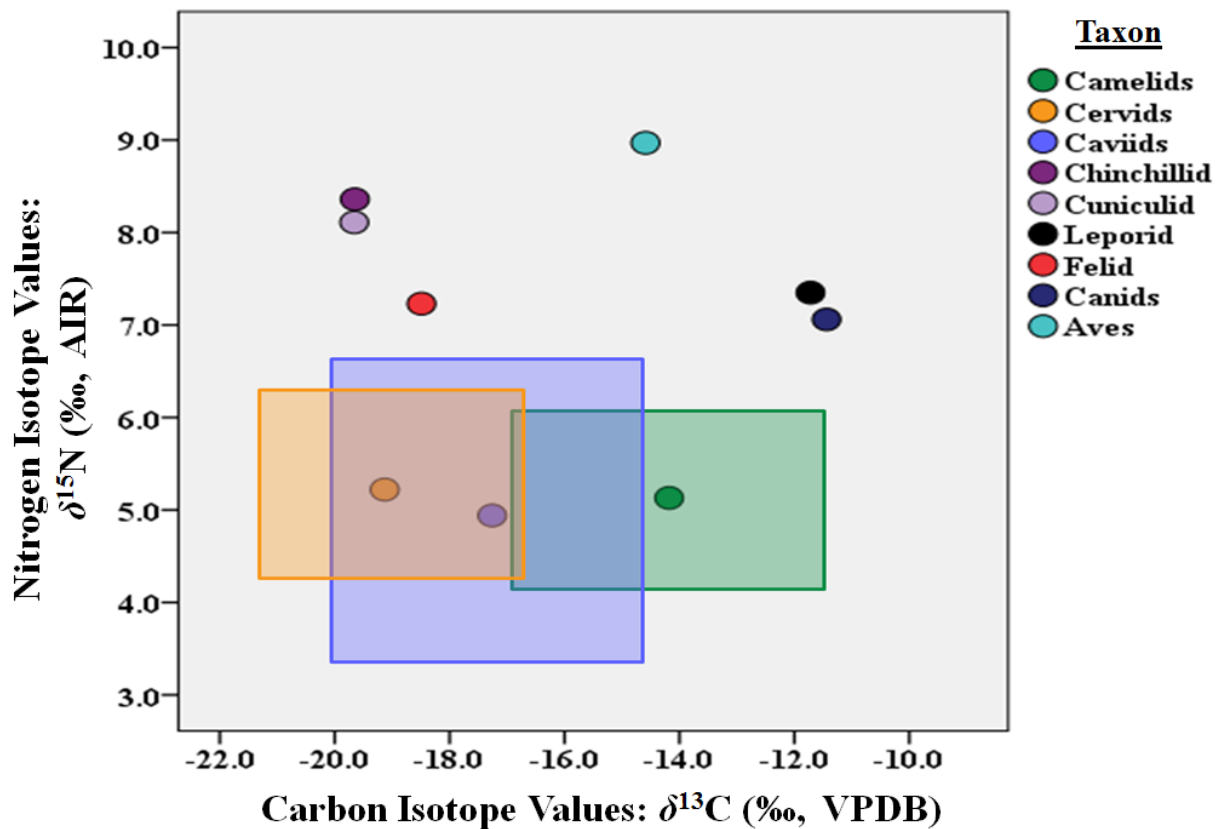


Figure 13. Biplot of taxonomic family stable isotope averages (shown as filled circles) and their standard deviations around the mean for camelidae, cervidae, and caviidae (shown as filled boxes).

#### Domestic and Wild Herbivores

The large-bodied herbivores (the camelids and cervids) from Kuelap display minimal overlap in carbon isotope values. The domesticated camelids are enriched in carbon compared to the wild cervids. These isotope results suggest discriminating dietary practices, with domesticated species consuming more  $\text{C}_4$  plants than wild species. There are five outliers present out of the 51 camelid and cervid archaeological samples (Figure 14). Four domesticated camelid samples (K-A28, K-A42, K-A46, and K-A66) displayed carbon values that are approximately 6‰ lower than the average of the total camelid sample. One wild cervid sample (K-A20)

displayed a carbon value that is approximately 6 ‰ higher than the average of the total cervid sample.

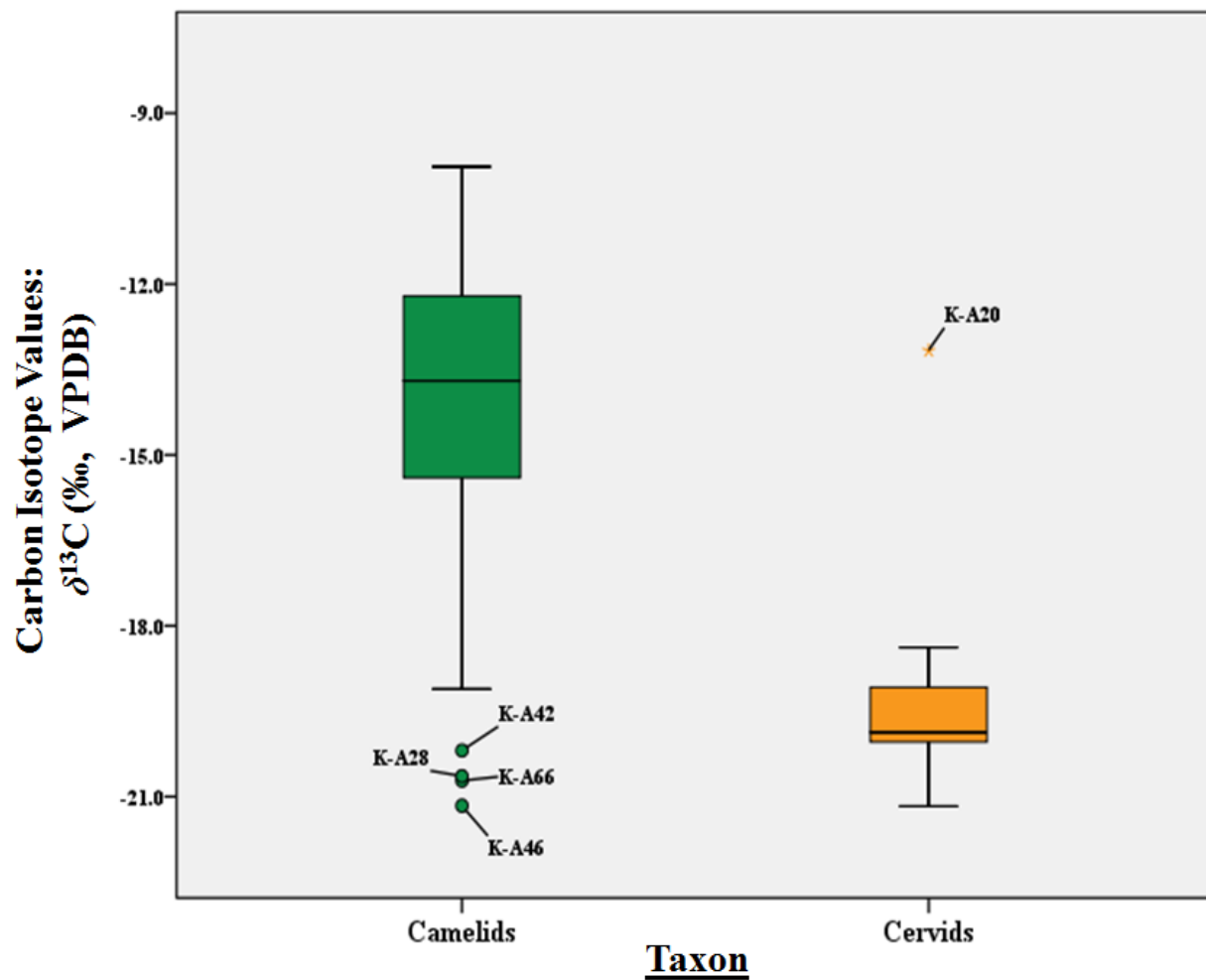


Figure 14. Box and whisker plot for  $\delta^{13}\text{C}$  values of camelids and cervids from Kuelap

To test if the differences in carbon isotope ratios are statistically different, the camelid and cervid samples were first tested for normality. To see if parametric testing could be performed, normality was tested using a Kolmogorov-Smirnov test and a Shapiro-Wilk test. Table 11 demonstrates that the normality results are contradictory. Overall, the tests produced a

significant p-value less than 0.05 (which indicates non-normality) for the carbon values of the camelids. The two tests produce opposite results for the carbon results of the cervids. For nitrogen values, the two tests once again produced opposing results for camelids but determined that the nitrogen results of the cervids were normally distributed. Due to these differing results, non-parametric t-tests were performed to ensure appropriate comparisons are made between the camelids and cervids samples. A Mann-Whitney Test was performed using SPSS® to compare the means of the camelids and cervids in order to determine if there is a statistical difference in mean and variance. The Mann-Whitney test (Table 12) produced a p-value less than 0.05 for carbon and greater than 0.05 for nitrogen. This statistical test shows that significant differences exist between domesticated camelids (llama/alpaca) and wild cervids (deer) in carbon isotope values, but not in nitrogen values.

*Table 11. Camelids and cervids data normality with the Kolmogorov-Smirnov and Shapiro-Wilk tests (non-normal results highlighted).*

Tests of Normality							
	Taxon	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Carbon	Camelids	0.140	43	<b>0.044</b>	0.922	43	<b>0.004</b>
	Cervids	0.270	9	<b>0.067</b>	0.721	9	<b>0.002</b>
Nitrogen	Camelids	0.143	43	<b>0.055</b>	0.944	43	<b>0.022</b>
	Cervids	0.222	9	<b>0.200</b>	0.888	9	<b>0.150</b>

a. Lilliefors Significance Correction



*Table 12. Non-parametric Mann-Whitney Test; used to determine if differences between camelids and cervids are significant.*

	Carbon	Nitrogen
Mann-Whitney U	52.00	189.50
Wilcoxon W	97.00	234.50
Z	-3.42	-0.097
<b>Asymp. Sig. (2-tailed)</b>	<b>0.001</b>	<b>0.923</b>
<b>Exact Sig. [2*(1-tailed Sig.)]</b>	<b>&lt;0.000</b>	<b>0.924</b>

### Chapter Summary

The sample sizes for the other small-bodied rodents and carnivores are too small for statistical testing, but the variation will be discussed in Chapter 5. Overall, the herbivore species display a large isotopic range both in carbon and isotope values. There are significant differences in carbon values between large-bodied herbivores. There are also some noticeable differences between the ranges of carbon and nitrogen isotope ratios between the archaeological and modern Caviidae collections. The interpretation of the isotopic variation seen in the data and plots is presented in Chapter 5, including an assessment of the groups based on taxon, and an exploration of the isotopic differences between domestic and wild species.

## **CHAPTER FIVE: DISCUSSION**

The research questions proposed at the beginning of this thesis will be addressed through the exploration of isotopic variation and range present of the faunal collagen samples from Kuelap. This chapter includes a discussion of the possible diet, human-animal interactions, and management practices that these animals experienced while they were alive in the Chachapoyas region. The overall carbon and nitrogen isotope ratios will be interpreted using basic isotopic theory and typical plant ranges, since no isotopic plant baselines values exist for this region. Other influences of isotopic compositions in collagen besides diet are discussed in context with the Kuelap samples. Differences within and between taxonomic families are evaluated, as well as differences between the Kuelap samples and other zoo-isotopic studies in the Peruvian Andes. Overall, this chapter discusses life at Kuelap, in the past and present, and the influences humans can have on isotopic compositions of faunal remains. This provides evidence for the usefulness of stable isotope analysis in archaeological and anthropological investigations of diet and human-animal interactions.

### **Anthropological Interpretations of Faunal Isotopic Data**

These faunal isotopic data for the Chachapoyas region are from a limited sample, yet they provide preliminary interpretations of dietary and behavioral patterns of animals in the Central Andes. The sample of animal remains comes from domestic refuse piles at the monumental center of Kuelap (AD 900 – 1535). Despite limitations such as the sample sizes and chronological control aside, the insights this dataset provides into the isotopic variation at Kuelap is a valuable contribution towards understanding the diet, subsistence strategies, and human-animal interactions of the past and future. Human-animal interactions have been an important

and re-occurring practice at Kuelap for over a thousand years. By transforming by-products of human-animal relationships into goods that are in demand, the people of Kuelap have been changing their dietary, social, and economic lives for years. This thesis pursued the anthropological investigation of diet, subsistence strategies, and human influences on local animals by using stable isotope analysis. Archaeologists have been using the behavior of carbon isotopes during photosynthesis and the behavior of nitrogen isotopes between trophic levels to measure the diet of ancient peoples and animals using skeletal tissue. This method is a quantitative technique that reconstructs diet based on the foundational principle that food molecules are incorporated into the consumer's body tissue after consumption.

Isotopic variation of faunal remains is highly influenced by a combination of environmental, ecological, biological, and social/behavioral factors; all of which can shift and change over time. Through comparisons, researchers can determine how these factors play a role in isotopic compositions and behavior in the archaeological record. This project provides a better understanding of the isotopic variation in the base of the food web at Kuelap. These faunal isotope results provide the first local isotopic baseline for this region, which future researchers can use for interpreting diet in humans and animals alike. By taking local variation into account, ranges of resources can be observed, and inaccurate interpretations can be avoided. The goal of this study is to quantify the isotopic variation in animals at Kuelap as a step towards understanding the rest of the Chachapoyas region of Peru.

The research questions stated at the beginning of this thesis will be addressed through three main topics; isotopic variation, human-animal interactions, and zoo-isotopic comparisons. This dataset provided an isotopic baseline and variation that future anthropological investigations can use to interpret isotopic behavior in the archaeological record.

## Isotopic Variation and Range of Bone Collagen Between and Within Species from Kuelap

These samples are the first faunal isotopic data from Kuelap and are preliminary interpretations of alimentary sources for the Chachapoyas region. Overall, the carbon and nitrogen isotopic values suggest these animals from both the archaeological and modern collections consumed both  $C_3$  and  $C_4$  plant foods and some terrestrial animal protein. These faunal results indicate that there were many isotopically different dietary sources available to the Chachapoya people.

### Carbon

As discussed in Chapter Two,  $C_3$  plants dominate regions with increased altitude and wet climates, so animals and humans consuming local/natural plant material in the elevated regions such as the grasslands and the cloud forest would be expected to have depleted  $\delta^{13}C$  values between  $-34$  to  $-19$  ‰.  $C_4$  plants, which become more predominate in the lower tropical regions of the Andes, have enriched  $\delta^{13}C$  values ranging from  $-15$  to  $-8$  ‰. These plants are more likely to have grown below 2500 m.a.s.l. but would still have made up a significant portion of the possible plants consumed in the Chachapoyas region.

Animals consuming local plant materials can be expected to have similar isotope values to the dominate plants in the region, however, as amino acids are routed from the diet into the tissue, a fractionation of approximately  $+5$  ‰ occurs (Ambrose & Norr, 1993; DeNiro & Epstein, 1978; van der Merwe & Vogel, 1978). This requires researchers to account for that fractionation ( $\Delta^{13}C_{\text{collagen-diet}}$ ) by depleting the bone collagen values by  $5$  ‰ before making interpretations of plant dietary sources. This chapter reflects these adjustments and will provide

the isotopic value for the bone and the adjusted-for-fractionation value throughout this discussion.

In Figure 15, the samples are plotted according to their taxonomic families and their carbon isotope ratios. Both the raw data and adjusted values are presented on the bottom axis. In addition to the sample values, the typical isotopic ranges for C<sub>3</sub> and C<sub>4</sub> plants are expressed by colored boxes; yellow and red respectively. This allows for a clear visual of how similar a faunal isotope value is to that of the plant isotopic ranges.

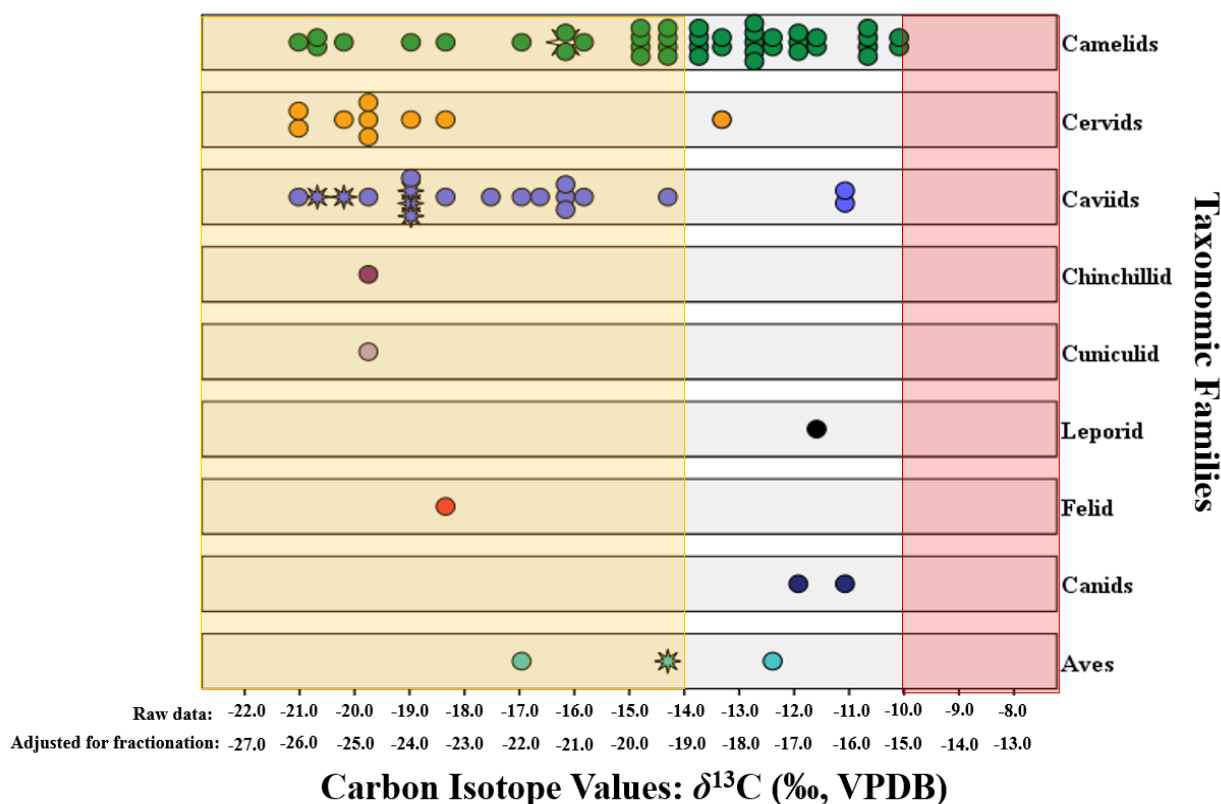


Figure 15. Archaeological (circle) and modern (star) carbon stable isotope values of Kuelap animals plotted against known C<sub>3</sub> (yellow) and C<sub>4</sub> (red) isotopic ranges. For direct comparison between fauna and plant isotopic compositions, a diet-tissue fractionation of +5‰ for  $\Delta^{13}\text{C}$  was used and displayed in the adjusted-for-fractionation row (Ambrose & Norr 1993).

The isotopic data from Kuelap produced during analysis supports the theory of a mixed diet of C<sub>3</sub> and C<sub>4</sub> plants by presenting  $\delta^{13}\text{C}$  values ranging between  $-21.17$  to  $-9.94$  ‰ (considering fractionation:  $-26.17$  to  $-14.94$  ‰). Over half of the sample ( $n = 49$ ) overlap with the isotopic range of C<sub>3</sub> plants. Over 36% of the thesis sample ( $n = 29$ ) ranged between the C<sub>3</sub> and C<sub>4</sub> isotopic ranges, indicating that both wild and domesticated animals were consuming some volumes of C<sub>4</sub> plants, enriching them compared to the animals in the C<sub>3</sub> range.

### Camelidae

Throughout the Andes, archaeologists have found that camelid samples have a broad range of carbon isotope signatures, suggesting a diet of both C<sub>3</sub> and C<sub>4</sub> plant materials (Dufour, Goepfert, Gutiérrez, Chauchat, Franco, Vásquez, 2014; Finucane et al., 2006; Szpak et al., 2014). Often, the enriched carbon isotope values in the Andes have been attributed specifically to the consumption and foddering of maize (Tykot & Staller, 2002).

The archaeological camelids collection has the largest isotopic variation in carbon values, but their average of  $-14.13$  ‰ ( $-19.13$  ‰ adjusted-for-fractionation) falls on the enriched end of the C<sub>3</sub> plant range in Figure 22. Only two of the fauna from Kuelap (two camelids) fall distinctively in the C<sub>4</sub> plant isotopic range. These data suggest that the camelids had diets consisting of more C<sub>4</sub>-based plant materials than the other large-bodied herbivores in the Chachapoyas region, but that C<sub>3</sub> plants still supplemented most of their diet. This is not surprising, considering Kuelap's elevation and the dominate plants of the Andean highlands. These animals may have been pasture dwellers (having their grazing and browsing areas controlled but humans, but still were consuming wild C<sub>4</sub> plants) or it is possible that they have been foddered some C<sub>4</sub> plants by humans.

The modern camelid was sampled from a herd that fed on the natural grasses and shrubs around Kuelap (Toyne, 2018 personal communication), providing this study with a local and modern value. The modern camelid had a carbon value of  $-16.21\text{‰}$  ( $-21.21\text{‰}$  adjusting-for-fractionation), suggesting a  $C_3$  diet with  $C_4$  plants playing a very small role in its diet. Different types of animal management strategies and herd sizes due to human variation may have also influenced these results, leading to the large variation and changes over chronological samples as seen here.

### Cervidae

The other large-bodied terrestrial mammals in this study are Cervidae. The cervids in this sample had an average carbon value of  $-19.13\text{‰}$  ( $-24.13\text{‰}$  adjusted-for-fractionation) and are almost  $3\text{‰}$  more depleted in carbon than the modern Kuelap local llama discussed above. Eight of the nine cervids have depleted carbon isotope ( $\delta^{13}C$ ) values, suggesting that most of the deer were consuming more  $C_3$  resources and very few  $C_4$  plants. This is more consistent with the cloud forest, *quechua* ecological zone. Cervids are wild forest dwellers that are influenced by human activity such as hunting and agriculture (Brokx, 1984; White, Pohl, Schwarcz, & Longstaffe, 2001). The humans of Kuelap may have been restricting the cervids habitat, leading to a lower variation diet, and therefore carbon isotope values.

### Caviidae

The archaeological Caviidae display a wide isotopic range in carbon isotope ratios from  $-21.04$  to  $-10.99\text{‰}$  ( $-26.04$  to  $-15.99\text{‰}$  adjusted-for-fractionation) This is expected from a scavenger/opportunistic diet such as household food scraps, which would have been foddered to the guinea pigs while being corralled in the floor of the Kuelap houses, as seen in Figure 23.

Since humans and Caviids were in such close living quarters, Caviids make a good proxy for the domestic refuse present at Kuelap. The carbon ( $\delta^{13}\text{C}$ ) values of the archaeological guinea pigs average of  $-16.42\text{‰}$  ( $-21.42\text{‰}$  adjusted-for-fractionation) and support a mixed diet of both  $\text{C}_3$  and  $\text{C}_4$  plants, where different individuals had more and less of each. This suggests household variation at Kuelap influenced the caviids' diet and isotopic composition.



*Figure 16. Photograph of the stone corrals built into the circular domestic household structures at Kuelap. These corrals were home to domesticated caviids, suggesting these guinea pigs were in close proximity to humans and likely was foddered domestic refuse.*



The five modern guinea pigs provide a view of the isotopic variation in small herbivores that had been directly foddered local grass from Kuelap. The modern collection of Caviidae has a much narrower isotopic range than that of the archaeological samples, between  $-20.71$  and  $-18.89$  ‰ ( $-25.71$  and  $-23.89$  ‰ adjusting-for-fractionation). The modern samples all produced stable isotope values more depleted in carbon than the archaeological collection and were consistent with  $C_3$  plant consumption. These data (and its low variation) provide evidence for the contemporary management style, in which the guinea pigs had their diets strictly controlled by modern humans, who fed them only local alfalfa.

#### Chinchillidae and Cuniculidae

The viscacha and mountain paca (chinchillid and cuniculid) had almost identical depleted carbon isotope values supporting the expectation that these rodents were eating large volumes of  $C_3$  plants. The small wild herbivores both had a  $\delta^{13}C$  value of  $-19.6$  ‰ ( $-24.6$  ‰ adjusted-for-fractionation). These wild rodents displayed very similar carbon values to those of the modern caviid collection and were clearly in the expected isotope range for  $C_3$  plants.

#### Leporidae

The rabbit (Leporidae), on the other hand, has an enriched carbon value at  $-11.7$  ‰ ( $-16.7$  ‰ adjusted-for-fractionation) almost identical to that of the canids, suggesting a mixed diet of  $C_3$  and  $C_4$  plants. This value is depleted less than  $2$  ‰ from the  $C_4$  plant isotopic range. This indicates that  $C_4$  plant resources played a larger role in the rabbit's diet compared to the wild rodents. This may suggest different ecological habitats, with the rabbit occupying an area of lower elevation near wild or domesticated  $C_4$  plants.

## Felidae

The puma displayed carbon values that fell mostly towards the C<sub>3</sub> range with some C<sub>4</sub> plants influence. The carbon value of  $-18.49\text{‰}$  ( $-23.49\text{‰}$  adjusting-for-fractionation) is reflective of the original plants material that was consumed by terrestrial mammals before being preyed upon by the large cat. The carbon value for the puma collagen is depleted and within the C<sub>3</sub> plant range, only  $1\text{‰}$  enriched from the wild rodents. Since pumas are strictly carnivorous (Nielsen et al., 2015; Perrig, et al., 2017), the mixed diet suggests that the puma was eating animals that ate mostly C<sub>3</sub> plants such as wild rodents, guinea pigs, deer, and/or some camelids.

## Canidae

Unlike the Felid, the archaeological canids display enriched carbon values ranging between  $-11.83$  and  $-11.05\text{‰}$  (with an average of  $-16.44\text{‰}$  adjusted-for-fractionation). These values suggest the wild dogs or foxes were eating small animals that consumed a large portion of C<sub>4</sub> plants (such as rabbits) or that the canids were eating a more omnivorous diet. Due to their scavenger behavior, wild species of canids have been known to use human domestic refuse to their dietary advantage (Burleigh & Brothwell, 1978; Souza et al., 2009). If humans were domesticating, consuming, and depositing scraps of C<sub>4</sub> plants, wild dogs scavenging the region and human settlements would be expected to display enriched carbon isotope values.

## Aves

These small birds displayed carbon isotope results ranging between  $-17.09$  and  $-12.45\text{‰}$  (average of  $-19.77\text{‰}$  adjusting-for-fractionation). Since they are enriched from the C<sub>3</sub> range, but not in the C<sub>4</sub> range in Figure 15, the values suggest the bird diets consisted of mixed plants, but

with C<sub>4</sub> plants making up a larger portion of their diet than most of the other animals. These C<sub>4</sub> resources could have come from consuming wild C<sub>4</sub> plants, or possibility by scavenging through human refuse like canids, leading to domestic or gathered C<sub>4</sub> plants in the diet of birds.

### Outliers

There are seven samples that produced carbon isotope values that were outliers in their taxonomic family subsamples. These outliers can be seen in Figure 17. There are four camelid samples (K-A28, K-A42, K-A46, and K-A66) that have depleted carbon isotope values that are outliers suggesting a diet of mostly C<sub>3</sub> plants. Another possibility is that these four camelid samples were misidentified during excavation and could belong to a different taxonomic family (likely cervid). Often the samples were fragments of long bones, which may have been misidentified in the commingled domestic refuse and mistaken for the wrong taxonomic family by the zooarchaeologist on site during excavations. There is one cervid samples, K-A20, which has carbon isotope values that is greatly enriched, compared to that of the rest of the subsample. The enrichment could suggest consumption of C<sub>4</sub> plants (either wild or from agricultural fields). Or like the camelid outliers above, this cervid outlier could indicate a misidentification of the remains.

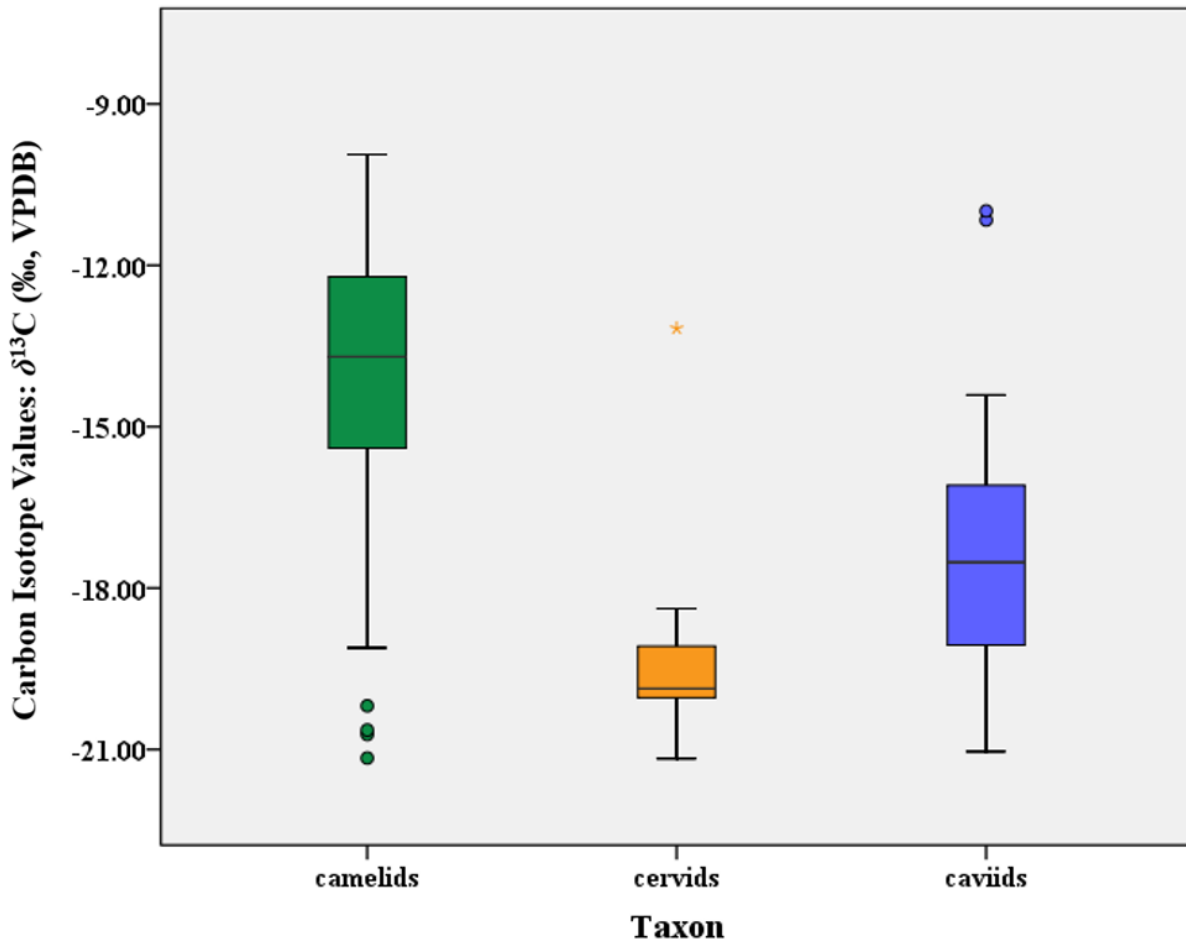


Figure 17. Box-and-whisker plot of Kuelap camelids, cervids, and caviids and the seven carbon isotope outliers.

The final two carbon outliers are caviid samples K-A14 and K-A15 who are significantly enriched compared to the rest of the subsample. This enrichment could be representative of larger amounts of C<sub>4</sub> plant consumption. There are two possibilities for this enrichment. One, is that this guinea pig was actually a wild species that ended up in the domestic refuse after living in the wild and consuming naturally occurring C<sub>4</sub> plants at >2500 m.a.s.l. The second possibility is that there were some C<sub>4</sub> plants either being grown or gathered by the humans at Kuelap for food resources.

## Nitrogen

Nitrogen stable isotope analysis is promising for evaluating trophic ecology, even though many factors can influence the collagen ratios. Hedges & Reynard (2007) discuss how little researchers currently understand about how much inter-individual  $^{15}\text{N}$  variation is to be expected in humans, let alone animals in this understudied region. These factors may make food webs somewhat nebulous, but they also have the potential to provide important insights to anthropologists on fractionation, climate, and physiology. This dataset provides a step towards understanding the habitat variation in local faunal nitrogen values from the Chachapoyas region.

Other changes in isotopic compositions of collagen can be due to the ecosystem from which it resides. Nitrogen depletion could be due to the wet environment of the cloud forest in the Chachapoya region. Nitrogen enrichment of faunal samples could be due to the arid environment of the highlands or consumption of low-nutrient forage (Metcalf, Longstaffe, & Hodgins, 2013). Ambrose (1991) discusses the need for local plant values due to the significant between-habitat variation that has been found in plant nitrogen values. A plant isotopic study has yet to be conducted on the Chachapoyas region near Kuelap, so there are no current baselines from which to distinguish “normal” nitrogen variation from trophic level shift fractionation.

If an animal is under nutritional stress, metabolic changes in the body could enrich nitrogen isotope values derived from tissue. This is also the case during illnesses and pregnancy if parallels are drawn with human based experiments (Fuller et al., 2004). Animals with different physiologies will have different degrees of nitrogen variation due to natural metabolic adaptations. Some isotopic researchers believe that the consumption of feces and bacteria could be responsible for increased nitrogen values (Ambrose, 1993; Metcalf et al., 2013). Rodents and

rabbits engaged in coprophagy to more effectively digest plant material (Clementz, Fox-Dobbs, Wheatley, Koch, & Doak, 2009; Soave & Brand, 1991). Once plant material is consumed, it is exposed to bacteria in the digestive system. Animals who consume feces and bacteria can gain more nutritional resources from the material than what is obtained the first time around thanks to bacterial communities (Soave & Brand, 1991). Little isotopic research has been done on nitrogen isotope values of rodents engaging (or not engaging) in coprophagy. But, a possible explanation for these higher nitrogen values could be due to the behavior of coprophagy (Metcalf et al., 2013; Clementz et al., 2009). More studies evaluating the isotopic behavior of different animal physiological and metabolic processes are necessary for clearer definition in zoo-isotopic studies.

This study reflects the changes in isotopic compositions due to tissue—diet fractionation ( $\Delta^{15}\text{N}_{\text{collagen-diet}}$ ). Due to the transition from plant material to organic bone, an enrichment of approximately +3 ‰ was applied during this discussion (Hedges & Reynard, 2007). Overall, these nitrogen isotope values are depleted, but this is not too surprising for a wet cloud forest climate such as the one at Kuelap.

### Camelidae

The archaeological camelids from Kuelap have nitrogen ( $\delta^{15}\text{N}$ ) values ranging from +2.34 to +7.57 ‰ (−0.34 to +4.57 ‰ adjusted-for-fractionation) and average at +5.13 ‰ (+2.13 ‰ adjusted-for-fractionation). These nitrogen values indicate a diet of plants with depleted nitrogen values due to the elevation and large amounts of precipitation present in the region. The modern camelid value was +6.85 ‰ (+3.85 ‰ adjusted-for-fractionation), which is enriched 2 ‰ more than the archaeological collection average. A possibility for the low variation and depletion of nitrogen values for the camelids overall could be due to the unique camelid

physiology and metabolism that allow these animals to efficiently absorb water in their digestive systems.

### *Cervidae*

The archaeological cervid have similar  $\delta^{15}\text{N}$  values to the camelid subsample group and average at +5.22 ‰ (+2.22 ‰ adjusted-for-fractionation) and range from +3.98 to +7.52 ‰ (+0.98 to +4.52 ‰ adjusted-for-fractionation). These depleted nitrogen values are expected for animals living a wet cloud forest environment such as that in the Chachapoyas region, who subsist primarily on plant materials directly.

### *Caviidae*

Figure 10 displays the archaeological caviid sample from Kuelap and a large range of  $\delta^{15}\text{N}$  values. The archaeological caviid collection averaged at +4.98 ‰ (+1.94 ‰ adjusted-for-fractionation) and range from +1.97 to +10.05 ‰ (−0.97 to +7.05 ‰ adjusted-for-fractionation). The wide range and outliers in this subsample suggest a variety of foods were available to the domestic guinea pigs in the past. This variety can be explained by considering the composition of domestic refuse that was likely variable due to human and household variation.

The modern caviids display a much smaller range than the archaeological sample and have  $\delta^{15}\text{N}$  values between +3.51 to +5.34 ‰ (+0.51 to +2.34 ‰ adjusted-for-fractionation). The modern caviids results suggest that the local grasses of Kuelap have naturally depleted nitrogen values. The same could be said for the modern camelid; however, is enriched 2 ‰ compared to the modern Caviidae average, meaning that the camelid were likely eating more of a variety of plants at Kuelap than the modern caviids.

## Chinchillidae and Cuniculidae

The two wild rodents (chinchillid and cuniculid) display some of the highest nitrogen values of the dataset at over +8.0 ‰ (+5.0 ‰ adjusting-for-fractionation). This enrichment could be due to several reasons. The chinchillid prefers habitats of high elevation with a more arid environment and dry terrain. This habitat preference would have enriched the nitrogen values in organic tissues. Cuniculids have been reported to supplement their diet with insects, which would lead to an enrichment of nitrogen values due to trophic ecology. Another factor mentioned earlier that could influence the nitrogen isotope values of faunal collagen could be the behavior of coprophagy, which is seen in both these taxonomic families.

## Leporidae

The Leporidae, or rabbit, has slightly depleted nitrogen values compared to the wild rodents, but is still more enriched than the domesticated caviids. With an average  $\delta^{15}\text{N}$  value of +7.35 ‰ (+4.35 ‰ adjusted-for-fractionation), this leporid had a similar nitrogen results more enriched than expected for a cloud forest environment. The enrichment in this small herbivore could also be due to the behavior of coprophagy as discussed previously.

## Felidae

The nitrogen isotopes values for the carnivores is not as enriched as we would expect for predators and carnivores who are consuming prey and rising trophic levels but may be an indication of climate's influence on isotopic compositions (Hedges & Reynard, 2007). The puma is believed to be an apex predator, it was expected to be one of the highest nitrogen values, and instead only the camelids, cervids, and caviids have lower mean values than the puma. The puma



has an almost identical nitrogen value as the rabbit at +7.23 ‰ (+4.23 ‰ adjusted-for-fractionation). The ~2 ‰ enrichment in nitrogen values trophic level enrichment of the felid (and canids) suggests this puma's diet included more terrestrial protein sources than the diet of the large herbivores (camelids and cervids) or guinea pigs (caviids). Food sources were likely small herbivores, cervids, and camelids.

### Canidae

The nitrogen values of the canids are only slightly enriched compared to the caviids and are equal to, if not less than, the wild rodents. The canids range in  $\delta^{15}\text{N}$  values from +6.26 to +7.86 ‰ (+3.26 to +4.86 ‰ adjusted-for-fractionation). Since small-bodied rodents are commonly canids' prey, a trophic level enrichment of +3 to 4 ‰ was expected to be seen, and was seen clearly in this study (Emmons, 1990). These results indicate that the canids in this study had a carnivore's diet of small animals (who were consuming mixed  $\text{C}_3$  and  $\text{C}_4$  plant material).

### Aves

These small birds displayed enriched nitrogen isotope results. The two archaeological Aves average at +8.12 ‰ (+5.12 ‰ adjusted-for-fractionation), while the modern bird had a  $\delta^{15}\text{N}$  value of +10.66 ‰ (+7.66 ‰ adjusted-for-fractionation) which is the most enriched nitrogen value of the Kuelap dataset. These enriched nitrogen values can be explained by diet, where consuming insects would have led to a trophic level shift. These birds were likely eating a large variety of plants and insects, creating the larger variation (Figure 24).

## Outliers

There are eight samples that produced nitrogen isotope values that were outliers in their taxonomic family subsamples. These outliers can be seen in Figure 18. There are four Camelid samples that are outliers for nitrogen isotope values; two enriched (K-A43 and K-A69) and two depleted (K-A68 and K-A101). There is one enriched nitrogen outlier in the cervid subsample: K-A06, who could possibly have lived in a drier and arid environment than the other deer. There are three caviids outliers for nitrogen values (K-A14, K-A33, and K-A61). K-A33 is enriched by more than two standard deviations from the average Caviidae nitrogen value. K-A61 was also enriched, but K-A14 was depleted in nitrogen. These outliers could have been influenced by a variety of factors. The wide range and outliers in this subsample suggest perhaps a more omnivorous diet, even though this animal was expected to be a strict herbivore. This is not surprising considering the composition of domestic refuse, which as we can see from this these sample contained a variety of animal species. Guinea pigs also engage in coprophagy, which influences nitrogen stable isotope compositions in organic tissues (Metcalf et al., 2013).

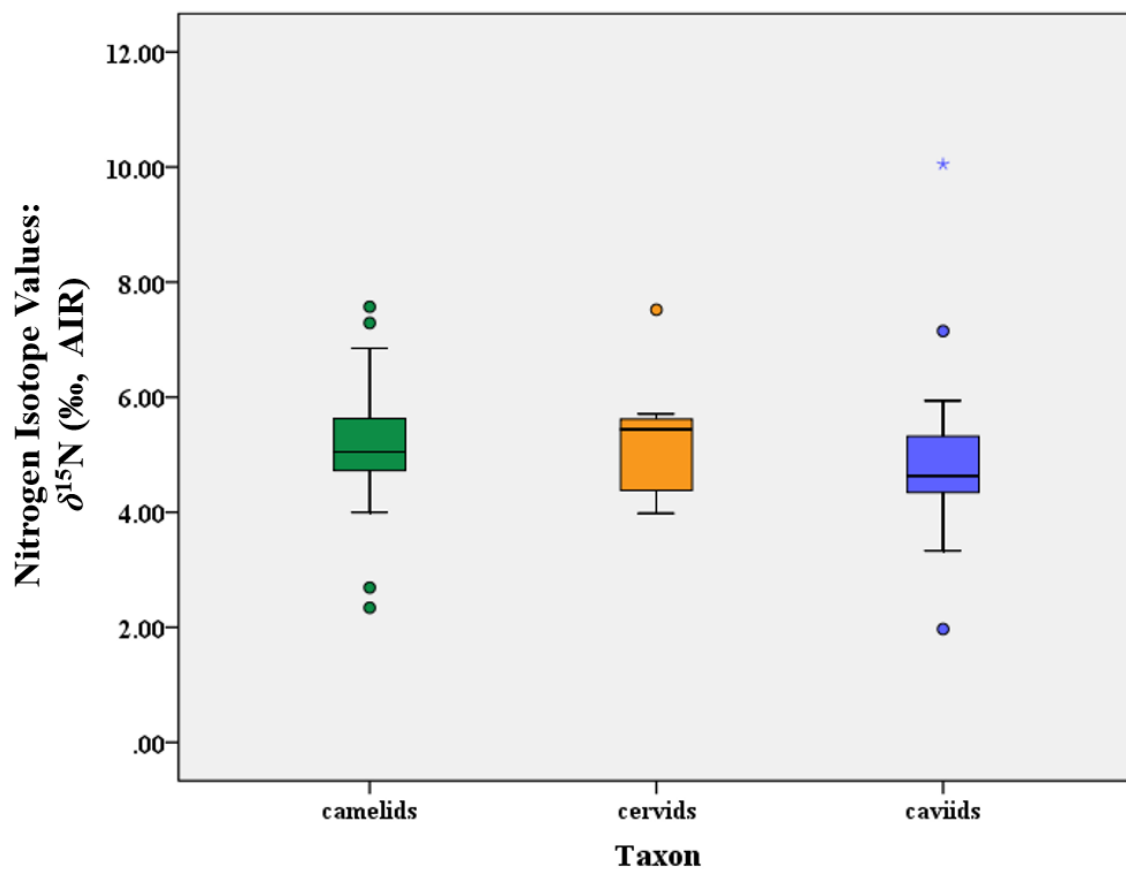


Figure 18. Box-and-whisker plot of Kuelap camelids, cervids, and caviids and the seven nitrogen isotope outliers.

## Stable Isotope Evidence for Human-animal Interactions at Kuelap

### Wild and Domesticated Animals

Since there were domesticated and wild animals present in the dataset, I compared them to see if different isotope results reflected management strategies or human influence on diet. The large-bodied herbivores (domesticated camelids and wild cervids) isotope values were compared using a non-parametric test. The Mann-Whitney test produced a p-value less than 0.05 ( $p < 0.001$ ) for carbon and greater than 0.05 ( $p = 0.923$ ) for nitrogen. This statistical test shows

that significant differences exist between domesticated camelids and wild cervids in carbon isotope values, but not in nitrogen values.

These isotope results suggest discriminating dietary practices, with domesticated species consuming more C<sub>4</sub> plants than wild species. This suggests the camelid and cervid were not occupying the same ecological niche in the region or that humans had an influence on both animal's diets either by foddering crops or by controlling/influencing the animal's mobility. Camelids were known domesticates that were likely being herded across ecological zones, it was expected that they would have a large isotopic variation compared to the wild large-bodied herbivores, who would naturally occupy a single ecological zone. Camelidae herds are reportedly taken out to the *puna* pasture during the day and corralled near the community in the *quechua* zone at night (Finucane et al., 2006). Being herded across ecological zones with different forage, it is expected that the camelids would have a larger isotopic variation than the cervids. Corraling or restricting Camelidae grazing may have led to greater consumption of C<sub>4</sub> plants, such as maize, but the possibility that unconfined camelids could have consumed wild C<sub>4</sub> plants in the Chachapoyas region should not be disregarded.

### Animal Management Strategies

Significant differences between archaeological and modern caviids were also detected using the same non-parametric test as above. The Mann-Whitney test produced a p-value less than 0.05 ( $p = 0.012$ ) for carbon and greater than 0.05 ( $p = 0.579$ ) for nitrogen. This statistical test shows that significant differences exist between the archaeological and modern domesticated Caviidae in carbon isotope values, but not in nitrogen values.

These five modern guinea pigs allow us to view the isotopic variation of herbivores that had been directly foddered local grass from Kuelap. This comparison proposes that the guinea pigs in the past were consuming a much larger variety of different foods (like those found in domestic refuse) than those of the present day. It also suggests that the modern guinea pigs' diet was more controlled by humans today than in the past. These results indicate that different management strategies of the same taxon can produce isotopically discriminating values.

### Zoo-isotopic Study Comparison

The two comparative studies I choose were conducted by Szpak and colleagues (2014) and Finucane and colleagues (2006). These two archaeological studies take place in different regions of the Peruvian Andes, but both utilize stable isotope analysis of faunal collagen remains to answer research questions regarding diet and human-animal interactions. These studies were directly focused on creating dietary baseline isotopic data and selected samples of plants and animals that were local and showed evidence of strong anthropogenic ties. Comparing faunal samples from the northern highlands of Peru with other zoo-isotopic studies in the Andes can be somewhat problematic, considering the different geography and small sample sizes. However, little research has been done on the fauna isotopic complexity and variation on the eastern montane of the Andes, so even small preliminary investigations are worthwhile and provide insights on isotopic variation in the archaeological record. The biplot in Figure 20 of the Kuelap faunal means and standard deviations (seen in the results chapter) will be used as a framework to compare other zoo-isotopic studies and their interpretations to the samples from Kuelap.

## Archaeological and Modern Camelids of the Northern Peruvian Coast

Szpak and fellow researchers (2014; 2015; 2016) have focused on using camelid bone, teeth, and hair to better understand the life histories and economic, social, and ritual significance of these animals in ancient coastal Andean culture. Szpak and colleagues (2014) compared bone collagen samples of archaeological camelid groups from the Virú Valley on the north coast of Peru with modern camelid samples from the highlands of northern Peru on the western slope of the Andes.

These researchers found that the archaeological camelids ( $n = 124$ ) on the coast had  $\delta^{13}\text{C}$  values ranging between  $-19.0$  and  $-12.0$  ‰ ( $-24.0$  and  $-17.0$  ‰ adjusted-for-fractionation). Because these animals have a large isotopic variability between the known  $\text{C}_3$  and  $\text{C}_4$  isotopic ranges (Figure 25), they are inferred to have mixed diets consisting of a variety of plants. While some archaeological camelids have enriched carbon values, their study's modern camelid sample displays low  $\delta^{13}\text{C}$  values between  $-20.0$  and  $-17.0$  ‰ ( $-25.0$  and  $-22.0$  ‰ adjusted-for-fractionation), which is consistent with a primarily  $\text{C}_3$  plant diet from pastures, as expected by the contemporary management strategies.

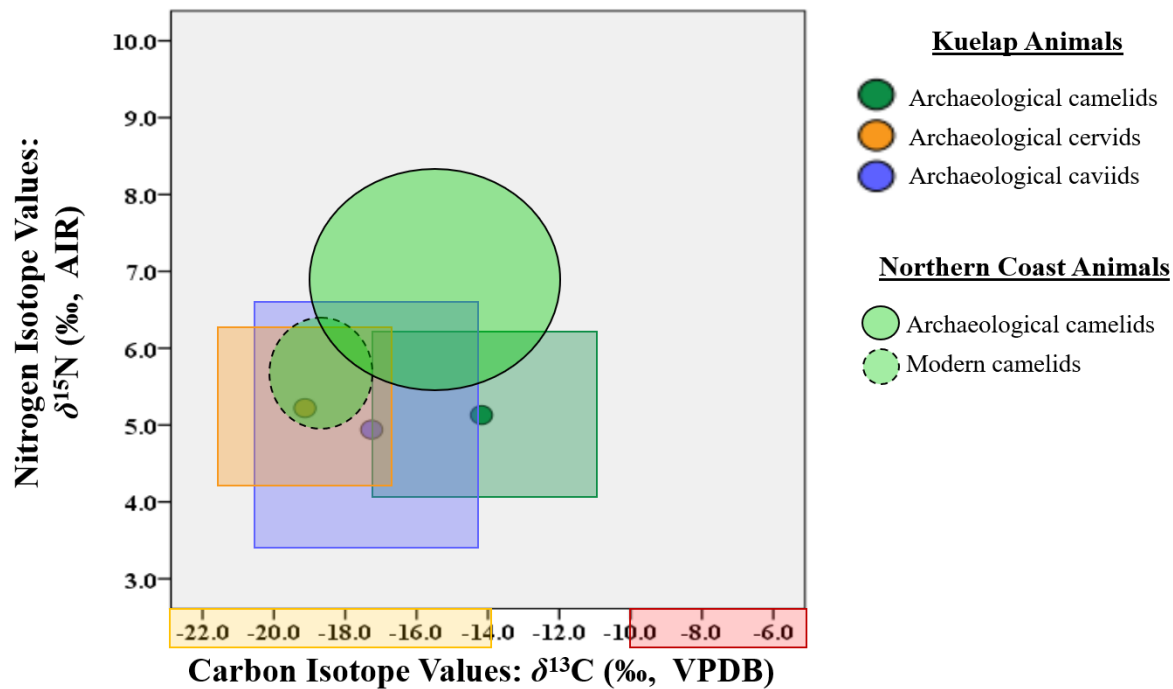


Figure 19. Biplot of Kuelap camelid, cervid, and caviid standard deviations and mean (shown as filled boxes) compared to the north coast sample of camelids from Szpak et al. (2014) study (shown as green circles).

The modern highland camelids isotopically reflected a diet of mostly  $\text{C}_3$  plants, but the coastal camelids isotopically reflected a large variety of local terrestrial vegetation, even though vegetation on the desert coast is sparse. Szpak et al (2014:125) states, “Given the relative dearth of wild vegetation [on the northern coast], the maintenance of local camelid herds would almost certainly have required camelid diets be supplemented by agricultural products and/or byproducts”. Szpak et al. (2014:123-124) suggest that the coastal camelids groups may have larger isotopic variation due to humans utilizing a smaller-scale herd management strategy. In smaller social units, the camelid groups would have been herded, raised, and foddered by different owners using different management strategies and would lead to higher intra-individual variation.

The archaeological camelids from Virú Valley are stated to have high levels of inter-individual isotopic variation for both carbon and nitrogen results. The carbon and nitrogen isotopic variation in the Kuelap archaeological camelids, however, is even higher with carbon values exceeding both the most enriched and depleted Virú Valley samples by 2 ‰ (Figure 19). The one modern camelid from Kuelap displayed a slightly enriched  $\delta^{13}\text{C}$  value of  $-16.21$  ‰ ( $-21.21$  ‰ adjusted-for-fractionation) compared to the nine modern camelids from Szpak et al.'s (2014) study, but is in the same  $\delta^{15}\text{N}$  range (supporting a herbivorous diet as observed and expected).

Small-scale herding may have attributed to the large isotopic variation of camelids at Kuelap, but I am not as confident in this interpretation since there is much more natural vegetation at Kuelap for the animals than on the sparse desert coast where humans would have had to intervene to keep the animals alive. The desert environment also explains the enriched nitrogen values presented by the coastal camelids compared to the nitrogen values of the highland camelids.

#### Archaeological Camelids and Caviids in Southern Peruvian Andes

Another study located in the central Andean highlands of southern Peru, at the Wari site of Conchopata, investigated human and animal diet patterns to see if there was evidence for maize agriculture and animal management practices during the Middle Horizon period (AD 600-1350) (Finucane et al., 2006). Animals in their study included Camelidae and Caviidae.

Finucane and colleagues (2006) found that the archaeological camelids from Conchopata had carbon isotope values that split into two distinct groups;  $\delta^{13}\text{C}$  (‰) enriched and  $\delta^{13}\text{C}$  (‰)



depleted, which can be seen in Figure 20. The enriched group (n = 11) had a mean  $\delta^{13}\text{C}$  value of  $-10.4\text{‰}$  and the depleted group (n = 6) had a mean  $\delta^{13}\text{C}$  value of  $-17.9\text{‰}$ .

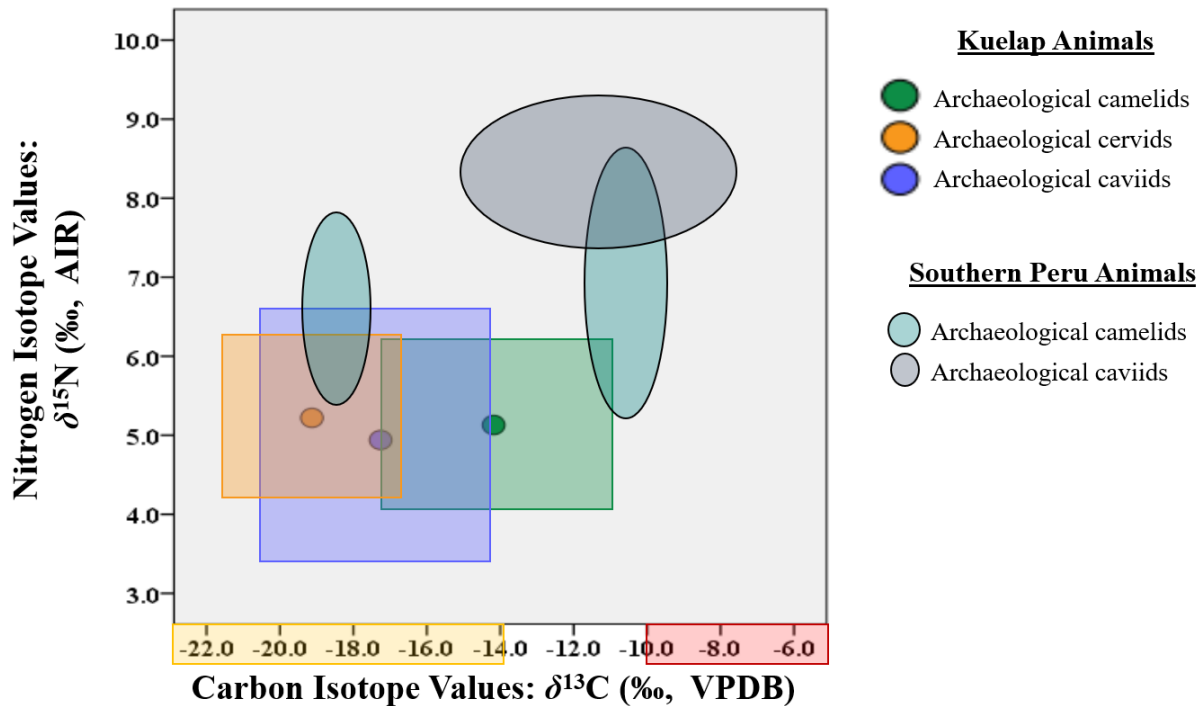


Figure 20. Biplot of Kuelap camelid, cervid, and caviid standard deviations and mean (shown as filled boxes) compared to the southern Peruvian highland camelids and caviids from Finucane et al. (2006) study (camelids as teal circles and caviids as gray circle).

These researchers suggest two different forms of camelid management strategies were likely taking place at the site. These two strategies would have taken place in two different ecological zones, the *puna* and the *quechua*, with Conchopata located just below 4000 m.a.s.l.

The first animal management strategy supported by the carbon depleted camelids suggests a majority of their diet came from wild  $\text{C}_3$  plants.  $\text{C}_3$  plants would have been grazed upon by the camelids on the *puna* pasture after being herded and restricted to that ecological zone. The second management strategy suggests that the  $^{13}\text{C}$  enriched camelid values indicate that these animals were interacting with humans in an urban context and were being foddered

with maize (a C<sub>4</sub> domestic crop) in the *quechua* zone. Finucane and colleagues (2006) argue that these results indicate that the animals' foraging habits were constrained by humans, which led to dietary restrictions and the exclusion of the wild occurring C<sub>3</sub> plants.

Additionally, the researchers in the Conchopata study considered the ecological and domesticated differences between species of camelids (llama and alpaca) and discussed how the depleted carbon values of the positively identified alpaca could be due to humans regulating animal movement and keeping them in the colder *puna* zone to produce better quality wool (Finucane et al., 2006: 1772). Meanwhile, the llamas were used by humans more as a food source and utility, so were kept near the domestic complexes and agricultural areas. The researchers suggest that carbon stable isotope analysis is a possible avenue for differentiating between camelid species in the archaeological record when skeletal evidence is not present. It is possible that the four depleted camelid Kuelap outliers are alpaca species, while the majority of the sample may be llamas living in an agro-pastoral complex in the *quechua* zone.

Camelids from Kuelap do not fit into either of the animal management strategies suggested by Finucane and researchers (2006). Instead, the camelids from Kuelap show one group (right in-between the Conchopata camelid groups in Figure 26) with large variation suggesting an animal management strategy that involved camelids at both the *puna* (C<sub>3</sub> plant abundant) and *quechua* (near urban context with some C<sub>4</sub> plants) zones. Corralling or restricting Camelidae grazing may have led to greater consumption of C<sub>4</sub> plants, such as maize, but the possibility that unconfined camelids could have consumed wild C<sub>4</sub> plants in the Chachapoyas region should not be disregarded.

Finucane and researchers (2006) also have 15 caviids in their study, which show enriched carbon and nitrogen values.  $\delta^{13}\text{C}$  values for the Conchopata caviids range between  $-18.6$  to  $-6$  ‰

–23.6 –11 ‰ adjusted-for-fractionation), while  $\delta^{15}\text{N}$  values range between +6 and +10 ‰ (+3 to +7 ‰ adjusted-for-fractionation). Seven of the caviids had carbon values enriched in the  $\text{C}_4$  plant range, and eight were depleted more than –18.6 –11 ‰ (–23.6 –16 ‰ adjusted-for-fractionation). This study's caviid sample had a wide variation and range, like the Kuelap caviids, again suggesting the consumption of a variety of  $\text{C}_3$  and  $\text{C}_4$  plants, kitchen or vegetational waste provided to them by the humans. The caviids from the southern Peruvian highlands are much more enriched in carbon-13 than the Kuelap sample, indicating that  $\text{C}_4$  plants (like maize as they suggest) may have played a much larger role in the households at this site than at Kuelap.

### Life at Kuelap

For archaeological interpretations of isotope ratios from past humans to be accurate, the results must be evaluated relative to the baseline variation of bioavailable carbon and nitrogen compositions from local sources such as fauna or plants, especially the taxon that humans would be consuming. This study provides a start towards understanding the baseline variation at Kuelap and the greater Chachapoyas region.

Results indicate that the Kuelap cervids (deer), caviids (guinea pigs), wild rodents (chinchillid and cuniculid – viscacha and paca), and the felid all have depleted carbon values consistent with a diet of  $\text{C}_3$  plants (or in the case of the cat, a diet of animals who had exclusively  $\text{C}_3$  plant diets).  $\text{C}_3$  plant material commonly consumed by humans and animals in the Chachapoyas region of Peru would have come from the *quechua* and *yunga* ecological zones include domesticated and wild tubers, legumes, and quinoa cereals. Maize, kiwicha, and other high-altitude  $\text{C}_4$  grains (either cultivated or wild) are also present in these zones on the eastern montane of the Central Andes, which can lead to enriched carbon isotope values (Turner et al.,

2010). The Kuelap camelids (llama/alpaca), canids (fox/dog), leporid (rabbit), and Aves (birds) produced enriched carbon isotope values which indicate that C<sub>4</sub> plants (most likely wild, but possibly maize) supplemented the diet of these animals more than the other taxa in this study.

The sample's depleted nitrogen values associated with the C<sub>3</sub> and C<sub>4</sub> plant foods suggests that animals in the Chachapoyas region had a diet consisting of mostly plant protein and some small amounts of animal protein. The depleted nitrogen values (especially in the carnivores) are interesting considering the large amounts of faunal remains present in the domestic refuses of the archaeological site. The quantity of material suggests that animal protein resources were present and available for consumption in the region. Lower nitrogen values in future human studies may indicate low volumes of animal protein represented in the past human diet at Kuelap, even though taxa such as those in this thesis are commonly found in domestic contexts at most archaeological sites in the region (Toyne et al., 2017).

This preliminary zoo-archaeological dataset provides the first insights into how past animals at Kuelap survived in the central Andes and what kind of interactions they had with the Chachapoya culture. The stable isotope results from this study indicate that there were many types of human-animal interactions occurring at Kuelap between AD 600 and 1535. These interactions influenced the diet and mobility of local wild and domesticated species and therefore influenced the isotopic composition of their bone collagen. By herding or corralling animals into certain ecological zones, the humans created isotopically distinct signatures from which local variation in the Chachapoyas region can be evaluated. These results support the utility of stable isotope analysis to the anthropological perspective of diet and human-animal interactions.

## Chapter Summary

This dataset provides evidence for the consumption of C<sub>4</sub> plants at 3000 m.a.s.l. indicating that while maize may not have been widespread throughout the Chachapoyas region, there were still prevalent C<sub>4</sub> plant materials being consumed by fauna in the Central Andes. The isotopic dataset produced from the Kuelap faunal remains also present lower nitrogen values than expected, especially considering the apex predators and large biodiversity present in the Chachapoyas region. The next section of the chapter compared Kuelap's dataset with two other faunal isotope studies in Peru. By investigating variation and comparing results to others in the region, stable isotope analysis has proven its utility in discovering patterns and providing insights on the life of animals and humans in the past.

## CHAPTER SIX: CONCLUSION

The goal of this thesis was to use stable isotope analysis to improve our understanding of the isotopic composition, variation, and human–animal interactions in the past Chachapoyas region of Peru. Carbon and nitrogen stable isotope values were generated through the analysis of bone collagen extracted from faunal bones excavated from the archaeological site of Kuelap. Dietary regimes and local variation for different taxonomic families was determined through the statistical analysis of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values, and animal management/subsistence strategies were estimated to help provide a new perspective on life in the past in the Chachapoyas region. These results support that stable isotope methods can be used on faunal remains to find evidence for human influences on animal collagen isotopic composition. Anthropologists can gain many insights about animal management strategies and the local diet by including stable isotope analyses in their archaeological investigations.

### Overall Findings

These results present a number of novel findings that require more work. Domesticated camelids made up a majority of the faunal sample from Kuelap and have been found to be invaluable assets to the Andean humans in the past. While subsisting on mostly  $\text{C}_3$  plants, the camelids displayed a wide range of carbon ( $\delta^{13}\text{C}$ ) values, with a large variation that could be due to management practices held by humans or species behavior variation. The enriched carbon values of the camelids indicate that  $\text{C}_4$  plants (either wild or domesticated) did supplement their diet more than other species in the sample. The wide variation is likely due to the influence humans had on mobility of camelids, either by corralling them in certain locations or by using

them as pack animals across many ecological zones. Cervids displayed isotope results suggesting most of their diet consisted of C<sub>3</sub> plants. Outliers of these two taxonomic families can be explained by a number of reasons, but their convenient alignment with the mean values of one other open up the possibility that the zooarchaeological samples could have been misidentified. Using the theory of Finucane and colleagues (2006), the camelid outliers could also represent some of the first archaeological evidence of alpacas in the region during this pre-Columbian period.

The domesticated archaeological caviids had a carbon isotope range almost as large as the camelids, but a nitrogen range 3 ‰ larger due to the large outliers present in the subsample. Two of these outliers had extremely enriched nitrogen values, which was unexpected for this supposedly strict herbivore. These results fully support the hypothesis that since the domesticated guinea pigs were being corralled and raised in households, their diet of kitchen scraps would be represented by a large isotopic variation. This subsample is very valuable towards understand human diet and subsistence strategies at Kuelap, since caviids were a major food source for the humans and also may have eaten “leftovers” from the human domestic refuse. The results indicate that the humans at Kuelap had many different types of food sources from which their diet relied on, leading to the large variation seen in this study. On the other hand, the five modern caviids (guinea pigs) had a very low variation for both carbon and nitrogen results and subsisted on C<sub>3</sub> grasses. The subsample in this thesis proved that stable isotope analysis has the ability to distinguish between different animal management strategies, as seen in the statistical differences between the modern and archaeological caviid groups.

The chinchillid, cuniculid, and leporid (wild rodents and rabbit) also expressed enriched nitrogen values, which again was unexpected for the typical diet of only plant material. The wet

cloud forest climate could have great influence on the nitrogen values of these animals, as well as any physiological differences. It is suggested in this thesis that perhaps coprophagy may play a direct role in nitrogen fixation and excretion in these types of animals, although limited research in these specific animals also makes isotopic interpretations difficult.

One of the most interesting results of this research was the lack of nitrogen enrichment in the high-end carnivores. The two types of carnivores in this thesis displayed different very different carbon isotope results. The puma (felid) likely consumed animals that ate  $C_3$  plants exclusively, while the foxes/dogs (canids) displayed enriched carbon values indicating a diet of animals or plants that display  $C_4$  isotopic signatures. Both carnivore families expressed nitrogen values that are less than the viscacha, paca, and some guinea pigs. This is odd, considering those animals listed are some of the most preferred choices of prey, however again, the climate and physiology could explain the depleted nitrogen values seen in the results. Three small birds were also included in the dataset, although taxonomic family or species could not be identified. These small birds displayed isotope results that suggest their diet consisted of mixed plants and insects. Overall, these results provide distinct values and variation that can be expected and compared at Kuelap in future isotopic studies.

### Limitations and Future Directions

Perhaps the largest limitation of this thesis is the small, unequal sample sizes and the lack of strict chronological control. A collection of faunal remains with large and equal sample sizes between taxonomic groups would allow researchers to statistically compare more groups in a reliable manner. Comparisons can be made between groups such as large- and small-bodied mammals, herbivores and carnivores, and wild and domesticated species. More clearly dated



archaeological material would also allow for comparisons across different occupational period at Kuelap.

Further zooarchaeological investigations at Kuelap would also prove to be productive towards understand human diet at Kuelap. The sample numbers represented in this thesis do not necessarily represent the amount of fauna that would have been available to humans in the past. For example, caviids likely made up a much larger portion of the animals consumed and disposed of at Kuelap than this thesis sample would suggest, however they are not the majority of the sample. This is likely due to diagenesis and the loss of material remains (often of smaller elements) over time. Regardless of the taxonomic limitations, these samples have distinct values and variation that are useful for understanding isotopic variation and trophic levels.

Isotopic variation can be driven by many different reasons. Access to forage (whether it is from domesticated agricultural produce or wild plants), individual animal diet and environmental preferences can be highly variable (Emmons, 1990; Emmons and Feer, 1997). Little research has been conducted on the isotopic behavior of many of the fauna included in this thesis, making the comparisons and interpretations sternly preliminary. Like Toyne and colleagues (2017) suggest, further testing of floral samples from the eastern montane is necessary to better understand the isotopic range and distribution present in the available plant resources present across the Chachapoyas landscape.

Human behavior and domestication practices can also greatly influence the diet and mobility of animals, which lead to changes in isotopic composition and variability as seen in this study. Contextual details such as the specific location at the site from which the remains were recovered could be evaluated in the future to see if there are any patterns or correlations present in different domestic or refuse contexts. Further research in all of these areas would provide

more confidence in local baselines, which would allow researchers to make more anthropologic interpretations by using the known isotopic behavior, variation, and patterns present at Kuelap.

### Kuelap Animals' Contribution to Anthropology

Like Szpak and colleagues (2014) did in their study, I expanded this isotopic study to investigate dietary variation, rather than just composition, and to demonstrate how human–animal interactions can be assessed using stable isotopic data. This study confirms that humans were modifying their environment (by growing and consuming C<sub>4</sub> plants in volumes that they do not typically grow at such elevations) and influencing the diet and mobility of local animals. This preliminary zooarchaeological dataset provides the first line of evidence and perspective into how past animals at Kuelap survived in the central Andes and what kind of interactions they had with the Chachapoya humans and culture.

**APPENDIX I:  
COLLAGEN QUALITY INDICATORS**

Lab ID	Collection	Collagen Yield (%)	Cwt%	Nwt%	C/N Ratio
Camelidae					
K-A01	arch	4.85	46.03	16.26	3.28
K-A02	arch	12.07	46.47	16.48	3.27
K-A03	arch	8.67	46.37	16.28	3.30
K-A07	arch	14.73	46.63	16.37	3.30
K-A08	arch	7.65	42.60	14.93	3.31
K-A09	arch	12.60	44.80	15.70	3.31
K-A11	arch	18.66	46.71	16.41	3.30
K-A12	arch	24.31	45.77	16.51	3.22
K-A16	arch	13.45	44.69	16.01	3.24
K-A18	arch	6.77	44.22	15.58	3.29
K-A19	arch	7.25	45.78	16.06	3.31
K-A21	arch	6.80	44.72	16.14	3.21
K-A28	arch	4.87	43.62	15.63	3.24
K-A29	arch	5.44	36.56	13.20	3.21
K-A30	arch	5.28	44.41	15.88	3.24
K-A31	arch	3.95	43.92	15.55	3.28
K-A34	arch	9.52	45.94	16.54	3.22
K-A35	arch	3.49	44.10	15.66	3.27
K-A37	arch	9.97	45.15	16.04	3.27
K-A38	arch	7.30	41.80	15.01	3.23
K-A39	arch	10.09	44.51	16.22	3.18
K-A40	arch	13.62	44.25	16.17	3.17
K-A42	arch	12.27	46.54	16.83	3.21
K-A43	arch	11.67	46.72	16.83	3.22
K-A45	arch	7.04	43.40	15.73	3.20
K-A46	arch	6.22	44.24	16.05	3.20
K-A50	arch	8.41	46.67	16.91	3.20
K-A52	arch	3.56	43.74	15.90	3.19
K-A54	arch	12.20	47.05	17.00	3.21
K-A55	arch	15.19	44.75	16.17	3.21
K-A56	arch	8.93	44.22	16.13	3.18
K-A59	arch	13.56	43.00	15.31	3.26
K-A62	arch	20.15	46.57	16.92	3.19
K-A64	arch	12.94	47.03	17.19	3.17
K-A66	arch	6.79	47.07	17.02	3.21
K-A67	arch	12.36	47.07	16.98	3.22

K-A68	arch	4.73	37.19	13.28	3.25
K-A69	arch	2.53	44.18	15.87	3.23
K-A70	arch	5.75	43.04	15.49	3.22
K-A71	arch	19.77	47.31	17.25	3.18
K-A101	arch	11.91	45.54	16.29	3.24
K-A103	arch	13.71	46.52	16.78	3.22
KLL	modern	18.22	47.01	17.01	3.21
Cervidae					
K-A06	arch	22.71	47.35	16.51	3.33
K-A17	arch	5.90	41.25	14.41	3.32
K-A20	arch	5.81	41.94	14.92	3.26
K-A27	arch	6.20	43.74	15.67	3.24
K-A32	arch	15.57	44.87	16.07	3.24
K-A44	arch	5.03	42.86	15.53	3.20
K-A47	arch	18.99	46.34	16.90	3.18
K-A65	arch	6.08	46.48	16.73	3.22
K-A102	arch	10.01	45.97	16.52	3.23
Caviidae					
K-A10	arch	11.87	44.74	15.57	3.33
K-A13	arch	7.56	44.89	15.72	3.31
K-A14	arch	10.54	45.16	15.73	3.33
K-A15	arch	7.48	44.16	15.38	3.33
K-A22	arch	15.32	44.60	16.28	3.18
K-A23	arch	11.55	44.22	15.95	3.22
K-A24	arch	12.19	44.04	15.94	3.20
K-A25	arch	12.87	44.16	16.11	3.18
K-A26	arch	19.51	44.10	15.61	3.28
K-A33	arch	15.33	46.03	16.90	3.16
K-A36	arch	9.51	45.32	16.42	3.20
K-A48	arch	16.06	45.69	16.45	3.22
K-A58	arch	15.61	46.14	16.63	3.22
K-A61	arch	18.61	46.44	16.90	3.19
MA1	modern	14.19	46.64	16.98	3.19
MA2	modern	12.47	47.32	17.12	3.21
MA3	modern	12.43	47.02	16.97	3.21
MA4	modern	15.42	45.93	16.78	3.18
MA5	modern	14.63	47.16	17.06	3.21
Chinchillidae (Viscacha)					
K-A41	arch	15.06	46.16	16.64	3.22

Cuniculidae (Mountain Paca)					
K-A53	arch	13.94	45.59	16.50	3.21
Leporidae (Rabbit)					
K-A05	arch	0.99	43.91	14.91	3.42
Felidae (Puma)					
K-A57	arch	19.80	45.82	16.58	3.21
Canidae (Dog or Fox)					
K-A51	arch	17.98	45.37	16.59	3.17
K-A60	arch	21.71	44.12	15.88	3.22
Aves (Small birds)					
K-A49	arch	20.05	46.12	16.60	3.22
K-A63	arch	17.21	46.18	16.84	3.18
K-A72	modern	14.84	47.50	17.07	3.23

**APPENDIX II:  
FIGURE 6 PERMISSION**



J. Marla Toyne

Sun 7/8, 9:49 AM

Samantha Michell



↻ Reply all | ▾

Dear Sam,

I give you permission to use the Kuelap plan figure in your thesis.

best

Dr. Toyne

\*\*\*\*\*

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