Title

Leporids, Landscapes, and Social-Environmental Dynamics in Arid North America : Stable Isotope Analysis of Rabbit and Hare Bones from Modern and Archaeological Sites

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Leporids, Landscapes, and Social-Environmental Dynamics in Arid North America: Stable Isotope Analysis of Rabbit and Hare Bones from Modern and Archaeological Sites

A dissertation submitted in partial satisfaction of the requirements for the degree
Doctor of Philosophy

in

Anthropology

by

Andrew D. Somerville

Committee in charge:

Professor Margaret Schoeninger, Chair
Professor Guillermo Algaze
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Professor Paul Goldstein
Professor Carolyn Kurle
Professor Ben Nelson

2015

The Dissertation of Andrew D. Somerville is approved and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

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Andrew D. Somerville, Melanie Martin, Lee Hayes, Philip Walker, Margaret Schoeninger. (In revisions) Exploring Patterns and Pathways of Dietary Change: Preferred Foods, Dental Health, and Dietary Isotope Ratios of the Mulia Dani, Papua, Indonesia. Submitted to *Current Anthropology*.

Kelly J. Knudson, Paul S. Goldstein, Allisen Dahlstedt, Andrew D. Somerville, Margaret J. Schoeninger. (2014) Paleomobility in the Tiwanaku Diaspora: Biogeochemical Analyses at Rio Muerto, Moquegua, Peru. *American Journal of Physical Anthropology* 155(3) 405-421.

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ABSTRACT OF THE DISSERTATION

Leporids, Landscapes, and Social-Environmental Dynamics in Arid North America:
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by

Andrew D. Somerville

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Professor Margaret Schoeninger, Chair

Environmental conditions provide significant constraints and opportunities for human behavior. Paleoenvironmental studies are thus an important component of archaeological investigations seeking to understand the organization, development and decline of past societies. This dissertation develops a method of paleoenvironmental research that uses stable isotope analysis of jackrabbit and cottontail (Leporidae) bones to quantify aspects of the landscapes in which they lived. The project then applies the technique to a sample of bones excavated from four archaeological sites in desert ecosystems of North America to obtain information about human-leporid and human-environmental relationships through time. Site locations include Pueblo Grande (Arizona, USA), La Ferrería (Durango, Mexico), La Quemada (Zacatecas, Mexico), and Teotihuacan (Mexico, Mexico). Results are explored across multiple temporal and spatial scales to refine the method and improve our understanding of the long-term dynamics of social-environmental systems within arid and semi-arid landscapes.

Results of baseline analyses on modern bones demonstrate significant correlations between stable oxygen isotope values and moisture variables (precipitation and humidity), and between stable carbon and nitrogen isotope values and temperature variables (min, max, and mean temperature), indicating the utility of leporids as paleoenvironmental proxies. Two primary conclusions result from analyses on archaeological specimens. First, results from La Ferrería leporids demonstrate changes through time suggesting a shift towards wetter conditions during the Las Joyas (AD 850-1000) phase, a period characterized by increasing population and new architectural construction. Importantly, these findings link social development in the region with environmental change. Secondly, results from Teotihuacan demonstrate rising carbon isotope values concomitant with the growth of the city, likely reflecting human modifications to the landscape, and falling carbon isotope values following its socio-political collapse. Notably, during the peak of population and complexity of Teotihuacan leporids from the residential complex of Oztoyahualco demonstrate significantly higher stable carbon isotope values than other contexts, supporting previous assumptions that residents there specialized in rabbit management or breeding. By using stable isotope values from jackrabbit and cottontail bones from modern and archaeological contexts, this dissertation improves our understanding of the baseline factors that influence bone isotope ratios and provides new information on the social-environment dynamics of the ancient New World.

CHAPTER 1: INTRODUCTION

Human societies affect and are affected by properties of the natural environment to such an extent that scholars across a range of disciplines now recognize the difficulty in drawing distinct boundaries between these realms. While decades of anthropological research have demonstrated strong associations between social and environmental factors, such as rainfall and human population density (Birdsell 1953), between ecological zones and culture areas (Kroeber 1947), and between climate change and social transformations (Kennett et al. 2012), an equally robust body of inquiry has demonstrated that such patterns are not deterministic, linear or predictable (e.g., Rosen 2007). Humans possess the ability to actively manipulate local environments in ways that alter their biotic and geomorphic properties (Redman 1999) - potentially increasing social resiliency or vulnerability - and these environmental impacts, in turn, can feedback and further alter human social institutions. Greater appreciation of the dynamic and entangled relationships between human societies and the environment has led many to consider the culture/nature binary to be unhelpful, and that integrative concepts such as "coupled human and natural systems" (Liu et al. 2007), "socioecological systems" (Redman 2005), or "naturecultures" (Haraway 2008) are more appropriate units of analysis.

By recognizing the importance of the environment to structuring and enabling human behavior, anthropological archaeologists are compelled to extend the scope of analyses past the site-level scale to include studies on broad networks of ecological relationships. Indeed, a recent trend in anthropology and the social sciences more broadly has been to adopt a "multispecies ethnography" (Kirksey and Helmreich 2010) that acknowledges the importance of human-animal and human-plant relationships within a given landscape (Haraway 2008; Tsing and the Matusutake Worlds Research 2009). Such perspectives emphasize that the subject of anthropological research ought to include beings “beyond the human” (Kohn 2013) and that situating human behavior within larger ecological contexts is essential to understanding more thoroughly the motivations and meanings behind observed actions and beliefs.

Archaeology can contribute to such a research agenda by adding a temporal perspective to human-plant and human-animal dynamics. Studies of past environmental landscapes of North America have benefited from a series of recent lake-core, tree-ring, and speleothem analyses, which have greatly enhanced our knowledge of the climate history throughout the Holocene (e.g., Bhattacharya et al. 2015; Hodell et al. 1995; Kennett et al. 2012; Metcalfe and Davies 2007; Stahle et al. 2011). Yet these proxies do little to inform our understanding of local environmental conditions that humans would have engaged with on a daily basis. How did exceptionally dry or wet periods affect human-plant and human-animal relationships? And how did such changes affect the structure and function of existing social and environmental dynamics? Complementing climatological proxies, methods of reconstructing aspects of past social-environmental landscapes at the scale relevant to specific settlements include studies on faunal remains, preserved pollen, macro-botanical samples, and geomorphology (e.g., Butzer 1982).

Additionally, a technique gaining popularity in European environmental archaeology and in paleontological research is stable isotope analysis of animal bones to quantify aspects of the environment in which the organisms lived (Hallin et al. 2012; Hedges et al. 2004; Schoeninger et al. 2003; Stevens et al. 2006). With few exceptions (e.g., Emery and Thornton 2008; Emery et al. 2000), similar methods have gone under-utilized in the archaeology of North America, despite the demonstrated utility of isotopic analyses in reconstructing aspects of past seasonality (Kohn et al. 1998), ecoregion type (Zazzo et al. 2000), climatic variables (Hedges et al. 2004), and trophic relationships between organisms (Minagawa and Wada 1984; Schoeninger and DeNiro 1984).

The aim of the dissertation chapters that follow is to further develop the use of stable isotope analysis of faunal bones as a method of reconstructing past social-environmental dynamics in arid and semi-arid environments, and to apply the technique to a series of archaeological sites. More specifically, this project evaluates the utility of the Leporidae (jackrabbits and cottontails) to serve as paleo-environmental proxies, and assesses the feasibility of using the human-leporid interface as a lens by which to explore past social-environmental landscapes. Leporids are a particularly attractive species to use as proxies as they were among the most commonly consumed mammals in pre-Hispanic North America and archaeological trash deposits often contain an abundance of their remains. Nevertheless, unlike static high-resolution records of paleoclimate such as tree rings or speleothems, leporids are themselves active agents within the landscape and their behaviors both influence and are influenced by the actions of humans. Each rabbit bone thus represents a calcified relationship between the hunter, rabbit, and the environment which sustained them both.

This dissertation attempts an in-depth assessment of the Leporidae as potential paleoenvironmental proxies through three analytical studies that range in scope from the continental scale to the level of an individual apartment compound. In the first analytical chapter (Chapter 2), results of stable isotope analyses of a broad sample of modern North

American jackrabbit and cottontail specimens are presented to develop our baseline understanding of how stable oxygen, carbon, and nitrogen isotope ratios of leporid bone tissue vary in response to a range of environmental variables, including temperature, moisture, and floral composition.

Chapter 3 builds off of this baseline research by applying stable isotope analysis to a sample of leporid remains recovered from excavations at three archaeological sites in desert environments: Pueblo Grande (Arizona, USA), La Quemada (Zacatecas, Mexico), and La Ferrería (Durango, Mexico). Drawing from methodological approaches of landscape ecology and historical ecology (Crumley 1994; Turner 1989) leporid isotope data from these centers are explored across two scales of analysis: a geographically demarcated spatial scale and a diachronic temporal scale. Landscapes are heterogeneous spaces, whether defined ecologically or socially, and display different properties when viewed at high-resolution local scales than when viewed at low-resolution regional scales; and an understanding of a landscape's structure, function, and change over time can diverge at alternate resolutions. After exploring leporid data at macro-regional (North America) and meso-regional (Northwest Mexico) scales, this chapter increases the granularity of analysis on the site of La Ferrería, situating local social-environmental dynamics within its broader geographic and temporal contexts.

In Chapter 4, leporid stable isotope data from Teotihuacan, the first urban state-level society of Mesoamerica, are presented in an attempt to reconstruct social-environmental interactions over the entire occupational history of the city. By concentrating on one site over a long temporal sequence, this chapter informs our understanding of the long-term dynamics of human-leporid relationship, and provides greater insight into Teotihuacanos' influence on the local environmental landscape. In particular, this chapter addresses previous assumptions concerning the nature of leporid management at the site, testing the hypothesis that rabbits were directly raised or bred through the specialized labor of humans during the height of the city.

By exploring the factors, social and environmental, that influence leporid stable isotope values this dissertation attempts to provide a new window to explore the entangled relationships between humans, plants, and animals within past social-environmental landscapes, and to investigate how such associations may have influenced the development and decline of particular human settlements. As all selected archaeological site locations represent desert environments this study ultimately aims to provide new information about the relationship between social change and aridity in the pre-Hispanic New World.

CHAPTER 2: CLIMATIC AND ENVIRONMENTAL INFLUENCES ON STABLE ISOTOPE RATIOS OF LEPORID BONES: IMPLICATIONS FOR ECOLOGICAL AND PALEOENVIRONMENTAL STUDIES

Introduction

Light stable isotope ratios of oxygen, carbon, and nitrogen derived from organic and inorganic tissues of animals are influenced by the properties of the environments in which they lived. As various genera have been demonstrated to exhibit isotopic correlations with local temperatures, humidity, precipitation, and floral composition, stable isotope studies are increasingly being utilized in ecological and paleoenvironmental research (Hedges et al. 2004; Koch 1998). The extent to which a particular animal proxy monitors environmental conditions, however, is influenced by the specific biology and behavior of the organism (e.g., Levin et al. 2006). Interpretations of such data must therefore consider each taxon according to its particular physiology, habitat use, and feeding ecology.

This study assesses the potential of using jackrabbits and cottontails (family Leporidae) as paleoenvironmental proxies. Specimens are commonly found in archaeological middens and are available in many museum collections, making them widely available for such studies and thus an attractive proxy taxon. Previous research on leporids suggests bone isotope values may reflect the environmental factors of relative humidity (Huertas et al. 1995), soil salinity (Ugan and Coltrain 2011), and the presence of grasslands (Smith et al. 2014). However, no broad, regional analysis has been conducted to explore such relationships in leporids, in contrast to large studies of marsupials (Ayliffe and Chivas 1990; Gröcke et al. 1997; Murphy and Bowman 2006; Pate and Anson 2008), deer (Cormie and Schwarcz 1996; Luz et al. 1990; Stevens et al. 2006), goats (Hartman 2011), and other mammals (Ambrose 1991; Heaton et al. 1986; Huertas et al. 1995).

This study analyzes a sample of 135 modern North American leporid bones from diverse environmental contexts across North America. Using interpolated multi-decade averages of climate and ecosystem data, each sample location is associated with local mean annual precipitation, relative humidity, and minimum, maximum, and average temperature. We isolate and analyze bone collagen for ratios of $^{13}C/^{12}C$ ($\delta^{13}C_{collagen}$) and $^{15}N/^{14}N$ ($\delta^{15}N_{collagen}$), and analyze bone mineral bioapatite for ratios of $^{13}C/^{12}C$ ($\delta^{13}C_{apatite}$) and $^{18}O/^{16}O$ ($\delta^{18}O_{apatite}$). To date this study represents the largest collection of leporid bones analyzed, and the first to simultaneously incorporate these four isotope variables. Because all climate data are interpolated, we consider our results conservative, likely underestimating environmental influences on bone isotope values. Nevertheless, significant correlations are observed between $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values and temperature, $\delta^{15}N_{collagen}$ values and temperature, and between $\delta^{18}O_{apatite}$ values and relative humidity and precipitation. These data enhance our capabilities to model extant ecological dynamics and, when combined with other paleoclimate and paleoenvironmental proxies, increase our ability to reconstruct paleoenvironments through fossil, archaeological, and curated museum specimens.

Principles of Stable Isotope Analysis and Paleoenvironmental Reconstruction

For mammals, $\delta^{18}O$ of structural carbonate (CO_3^{2-}) and phosphate (PO_4^{3-}) in bone hydroxyapatite ($\delta^{18}O_{apatite}$) are in equilibrium with $\delta^{18}O$ of body water (Bryant et al. 1996; Iacumin et al. 1996), which is principally influenced by $\delta^{18}O$ of consumed water (Longinelli 1984; Luz et al. 1984). Since oxygen isotope ratios of meteoric water are strongly influenced by temperature (Dansgaard 1964; Yurtsever and Gat 1981), animals that are obligate drinkers exhibit species-specific $\delta^{18}O_{apatite}$ correlations with ambient temperature (Huertas et al. 1995). Organisms that obtain water primarily through consumed vegetal material, however, exhibit $\delta^{18}O_{apatite}$ values that correlate negatively with relative humidity (RH), and not with temperature (Ayliffe and Chivas 1990; Levin et al. 2006), as leaf water is sensitive to evaporative enrichment of ^{18}O, and varies as a factor of RH (Burk and Stuvier 1981; Dongmann et al. 1974; Förstel 1978). Previous research on a small sample of European and African leporids suggests that oxygen stable isotope ratios in jackrabbit and rabbit bone are negatively correlated with local relative humidity as they acquire most water from leaves (Huertas et al. 1995). Our hypothesis is that we will find a similar relationship between $\delta^{18}O_{apatite}$ and RH, and also between $\delta^{18}O_{apatite}$ and mean annual precipitation (MAP), as RH and MAP are themselves strongly correlated.

Analyses from multiple precipitation gradients across the globe find that $\delta^{15}N$ values of soils, plants, and animals are consistently ^{15}N-enriched in warm and dry environments relative to cooler and wetter zones (Ambrose 1991; Amundson et al. 2003; Aranibar et al. 2004; Hartman 2011; Heaton et al. 1986; Murphy and Bowman 2006; Pate and Anson 2008; Sealy et al. 1987). Open systems, which tend to be warm and dry, are more susceptible to ^{14}N depletion in soils through mineral leaching, and by fractionation processes of denitrification and ammonia volatilization which lead to higher δ^{15}N ratios in soils and plants (Amundson et al. 2003; Austin and Vitousek 1998; Martinelli et al. 1999; Shearer and Kohl 1986). In contrast, closed systems that tend to be wet and cool conserve and recycle mineral N more efficiently, leading to lower δ^{15}N values in soil and plants. Herbivore $\delta^{15}N_{collagen}$ values are determined by plant δ^{15}N values (DeNiro and Epstein 1981; Murphy and Bowman 2006) and thus $\delta^{15}N_{collagen}$ values often vary between open and closed ecosystems. Studies on Australian macropods (Murphy and Bowman 2006; Pate and Anson 2008) and eutherian mammals of Africa (Heaton et al. 1986), however, found the relationship between moisture and $\delta^{15}N_{collagen}$ to be nonlinear, with the highest $\delta^{15}N_{collagen}$ values occurring in regions with less than 400 mm of precipitation per year.

Variables such as soil salinity and local topography also have a strong influence on plant and bone δ^{15}N values, particularly in xeric environments, which may confound the use of δ^{15}N as a measure of MAP or temperature if sample locations span diverse terrains (Hartman 2011; Hartman and Danin 2010; Ugan and Coltrain 2011). Previous studies on North American leporidae have found no evidence for a relationship between $\delta^{15}N_{collagen}$ and local temperature or precipitation, but showed that soil salinity had a stronger effect on bone values (Ugan and Coltrain 2011). Our study explores whether broadening the sample reveals relationships between leporid $\delta^{15}N_{collagen}$ and environmental and climatological conditions that have gone undetected in previous studies.

Mammalian bone and enamel δ^{13}C values are primarily influenced by the relative proportions of C_3, C_4, and crassulacean acid metabolism (CAM) plants in an organism's diet (DeNiro and Epstein 1978; Schoeninger and DeNiro 1984). C_3 plants include most plants on earth, including temperate shrubs, forbs, trees, and leguminous species, and have average δ^{13}C values of -26.5‰. C_4 plants are primarily dry-adapted grasses with average δ^{13}C value of -12.5‰. CAM plants include arid-environment cacti and succulents and have δ^{13}C values that overlap substantially with C_4 plants (O'Leary 1988; Smith and Epstein 1971). In contrast to C_3 plants, C_4 and CAM plants thrive in environments characterized by low moisture, warm temperatures, and long periods of sunlight (Ehleringer 1978; Stowe and Teeri 1978; Tieszen et al. 1979). Stable carbon isotope ratios in bone collagen ($\delta^{13}C_{collagen}$) and bioapatite ($\delta^{13}C_{apatite}$) both monitor dietary inputs, but $\delta^{13}C_{collagen}$ is biased towards the δ^{13}C of dietary protein, while $\delta^{13}C_{apatite}$ is composed of carbon atoms from all macronutrient sources (Ambrose and Norr 1993; Froehle et al. 2010; Howell 1999; Krueger and Sullivan 1984; Lee-Thorp et al. 1989).

Additionally, due to higher foliar CO_2 assimilation to transpiration ratios (A/E) in xeric conditions, even C_3 plants display higher δ^{13}C values during droughts and in arid environments than in cooler and wetter locations or times (Kohn 2010; Sternberg et al. 1984). This variation can be observed across individual days, seasons, and years (Farquhar et al. 1982; Garten and Taylor 1992). Moreover, C_3 plants from closed canopy forest environments are more depleted than C_3 plants from open habitats, due to plant recycling of ^{13}C-depleted CO_2 released from soil respiration (van der Merwe and Medina 1991; Vogel 1978). Thus, even within entirely C_3 environments, plant and hence animal tissues reflect environmental changes through shifting δ^{13}C values (Schoeninger et al.

1998). This study tests the hypothesis that, in addition to monitoring the contribution of C3, C4, and CAM plants in leporids diet, δ^{13}C values will also reflect properties of the local climate or environment such as precipitation, temperature, and ecoregion type.

Leporidae Evolution and Ecology

Together with the pika family (Ochotonidae), the Leporidae belong to the Lagomorpha order, which originated in North America during the Pliocene epoch (Ge et al. 2013). A radiation of leporids occurred during the late Miocene (~ 8 mya) when they spread from North America to much of Eurasia and into Africa (Flynn et al. 2014), likely due to the spread of C_4 grasslands (Ge et al. 2013). Extant North and Central American leporid genera include jackrabbits (*Lepus* spp.), cottontails (*Sylvilagus* spp.), pygmy rabbits (*Brachylagus idahoensis*), and the volcano rabbit (*Romerolagus diazi*). Because *Brachylagus* and *Romerolagus* are relatively rare, this study focuses on *Lepus* and *Sylvilagus*. Both genera are common through large portions of North and Central America.

Leporids are relatively short lived mammals, rarely living more than three years and usually less than one (Lechleitner 1959; Rose 1977). Due to litter sizes of 2-6 young and gestation periods of about 28 days for cottontails and about 43 days for jackrabbits, leporid populations are able to withstand significant predation. In fact, mortality rates among some communities reach 90% annually (Chapman and Flux 2008:4).

Jackrabbits and cottontails both occupy relatively small home ranges. Most stay within 1 km^2 for their entire lives. Jackrabbits typically inhabit areas between 20-140 hectares, grouping towards the smaller end of this range (Best 1996; Smith 1990; Vorhies and Taylor 1933), though some *Lepus* species have been documented traveling seasonally over 5 km between foraging locations (Smith et al. 2002). Cottontails inhabit smaller regions than jackrabbits, often under 5 ha and rarely larger than 10 ha (Bobby et al. 2001; Swihart 1986; Trent and Rongstad 1974). In general, *Lepus* prefers open and desert habitats (Flinders and Chapman 2003a) while *Sylvilagus* prefers habitats with more structure, including shrublands, shrub-woodlands, and areas with dense understory cover (Flinders and Chapman 2003b). These differential habitat preferences are related to behavioral differences in predator avoidance: jackrabbits outrun predators by sprinting over open ranges, whereas cottontails escape by hiding under cover. We expect leporid bone isotopic ratios in general to reflect environmental conditions within localized regions, and that *Lepus* and *Sylvilagus* signatures will monitor slightly different niches within them.

The genera have similar generalized foraging practices. As mixed feeders, both consume a variety of grasses, forbs, shrubs, and succulents, but the ratio of these plants in the diet varies by the time of year with the availability of seasonally green flora (Best 1996; Trent and Rongstad 1974; Turkowski 1975; Vorhies and Taylor 1933). Feeding occurs most actively near sunrise and sunset (Arias-Del Razo et al. 2011; Mech et al. 1966). Because of the wide range of plants consumed, and due to the fact that bone isotope values are considered to be lifetime averages, ratios derived from collagen and bioapatite are expected to represent various aspects of the local environment across several seasons, depending on the age of the specimen.

Behavioral and physiological adaptations of leporids to foraging in arid environments, such as urine concentration, urea conservation and coprophagy involve the flux of nitrogen through the body (Nagy et al. 1976), but we follow Ugan and Coltrain (2011) and assume these practices will not significantly confound $\delta^{15}N_{collagen}$ values.

Materials and Methods

Samples

The sample includes 135 leporid bones, consisting of 54 jackrabbits (*Lepus californicus*) and 81 cottontails (*Sylvilagus audubonii* and *Sylvilagus floridanus*) from multiple locations across the United States, Mexico, and Guatemala (Figure 1). Only adult individuals, determined by epiphyseal closure of long bones, are included in the sample. Specimens originate from nine separate ecoregions ranging from closed canopy tropical forests to open deserts. Forty six specimens were acquired from the mammalian collections of the Los Angeles County Natural History Museum (LACNHM), 70 were obtained from mammalian collections at the Smithsonian Institution's United States National Museum (USNM), and 19 were acquired from collections at the University of Texas, San Antonio Archaeological Center (UTSA).

In all cases, leporids were acquired by hunting near areas listed in Appendix I. Samples from LACNHM were collected during the middle of the 20th century, ranging from 1966 to 1975. SNMNH samples were collected between 1865 and 1985. UTSA specimens were collected between 1991 and 2009. Because our sample spans a period of

144 years, carbon isotope values are adjusted to compensate for the depletion of $^{13}CO_2$ in the atmosphere as a result of the burning of fossil fuels (Keeling 1979). Stable carbon isotope results ($\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$) from specimens collected between 1800 and 1910 were corrected by -1.5‰; between 1911 and 1959 by -1‰; between 1960 and 1980, by -0.75‰; between 1980 and 2000 by -0.25‰; and after 2000 no correction. In most cases, cranial fragments were selected for analysis, but when not available other skeletal elements were analyzed (Appendix I). Museum practices of defleshing and preserving specimens are not known. The integrity of bone collagen was assessed through atomic C:N ratios and percent of collagen yield after sample processing, with acceptable ranges of 2.9-3.6 (DeNiro 1985) and >1% (Ambrose 1990), respectively.

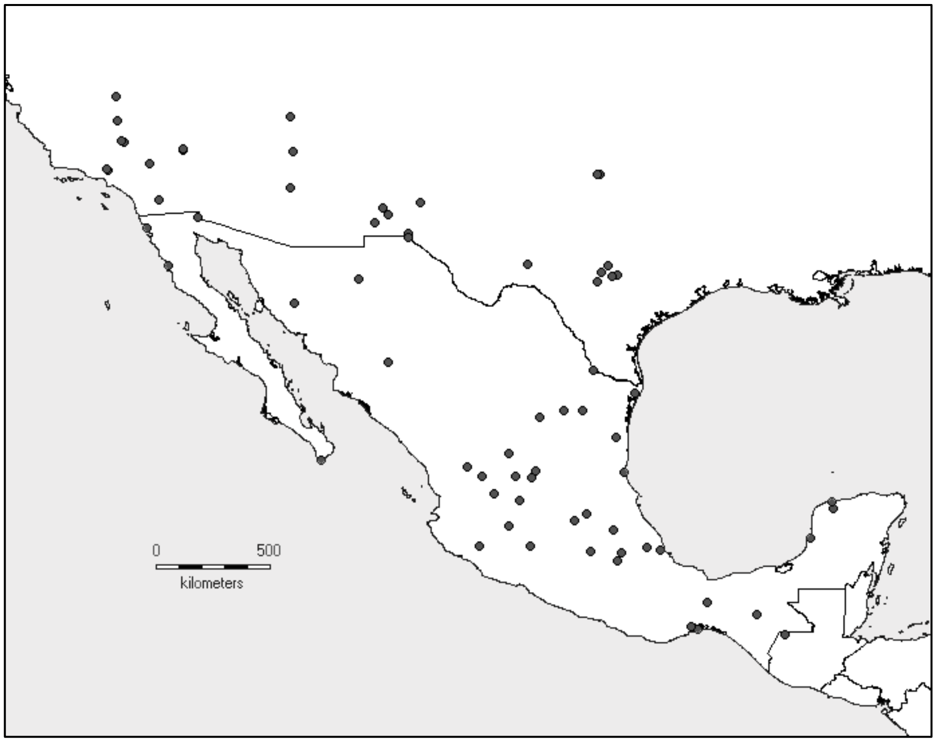

Figure 1. Map of locations of modern leporid specimens.

Laboratory Preparation

Preparation of bone bioapatite followed procedures similar to those of Koch et al. (1997). Samples were powdered, treated for 48 hours with 2% bleach (NaOCl) and 24 hours with 0.1M acetic acid (CH_3COOH), and rinsed with doubled distilled and deionized water after each treatment. Collagen preparation followed procedures similar to those of the whole-bone method described by Sealy et al. (2014). Bone samples were demineralized for several weeks with 0.25M hydrochloric acid (HCl), and humic acids were removed by a 24 hour treatment with 0.125M sodium hydroxide (NaOH). Collagen gelatin samples were solubilized in in pH 3 HCl at 75°C and lyophilized for 24 hours in a benchtop freeze dryer.

Stable isotope analyses of bone were conducted at the Scripps Institute for Oceanography's Analytical Facility. Analysis of structural carbonate was conducted on a Gas Bench Thermo MAT 253 coupled to a Thermo-Finnigan Delta XP Plus mass spectrometer. Nine months of recurring analysis of an internal CO_3 standard (N=35) calibrated to NBS-18 and NBS-19 resulted in reproducibility of ± 0.2‰ for both $\delta^{13}C$ and $\delta^{18}O$. Stable carbon isotope data are presented relative to the Pee Dee Belemnite (PDB) international standard, and stable oxygen isotope data are presented relative to the Standard Mean Ocean Water (SMOW). Isotopic analyses of $\delta^{13}C$ and $\delta^{15}N$ in collagen were performed on a Costech 4010 EA coupled to the Thermo-Finnigan Delta XP Plus mass spectrometer. Carbon isotope ratios are presented relative to the PDB international standard and nitrogen isotope ratios are presented relative to atmospheric $\delta^{15}N$ (AIR).

Replicates of an internal calibrated standard resulted in a reproducibility of ±0.2‰ for both δ^{13}C and δ^{15}N values.

Environmental Parameters

The independent variables of mean annual temperature (AvgTemp), maximum temperature of the warmest month of the year (MaxTemp), minimum temperature of the coldest month of the year (MinTemp), and mean total annual precipitation (MAP) averaged across the years of 1950-2000 were obtained from the WORLCLIM online dataset of interpolated climate data (Hijmans et al. 2005). Data layers were created by interpolating climate data from worldwide climate stations on a 1 km^2 resolution grid. Mean annual relative humidity (RH) was obtained through the NASA Surface Meteorology and Solar Energy (SSE) data set, available online as a shapefile, which averages 22 years of RH percentages (July 1983 - June 2005) at 10 m above the earth's surface. Leporids were assigned to nine separate terrestrial ecosystem types according to The Nature Conservatory's (TNC) spatial dataset (available online) and were coded with the following numbers: (0) Deserts and xeric shrublands [*Lepus* N = 38; *Sylvilagus* N = 28]; (1) Mediterranean forests, woodlands, and scrub [*Lepus* N = 8.]; (2) Temperate grasslands, savannas, and shrublands [*Lepus* N = 5; *Sylvilagus* N = 4]; (3) Tropical and subtropical broadleaf forests [*Sylvilagus* N = 3]; (4) Tropical and subtropical coniferous forests [*Sylvilagus* N = 27]; (5) Tropical and subtropical dry broadleaf forests [*Sylvilagus* N = 11]; (6) Tropical and subtropical grasslands, savannas, and shrublands [*Sylvilagus* N = 3]; (7) Tropical and subtropical moist broadleaf forests [*Lepus* N = 3; *Sylvilagus* N =

3]; (8) Mangroves [*Sylvilagus* N = 2]. All environmental parameters from the above datasets were determined for the locations in which leporids were sampled by using the Geographic Information Systems software, DIVA-GIS.

Statistical Analysis

All statistical analyses were performed in SAS 9.3 (SAS Institute Inc., Cary, NC) with α set to 0.05. To derive an overall picture of climate variation across the region sampled, relationships between climate and geographical variables in the sample were analyzed using Pearson's correlation coefficients. Relationships between climate variables and isotope values were also analyzed using Pearson's correlation coefficients across the entire sample (pooling the two genera), with significance levels adjusted for multiple comparisons (Holm-Bonferroni). Differences in climate and isotope variable means between the two genera were analyzed using two-sample t-tests. Climate variables that were significantly related to a given isotope were then included in multiple regression analyses to determine which environmental parameters were the most influential on values of each respective isotope. To test for taxon-level effects on regression relationships, genus was also included in all multiple regression analyses, with *Lepus* assigned a value of 0 and *Sylvilagus* assigned a value of 1. For each isotope variable, all possible combinations of relevant independent variables were tested and the regression parameters derived. The best fit model was determined on the basis of Akaike's information criterion (AIC), such that the combination of independent variables with the lowest AIC was chosen as the final model. Predicted isotope values plus/minus one standard error were then calculated for each genus (where genus was included in the final model) with the final model parameters and using climate variable means for each ecosystem type.

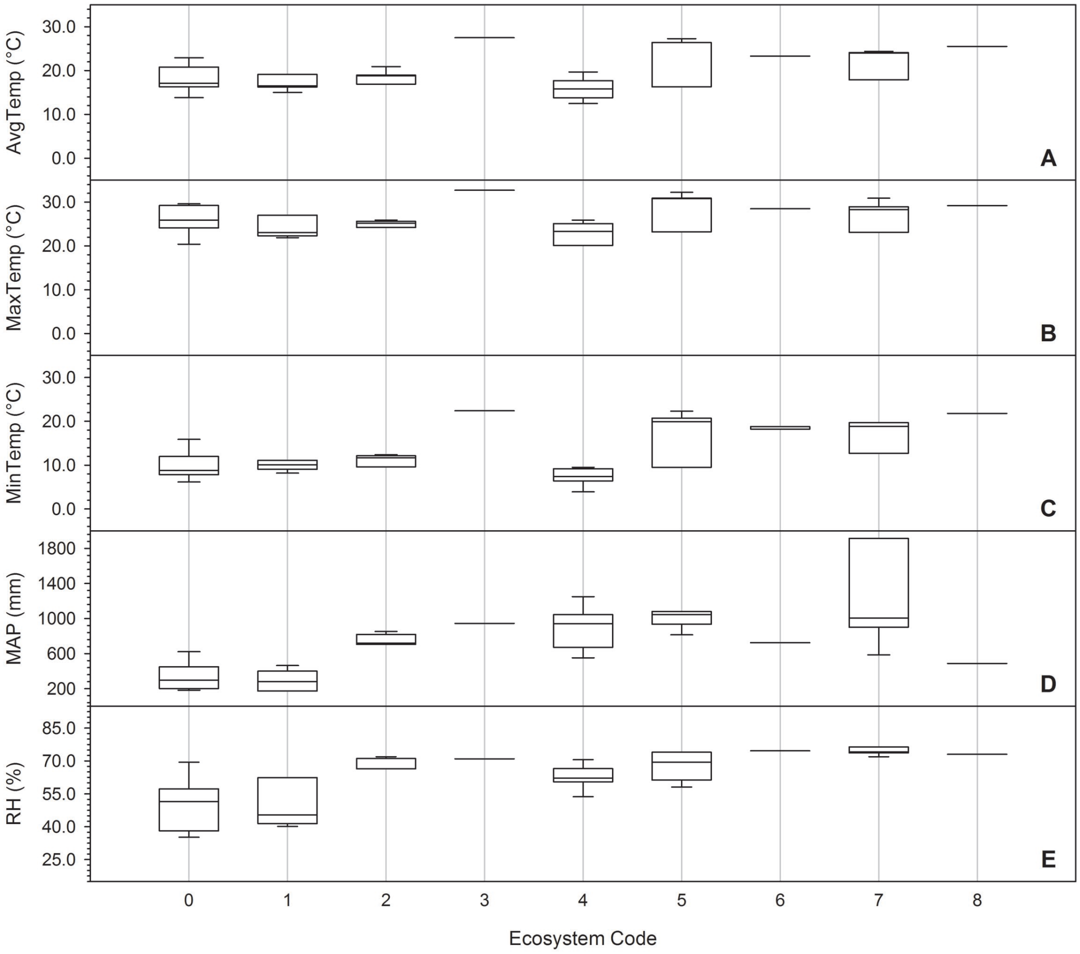

Figure 2. Climate variable distributions in the nine ecosystem types represented in the sample. Climate variables include mean annual temperature (AvgTemp; Figure. 2A), maximum temperature of the warmest month of the year (MaxTemp; Figure. 2B), minimum temperature of the coldest month of the year (MinTemp; Figure. 2C), mean total annual precipitation (MAP; Figure. 2D), and mean annual relative humidity (RH; Figure. 2E). See Methods for ecosystem codes and sample size by genus for each ecosystem.

Results

Geographic variables

The ecosystem types represented in the sample were all relatively similar in terms of temperatures, but varied considerably for rainfall and relative humidity (Figure 2). Despite similarities in temperature across sites, higher latitude sites were associated with colder temperatures, less rainfall, and less humidity (for each, $P < 0.01$), whereas sites from more western longitudes tended to be slightly cooler and drier (for each, $P < 0.05$; Table 1). Higher elevations were also associated with cooler temperatures ($P < 0.01$) and more rainfall ($P = 0.01$), but not with variation in humidity ($P = 0.52$). The two genera (*Lepus* and *Sylvilagus*) differed for geographic and climate variables (Table 2) such that the *Lepus* individuals in the sample came on average from more northern and western sites and from lower elevations ($P < 0.01$). The genera did not differ for means of any temperature variable, but *Lepus* tended to live in areas with less rainfall and lower humidity ($P < 0.01$).

Table 1. Pearson's correlation coefficients (r) between geographical and climate variables. AvgTemp = mean annual temperature; MaxTemp = maximum temperature, warmest month of year; MinTemp = minimum temperature, coldest month of year; MAP = mean total annual precipitation; RH = mean annual relative humidity.

	Longitude (°)	Elevation (m)	AvgTemp (°C)	MaxTemp (°C)	MinTemp (°C)	MAP (mm)	RH (%)
Latitude (°)	-0.77 **	-0.37 **	-0.32 **	-0.23 **	-0.30 **	-0.71 **	-0.71 **
Longitude (°)		0.19 *	0.31 **	0.19 *	0.34 **	0.75 **	0.84 **
Elevation (m)			-0.62 **	-0.59 **	-0.73 **	0.21 *	-0.06
AvgTemp (°C)				0.82 **	0.89 **	0.21 *	0.43 **
MaxTemp (°C)					0.82 **	-0.02	0.27 **
MinTemp (°C)						0.24 **	0.51 **
MAP (mm)							0.71 **

* $P < 0.05$

** $P < 0.01$

Isotope values by genus

Nineteen collagen samples were excluded due to C:N and percent yield values falling outside of acceptable ranges. Of these, most were from the Smithsonian's USNM collection and over 100 years old. One δ^{18}O value was excluded because it was an extreme statistical outlier, likely due to atmospheric water contamination of the sample. Pooling *Lepus* and *Sylvilagus*, the sample yielded mean values of $\delta^{18}O_{apatite}$ = 26.8 ± 2.8‰ (N = 131, 1 SD), $\delta^{13}C_{apatite}$ = -13.1‰ ± 2.9 (N = 132, 1 SD), $\delta^{13}C_{collagen}$ = -18.7 ± 2.7‰ (N = 115, 1 SD), and $\delta^{15}N_{collagen}$ = 5.9 ± 2.7‰ (N = 116, 1 SD).

Table 2. Geographical and climate variable descriptive statistics by genus

Variable*	*Lepus* spp. (N = 52)						*Sylvilagus* spp. (N = 81)					
	Mean	±	SD	Range			Mean	±	SD	Range		
Latitude (°)	29.4	±	5.1	(20.5	-	37.3)	23.2	±	5.9	(16.2	-	35.5) **
Longitude (°)	-108.1	±	6.9	(-118.4	-	-97.9)	-101.1	±	6.8	(-117.8	-	-89.6) **
Elevation (m)	933.0	±	718.4	(8.0	-	2291.0)	1353.0	±	977.4	(1.0	-	3454.0) **
AvgTemp (°C)	18.2	±	3.2	(10.6	-	24.1)	18.8	±	4.7	(7.4	-	27.6)
MaxTemp (°C)	25.6	±	2.6	(18.1	-	31.8)	25.7	±	3.9	(17.9	-	32.7)
MinTemp (°C)	10.4	±	4.1	(2.7	-	19.7)	11.3	±	5.3	(2.7	-	22.5)
MAP (mm)	365.7	±	237.5	(110.0	-	1006.0)	745.5	±	352.5	(165.0	-	1914.0) **
RH (%)	53.2	±	12.7	(34.2	-	74.2)	61.1	±	11.7	(34.9	-	76.4) **

* AvgTemp = mean annual temperature; MaxTemp = maximum temperature, warmest month of year; MinTemp = minimum temperature, coldest month of year; MAP = mean total annual precipitation; RH = mean annual relative humidity.

** Means differ significantly between genera (Wilcoxon-Mann-Whitney tests with Monte Carlo estimation of *P*-values; for each, $P < 0.01$).

Data from individual specimens are available in supplementary materials (Appendices I, II, and III). Mean *Lepus* stable isotope ratios ($\delta^{18}O_{apatite}$ = 27.1 ± 2.4‰ [N = 51, 1 SD], $\delta^{13}C_{apatite}$ = -12.0‰ ± 2.9 [N = 51, 1 SD], $\delta^{13}C_{collagen}$ = -18.0 ± 3.0‰ [N = 51, 1 SD], and $\delta^{15}N_{collagen}$ = 6.4 ± 2.5‰ [N = 51, 1 SD]), were all higher than mean *Sylvilagus* stable isotope ratios ($\delta^{18}O_{apatite}$ = 26.6 ± 3.1‰ (N = 80, 1 SD), $\delta^{13}C_{apatite}$ = -13.8‰ ± 26 [N = 80, 1 SD], $\delta^{13}C_{collagen}$ = -19.3 ± 2.3‰ [N = 64, 1 SD], and $\delta^{15}N_{collagen}$ = 5.6 ± 2.8‰ [N = 65, 1 SD]). Mean $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ were both significantly higher (less negative) in *Lepus* than in *Sylvilagus* ($P < 0.01$), but mean $\delta^{15}N_{collagen}$ ($P = 0.12$) and $\delta^{18}O_{apatite}$ (P = 0.46) did not differ significantly between genera (Figure 3).

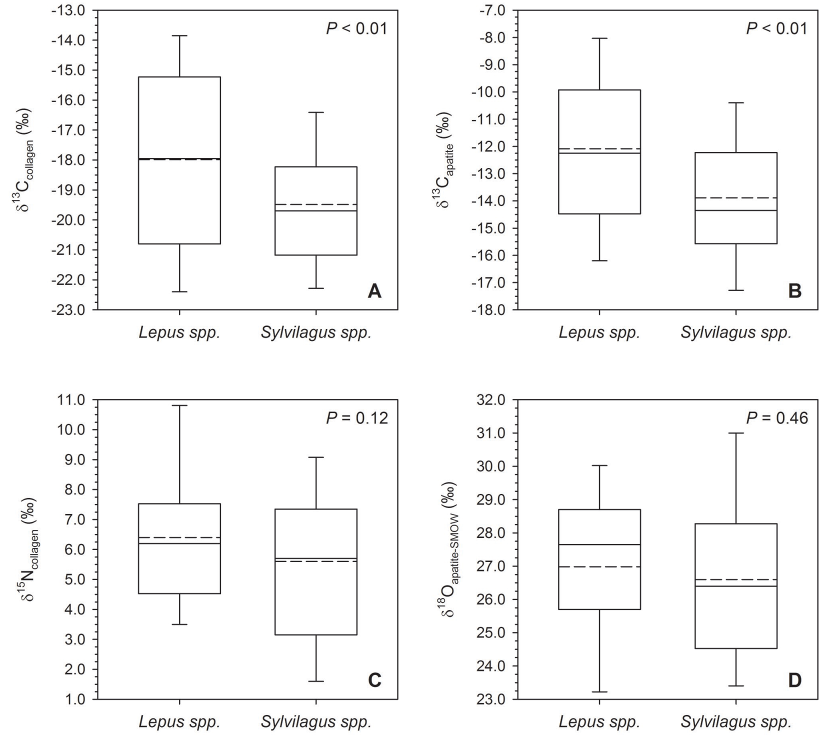

Figure 3. Distribution of collagen and apatite isotope values within each genus. Solid lines crossing the boxes indicate medians; dashed lines indicate means. Two-tailed t-tests comparing mean isotope values between *Lepus* vs. *Sylvilagus* showed that the two genera differed significantly for δ^{13}Ccollagen (Figure. 3A: -18.0 ± 3.0‰ vs. -19.5 ± 2.1‰; P < 0.01) and δ^{13}Capatite (Figure. 3B: -12.1 ± 2.9‰ vs. -13.9 ± 2.7‰; P < 0.01), but not for δ^{15}Ncollagen (Figure. 3C: 6.4 ± 2.4‰ vs. 5.6 ± 2.8‰; P = 0.12) or δ^{18}Oapatite-SMOW (Figure. 3D: 27.0 ± 2.6‰ vs. 26.6 ± 3.1‰; P = 0.46).

Climate and isotope correlations

After adjusting for multiple comparisons, Pearson's correlation coefficients demonstrated that carbon and nitrogen isotope values were significantly correlated with temperature variables in the full, pooled sample (Figure 4). Specifically, $\delta^{13}C_{collagen}$ was significantly related to MaxTemp ($r = 0.38$); $\delta^{13}C_{apatite}$ was significantly related to AvgTemp ($r = 0.29$), MaxTemp ($r = 0.36$), and MinTemp ($r = 0.30$); and $\delta^{15}N_{collagen}$ was significantly related to AvgTemp ($r = 0.44$), MaxTemp ($r = 0.48$), and MinTemp ($r = 0.41$). Neither carbon nor nitrogen isotope variables were correlated with MAP or RH. Oxygen isotope values were not correlated with temperatures (for each, $r \leq |0.18|$), but $\delta^{18}O_{apatite}$ was the only isotope variable significantly correlated with mean annual precipitation ($r = 0.64$) and relative humidity ($r = 0.62$; see Figure 5). Two *Sylvilagus* individuals with the highest MAP values in the sample were outliers. The relationship between $\delta^{18}O_{apatite}$ and MAP was analyzed with and without these outliers included to determine whether they biased the regression line. In both cases, the correlation was significant and the slope did not differ meaningfully when the outliers were included or excluded.

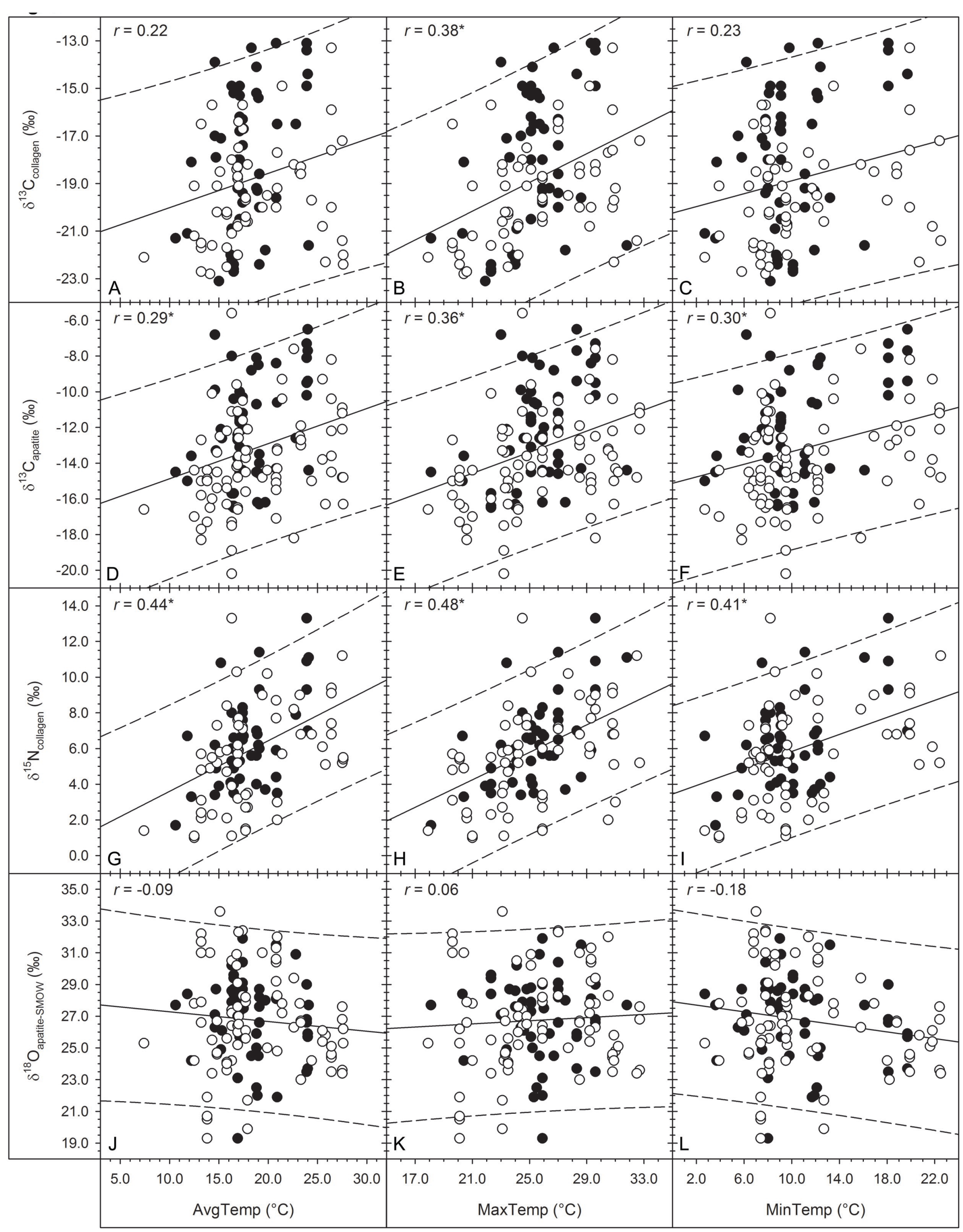

Figure 4. Univariate linear regression relationships between isotopes and temperature variables (AvgTemp = mean annual temperature; MaxTemp = maximum temperature of the warmest month of the year; MinTemp = minimum temperature of the coldest month of the year). Regression lines (solid) and 95% prediction interval lines (dashed) are for the entire pooled sample. Data points are plotted by genus (black circles = *Lepus*; white circles = *Sylvilagus*). Asterisks indicate statistically significant r-values after adjusting α-levels for multiple comparisons using (Holm-Boneferroni method).

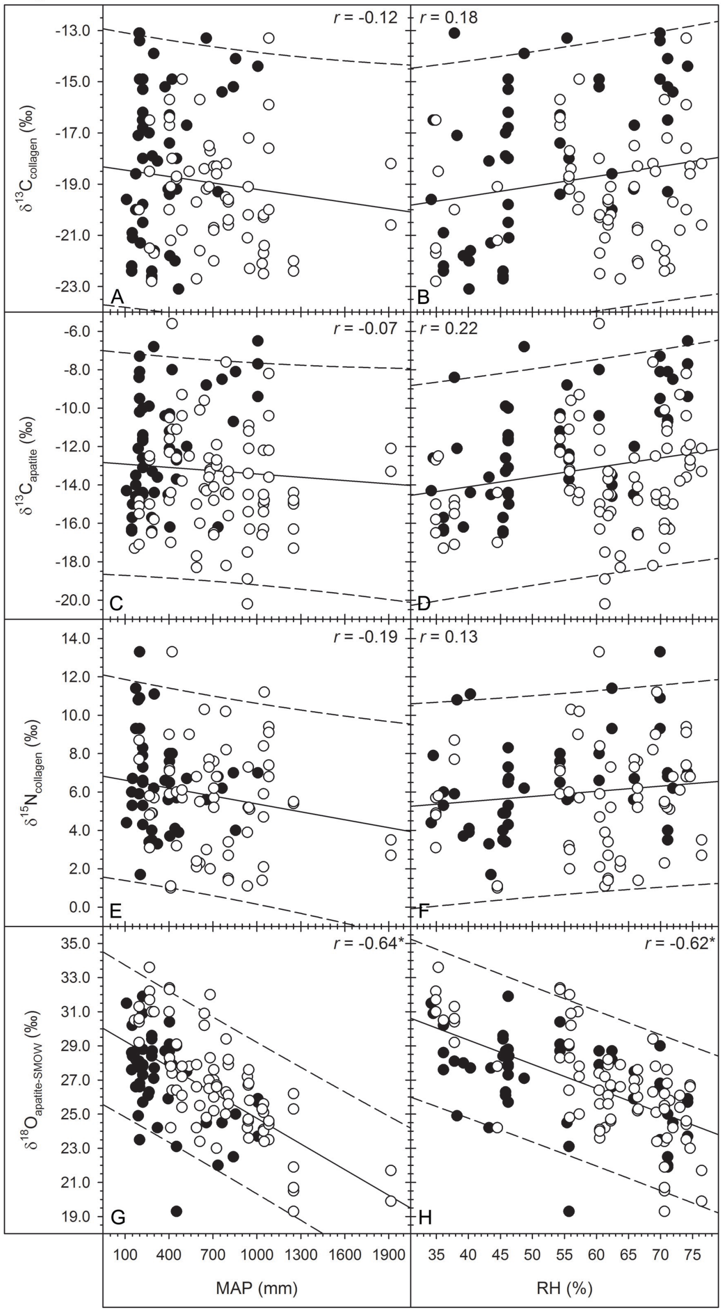

Figure 5. Univariate linear regression relationships between isotopes and moisture values (MAP = mean total annual precipitation; RH = mean annual relative humidity). Regression lines (solid) and 95% prediction interval lines (dashed) are for the entire pooled sample. Data points are plotted by genus (black circles = *Lepus*; white circles = *Sylvilagus*). Asterisks indicate statistically significant r-values after adjusting α-levels for multiple comparisons using (Holm-Bonferroni method). The relationship between δ^{18}Oapatite-SMOW and MAP was analyzed with and without the two *Sylvilagus* individuals with the highest MAP values to determine whether they biased the regression line. The correlation was significant in both cases and the slope did not change meaningfully when those two individuals were excluded.

Multiple regression analysis

Parameters for the final regression models built using the best fit (lowest AIC) subset of climate variables and genus are shown in Table 3. Each overall regression model was statistically significant (for each, $P < 0.01$), with r^2-values ranging from 0.22 to 0.53, and all final regression models met the assumption of normally distributed residuals. The final set of predictors for each isotope variables was as follows: $\delta^{13}C_{collagen}$ = MaxTemp, genus; $\delta^{13}C_{apatite}$ = MaxTemp, genus; $\delta^{15}N_{collagen}$ = AvgTemp, MaxTemp, genus; $\delta^{18}O_{apatite}$ = MAP, RH, genus. Variability between ecosystem types and predicted values of each isotope are shown in Figure 6. Predicted values were calculated for each genus (where genus was included in the final model) with the final model parameters and using climate variable means for each ecosystem type.

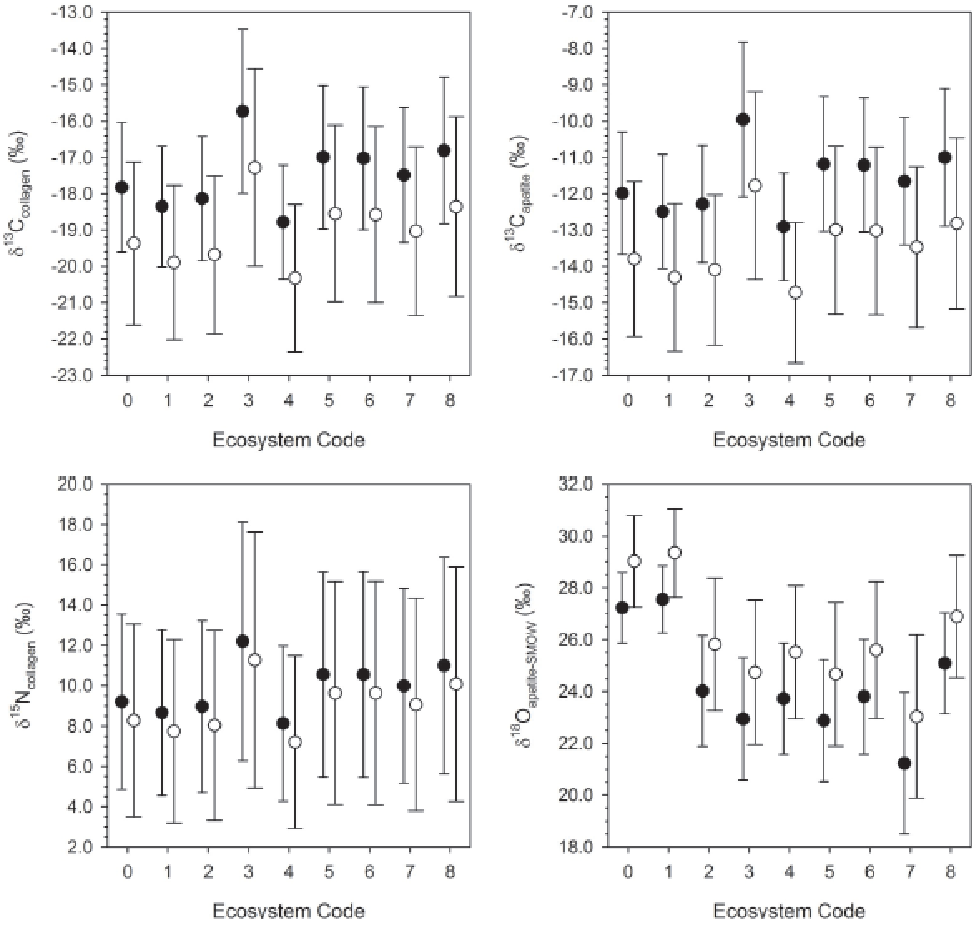

Figure 6. Predicted isotope values for each genus (filled circles = *Lepus*; open circles = *Sylvilagus*) in each ecosystem type, using ecosystem-average climate variable values. Error bars represent estimates derived from the regression coefficients ± 1 standard error. Leporids were assigned to nine separate terrestrial ecosystem types according to The Nature Conservatory's (TNC) spatial dataset: (0) Deserts and xeric shrublands [*Lepus* N = 38; *Sylvilagus* N = 28]; (1) Mediterranean forests, woodlands, and scrub [*Lepus* N = 8.]; (2) Temperate grasslands, savannas, and shrublands [*Lepus* N = 5; *Sylvilagus* N = 4]; (3) Tropical and subtropical broadleaf forests [*Sylvilagus* N = 3]; (4) Tropical and subtropical coniferous forests [*Sylvilagus* N = 27]; (5) Tropical and subtropical dry broadleaf forests [*Sylvilagus* N = 11]; (6) Tropical and subtropical grasslands, savannas, and shrublands [*Sylvilagus* N = 3]; (7) Tropical and subtropical moist broadleaf forests [*Lepus* N = 3; *Sylvilagus* N = 3]; (8) Mangroves [*Sylvilagus* N = 2].

Table 3. Final regression models

Dependent isotope variable	Overall Model			Parameter estimates		
	r^2	P	Intercept*	Independent variable**	$b \pm s_b$***	β****
$\delta^{13}C_{collagen}$	0.23	< 0.01	-25.8	MaxTemp	0.308 ± 0.069	0.38
				Genus*****	-1.549 ± 0.459	-0.29
$\delta^{13}C_{apatite}$	0.22	< 0.01	-19.7	MaxTemp	0.298 ± 0.065	0.36
				Genus	-1.817 ± 0.458	-0.31
$\delta^{15}N_{collagen}$	0.27	< 0.01	-2.7	AvgTemp	0.119 ± 0.088	0.18
				MaxTemp	0.273 ± 0.107	0.34
				Genus	-0.927 ± 0.444	-0.18
$\delta^{18}O_{apatite\text{-}SMOW}$	0.53	< 0.01	32.2	MAP	-0.005 ± 0.001	-0.59
				RH	-0.064 ± 0.020	-0.28
				Genus	1.798 ± 0.421	-0.31

* All intercepts differ signifcantly from zero ($P < 0.01$) except for $\delta^{15}N_{collagen}$ ($P = 0.14$).

** AvgTemp = mean annual temperature; MaxTemp = maximum temperature, warmest month of year; MAP = mean total annual precipitation; RH = mean annual relative humidity.Genera are assigned numerical values as follows: *Lepus* = 0; *Sylvilagus* = 1.

*** Unstandardized regression coefficients b, where s_b is the standard error of b.

**** Standardized regression coefficients.

***** Genera assigned numeric values as follows: *Lepus* = 0; *Sylvilagus* = 1.

Discussion

Lepus vs *Sylvilagus*

Due to different habitat preferences, we hypothesized that jackrabbit and cottontail bone isotope ratios would reflect different niches of the environments in which they live. Notably, *Lepus* values appear higher on average than *Sylvilagus* values for $\delta^{13}C_{collagen}$ $\delta^{13}C_{apatite}$ and $\delta^{15}N_{collagen}$, and $\delta^{18}O_{apatite}$. Across the sample, no significant differences were observed in $\delta^{15}N_{collagen}$ and $\delta^{18}O_{apatite}$ values between the genera. However, *Lepus* mean $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values were significantly higher (*P*<0.01) than *Sylvilagus*. The jackrabbit preference for open and xeric environments, which more often contain C_4 grasses, succulents, and warmer temperatures, likely explains the high $\delta^{13}C$ values relative to cottontails. The cottontail preference for environments with greater structure, on the other hand, puts them in areas with more C_3 relative to C_4 and CAM plants. Nevertheless, although the two genera tend to inhabit different ecological niches, their bone isotope ratios appear to vary as functions of environmental conditions according to similar principles (see Figure 3). Our findings were in accordance with previous studies on leporid bones across smaller geographic scales, which found that *Lepus* and *Sylvilagus* bone carbon isotope ratios differed slightly within and between regions as predicted by the percentage of C_4 grass cover (Munoz et al. 2011; Smith et al. 2014).

Temperature

Stable carbon isotope ratios from both collagen and bioapatite were found to exhibit weak but significant positive correlations with temperature variables. Generally, stable carbon isotope ratios from bone apatite seem to be more sensitive environmental indicators than from collagen. Positive correlations between bone $\delta^{13}C$ and temperature are likely due to the fact that warmer environments are more frequently associated with the presence of C_4 grasses, cacti, and succulents, which exhibit higher $\delta^{13}C$ values than

C_3 plants. Incorporation of these plants into the diet of cottontails and jackrabbits would serve to raise their $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values.

The strongest correlation between an isotopic variable and temperature was the moderate positive correlation between $\delta^{15}N_{collagen}$ values and MaxTemp ($r = 0.48$, $P < 0.001$; see Figures 4H and 7), but $\delta^{15}N_{collagen}$ was also correlated with AvgTemp ($r = 0.44$, $P < 0.001$) and MinTemp ($r = 0.41$, $P < 0.001$). The results are consistent with previous studies demonstrating that warm and dry regions exhibit higher soil, plant, and consequently animal $\delta^{15}N$ values (Amundson et al. 2003; Hartman 2011; Murphy and Bowman 2006). These correlations have been observed for other mammalian genera (Stevens et al. 2006), but not previously in leporids (Ugan and Coltrain 2011). Differences in topography and soil salinity strongly influence plant isotope ratios and hence $\delta^{15}N_{collagen}$ of leporids that consume them. The small home ranges of leporids then may bias $\delta^{15}N_{collagen}$ values towards the microenvironments they inhabit. Our analysis included sites from a broader range of local temperature regimes, which likely contributed to our finding of significant correlations where previous research did not. Within a localized area, where topography and salinity remain constant through time, we suggest that leporid $\delta^{15}N_{collagen}$ can serve as a proxy for changes in ambient temperature.

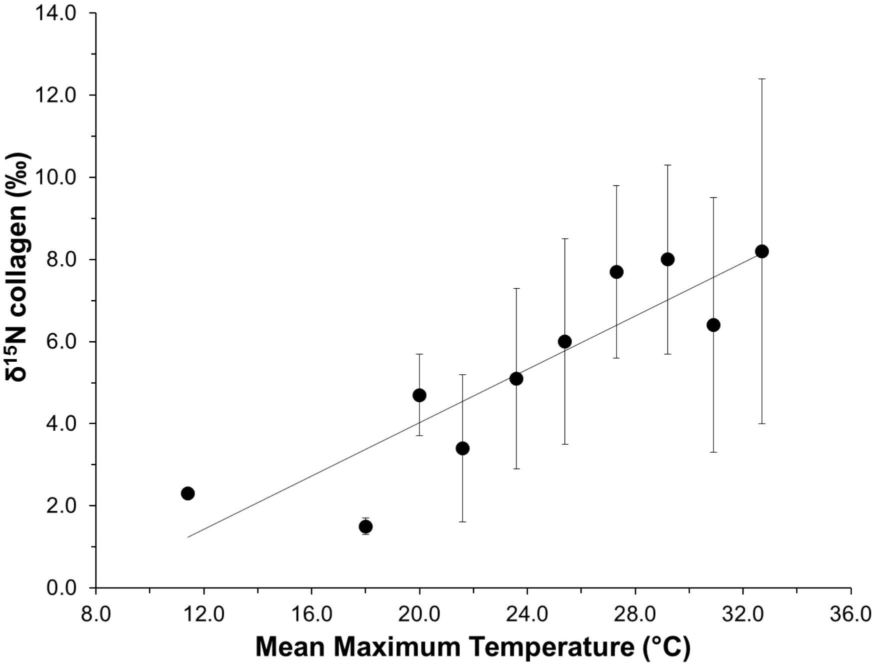

Figure 7. Stable nitrogen isotope ratios of 135 modern leporid bones plotted as a factor of the mean annual temperature of the regions in which they lived. Specimens are grouped into 2 °C bins. Circles represent mean values within bins and error bars represent 1 SD. The positive correlation is significant ($P<0.001$).

Aridity

Although $\delta^{13}C$ values of C_3 plants (Kohn 2010) and some animals (Schoeninger et al. 1998) have been shown to correlate with local moisture levels, our study found no significant influence of MAP or RH on leporid $\delta^{13}C_{apatite}$ or $\delta^{13}C_{collagen}$ values. Because both jackrabbits and cottontails are mixed feeders consuming C_4 grasses, succulents, and C_3 plant material, any environmentally induced changes to C_3 plant $\delta^{13}C$ values may have been masked by simultaneous consumption of CAM and C_4 plants, which are less susceptible to fluctuations in moisture and are much more enriched in ^{13}C than C_3 plants.

The finding that leporid $\delta^{15}N_{collagen}$ values were not correlated with aridity/moisture is in contrast to previous studies on diverse taxa demonstrating significant, positive correlations between MAP and $\delta^{15}N_{collagen}$ (Ambrose 1991; Gröcke et al. 1997; Hartman 2011; Heaton et al. 1986; Johnson et al. 1998; Murphy and Bowman 2006; Pate and Anson 2008). On the other hand, this result is consistent with Ugan and Coltrain's (2011) findings among jackrabbits from Utah, reinforcing that study's conclusions. Although those authors suggested that a significant relationship between aridity and $\delta^{15}N$ in leporids might emerge through analysis of a broader, more climatically variable sample, our results do not support that assertion. This study found no relationship between leporid $\delta^{15}N_{collagen}$ and precipitation or humidity, likely due to confounds of the short lifespans of leporids, local topography, salinity, and variation in microenvironments across our broad regional sample. Further research is needed to clarify this issue.

Leporid bone $\delta^{18}O_{apatite}$ values appear to be the most sensitive to different ecoregions, with the strongest correlations between isotope variables and climate variables occurring between $\delta^{18}O_{apatite}$ and MAP ($r = 0.64$; see Figure 8) and between $\delta^{18}O_{apatite}$ and RH ($r = 0.62$). As such, leporids living in arid environments exhibit higher $\delta^{18}O_{apatite}$ than those living in wetter regions. These findings confirm behavioral observations that leporids are non-obligate drinkers, and support preliminary research linking leporid bone $\delta^{18}O_{apatite}$ to local relative humidity as opposed to ambient temperature (Huertas et al. 1995). Correlations between stable oxygen isotope ratios with both precipitation and humidity were anticipated, as the variables of MAP and RH were themselves strongly correlated across site locations (Table 1).

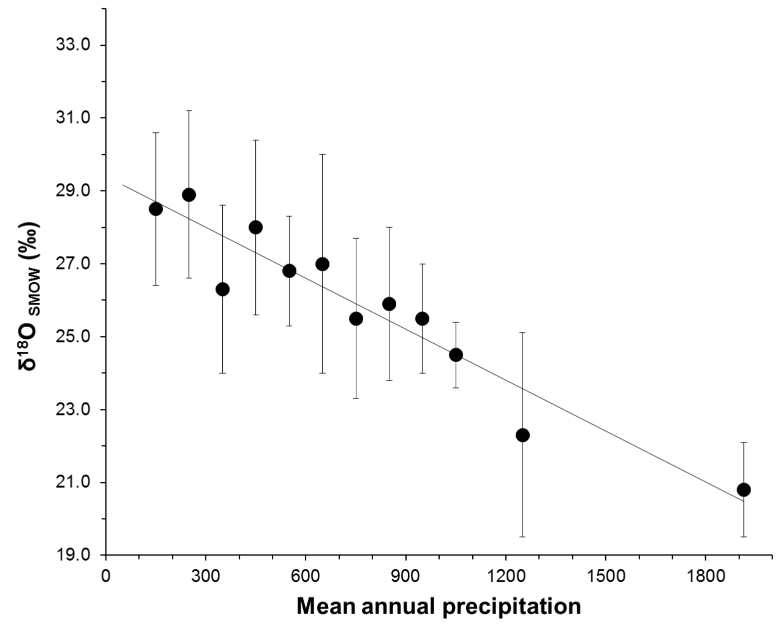

Figure 8. Stable oxygen isotope ratios of 135 modern leporid bones plotted as a factor of mean annual precipitation of the regions in which they lived. Samples are grouped into 100 mm bins. Circles represent mean isotope values of bins and error bars represent 1 SD. The negative correlation is significant (P<0.001).

Geography

No significant relationships were found between elevation, latitude, or longitude of sample locations and isotope variables. However, such differences might manifest at finer resolutions, where effects of moisture, soil salinity, and local botanical composition can be controlled. Across the sample, leporids originating near coastal environments tended to have higher $\delta^{15}N_{collagen}$ values than inland locations. A sample of 12 specimens with proveniences < 5 km distance from either the Atlantic or Pacific Coasts (AS-0668, AS-0669, AS-0670, AS-0671, AS-0672, AS-0684, AS-0688, AS-0695, AS-0696, AS-0697, AS-0699, AS-0700) was selected to compare stable isotope results from coastal leporids to inland specimens. Results of a Mann-Whitney U test indicated that the distributions between coastal and terrestrial leporids differed significantly for $\delta^{15}N_{collagen}$ values ($U = 377$, $P = 0.01$), but not for $\delta^{13}C_{collagen}$ ($U = 656$, $P = 0.91$), $\delta^{13}C_{apatite}$, ($U = 788$, $P = 0.49$), or $\delta^{18}O_{apatite}$ ($U = 838$, $P = 0.78$).

Two primary factors may account for the higher stable nitrogen isotope values among coastal leporids. Soils with higher salinity levels, a factor of being near the coast, tend to exhibit higher $\delta^{15}N$ values, which can raise plant and herbivore $\delta^{15}N$ (e.g., Britton et al. 2008; Virginia and Delwiche 1982). Additionally, the presence of seabirds and other animals depositing feces near coastal environments, in addition to other organic matter washing up from the ocean, serves to enrich soils in ^{15}N relative to inland terrestrial soils (Mizutani and Wada 1988). The findings therefore suggest caution when interpreting ecological dynamics near coastal regions, as high ^{15}N inputs may confound interpretations of trophic effects. These data also suggest that high $\delta^{15}N$ values in leporid bone may be used as a tracer for exploitation of coastal environments by predators or archaic human populations. Nevertheless, these specific coastal locations are also characterized by high temperatures, which have been demonstrated to raise $\delta^{15}N_{collagen}$ values indirectly through diet. The relationships between these variables in coastal deserts warrant further exploration.

Conclusion

This study demonstrated significant correlations between carbon, nitrogen, and oxygen isotopes in leporid bone tissues and climate-related aspects of the environments from which the samples originated. Specifically, across both *Lepus* and *Sylvilagus* specimens, carbon and nitrogen isotope ratios were significantly influenced by temperature, while oxygen stable isotope ratios were significantly influenced by levels of local precipitation and humidity. Due to different habitat preferences between the genera, isotopic ratios from jackrabbits and cottontails monitor slightly different aspects of the environments they inhabit. Such differences were reflected most strongly in $\delta^{13}C$ values, with *Lepus* exhibiting significantly higher mean $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values than *Sylvilagus* specimens. Behavioral data suggest that these differences were a factor of *Lepus* preferring more open habitats than *Sylvilagus*. Nevertheless, both genera reflect environmental factors according to similar principles, and paleoenvironmental reconstructions can therefore incorporate either genus in the reconstruction of past landscapes.

Because the degree of correlation between isotope and climate variables was moderate, we suggest that any use of these results to predict ecoregion from bone be considered preliminary. Interpretations of our findings should be tempered by consideration of the small sample sizes from some of the ecoregions, the wide temporal range of the specimens, and the conservative nature of the project design with regard to climate data. Nevertheless, we suggest that stable isotope analysis of leporid bones can serve as a valuable tool for paleoenvironmental reconstructions due to the clear relationships identified. We anticipate that future research incorporating greater control on sample location, local geography, flora, and climatic factors will find much stronger relationships between leporid bone isotope ratios and local environmental conditions. Additionally, future research including larger sample sizes and multivariate modeling will further improve our ability to estimate qualities of the habitat and ecology of leporids, enhancing their utility in studies of ecological and paleoenvironmental reconstruction.

Stable isotope analyses of organic and inorganic tissues are increasingly being utilized as tool for studies on habitat use, niche partitioning, migration, and environmental reconstructions. By analyzing a large sample of jackrabbits and cottontail from a series of locations across North America, this study improved our baseline understanding of how local environmental conditions influence isotopic ratios of these common mammalian species. Because jackrabbits and cottontails were among the most frequently consumed mammals by pre-Columbian North and Central Americans, their remains often comprise large portions of excavated midden material. The results of this study indicate that preserved leporid remains contain information on various aspects of the paleoenvironment, and can be combined with palynological, botanical, geophysical, and lake-core studies to improve our understanding of the history of human social-environmental dynamics.

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CHAPTER 3: EXPLORING SOCIAL-ENVIRONMENTAL LANDSCAPES IN DESERT ECOREGIONS: STABLE ISOTOPE ANALYSIS OF LEPORID BONES ALONG THE NORTHERN FRONTIER OF MESOAMERICA

Introduction

Climatic change and increasing aridity have featured prominently in explanations for past social change for many societies across the globe. While prolonged droughts and other climate catastrophes have been associated with collapse and site abandonments (DeMenocal 2001; Kennett et al. 2012; Ortloff and Kolata 1993; Weiss et al. 1993), it is also notable that many of the earliest state-level societies of the world developed in exceptionally arid regions, including ancient Egypt, Mesopotamia, South Asia, and northern China (Brooks 2006). In the New World, too, the largest early city of pre-Hispanic Mexico, Teotihuacan, was established within a highland desert (Cowgill 2015; Sanders et al. 1979), and the first complex chiefdoms of South America developed along the hyper-arid coastal plains of Peru (Billman 2002; Millaire 2010). As desert environments have been convincingly associated with both the rise and decline of social complexity, the connection is clearly not linear or deterministic and warrants further investigation.

Complex societies, here characterized as social organizations containing internal divisions of labor, hierarchical or heterarchical systems of decision making and relatively large populations localized on the landscape (Brooks 2006:30; Crumley 1995; Tainter 2006:92), require significant subsistence bases to support the associated "costs of complexity" (Tainter 1988). In desert environments, moisture is often a limiting factor for the development and function of such societies, due to the necessity of producing agricultural surpluses to support large aggregates of people and to fund specialized non-agricultural labor. Maize (*Zea mays*) served as the primary staple crop for most agricultural societies of the pre-Hispanic New World (Staller et al. 2009), and, for non-irrigated agricultural lands in arid and semi-arid regions of North America, maize yields then as now are principally influenced by the extent of summer rains (Dilley 1997; Therrell et al. 2006). Climatic changes leading to increases or declines in seasonal precipitation could therefore have significant ramifications for settlements in marginal environments practicing rain-fed agriculture. By enabling greater food surpluses, increasing rainfall could make more food available to support large populations, to fund specialized labor, and to permit aspiring elites to sponsor feasting events, a cross-cultural phenomenon linked to specialized production and the establishment of hierarchical social structures (Spielmann 2002; Wiessner and Schiefenhövel 1996). Conversely, declines in precipitation and hence lower maize yields could hinder surplus accumulation, making the costs of complexity higher than a society could support with existing social and technological frameworks, a strain that could potentially lead to sociopolitical collapse (e.g. Tainter 1988).

This chapter explores the relationship between social complexity and environmental change in the arid and semi-arid ecoregions of North America (United States and Mexico) by using stable isotope analysis of jackrabbit and cottontail (family Leporidae) bones recovered from three archaeological settlements (Pueblo Grande, La Quemada, and La Ferrería; Figure 9) of the Epiclassic (AD 600-900) and Postclassic (AD

900-1500) temporal periods. Preliminary baseline research (see Chapter 2) indicates that isotopic ratios of leporid bones are influenced, in part, by local floral composition, temperature, precipitation, and humidity, providing the opportunity to reconstruct various aspects of past environmental landscapes. Analyses of bones from each site context permit explorations of environmental properties through time.

The sites selected for this study are located within three distinct desert terrestrial ecoregions of The Nature Conservatory's (TNC) online spatial dataset for the terrestrial ecoregions and biomes of the world (see http://maps.tnc.org/). La Quemada lies within the Central Mexican Matorral in modern Zacatecas, Mexico; La Ferrería lies within the Chihuahuan Desert in modern Durango, Mexico; and Pueblo Grande lies within the Sonoran Desert in modern Arizona, USA. Categories of the TNC system were assigned through the collaborative efforts of the World Wildlife Fund and over 1000 scholars from diverse fields, including ecologists, biogeographers, taxonomists, and conservationists (Olson et al. 2001; Ricketts et al. 1999).

By reconstructing aspects of past environmental landscapes at each site location, this chapter tests previous assumptions that the development of complex societies in marginal environments of North America was enabled by increases in moisture availability and that their decline was due to sustained periods of drought. Such notions have long been incorporated into models describing the cultural history of marginal regions of North America (Armillas 1964; Armillas 1969). To test these hypotheses, results of stable isotope analyses from leporid bones are explored across three scales of analysis: the macro-regional scale, the meso-regional scale, and the site-specific scale. The discussion first examines stable isotope results at the macro-regional scale, quantifying differences between ecoregions and site locations to refine our ability to interpret features of past landscapes from leporid proxies. Broad characteristics of social development across the region are also discussed at this scale. Next, the meso-regional scale narrows the scope of analysis to the region of Northwest Mexico, focusing on the archaeological sites of La Quemada and La Ferrería to quantify aspects of Northwest Mexico environments during Epiclassic period (AD 600-900). Finally, the discussion concentrates on the site of La Ferrería, one of the northernmost complex societies of Mesoamerica, and examines isotope results with higher resolution than at other site locations, paying particular attention to both temporal changes and differences between leporid genera. Changes in human population levels, architectural construction, and trade ties are considered together with isotopic changes at this scale of analysis. By exploring social and environmental conditions across multiple geographic and temporal scales, this chapter situates La Ferrería within broader regional contexts, ultimately providing a greater understanding of the relationship between social complexity and aridity in North America.

Macro-Regional Background: Epiclassic Period in Arid North America

The Epiclassic period (AD 600-900) in Mesoamerican archaeology may be defined as the era that began with the collapse of Teotihuacan, the first urban state society of highland Mexico, and ended with the ascent of the Toltec state at Tula, Hidalgo. This period was characterized by political fragmentation, dispersed settlement patterns, and heightened militarism, but also by broadly shared religious concepts, high levels of long-distance trade, and a widespread distribution of red-on-buff ceramic traditions (Cowgill 2013; Diehl and Berlo 1989; Manzanilla 2005; Solar Valverde 2006). This period also saw the greatest expansion of agricultural societies into the desert regions of North America. For the first time, complex polities boasting pyramids, ballcourts, and nucleated populations developed in the marginal desert zones between central Mexico and the Southwest United States, including the centers of La Quemada and La Ferrería (Armillas 1964; Armillas 1969; Beekman 2010; Foster 2000; Jiménez and Darling 2000).

Figure 9. Map indicating geographic locations of Pueblo Grande, La Ferrería, and La Quemada.

During the Epiclassic, full-time sedentary agricultural villages also developed within the American Southwest in a phase locally known as the Pueblo I period (AD 700-900). Hohokam societies of central Arizona, including the Pueblo Grande site, came to exhibit many cultural features analogous with their southern neighbors during this time, and were likely connected to centers such as La Quemada and La Ferrería indirectly through broad networks of material and cultural exchange. Indeed, residents of Pueblo Grande, La Ferrería, and La Quemada all crafted red-on-buff ceramic wares, played a similar ritual ballgame, and possessed comparable prestige goods such as pyrite discs and pseudo-cloisonné vessels (Bayman 2001; Haury 1976; Lelgemann 2000; Nelson and Crider 2005).

In Northwest Mexico, the Epiclassic period ended with the collapse of some complex, sedentary societies around AD 900. In fact, political collapse and social transitions were widespread across much of Mexico at this time, with many Maya states of southern Mexico and highland polities such as Xochicalco and Cantona being abandoned at around AD 900 (Evans 2004). In the American Southwest, AD 900 marked the end of the Pueblo I period and the beginning of Pueblo II, a time of wide-spread social transformation and the founding of larger population centers with more labor intensive architecture (Plog 1997), although some of the most significant cultural changes began earlier, around AD 800 (Plog and Heitman 2010).

In addition to the social and political changes associated with the beginning of the Epiclassic, a considerable amount of evidence suggests that the period was notable for its exceptional aridity, and many scholars have argued that site abandonments and social changes around AD 900 were due to peak drought conditions. Here I provide a brief review of paleoclimatic evidence from across a wide geographic area to provide a broad-scale assessment of climatic conditions during the occupational histories of selected site locations. It is not an exhaustive analysis of every published paleoclimate study in North America, but it focuses on well-controlled and representative cases that include the

Epiclassic period. Examples span a transect of North America, including proxy data from the US Southwest, West Mexico, Central Mexico, and the Yucatan Peninsula. A summary of paleoenvironmental research in Northwest Mexico is reserved for the Meso-regional section below.

***Southwest U.S.A**:* By combining modern and archaeologically-recovered tree-ring records from western New Mexico, Grissino-Mayer (1996) and Grissino-Mayer et al. (1997) developed precisely-dated high-resolution chronologies of Southwest rainfall dating back to BC 136. Their data demonstrate that the years of AD 661-1023 were among the driest of the past 2000 years (Grissino-Mayer 1996:200). Additionally, through a statistical integration of two primary data sets, Grissino-Mayer et al. (1997:2) found that within this period "the most severe long-term drought during the last 1,373 years occurred between AD 940 and 1040." Analyses of tree-ring datasets from the Four-Corners region (intersection of Arizona, Colorado, New Mexico, Utah) have similarly demonstrated increased climatic variability and decreased precipitation between approximately AD 750-950 (Dean et al. 1985; Euler et al. 1979; Woodhouse and Overpeck 1998). Multiple proxy data from the Southwest agree, then, that the Epiclassic (Pueblo I) period generally overlapped with an exceptionally dry period with a peak potentially around AD 950.

West Mexico: Lago de Patzcuaro, a highland lake basin in the modern Mexican state of Michoacán, has been the focus of numerous climatological and environmental studies over the past 60 years (Bradbury 2000; Fisher 2005; Metcalfe et al. 2007; Watts and Bradbury 1982). By bringing together data from multiple lake cores, Metcalfe and Davies (2007) observed widespread ostracod layers, which suggest lake dessication and hence a period of aridity, dating from AD 700 to 1260. Additionally, soil core analyses along the banks of the lake found that lake levels receded around AD 776 and remained low through the Postclassic period (Fisher et al. 2003:49-60). Other lake cores from West Mexico, including those from lakes San Pedro, Guzman, Zacapu, Hoya San Nicholas, and La Piscina de Yuria (Brown 1984; Metcalfe et al. 1989; Metcalfe et al. 1994; O'Hara et al. 1994), have produced similar results, and many scholars found the most severe aridity occurring at ~AD 900 (see Metcalfe and Davies 2007 for a review).

***Central Mexico**:* Studies on lake basins from Central Mexico also found evidence for the Epiclassic period being a period marked by aridity and framed by wetter conditions. Sediment cores from the Upper Lerma, a high altitude basin in the state of Mexico, were analyzed for magnetic properties, loss on ignition, and diatoms to reconstruct lake level fluctuations over time (Caballero et al. 2002). Their study found that the largest lake of the Upper Lerma system, Lake Chignahuapan, reached its shallowest level over the past 22,000 years during the period of approximately AD 550-900 (Caballero et al. 2002:232). Additionally, a recent tree-ring chronology from Queretaro, Mexico demonstrates extremely arid conditions in Central Mexico between AD 897-922, “where it was one of the worst megadroughts of the past 1200 years” (Stahle et al. 2011:3). Supporting these findings, a recent core sample from Lake Aljojuca in Puebla, Mexico, near the archaeological site of Cantona, found evidence for a period of sustained aridity from AD 500 to 1050, with a peak around AD 900-1050 (Bhattacharya et al. 2015).

Yucatan Peninsula: Data from the Yucatan Peninsula support the observations of the above studies and indicate the presence of arid conditions in the Maya region as well.

Hodell et al. (1995) analyzed $\delta^{18}O$ ratios of ostracods and gastropods to reconstruct the ratio of evaporation to precipitation at Lake Chichancanab over the past 3,500 years. Their results demonstrate a pronounced dry period from AD 800 to AD 1000. Similarly, Curtis et al. (1996) analyzed ostracods and gastropods $\delta^{18}O$ ratios from Punta Laguna, another Yucatecan lake, and found evidence for marked aridity between AD 724 and 1020. Both studies found evidence of an exceptionally dry period at about AD 900 and suggest that the collapse of the Classic Maya was related to this event.

***Global**:* More broadly, the Mesoamerican Epiclassic Period significantly overlaps with what Mayewski et al. (2004) describe as one of six global periods of rapid climate change in the Holocene. By synthesizing paleoclimate data from world-wide reports, they observed that the years AD 750-950 were characterized by high-latitude cooling and low-latitude aridification (Mayewski et al. 2004:251). It is also notable that the survey of paleoclimate proxies from the Southwest USA, West Mexico, Central Mexico, and the Yucatan Peninsula presented here all suggest that the period of approximately AD 700-1000, beginning earlier in some areas, was characterized as being exceptionally dry. This extended drought period overlaps significantly with the culturally defined Epiclassic period (AD 600-900). Thus, in a global context, the Epiclassic roughly corresponds to a global climatic anomaly, which may be due to fluctuations in solar output (Poore et al. 2003) or to a southern migration in the mean annual latitude of the Intertropical Convergence Zone (ITCZ), which brings the majority of Mexico's moisture (Haug et al. 2001).

Although at a regional level this period may have been characterized by drought conditions, the exact manifestation of these changes is not necessarily predictable at the scale of individual settlements. For example, pollen assemblages from lake cores from Lake Azteca in Hidalgo, Mexico find that the nearby cloud forest expanded at this time and that during the interval of AD 890-1030 the climate may have been wetter than the present (Conserva and Byrne 2002), contrary to the evidence from nearby Yucatan Peninsula and central Mexican lake cores. The presence of apparent regional heterogeneity underscores the importance of assessing social and environmental conditions at multiple scales of analysis.

Meso-Regional Background: Northwest Mexico

The relationship between society and environment has long been an issue in studies of the archaeology of Northwest Mexico. Upon the 16th century arrival of the Spanish in Mexico, the division between complex agricultural societies of Central Mexico (e.g. the Aztec and Tarascan Empires) and the nomadic hunter gatherers of Northwest Mexico formed a distinct border that ran across the 20th and 21st parallel from the base of the Sierra Madre Occidental to the eastern highlands of the Central Mexican Plateau (Armillas 1964). Environmental and cultural differences were clearly present between these regions, suggesting strong relationships between environmental landscapes, subsistence strategies, and socio-political complexity (Palerm and Wolf 1957). Yet, ruins of monumental architecture and the traces of large population centers in the desert regions of Northwest Mexico, abandoned centuries before the Spanish conquest, indicate a previous expansion of sedentary societies with large populations characterized by hierarchical social organizations into these semi-arid zones.

Archaeological research demonstrates that beginning around AD 500 or earlier several cultural traditions of complex agricultural societies with Mesoamerican cultural features began to develop in Northwest Mexico. The *Chalchihuites* culture spread across the arid regions of Zacatecas and Durango and has been divided into two closely-related sub-groups: the southern Suchil Chalchihuites and the northern Guadiana Chalchihuites (Kelley 1971; Kelley 1985; Kelley and Kelley 1971). The ceremonial center of Alta Vista in Zacatecas is the best-studied Suchil branch site, while La Ferrería in Durango is the best-described Guadiana branch settlement. Additional northern cultures exhibiting Mesoamerican characteristics have been identified in the Malpaso and Bolaños Valleys of southern Zacatecas (Jiménez and Darling 2000). Indeed, La Quemada of the Malpaso Valley was the largest and likely most influential polity north of central Mexico during the Epiclassic (Jiménez 2010; Nelson 1995; Nelson 1997).

Despite centuries of occupation, a number of complex settlements in Northwest Mexico collapsed around AD 900. Armillas (1964, 1969) put forward one of the earliest and still most influential explanations for this retraction of the Mesoamerican frontier. He argued that the Mesoamerican culture area expanded and contracted as climatic changes extended and retracted the area where rain-fed agriculture, and hence full-time sedentism, were possible. Thus, the expansion was a result of wetter times, and the retraction was due to drought. Many models of Northwest Mexico’s developmental history rely on the observed marginality of the region and incorporate Armillas’s hypothesis of a climatically driven expanding and contracting frontier (Beekman 2010:44; Braniff 1974; Braniff 1998). However, few paleoclimate studies have actually been conducted in the region.

Investigations by Elliott et al. (2010) and Trombold and Israde-Alcantara (2005) have been the only two studies to explicitly address the question of environmental change during the Epiclassic period in Northwest Mexico. Both analyzed soil samples from the Malpaso Valley, Zacatecas. Trombold and Israde-Alcantara analyzed pollen, diatoms, and phytoliths from agricultural terraces of La Quemada. The results suggest that environmental conditions throughout the period were warm and dry, similar to the present (Trombold and Israde-Alcantara 2005). Elliott et al. (2010) conducted phytolith, organic carbon, and magnetic susceptibility analyses of sediment samples from alluvial floodplain trenches near La Quemada. Their results demonstrated a shift to more arid conditions around 500 BC, long before the Epiclassic occupations, and a continuation of those conditions to the present. Thus, neither study supported environmental explanations for the expansion and retraction of Mesoamerica (contra Armillas 1964; 1969). Instead, they found sustained dry and warm conditions throughout the occupational history of La Quemada. However, many of the local flora are dry-adapted species and their general distribution may not be the most sensitive indicator of climatic fluctuations on the scale relevant to human decision-making, such as decade-long variations in the frequency, predictability, and overall amount of precipitation. Further research with high-resolution paleo-environmental proxies will contribute greatly to this debate.

Site-Specific Backgrounds: Pueblo Grande, La Ferreria, La Quemada

The three archaeological sites selected for analysis developed in desert environments, they overlapped in their occupational histories for several hundred years, and were all characterized by intermediate levels of socio-political complexity. Each site belonged to different a different cultural tradition and occupied a different type of desert ecoregion. Here, these archaeological settlements are each considered in greater detail.

Pueblo Grande

The site of Pueblo Grande belongs to the Hohokam cultural tradition and is located in modern day Phoenix, Arizona, USA. The Hohokam are best known for their extensive system of irrigation canals and the construction of ballcourts and monumental platform mounds (Bayman 2001; Haury 1976). Pueblo Grande was constructed along Canal System 2, a main artery of the Phoenix Basin's irrigation network, drawing water north of the Salt River (Abbott 2000). Although occupied as early as AD 100, the site grew into a large village around AD 750 during the Gila Butte phase of the Hohokam Colonial period. The settlement remained occupied through approximately AD 1450 (Abbott et al. 1994; Mitchell 1994b). Social complexity was intermediate at Pueblo Grande, and an upper class may have derived authority through their control of the intensive irrigation infrastructure (Howard 2006). The population of several hundred individuals at Pueblo Grande, one of the largest and longest occupied Hohokam settlements (Abbott 2000), was sustained by the agricultural production of maize, beans, squash, and agave (Kwiatkowski 1994). Among recovered faunal species, cottontails and jackrabbits were by far the most commonly represented (James 1994).

According to The Nature Conservatory's categorization, Pueblo Grande lies within the Sonoran Desert, which stretches from southern Arizona through the northern parts of the Mexican states of Baja California and Sonora. This ecoregion is characterized by diverse cacti and shrub species, particularly saguaro (*Cereus giganteus*), creosote bush (*Larrea*), yucca (*Yucca*), and a range of *Opuntia* species (e.g., Fish 2000). In addition to the desert flatlands, Hohokam communities interacted intensely with local riparian environments of the Salt and Gila Rivers, diverting water for intensive irrigation agriculture and exploiting river ecosystems for fish, waterfowl, and other fauna (James 1994; Kwiatkowski 1994). Using the WORLDCLIM online spatial database and the geographic information software, DIVA-GIS (Hijmans 2001; Hijmans et al. 2005) the 50 year (AD 1950-2000) mean annual precipitation at Pueblo Grande was estimated to be 220 mm, and the mean annual temperature was 21.6 °C. See Table 4 for climatological and environmental characteristics of each selected site.

La Ferrería

The site of La Ferrería, also known as the Schroeder Site, was a regional center of the Guadiana branch of the Chalchihuites culture, and was among the most northern complex societies of Mexico. Decorated ceramics, a low stepped pyramid with a sunken court, and a ballcourt demonstrate its connections with Mesoamerican societies to the south (Kelley 1971). The settlement was constructed across two hills within the Sierra de Ayala just south of a bend in the Tunal River. Inhabited from approximately AD 600 to 1400, La Ferrería remained an active center long after the collapse of many other settlements in Northwest Mexico (Foster 2000; Kelley 1985; Punzo Díaz 2008). During the Ayala phase (AD 600-850), La Ferrería was a contemporary of the Suchil

Chalchihuites regional center at Alta Vista and with the Malpaso Valley center of La Quemada, and shared many stylistic similarities in decorated ceramics with these sites. During the Las Joyas phase (AD 850-1000), around the time that Alta Vista and La Quemada were abandoned, residents of La Ferrería developed closer relations with the Pacific Coast Aztatlán trading network, as evidenced by the presence of diagnostic ceramics, clay pipes, and copper artifacts (Foster 2000; Kelley 1990; Kelley 2000).

According to The Nature Conservatory's categorization of terrestrial ecoregions, La Ferrería lies within what is today known as the Chihuahuan desert, though it closely borders the Sierra Madre Pine Oak Forests on the west. In fact, the site was settled along the foothills that define the official border of these two terrestrial ecosystems. The Chihuahuan Desert is one of the largest deserts of North America, stretching from the Southwestern United States into Central Mexico. The ecoregion is bordered on either side by the Sierra Madre mountain ranges, which cast a rain shadow over the highland plains. Large stretches of the desert are dominated shrubs (e.g. *Acacia*), cacti (e.g. *Opuntia*), and grasses (e.g. *Bouteloua, Leptochloa, Leersia, Cynodon,* and *Digitaria*).

Within a day's travel of La Ferrería residents had access to two smaller-scale environments containing different resources. These included the pine and oak covered hills of the Sierra de Ayala, and the riparian habitat of the Tunal River (Parmalee 1964). The nearby pine-oak forests of the Sierras, characterized by *Pinus cf. Montezuma,* used to extend to the hills of the archaeological site, but were cleared ~150 years ago (Parmalee 1964:101). Habitats near the river include several tree varieties, including cottonwoods (*Populus*) and willows (*Salix*). Maize, beans, squash, and agave were likely primary cultigens at La Ferrería, and leporids were the most commonly consumed mammal

(Parmalee 1964). At the site core, interpolated climate data from the WORLDCLIM 50 year (AD 1950-2000) dataset indicated a local mean annual precipitation of 515 mm, and a mean annual temperature of 17.6 °C.

Table 4. Modern environmental characteristics of site locations. Key: Elev=elevation (m), MAP=mean annual precipitation (mm), RH=relative humidity, Min Temp=average minimum temperature of the coldest month (°C), Max Temp=average maximum temperature of the warmest month (°C), Avg Temp=average temperature across all months (°C). Climate variables are 50 year averages (AD 1950-2000) from the WORLDCLIM online spatial dataset.

Site	Ecoregion	Elev (m)	MAP (mm)	RH (%)	Min Temp (°C)	Max Temp (°C)	Avg Temp (°C)
Pueblo Grande	Sonoran Desert	350	220	39.2	12.9	30.3	21.6
La Ferrería	Chihuahuan Desert	1900	515	55.6	10.4	24.8	17.6
La Quemada	Central Mexican Matorral	2100	550	55.7	8.4	26.3	17.4

La Quemada

Located in the Malpaso Valley of southern Zacatecas, Mexico, La Quemada was one of the largest and most complex settlements of the northern frontier of Mesoamerica. Its monumental architecture and fortified hilltop location resemble architectural ruins of Central Mexican city-states of the Epiclassic period, including Xochicalco in Morelos and Caxcatla in Tlaxcala, albeit on a smaller scale. Socio-political complexity was probably that of a complex chiefdom (Nelson 1995). The ceremonial center of the site, containing multiple pyramids, a colonnaded hall, and radiating causeways, has been the focus of diverse research projects over the past few decades (e.g., Elliott 2005; Jiménez 2010; Kelley 2008; Nelson 1995; Nelson 1996; 1997; Nelson and Martin 2015; Trombold

1991; Turkon 2004). Like many other northern settlements, La Quemada was founded around AD 500/600 and collapsed around AD 900. Its fortifications and the display of disarticulated human remains in public locations suggests the site was inhabited during a period of heightened inter-ethnic violence (Nelson and Martin 2015).

Nucleated populations in the Malpaso Valley were likely sustained by agricultural domesticates of maize, beans, and squash, with maize being the primary staple (e.g., Turkon 2006). Agave (*Agave*) was also likely an important and resilient food source (Anderies et al. 2008; Nelson 1992; Trombold and Israde-Alcantara 2005). Leporids were among the most commonly consumed animals (Cleland 2010; Dvorak 2000).

According to The Nature Conservatory's categorization, La Quemada today lies within the Central Mexican Matorral desert. At about 2100 meters above sea level, this highland ecoregion is enclosed by the Sierra Madre Occidental Mountains on the west, the Sierra Madre Oriental Mountains to the east, and the Trans Volcanic Belt of central Mexico to the south. The mountain ranges cast a rain shadow, resulting in low rainfall, often below 500 mm a year. Focusing on the state of Zacatecas, Matson and Baker (1986) split the territory into six different floral zones, offering a higher-resolution assessment of local environmental conditions. Their system placed the Malpaso Valley within a crassicaulescent scrub environment, bordered by desert to the north and grasslands to the south. In general, the Malpaso Valley is characterized by a high prevalence of grasses, likely in greater abundance than at Pueblo Grande and La Ferrería.

From the perspective of the archaeological site, three ecological zones were particularly relevant for inhabitants of La Quemada. Within a day's walking distance (~25 km) the Sierra Madre pine-oak forests were located to the east, which were probably exploited for hunting and wood. The site itself developed on a low hill within the desert flatlands, characterized by desert scrub such as mesquite (*Prosopis* spp.) and huizache (*Acacia* spp.), cacti (*Opuntia* spp.) and a variety of short grasses (Matson and Baker 1986). Finally, the Rio Malpaso runs just east of the site and provided habitat for cottonwood (*Populus* spp.) and willow (*Salix* spp.) trees. Using the WORLDCLIM online spatial database and the geographic information software, DIVA-GIS (Hijmans 2001; Hijmans et al. 2005) the 50 year (AD 1950-2000) interpolated mean annual precipitation at La Quemada was 550 mm, and the mean annual temperature was 17.4 °C.

MATERIALS AND METHODS

Leporid Bone Specimens

In total, 214 leporid bone samples, including both *Lepus* and *Sylvilagus* genera, were selected from the three site locations. For Pueblo Grande, I worked with collections curator Holly Young and collections aide, Lindsey Vogel, to select a sample of 85 rabbit and hare bones from the faunal collections at the Pueblo Grande site museum. Initial genus and species identifications were made by James (1994). Most of the Colonial and Sedentary Period remains came from early excavations at a large midden (Trash Mound 1) located south of the primary platform mound (Bostwick and Downum 1994), while the Classic Period remains came from excavations by the contract archaeology company, Soil Systems, in the habitation areas to the north and east of the platform mound (Abbott et al. 1994; Mitchell 1994b). More specific temporal assignments were made for each bone by determining which ceramic types were found in contextual association. This was done by using the Hohokam chronology employed by Dr. Abbott and by Soil Systems, and by consulting the proveniences described in excavation reports (Bostwick 1994; Mitchell 1994a). With the exception of one bone from a Pioneer Period (Snaketown ceramics) context, bones selected for the present study span the Colonial through Classic Periods and represent about 675 years of the occupational history of Pueblo Grande (AD 725-1450). Exploring potential environmental changes at Pueblo Grande through time, however, will be reserved for future studies.

Working with Dr. Heather Lapham of the Center for Archaeological Investigations at the Southern Illinois University, Carbondale, I selected 49 leporid specimens from La Ferrería contexts for analysis, which were originally excavated by J. Charles Kelley in the late 1950s. Specimens came from sealed architectural fill deposits and are dated principally by ceramic association (Abbott 1955; Kelley 1971). Although associated cultural materials span the entire occupational history of La Ferrería, the majority of reasonably well-dated contexts represent the Ayala (AD 600-850) and Las Joyas (AD 850-1000) phases, and thus subsequent temporal considerations in the chapter will focus on these time periods. Ayala phase bones sampled for the present come from architectural fill of Structures 2, 7, and 10 and Las Joyas phase samples come from architectural fill of Structures 1 and 5. La Ferrería fauna were previously analyzed by Parmalee (1964), demonstrating a high prevalence of leporids, with more *Lepus* than *Sylvilagus*, a finding discussed in more detail below.

For La Quemada, I selected 79 leporid specimens from Midden 6 and 11 in collaboration with Dr. Ben A. Nelson, project director of the La Quemada-Malpaso

Valley Archaeological Project, and with Robin Cleland, who identified the bones. Because the stratigraphy is better dated in Midden 11 than Midden 6 (Nelson 1997), chronological assessments focus exclusively on samples from the latter context and are roughly sorted into early, middle, and late phases. The midden spans the years of approximately AD 500-900. All leporid specimens included in the study are *Lepus*.

Laboratory procedures

Preparation of bone bioapatite and collagen of leporid bone specimens occurred at the University of California San Diego (UCSD). Bioapatite and collagen preparation followed procedures similar to those of described in Chapter 2 with the exception of archaeological specimens receiving 24 hours of bleach treatment in contrast to the 48 hours used on modern bones.

To assess the degree of bone mineral diagenesis, a sample (N=179, 84%) of archaeological specimens was analyzed by Fourier-Transform Infrared spectroscopy with the Attenuated Total Reflection technique (FTIR-ATR) at the Department of Chemistry and Biochemistry at the University of California at San Diego. Following calibration experiments on modern bone in the Paleodiet Laboratory and in consultation with previous literature (Hollund et al. 2013; Smith et al. 2007), produced ratios of carbonate to phosphate (C/P) and infrared splitting factor (IR-SF) are considered biogenic if they fall within the C/P range of 0.10-0.50 and IR-SF range of 2.0-4.0. For all samples, diagenesis of collagen was assessed through C/N ratios and percent of collagen yield, with acceptable ranges of 2.9-3.6 (DeNiro 1985) and >1% (Ambrose 1990), respectively.

Because bone collagen and mineral are subject to different processes of diagenetic contamination, we do not assume that contamination in one phase represents the state of the other (Beasley et al. 2014; Smith et al. 2007).

Statistical Analyses

Because of non-normal distributions of the data, non-parametric tests were used. Comparisons between two groups were made by Mann-Whitney U tests and comparisons between three or more groups were made by Kruskal Wallis one-way-analyses of variance. Significance was set at $\alpha=0.05$. All analyses were done with SPSS v. 22.

Results

Assessments of diagenesis found several specimens that fell outside of predetermined parameters. Excluded samples include five apatite samples with C/P ratios <0.10, three apatite samples with IR-SF values < 2.00, five apatite samples with IR-SF values >4.00, and one collagen sample with a C/N ratio >3.6. One oxygen value was dropped because of an exceptionally low value (11‰) suggesting water contamination. These specimens are not included in subsequent discussions and their isotopic values are not listed in the appendices. Across all archaeological contexts and time periods mean $\delta^{13}C_{apatite} = -6.9 \pm 2.7$‰ (N=190, 1 S.D.), $\delta^{18}O_{apatite} = 26.7 \pm 3.6$‰ (N=190, 1 S.D.), $\delta^{13}C_{collagen} = -14.0 \pm 3.2$‰ (N=142, 1 S.D.) and $\delta^{15}N_{collagen} = 7.0 \pm 2.0$‰ (N=142, 1 S.D.).

Summary statistics for each site location are presented in Table 5. A list of all isotope values is presented in Appendix IV.

Table 5. Summary statistics of stable isotope values sorted by site location.

	$\delta^{13}C_{apatite}$			$\delta^{18}O_{apatite}$			$\delta^{13}C_{collagen}$			$\delta^{15}N_{collagen}$		
	n	**Mean**	**SD**	***n***	**Mean**	**SD**	***n***	**Mean**	**SD**	***n***	**Mean**	**SD**
Pueblo Grande	79	-9.0	1.9	78	29.7	2.9	68	-16.1	2.5	68	8.0	1.7
La Ferrería	46	-6.1	2.2	46	25.5	2.3	32	-12.7	2.5	32	5.8	1.9
La Quemada	65	-4.9	1.8	65	23.9	2.4	42	-11.5	2.5	42	6.2	1.6

Discussion

Macro-Regional Scale: Inter-Site Comparisons

The sites of Pueblo Grande, La Ferrería, and La Quemada overlapped in their occupational histories during the Epiclassic period and all developed into important regional centers in desert environments. Here differences between their environments are quantified and compared, setting the stage for more detailed assessments below. A Kruskal-Wallis one-way analysis of variance found highly significant differences between leporid means from all three sites in terms of $\delta^{13}C_{apatite}$ (H=91.70, df=2, $P<0.001$), $\delta^{18}O_{apatite}$ (H=97.79, df=2, $P<0.001$), $\delta^{13}C_{collagen}$ (H=59.63, df=2, $P<0.001$), and $\delta^{15}N_{collagen}$ (H=36.82, df=2, $P<0.001$). Post-hoc Mann-Whitney U tests with a Bonferroni correction revealed that all pairwise comparisons of isotopic variables between sites were significantly different at the level of at least $P<0.05$ except for $\delta^{18}O_{apatite}$ ($P<0.063$),

$\delta^{13}C_{collagen}$ (P=0.316) $\delta^{15}N_{collagen}$ values (P=0.804) values between La Ferrería and La Quemada. In general, these results indicate that all three sites exhibited measurably different environmental characteristics from one another, but that La Ferrería and La Quemada were more similar to each other than either was to Pueblo Grande (Figures 10 & 11).

When considering modern environmental characteristics of the three site locations (Table 4) several predictions may be tested. Because stable oxygen isotope ratios correlate negatively with moisture variables (precipitation and humidity), stable nitrogen isotope ratios correlate positively with ambient temperature, and stable carbon isotope ratios reflect the amount of local C4 grass, cacti, and succulent cover (see Chapter 2), mean isotope values from each site may be assessed according to their relative rankings of these variables.

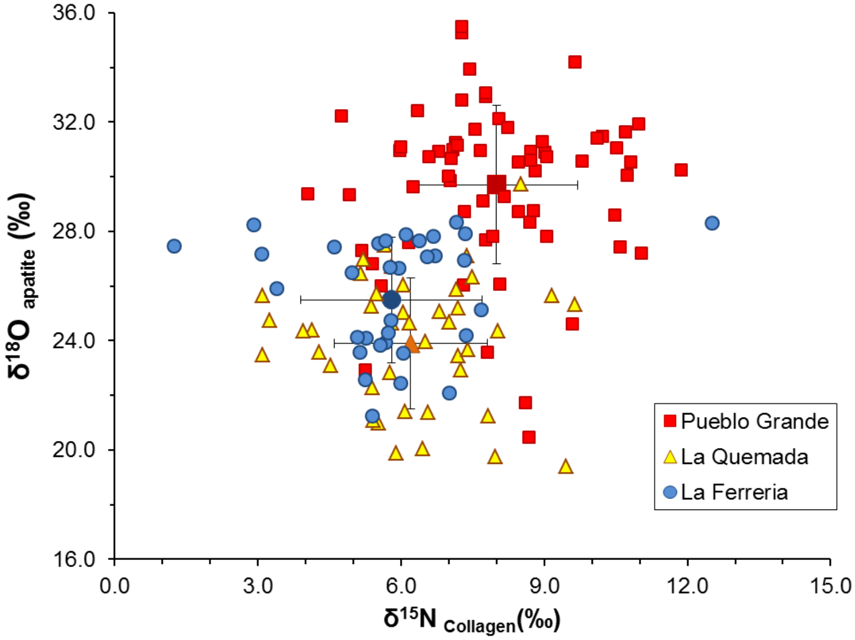

Figure 10. Scatterplot of stable nitrogen isotope values vs. stable oxygen isotope values. Increasing values on the Y axis represent increasing aridity while increasing values on the X axis represent increasing temperature. Error bars represent 1 SD from the site means.

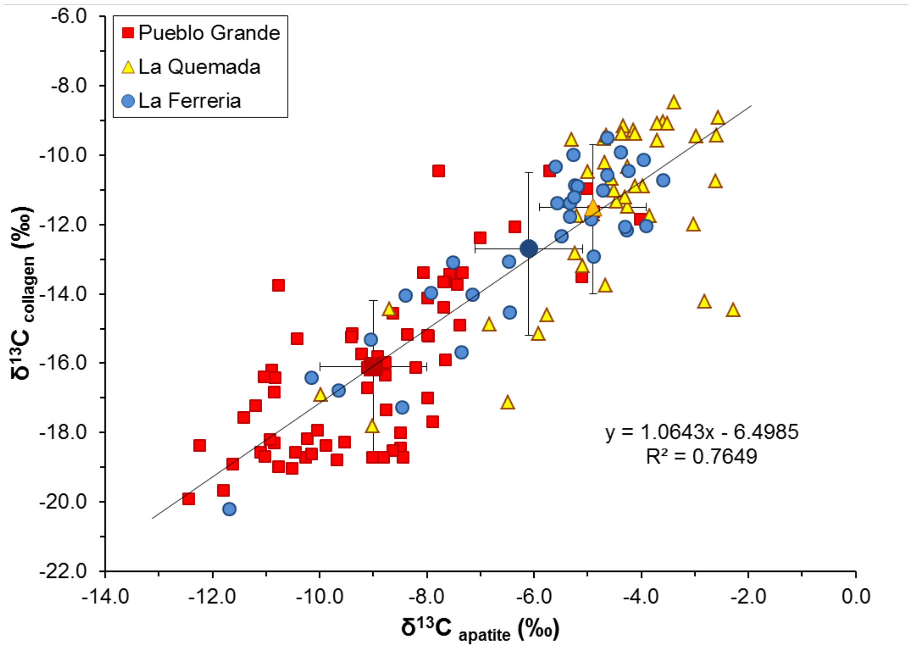

Figure 11. Scatterplot of stable carbon isotope values from apatite vs. stable carbon isotope values from collagen. Moving from left to right and from bottom to top indicates increasing C4/CAM consumption. Error bars represent 1 SD from site means.

As anticipated, leporids from Pueblo Grande, the Sonoran Desert site with the lowest modern mean annual precipitation and highest modern mean temperature values, exhibited the highest mean $\delta^{18}O_{apatite}$ and $\delta^{15}N_{collagen}$ values (Figure 10; Table 5). Pueblo Grande leporids also exhibited the lowest mean $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values, a finding consistent with modern characteristics of the Sonoran Desert, which does not contain as much grass cover as do the sites from Northwest Mexico. Although the Sonoran Desert contains many CAM plants, leporids prefer grasses and forbs over cacti and succulents, and, indeed, the low carbon values from Pueblo Grande leporids indicate that neither grasses nor cacti formed a large portion of their diet. This is in agreement with field analyses in Arizona, which indicate that over 60% of cottontail diets consisted of forbs and shrubs (Turkowski 1975), both of which use C3 photosynthesis. Also, as anticipated due to its status as the site with the highest mean annual precipitation, La Quemada leporids displayed the lowest $\delta^{18}O_{apatite}$ values. La Ferrería leporids exhibited somewhat intermediate oxygen and carbon values between those of Pueblo Grande and La Quemada, suggesting an environment with intermediate moisture and botanical characteristics, but, again, these values were much closer to La Quemada results than Pueblo Grande results. Differences in $\delta^{15}N_{collagen}$ values between La Ferrería and La Quemada were not significant, which was anticipated due to overall similar temperatures between the regions (Table 4). Thus, to the extent that past environmental conditions at all three sites are similar to the present, results of the macro-scale comparisons confirm the overall findings of Chapter 2 in that they demonstrate the utility of using multiple isotopic variables to quantify aspects of the paleoenvironment.

When considering changes in environmental signals through time (Figure 12), several findings were notable. In accordance with paleoclimate data, Pueblo Grande leporids exhibited their highest mean $\delta^{18}O_{apatite}$ values during the Santa Cruz period (AD 825-1000), a time that corresponds to severe drought conditions throughout much of North America. A more detailed assessment of stable isotope ratios at Pueblo Grande, however, is reserved for future studies. A similar peak in oxygen values from comparable temporal contexts was not observed at La Quemada or La Ferrería. La Quemada leporids exhibited fairly consistent stable isotope values throughout the Epiclassic period. Leporid $\delta^{18}O_{apatite,}$ $\delta^{13}C_{apatite}$, and $\delta^{13}C_{collagen}$ values from La Ferrería decreased near the end of the

Epiclassic, contrary to what would be expected during a time of widespread drought. This is considered in greater detail during the discussion of La Ferrería below.

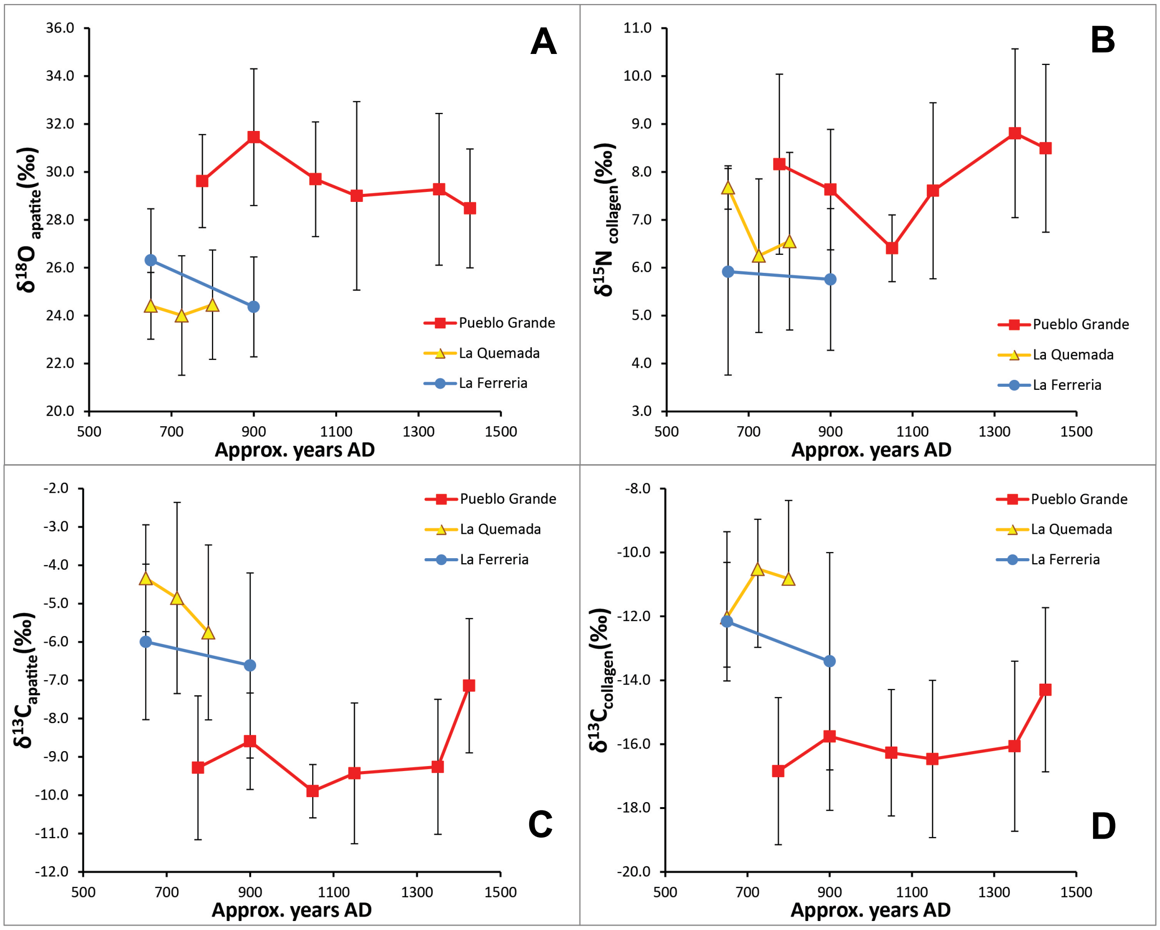

Figure 12. Temporal trends in stable isotope means from sites discussed in text. Symbols represent mean values and error bars represent 1 SD. A) Stable oxygen isotope ratios from leporid bone apatite. B) Stable nitrogen isotope ratios from leporid collagen. C) Stable carbon isotope values of leporid bone apatite. D) Stable carbon isotope values from leporid bone collagen.

Meso-Regional Scale: Landscapes of Northwest Mexico

To narrow the focus of investigation, Pueblo Grande leporids were set aside and the Northwest Mexico sites of La Quemada and La Ferrería were considered in greater detail. Both sites were hilltop settlements within semi-arid desert environments closely bordered by pine-oak forests of the Sierra Madres and by local riverine habitats (Figure 13). La Ferrería developed about 250 km northeast of La Quemada and is about 200 m lower in elevation. Near the onset of the Epiclassic period, these two sites became important regional centers and shared similar stylistic elements in pottery, lithics, and iconography.

Results of isotopic analyses found that differences in $\delta^{18}O_{apatite}$ values between La Ferrería and La Quemada were trending towards significance ($P<0.063$), with La Ferrería leporids exhibiting higher mean $\delta^{18}O_{apatite}$ values than La Quemada (Table 5). Although post-hoc tests from the Kruskal Wallis macro sample analysis found no significant differences in $\delta^{18}O_{apatite}$ values between the two sites, a Mann-Whitney U test including only La Quemada and La Ferrería did identify a significant difference ($U=956.5$, $P=0.001$). This pattern of higher $\delta^{18}O_{apatite}$ values at La Ferrería than at La Quemada was consistent with the 50 year mean modern rainfall values for the regions, which indicated that La Quemada received an average of 35 mm more rain per year than La Ferrería.

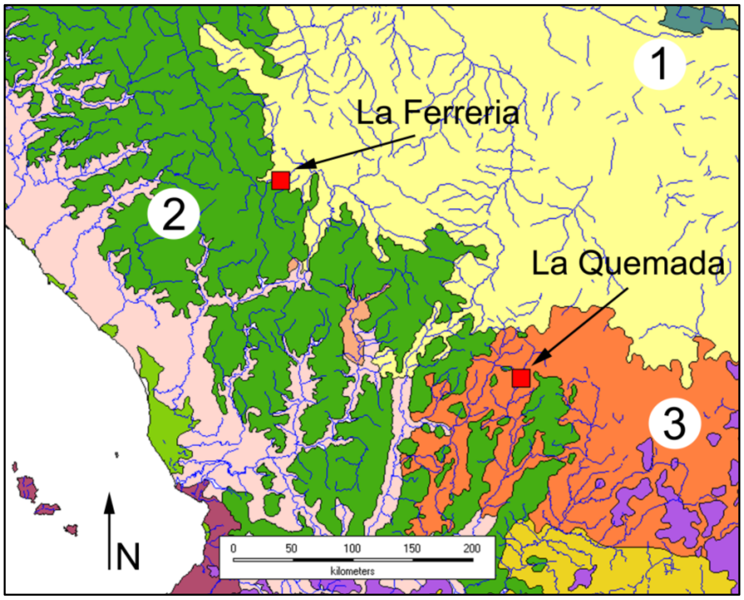

Figure 13. Map depicting archaeological sites of Northwest Mexico in relation to terrestrial ecosystems. 1) Chihuanhuan Desert; 2) Sierra Madre Pine-Oak Forest; 3) Central Mexican Matorral.

The relatively high mean $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values from both La Quemada and La Ferrería suggested that leporids there lived in environments with high amounts of C4 grasses and CAM plants. These findings were consistent with the overall characteristics of the Central Mexican Matorral and Chihuahuan deserts, which contain naturally high abundances of such flora. Between sites, La Quemada leporids exhibit significantly higher $\delta^{13}C_{apatite}$ values than La Ferrería leporids ($P<0.033$), and higher, but not significantly so, $\delta^{13}C_{collagen}$ values. A linear mixed model using mean $\delta^{13}C_{apatite}$ values[1], which most accurately reflect total dietary $\delta^{13}C$, found that La Quemada leporids

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[1] %C_4/CAM= ((-25.5-($\delta^{13}C_{apatite}$ -9.7))/-15.5)*100, where 25 represents the per mil C_3 end member, $\delta^{13}C_{apatite}$ represents the observed isotopic ratio, 9.7 represents $\Delta\delta^{13}C_{apatite-diet,}$ and -15.5 is the expected difference between dietary C4 and C3 end members, assuming a -10‰ $\delta^{13}C$ value for archaeological (pre-industrial) C4/CAM products.

consumed a diet of approximately 70% C4/CAM resources, while La Ferrería leporids consumed a diet of approximately 63% C4/CAM resources. As mentioned above, higher carbon values from La Quemada are as expected due to the high prevalence of grasses in the Malpaso Valley and due to the fact that La Ferrería was settled closer to pine-oak forests of the Sierra Madre Occidentals than La Quemada (Figure 13).

A trend was observed in carbon values from both site locations (Figure 14). Stable carbon isotope ratios in both apatite and collagen from both sites were strongly negatively skewed. This indicates that while the majority of acquired leporids had consumed diets heavy in C4/CAM resources, a number of specimens were acquired from more C3 rich ecosystems, likely including those from riparian and pine-oak forest habitats. Because the distribution was continuous and not bimodal, the skew suggests that leporids were acquired from a range of continuous habitats but with an emphasis on those living near open grassy areas populated by cacti and succulents, or within human-cultivated systems emphasizing C4 and CAM plants such as maize (*Zea mays*), maguey (*Agave* spp.) and nopal (*Opuntia* spp.). Indeed, it is likely that crop raiding of maize fields was practiced by many of the leporids in the sample, and this issue is considered further in the final chapter of the dissertation. It should be noted, however, that Pueblo Grande specimens in Arizona probably were equally as likely to raid maize fields as La Quemada and La Ferrería leporids, but carbon isotope results from Pueblo Grande produced statistically lower δ^{13}C values, suggesting that the local environments of La Quemada and La Ferrería contained naturally ^{13}C-enriched landscapes in addition to human-cultivated crops.

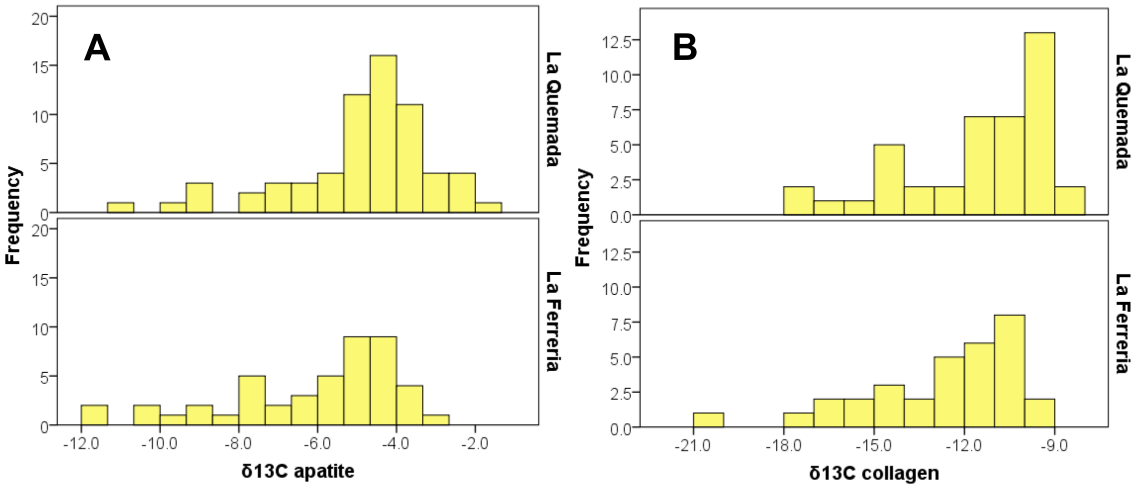

Figure 14. Histograms of stable carbon isotope values from La Quemada and La Ferreria. A) Results derived from bone mineral apatite. B) Results derived from organic bone collagen.

Although no significant differences were found between the two sites in terms of $\delta^{15}N_{collagen}$ values (P=0.804), the higher average $\delta^{15}N_{collagen}$ value at La Quemada than at La Ferrería (6.2‰ vs. 5.8‰) is consistent with the fact that La Quemada experiences higher mean maximum temperatures (Figures 10 & 12; Tables 4 & 5), the environmental variable most strongly correlated with leporid $\delta^{15}N_{collagen}$ values (see Chapter 2). However, the mean annual temperature is virtually indistinguishable between the two sites, and La Quemada has lower mean minimum temperatures than La Ferrería. The non-significant difference is thus unsurprising given the overall similar modern characteristics in temperature between the sites.

Within the La Quemada sample, temporal change in environmental conditions was assessed by analyzing leporid specimens from Midden 11 (see Figure 12), which overall spans the years of AD 600-900 and may be divided into Early, Middle, and Late levels (Nelson 1997). A Kruskal-Wallis one-way ANOVA comparing ranks across midden levels found no significant differences (P>0.05) between any isotope variable and midden levels suggesting no significant environmental changes over the occupational history of the settlement. These findings were similar to previous studies at La Quemada which similarly proposed that the site was warm and dry throughout the Epiclassic (Elliott et al. 2010; Trombold and Israde-Alcantara 2005). When assessing change over time at La Ferrería, however, significant differences in isotope ratios were observed, and these are considered in greater detail in the next section.

Site-Specific Scale: Landscape at La Ferrería

While many centers societies across Northwest Mexico, including La Quemada, were abandoned at around AD 900, La Ferrería remained a habitational and ritual center for approximately 500 additional years after these regional collapses. This section increases the granularity of analysis and focuses exclusively on social-environmental dynamics at La Ferrería.

Unlike La Quemada, which is only represented by *Lepus* specimens, the faunal collection from La Ferrería also contains *Sylvilagus* remains, which is likely due to the fact that La Ferrería lies closer to the Sierra Madre foothills (Figure 15), an environment with more botanical structure, such as woody plants, bushes and shrubs, making it more amenable to cottontails. In fact, the site of La Ferrería straddles on the border of Chihuahuan Desert and the Sierra Madre Pine-Oak Forest terrestrial ecoregions designated by The Nature Conservatory. The leporid genera were considered separately as they tend to inhabit different ecological niches and may thus reflect different facets of the paleoenvironment (see Chapter 2).

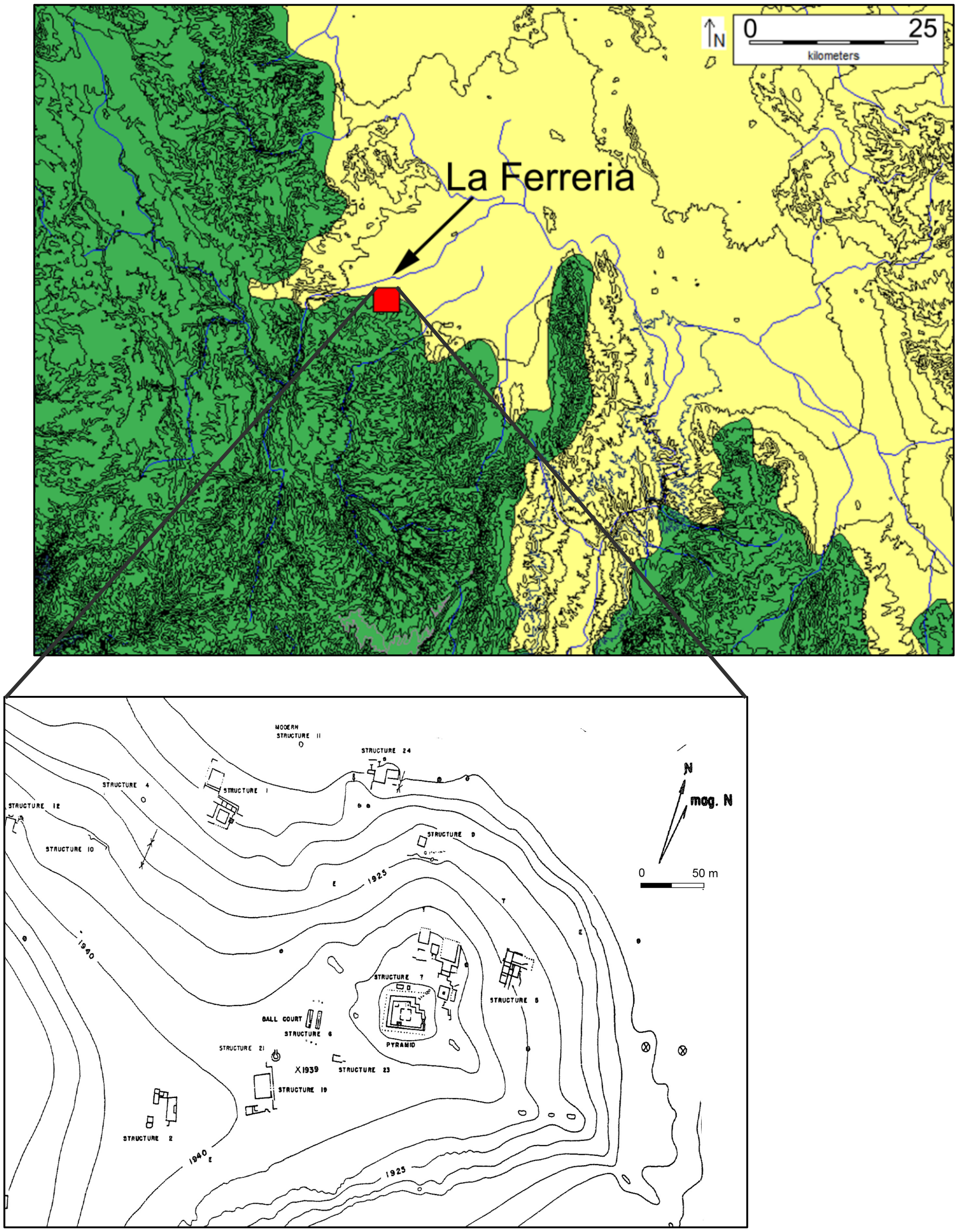

Figure 15. Map detailing the location of the site core of La Ferrería and its major structures relative to the Sierra Madre Pine-Oak Forest (Green) and the flatlands of the Chihuahuan Desert (Yellow). Site map of La Ferrería adapted from Abbott (1955). Ecoregion map generated from DIVA-GIS using TNC's online spatial data.

When arranging the resulting isotopic data from La Ferrería according to the two principle temporal phases represented by associated archaeological materials, several trends were observed. First, jackrabbit oxygen isotope ratios decreased through time (Figure 16A). Ayala phase (AD 600-850) jackrabbits exhibited significantly higher $\delta^{18}O_{apatite}$ values ($P<0.001$) than Las Joyas phase (AD 850-1000) specimens. This indicated that the Las Joyas phase was generally a wetter time than the preceding period, but that such changes appear to have affected jackrabbit habitats more strongly than cottontail habitats. Open flatlands of the Chihuahuan Desert, traditional habitat of jackrabbits, appear to have been more sensitive to moisture changes than were cottontail habitats, which were locations that likely included more woody plants, such as bushes, shrubs, and trees.

Additionally, cottontail $\delta^{13}C$ values of collagen and apatite declined across this temporal shift (Figure 17A and 17B). Cottontail $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values were both significantly lower in Las Joyas phase deposits than in Ayala phase deposits ($P<0.001$), suggesting that cottontails were feeding on more C3 plants during the Las Joyas phase, potentially due to wetter conditions, which would have favored forbs and other C3 plants. No significant differences were observed across time in jackrabbit $\delta^{13}C_{apatite}$ or $\delta^{13}C_{collagen}$ values, suggesting that cottontails inhabited areas of less C4 grass through time, but the amount of grass in jackrabbit habitats remained constant. Finally, no significant differences were observed in stable nitrogen isotope ratios through time for either genus, suggesting fairly consistent temperatures between temporal periods. Las Joyas phase cottontails, however, displayed a larger interquartile range than Ayala phase specimens (Figure 16B), suggesting the possibility of more variability in temperature at this time.

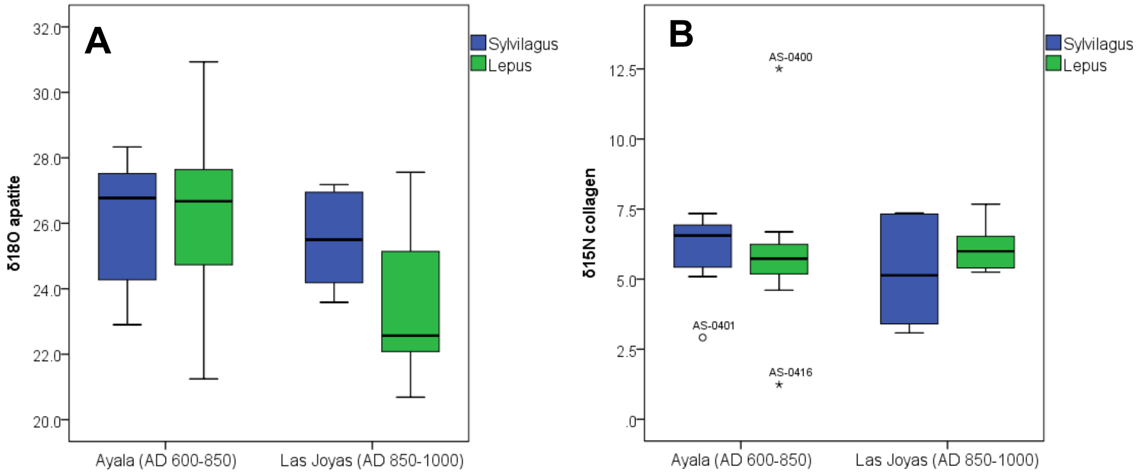

Figure 16. Box plots displaying the distribution of isotope values grouped by genus and time period. A) Stable oxygen isotope values; B) Stable nitrogen isotope values.

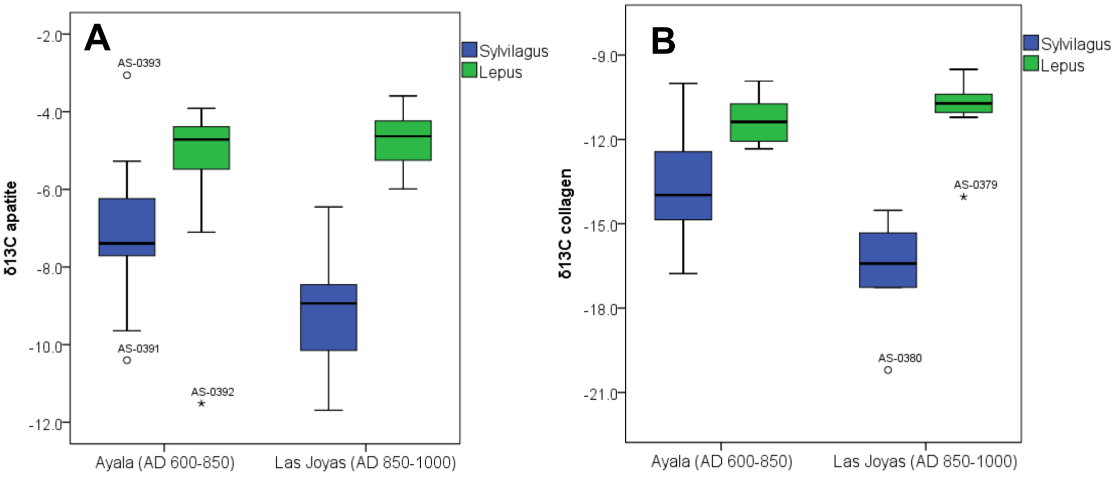

Figure 17. Box plots displaying the distribution of isotope values grouped by genus and time period. A) Stable carbon isotope values from bone mineral apatite; B) Stable carbon isotope values from organic bone collagen.

Archaeologically, the Las Joyas phase of the Guadiana Chalchihuites culture area, was characterized as a time of widespread population growth and new construction projects, and can be considered the apex of development in the region (Punzo Díaz 2008). In fact, recent survey work by Punzo Díaz (e.g., 2008) found that 100% of Guadiana Chalchihuites sites in the valley contain ceramics dating to this phase, which demonstrates that this period saw the greatest extent of human population in the region. Kelley (2000:143) has suggested that the collapse of other centers across Northwest Mexico, particularly Alta Vista of the Suchil Valley in Zacatecas around AD 875-925, led to a "major emigration" of people to the Guadiana Valley and La Ferrería. Preexisting trade ties with the Pacific Coast also intensified during the Las Joyas phase, and many items associated with Aztatlán mercantile trading network appeared at La Ferrería, including Chametla and Amapa pottery types, ceramic pipes, copper ornaments, and marine shells (Kelley 1971; Kelley 2000).

The association between wetter environmental conditions, increasing population, the arrival of foreign immigrants, foreign goods, and the instigation of new construction projects during the Las Joyas phase is important for two reasons: first, it suggests that the period of largest population growth in the valley may have been, at least in part, enabled by wetter environmental conditions. Although the Epiclassic period in general was characterized by exceptionally dry conditions and indeed aridity was reaching a peak for many regions throughout North America around AD 900, the leporid isotopic evidence presented here suggests that the environment around La Ferrería was an exception, experiencing measurably wetter conditions at this time. It is therefore possible that migrants from regions experiencing drought may have arrived in the Guadiana Valley seeking refuge and a place to continue their agricultural lifestyles which were becoming increasingly difficult elsewhere. Indeed, the combined genera mean $\delta^{18}O_{apatite}$ value for La Ferrería leporids dropped from 26.3 to 24.3‰ during the Las Joyas phase, a value quite close to the Epiclassic average from La Quemada of 23.9‰, suggesting that the Las Joyas phase exhibited environmental conditions more similar to that of Epiclassic La Quemada at this time. If drought conditions did intensify at La Quemada near the end of the Epiclassic, La Ferrería may have been a desirable destination for those seeking to continue their established ways of life under familiar environmental conditions. Additionally, if rainfall and general moisture levels were higher during the Las Joyas phase at La Ferrería, agricultural yields may have been consistently higher, enabling the center to absorb climate refugees from collapsing societies to the south. Agricultural surpluses may have been able to fund the costs required of large complex societies that southern centers could no longer afford. Some families and aspiring elites, moreover, may have been able to produce a surplus of food or other plant commodities to fund public feasts and labor-intensive work parties, thereby expanding their social networks and prestige.

Secondly, the apparent relationship between wetter conditions and social change during the Las Joyas phase is significant in that it suggests that the relationship between occupational history and environmental change across the northern frontier was more complex than previously hypothesized (Armillas 1964; Armillas 1969; Palerm and Wolf 1957). Indeed, the initial period of construction of public architecture at La Ferrería appears to have occurred during the more arid Ayala phase and not during an exceptionally wet period. Wetter conditions during the Las Joyas phase may have led to increased maize yields, thereby allowing larger populations, permitting more specialized labor, and enabling aspiring elites to sponsor feasting events. The increase of population in the valley and the construction of new public buildings at this time support this notion.

Changing environmental conditions nonetheless only enable a partially increased understanding of the developmental history at La Ferrería, and a range of other factors, including social and political dynamics, also likely influenced the pace of development in the Guadiana Valley. In particular, the role of trade during the Las Joyas periods may have served as additional contributing factor to social development and resiliency. Connections with the Pacific Coast Aztatlán mercantile system during the Las Joyas phase may have been a further source of growth and economic opportunity at La Ferrería (e.g., Jiménez 2011; Kelley 2000), enabling aspiring elites to acquire foreign prestige goods for personal status demarcation, for gift-giving, or for further exchange.

Potential complications with the environmental interpretation presented here may arise from the different sources of variation in the leporid bone isotope ratios. If, for example, the Las Joyas phase was actually an exceptionally dry period or if leporid numbers were reduced due to over-hunting and environmental degradation, jackrabbits and cottontails may have been less available locally, requiring hunting expeditions to travel further into the Sierra Madres or along the Rio Tunal. In such a scenario, the lower oxygen and carbon stable isotope ratios observed in Las Joyas phase specimens may have been due to non-local habitats of captured leporids rather than from changes in the local environment at La Ferrería. However, the fact that stable nitrogen isotope values, which reflect local temperature and properties of local soils, do not change through time indicates that leporids from both periods came from similar regions in both time periods.

Additionally, an analysis of the ratio of *Sylvilagus* to *Lepus* bones (*Sylvilagus*/(*Sylvilagus* + *Lepus*)), a commonly employed measure in environmental archaeology (Driver and Woiderski 2008; Szuter 1991), between the Ayala (Structures 2, 7 & 10) and Las Joyas phases (Structures 1 & 5) (Parmalee 1964) supports the isotopic patterns described above. Sampled Ayala phase deposits exhibit a lower ratio (0.23; *Syl*=15, *Lep*=49) than subsequent Las Joyas phase deposits (0.33; *Syl*=22; *Lep*=66), indicating a greater prevalence of cottontails relative to jackrabbits at this time. Because an increase in the prevalence of jackrabbits is thought to reflect the presence of more open and dry landscapes, the lower *Sylvilagus/Lepus* ratio during the Ayala phase supports the idea that the environment was drier and more open than the following Las Joyas phase. Notably, isotopic evidence for wetter times during the Las Joyas phase is close to agreeing with the findings of Butzer et al. (2008), who studied soil-geomorphology profiles in Durango and found evidence for the onset of a heavy wet cycle from AD 1050–1200, a period close to the Las Joyas phase, albeit slightly later in time.

Summary and Conclusions

This study conducted stable isotope analysis on jackrabbit and cottontail bones recovered from three archaeological sites in desert environments of North America: Pueblo Grande in Arizona, USA; La Ferrería in Durango, Mexico; and La Quemada in Zacatecas, Mexico. Data were assessed across three scales of analysis: 1) the macro-regional scale, which included all three archaeological sites; 2) the meso-regional scale, which focused on the two sites from Northwest Mexico; and 3) the site-specific scale, which focused in detail on the site of La Ferrería. Stable isotope data were used to test the assumption that moisture availability was an important factor for the development and maintenance of social complexity in the marginal regions of North America, as the productivity of maize - the staple crop for all selected sites - depends largely on the amount of local precipitation when not supplemented by irrigation. While most crops from Pueblo Grande were watered by canal irrigation, maize from La Ferrería and La Quemada likely depended more heavily on seasonal rains.

Results of the macro-regional comparisons found significant differences in isotope variables between all site locations, demonstrating the utility of the method for distinguishing between ecoregion types. Assessments of the data from the meso-regional scale further explored differences and similarities in environmental conditions between La Ferrería and La Quemada, demonstrating that, on average, La Quemada was characterized by greater amounts of C4/CAM vegetation while La Ferrería exhibited slightly drier conditions, though both were consistent with semi-arid environments with open grassy areas. Finally, by exploring stable isotope results at the site-specific scale, this chapter added detailed assessments of the dimensions of time and genus to the analysis. Between the Ayala (AD 600-850) and Las Joyas (AD 850-1000) phases at La Ferrería, jackrabbit oxygen isotope values decreased significantly, indicating greater rainfall and humidity in *Lepus* habitats. Cottontail carbon isotope values also decreased significantly across these periods, indicating a greater presence of C3 plants in *Sylvilagus* habitats, possibly due to an increase in forbs and shrubs across the slopes of the Sierra Madre foothills and the flatlands of the Guadiana Valley.

The results of this study are significant in that they contribute to our knowledge of the occupational and environmental histories of desert landscapes of pre-Hispanic North America. The hypothesis that wetter conditions enabled the expansion of complex societies into desert environments (e.g. Armillas 1964; Armillas 1969) was not supported by the leporid isotope data as Pueblo Grande, La Quemada, and La Ferrería all displayed no evidence for exceptionally wet conditions in their earliest phases of occupation at the macro and site-specific scales. However, the Las Joyas phase at La Ferrería, occurring approximately 250 years after the site's initial founding, was characterized by increases in population, architectural construction, long-distance trade, and also by increases in local moisture. Such findings provisionally link social change with environmental change at this time. As wetter conditions prevailed at La Ferrería at the end of the Epiclassic period, the site may have served as a center for displaced agriculturalists suffering from drought conditions in the southern valleys, which could no longer sustain the established levels of social complexity.

The assumption that socio-political collapses across the northern frontier of Mesoamerica were instigated by drought conditions (Armillas 1964; Armillas 1969) found support from the survey of paleoclimate records, though not from the leporid isotope data. The abandonment of population centers in the Suchil and Malpaso Valleys south of La Ferrería around AD 900, including the site of La Quemada, appear to correlate with a period of severe and widespread drought across North America. Reduced precipitation likely lowered maize yields, which may have undermined the ability of complex societies to fund the established "costs of complexity" (e.g. Tainter 1988, Tainter 2006). Such societies - relying on agricultural surpluses to provision large populations, specialized labor, and feasting events - may have been unable to maintain existing social organizations in periods of reduced agricultural productivity. Nevertheless, no significant changes in moisture, grass cover, or temperature were observed through time with the leporid bone proxies at La Quemada. The possibility remains that these negative findings may have been due to relatively small sample sizes and rough chronological control of the present sample, and further research is suggested. Neverthess, these findings are in agreement with previous paleoenvironmental studies at La Quemada, which found no evidence for environmental change throughout its occupational history (Elliott et al. 2010; Trombold and Israde-Alcantara 2005).

In conclusion, results of this study paint a complicated picture of the relationship between society and environment across the northern frontier of Mesoamerica. While moisture availability does appear to have been important at La Ferrería, the general model that suggests that wet conditions enabled the expansion of complex societies into marginal environments and dry conditions caused socio-political collapse (e.g. Armillas 1964; Armillas 1969; Parlem and Wolf 1957) does not accurately explain the culture history of the northern frontier of Mesoamerica. Indeed, none of the three selected site locations appear to have developed during exceptionally wet periods. Nevertheless, future paleoclimate research using dendrochronology, speleothems, and lake core sediments in the regions of Northwest Mexico will increase our understanding of the role of moisture in social development. Overall, the findings of this chapter highlight the importance of exploring environmental and archaeological data at multiple scales of analysis, and increase our understanding of the dynamic relationship between environment and social complexity in the pre-Hispanic New World.

CHAPTER 4: STABLE ISOTOPE EVIDENCE FOR LEPORID MANAGEMENT AND LANDSCAPE MODIFICATION AT THE ANCIENT METROPOLIS OF TEOTIHUACAN, MEXICO

Introduction

Mutualistic relationships between human and terrestrial herbivores have played critical roles in the history and development of complex societies. The coevolution of Eurasian and African societies with ungulates, such as cows (*Bos* spp.), goats (*Ovid*. spp.) and sheep (*Caprid* spp.) has resulted in their domestication for transportation, meat, milk, and secondary products, and in drastic transformations to natural landscapes (Gifford-Gonzalez and Hanotte 2011; Larson et al. 2007; Redman 1999; Zeder 2006). Fewer large mammals suitable for domestication were available in Pre-Columbian North and Central America (e.g., Diamond 1997:157-175), and their absence has led some to explore constraints on the growth of New World cities including the limits of long-distance trade networks (Drennan 1984) and the availability of high-quality protein (Harner 1977; Harris 1977; Parsons 2010).

Located in the northeast of the Basin of Mexico, the UNESCO World Heritage site of Teotihuacan (150 BC-AD 600; Figure 18) covered 20 km^2 and possessed a population of approximately 100,000 residents, making it the largest urban center of its time and an opportunity to explore human-animal dynamics in a pre-Hispanic complex society of Mexico (Cowgill 2015; Millon 1973). There, faunal analyses demonstrate that wild leporids (cottontails and jackrabbits) were among the most frequently represented mammals, suggesting their importance to the nutritional and economic history of the city (Starbuck 1987; Sugiyama and Sugiyama 2013). By using stable isotope analysis of archaeological and modern leporid bones from multiple locations across the urban core of Teotihuacan, this study produces quantitative data on the diet and ecology of these small mammals in an effort to contribute to our growing knowledge of the importance human-animal interactions played in the organization of complex societies of the New World.

At its peak, the population density of the urban core of Teotihuacan may have limited hunting opportunities for many households, and domestic management or breeding of small game may have been an adaptive alternative. Archaeological evidence suggests that rabbits and hares may have been managed and bred at select locations within the city (Manzanilla 1993; Manzanilla 1996:235-237; Valadez 1993). The Xolalpan period (AD 350-550) apartment compound of Oztoyahualco, located in the northwest portion of the site (15B:N6W3), contained a high percentage of rabbit and hare remains, accounting for approximately half of all identified fauna (48% using the minimum number of individuals [MNI]; Valadez 1993). Several rooms with high soil phosphate levels in the floor suggest the presence of disintegrated fecal matter or blood from butchering (Ortiz Butrón and Barba 1993), and a unique stone sculpture of a rabbit was found within one of the three public courtyards of the complex (Figure 19). Rooms 9 and 10 of Oztoyahualco, in particular, display the most evidence of leporid breeding. Both rooms exhibit high soil phosphate levels (Ortiz Butrón and Barba 1993), some of the highest concentrations of obsidian blades within the complex (Hernández 1993), and neither appears to have been used for habitation. Room 9 may have been a location for butchering rabbits as multiple foot and limb bones were discovered as well as 58 obsidian blades and a half-sphere decorated dolomite groundstone, perhaps serving as an "anvil" for cutting hides (Hernández 1993). Excavations of Room 10 revealed obsidian blades in all stages of manufacturing and 50% of all the leporid remains from the compound, suggesting its association with leporid butchering (Hernández 1993). Room 10 also contained a small room with low adobe walls (Room 30) in the southwest corner, suggestive of a pen for domestic animal management (Valadez 1993).

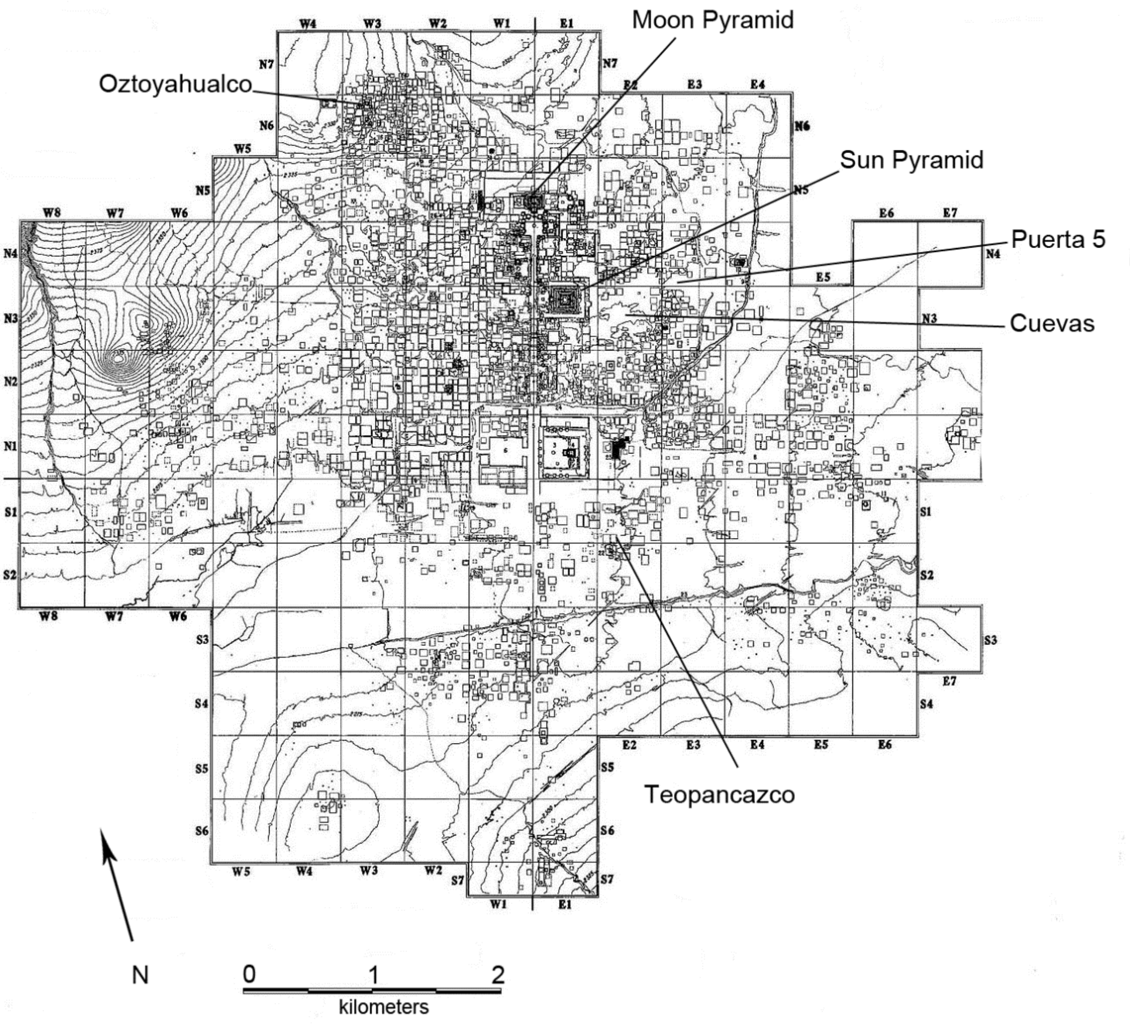

Figure 18. Map of Teotihuacan highlighting site locations mentioned in the text (After Millon 1973).

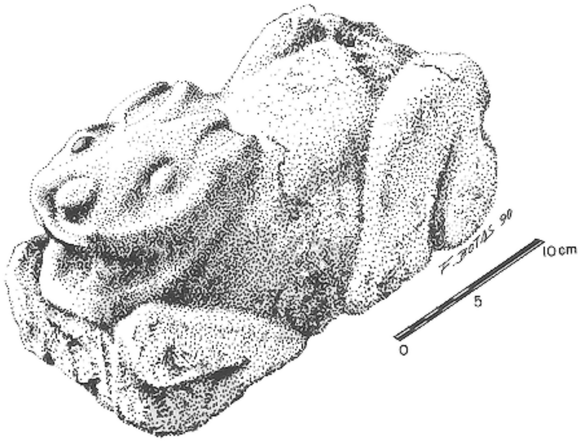

Figure 19. Illustration of stone rabbit sculpture from the Oztoyahualco apartment compound. (Manzanilla [ed.]1993; drawing by Fernando Botas).

To investigate long-term dynamics of human-leporid ecology at Teotihuacan and to test whether jackrabbits and cottontails were managed or bred at Oztoyahualco through specialized labor, this study uses stable carbon and nitrogen isotope analysis of leporid bone mineral ($\delta^{13}C_{apatite}$) and collagen ($\delta^{13}C_{collagen}$ & $\delta^{15}N_{collagen}$) from several contexts within the city, and from a sample of modern specimens from central Mexico. As wild animals, leporids also represent a point of juncture between humans and the natural environment, and an understanding how human-leporid relationships changed through time will inform our understanding of Teotihuacan's relationship with the environment over the development and decline of the city, a period of approximately 1350 years. This study, then, explores results across both spatial and temporal scales, attempting to situate the dynamics of human-leporid interactions within their broader social and environmental contexts. Specifically, stable isotope results are used to test hypothesis that leporids from

Oztoyahualco 15B, as the products of specialized labor dedicated to their management or breeding, will display greater evidence for human provisioning (i.e. maize, nopal, and maguey consumption) that leporids from other locations and times.

Isotope Ecology of Highland Mexico

Carbon isotope ratios of bone tissue are principally determined by the photosynthetic pathway of consumed plants, which can be C3, C4, or Crassulacean acid metabolism (CAM) (DeNiro and Epstein 1978; van der Merwe 1982). Most plants utilize the C3 photosynthetic pathway, including all trees, forbs, and shrubs. These plants exhibit $\delta^{13}C$ values of approximately -27‰ (Kohn 2010; O'Leary 1988; Smith and Epstein 1971). C4 plants primarily include dry adapted grasses, and exhibit much higher (less negative) $\delta^{13}C$ values than C3 plants, with a global average of approximately -12.5‰ (O'Leary 1988). CAM plants include cacti and succulents and exhibit values similar to C4 plants (O'Leary 1988; Warinner et al. 2013). Notably, many of the most important foods cultivated by humans in pre-Hispanic Mexico (Zuria and Gates 2006), such as maize (*Zea mays*), amaranth (*Amaranthus* spp.), nopal cactus (*Opuntia* spp.) and maguey (*Agave* spp.), are either C4 or CAM plants and are characterized by relatively high $\delta^{13}C$ ratios, with average values of approximately -11.0‰ (O'Leary 1988; Warinner et al. 2013). While carbon isotope ratios from bone collagen ($\delta^{13}C_{collagen}$) are biased towards the $\delta^{13}C$ of dietary protein, carbon isotope ratios from bone mineral apatite ($\delta^{13}C_{apatite}$) reflect $\delta^{13}C$ of total dietary input (Ambrose and Norr 1993; Froehle et al. 2010).

Stable carbon isotope values, then, may be used to represent the degree of integration of leporids into human-dominated social-environmental systems under the assumptions that higher bone δ^{13}C values represent greater consumption of human-cultivated food staples (Rawlings and Driver 2010; Somerville et al. 2010; White et al. 2001). Naturally occurring C4/CAM plants are also present in Highland Mexico (Warriner et al. 2013), and their consumption by archaeologically recovered leporids included in the sample is accounted for by incorporating a selection of modern wild jackrabbits and cottontails from the region. I anticipate that $\delta^{13}C_{apatite}$ and $^{13}C_{collagen}$ values from Teotihuacan-era leporids will be higher than modern wild specimens due to the extensive agricultural fields likely in place during the Classic Period in comparison to the period of modern specimen collection, assuming that leporids would have incorporated a percentage of such foods into their diet through the practice of agricultural crop raiding. Notably, human hunting of garden pests, such as leporids, was a significant source of protein elsewhere in the Americas (Linares 1976; Neusius 2008; Schollmeyer and Driver 2013), and this chapter anticipates that many Teotihuacan leporids were acquired through this practice. Additionally, I hypothesize that Oztoyahualco specimens will exhibit higher $\delta^{13}C_{apatite}$ values than leporids from other contexts within the city and from modern wild specimens due to their direct provisioning of human-cultivated foodstuffs.

Nitrogen isotope ratios in bone collagen ($\delta^{15}N_{collagen}$) reflect the δ^{15}N of dietary protein sources (DeNiro and Epstein 1981), which are entirely plant-based for herbivorous leporids. Plant δ^{15}N values are influenced by aspects of the local environment, such as aridity and salinity of the soil in which they were grown (Amundson et al. 2003; Hartman 2011; Ugan and Coltrain 2011). Because $\delta^{15}N_{collagen}$ is sensitive to dietary inputs, these data are considered alongside bone $\delta^{13}C$ values to assess dietary differences between leporids of various contexts. Without baseline data on the isotope ecology of the Basin of Mexico, however, we do not anticipate either a positive or negative shift in $\delta^{15}N$ ratios, but assume that significantly different nitrogen values at Oztoyahualco would further support the integration of leporids into human-dominated systems. Although stable oxygen isotope data were produced as a by-product of bone mineral analysis and are presented in Appendix V, their interpretation will be reserved for future studies.

Materials and Methods

Leporid Bone Specimens and Contexts

The sample includes 134 leporid bones from multiple locations within the city and 13 modern specimens from the Mexican states of Puebla, Queretaro, and Distrito Federal. Stratigraphic association and radiocarbon dating demonstrate that leporids form archaeological contexts represent a temporal transect of approximately 1350 years that spans the growth and decline of the city (Table 6). Modern leporids come from the U.S. Geological survey and were collected during the years of 1892, 1893, 1966, and 1996 by hunting and are considered to represent “wild” values from the environs surrounding Teotihuacan. Across the total sample, jackrabbits (*Lepus* spp.) and cottontails (*Sylvilagus* spp.) were grouped together for statistical analyses as both provide similar resources (e.g. meat, hide, fur), have similar food requirements, and specialized breeders may have kept both in managed fields or in domestic courtyards. Nevertheless, it is likely that *Sylvilagus* would have been more amenable to small enclosures than *Lepus* and an overall better candidate for active management and thus some consideration of differences between the genera are considered. Here we present a description of each site location sampled for leporid remains in rough chronological order.

Moon Pyramid (150 BC- AD 450): The Moon Pyramid, one of three monumental complexes at Teotihuacan, was first constructed at about AD 100 but was expanded and modified several times until sometime in the 5th century AD (Sugiyama and Cabrera 2007). Leporid bones were recovered from within the fill of six superimposed structures. Fill materials likely predate the construction of each phase. Ceramics from associated contexts predominantly date to the Tzacualli phase (1 BCE-150 AD) but span the Patlachique to early Tlamimilolpa periods. This estimated temporal range is confirmed by radiocarbon dating of discrete burial events within the pyramid (Sugiyama and Cabrera 2007). Because the final building episode occurred around AD 450, older structures and their associated fill predate this time, and most leporid remains likely date to the earliest years of Teotihuacan (BC 1to 150 AD). Primary excavations of this monumental structure were conducted by Saburo Sugiyama and Ruben Cabrera Castro from 1998-2004 as part of the *Proyecto Pirámide de la Luna*. In total, 56 leporid bones were sampled from the pyramid.

Teopancazco (AD 200-550): Teopancazco was a multiethnic neighborhood center located in the southeastern periphery of the urban core of Teotihuacan. In addition to habitation, the complex served as a center for diverse activities, including craft production, ritual ceremonies, and administration (Manzanilla 2007). Teopancazco was occupied between approximately AD 200-550 (Beramendi et al. 2012), but the contexts sampled in this study date mainly to the Xolalpan period (350-550 AD). Materials were recovered from excavations directed by Linda Manzanilla between 1997-2004 as part of the project, *Teotihuacan Elite y Gobierno*. Twenty leporid bones were sampled for this study.

Oztoyahualco 15B (AD 350-550): The Oztoyahualco apartment compound is located northwest of the Pyramid of the Moon in one of the oldest sectors of the city (Millon and Bennyhoff 1961), but excavated contexts at the compound (15B:N6W3) date exclusively to the Xolalpan period (Manzanilla 1993). Archaeological evidence, as mentioned above, suggests that residents of the compound may have specialized in leporid management or breeding (Valadez 1993). Excavations between 1985-1988 as part of the project *Antigua ciudad de Teotihuacan*, directed by Linda Manzanilla, recovered leporid remains from multiple contexts, and 17 were selected for the present study.

Puerta 5 (AD 600-1150): The Puerta 5 site is a post-Teotihuacan human-made cave/tunnel complex that likely had a ceremonial function. The site is located near the Gate-5 entrance to the archaeological zone, immediately to the east of the Sun Pyramid. Leporid samples primarily come from the two contexts of Cueva III and Cala II and were associated with Coyotlatelco (AD 600-900) and Mazapan (AD 900-1150) phase ceramics. These periods represent the time following the political collapse of Teotihuacan (Moragas Segura 2002). Puerta 5 was excavated under the direction of Eduardo Matos Moctezuma and Ruben Cabrera as part of the salvage excavation, *Proyecto Especial*

Teotihuacán 1992-1994 (Moragas Segura 1994). Twenty nine bones were sampled for this study.

Túneles y Cuevas (AD 1150-1500): Leporids from two tunnels with Epiclassic and late-occupation Postclassic period contents were collected at Cueva Pirul and Cueva de las Varillas. These tunnels are adjacent to each other and are located east of main axis of the city, immediately behind the Pyramid of the Sun. Although the caves were in use as early as the Coyotlatelco phase, most selected leporids are associated with Aztec phase (AD 1150-1500) materials (Manzanilla et al. 1996). These human-made tunnels were used for a variety of purposes, including habitation, storage, ritual, burial, and extraction of construction material (Manzanilla et al. 1994). Samples were recovered during excavations of the *Tunnels and Caves at Teotihuacan* project, directed by Linda Manzanilla in 1992-1996 (Manzanilla 1994). Twelve bones from fill contexts were sampled for analysis.

Modern (AD 1892-1966): To provide a comparative sample, 13 modern leporids were sampled from the Smithsonian Institution's mammalian vertebrate collection. These wild specimens are considered a baseline signal for natural habitats around the Basin of Mexico. Unfortunately, no specimens were available from the Teotihuacan valley itself. Museum specimens were collected through hunting in the regions of Tlalpan of Distrito Federal, Tulancingo and Zimpan of Hidalgo, Tesquisquiapam from Queretaro, and from San Baltazar Tetla and Malinche Volcano in Puebla. Areas represent primarily Central Mexican matorral deserts and pine-oak forest landscapes, similar to the general setting of Teotihuacan. To account for the decrease in atmospheric $^{13}CO_2$ because of the industrial (Suess) effect (Keeling 1979), the 20th century (1966 and 1996) leporid $\delta^{13}C_{apatite}$ and

$\delta^{13}C_{collagen}$ values are corrected by +1‰ to match archaeological values, but 19th century samples (1892 and 1893) are assumed to be comparable to pre-industrial specimens and no correction is applied.

Table 6. Chronology of Teotihuacan with associated ceramic phases and site contexts.

Period	Calendar Dates	Ceramic Phase	Sampled Site Contexts		
Postclassic	AD 1150-1500	Aztec	Túneles y Cuevas		
	AD 900-1150	Mazapan	Puerta 5		
Epiclassic	AD 600-900	Coyotlatelco			
Classic	AD 550-600	Metepec			
	AD 350-550	Xolalpan	Moon Pyramid	Teopancazco	Oztoyahualco
	AD 275-350	Tlamimilolpa late			
	AD 200-275	Tlamimilolpa early			
	AD 150-200	Miccaotli			
Formative	1 BC - AD 150	Tzacualli			
	150-1 BC	Patlachique			

Laboratory Procedures

Preparation of bone apatite samples for stable isotope analysis occurred at the University of California, San Diego (UCSD) in the Paleodiet Laboratory following procedures similar to those of described in Chapter 2. Isotopic analyses were conducted at Scripps Institution of Oceanography's Analytical Facility. To assess the degree of bone mineral diagenesis, a random sample (N=101, 74%) of archaeological specimens was analyzed by Fourier-Transform Infrared spectroscopy with the Attenuated Total Reflection technique (FTIR-ATR) at the Department of Chemistry and Biochemistry at the University of California at San Diego. Following calibration experiments on modern bone in our laboratory and in consultation with previous literature (Hollund et al. 2013; Smith et al. 2007), we consider produced ratios of carbonate to phosphate (C/P) and infrared splitting factor (IR-SF) biogenic if they fall within the C/P range of 0.10-0.50 and IR-SF range of 2.0-4.0. For all samples, diagenesis of collagen was assessed through C/N ratios and percent of collagen yield, with acceptable ranges of 2.9-3.6 (DeNiro 1985) and >1% (Ambrose 1990), respectively. Because bone collagen and mineral are subject to different forces of diagenetic contamination, we do not assume that contamination in one phase represents the state of the other (Beasley et al. 2014; Smith et al. 2007).

Statistical Analyses

Parametric tests were used to identify differences between groups of two (independent samples t-test) and more than two (One-way between subjects analysis of variance [ANOVA]). Significance was assumed at $\alpha=0.05$. All analyses were conducted in Statistical Package for the Social Sciences (SPSS v.22).

Results and Discussion

Assessments of diagenesis found several specimens that fell outside of predetermined parameters. Five apatite samples with C/P ratios <0.10, three apatite samples with IR-SF values < 2.00, five apatite samples with IR-SF values >4.00, and one collagen sample with a C/N ratio >3.6 were excluded from the study. These specimens are not included in subsequent discussions. Across all archaeological contexts and time periods the means were: $\delta^{13}C_{apatite}$ = -7.8 ± 2.3‰ (N=112, 1 S.D.), $\delta^{13}C_{collagen}$ = -15.7 ± 2.6‰ (N=118, 1 S.D.) and $\delta^{15}N_{collagen}$ = 5.4 ± 2.2‰ (N=118, 1 S.D.). The modern specimens exhibit mean values of $\delta^{13}C_{apatite}$ = -12.3 ± 1.6‰ (N=13, 1 S.D.), $\delta^{13}C_{collagen}$ = -17.7 ± 1.8‰ (N=12, 1 S.D.), and $\delta^{15}N_{collagen}$ = 4.4 ± 2.5‰ (N=12, 1 S.D.). Summary statistics for each site context are found in Table 7.

Carbon isotope ratios of archaeological bone from both apatite and collagen were notably ^{13}C-enriched relative to modern specimens ($P<0.001$). Combining genera, a linear mixed model[2] of bone apatite carbon values, which most closely approximate the $\delta^{13}C$ of the total diet, found that Teotihuacan leporids consumed a diet of approximately 53% C4/CAM foods. The mean $\delta^{13}C_{apatite}$ value of archaeological specimens was significantly ($P<0.001$) higher than the $\delta^{13}C_{apatite}$ values from modern specimens, which had a diet composed of approximately 22% C4/CAM inputs. Relative to the modern reference, isotope values from Teotihuacan leporids indicated greater consumption of foods from human-dominated C4/CAM ecosystems, and that the Teotihuacan-era landscapes were considerably different than the regions represented by the modern specimens.

High bone $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values, then, suggest that leporids deposited in Teotihuacan fill contexts acquired about half of their calories through the consumption of local C4 grasses, crop raiding for maize, nopal fruits, amaranth, or through direct human

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[2] $\%C_4/CAM = ((-25.5-(\delta^{13}C_{apatite}-9.7))/-15.5)*100$, where 25 represents the per mil C_3 end member, $\delta^{13}C_{apatite}$ represents the observed isotopic ratio, 9.7 represents $\Delta\delta^{13}C_{apatite-diet}$, and -15.5 is the expected difference between dietary C4 and C3 end members, assuming a -10‰ $\delta^{13}C$ value for archaeological (pre-industrial) C4/CAM products.

provisioning of these items. Nevertheless, it is important to note that a diet of ~50% C4/CAM plants is appreciably lower than leporids from La Quemada and La Ferrería (see Chapter 3), presumably due to the greater natural abundance of C4 grasses at these sites than in the Basin of Mexico.

Table 7. Descriptive statistics for isotope values grouped by genus and selected site locations.

		δ^{13}C apatite (‰)			δ^{13}C collagen (‰)			δ^{15}N collagen (‰)		
		n	**Mean**	**SD**	***n***	**Mean**	**SD**	***n***	**Mean**	**SD**
Moon Pyramid	*Sylvilagus*	35	-8.8	2.1	33	-16.5	2.3	33	5.8	1.9
	Lepus	16	-8.4	3.1	17	-15.8	3.9	17	3.6	2.2
	Subtotal	51	-8.7	2.5	50	-16.3	2.9	50	5.1	2.3
Teopancazco	*Sylvilagus*	14	-7.1	1.1	15	-15.3	1.7	15	6.8	2.3
	Lepus	5	-6.8	2.2	4	-15.0	3.1	4	6.1	2.2
	Subtotal	19	-7.0	1.4	19	-15.3	2.0	19	6.7	2.3
Oztoyahualco	*Sylvilagus*	12	-6.1	2.2	12	-15.0	3.4	12	4.9	1.7
	Lepus	3	-5.0	1.4	4	-11.8	1.3	4	6.2	0.9
	Subtotal	15	-5.9	2.1	16	-14.2	3.3	16	5.2	1.6
Puerta 5	*Sylvilagus*	17	-7.4	2.1	19	-15.8	3.0	19	4.7	2.1
	Lepus	2	-6.2	.8	2	-13.6	.2	2	4.3	.2
	Subtotal	19	-7.3	2.1	21	-15.6	2.9	21	4.6	2.0
Cuevas	*Sylvilagus*	6	-9.9	1.8	7	-17.8	1.4	7	7.1	3.0
	Lepus	4	-7.5	1.4	5	-14.2	2.3	5	4.7	1.1
	Subtotal	10	-8.9	2.0	12	-16.3	2.6	12	6.1	2.6
Modern	*Sylvilagus*	12	-12.5	1.6	11	-17.9	1.7	11	4.2	2.5
	Lepus	1	-10.5	.	1	-15.2	.	1	6.7	.
	Subtotal	13	-12.3	1.6	12	-17.7	1.8	12	4.4	2.5

A one-way between subjects ANOVA found significant differences between site contexts in terms of $\delta^{13}C_{apatite}$ (F[4, 107]=5.8, *P*<0.001) but not for $\delta^{13}C_{collagen}$ (F[4, 113]=1.9, p=0.109). Post-hoc Tukey tests indicated that Oztoyahualco leporids had significantly higher $\delta^{13}C_{apatite}$ values than those of the Moon Pyramid and the Cuevas, and higher mean $\delta^{13}C_{apatite}$ values than every other context (see Figures 20 & 21). Although the ANOVA did not register significant differences between sites in terms of $\delta^{13}C_{collagen}$ values, the Oztoyahualco $\delta^{13}C_{collagen}$ mean was higher than every other site location (Table 7). In fact, after splitting the genera, *Lepus* specimens from Oztoyahualco exhibited the highest $\delta^{13}C_{collagen}$ values of the entire sample (Figure 22). Together, $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values, then, demonstrate that leporids from Oztoyahualco consumed a diet much higher in C4/CAM foods than modern leporids from similar environments and indeed from every other site location within the city (Figure 22).

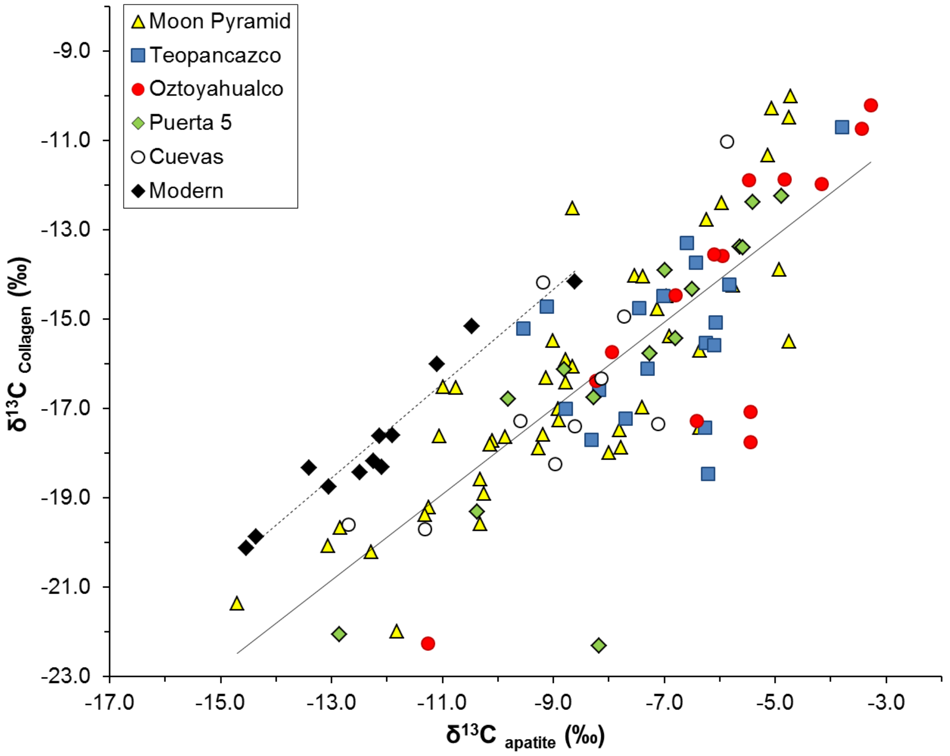

Figure 20. Scatterplot of stable carbon isotope values from bone apatite and collagen. Markers are labeled according to site locations. Two separate regression lines are drawn through archaeological and modern specimens. Modern: y = 1.0535x - 4.8619; R² = 0.9364. Archaeological: y = 0.9626x - 8.3319; R² = 0.6403.

Stable nitrogen isotope data were less conclusive. An ANOVA on pooled Teotihuacan leporid genera revealed a significant effect of site location on $\delta^{15}N_{collagen}$ values (F[4, 113]=4.8, *P*=0.001), but no clear spatial or temporal trends were apparent (Figure 23). The lack of meaningful patterning of $\delta^{15}N_{collagen}$ values neither supports nor refutes the hypothesis that Oztoyahualco served as a leporid production center, as previous studies have documented a high degree of variability among leporid $\delta^{15}N_{collagen}$ values (Ugan and Coltrain 2011) and no a priori $\delta^{15}N_{collagen}$ difference was assumed between human-dominated social-environmental systems and otherwise.

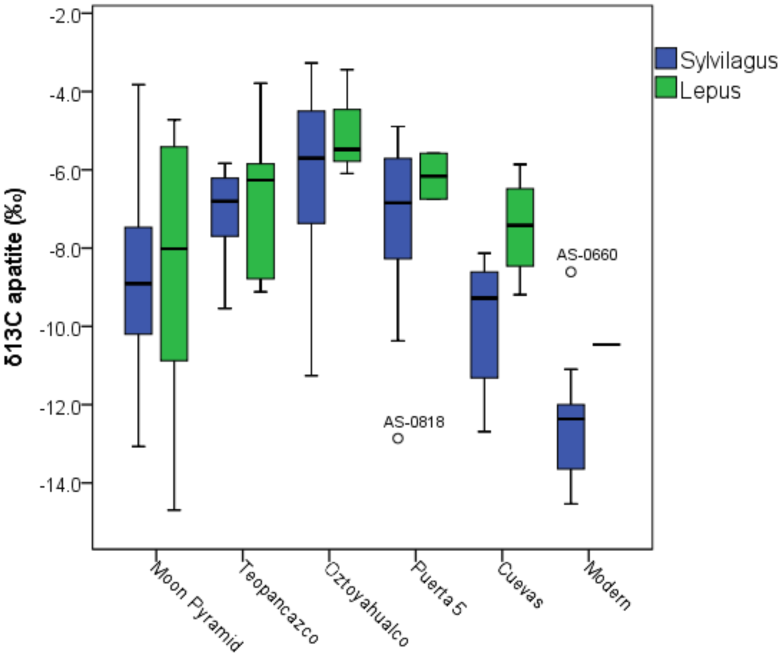

Figure 21. Box plots of stable carbon isotope values of bone apatite from each site location. Results are grouped according to genus and are arranged in rough chronological order moving from left (oldest) to right (most recent).

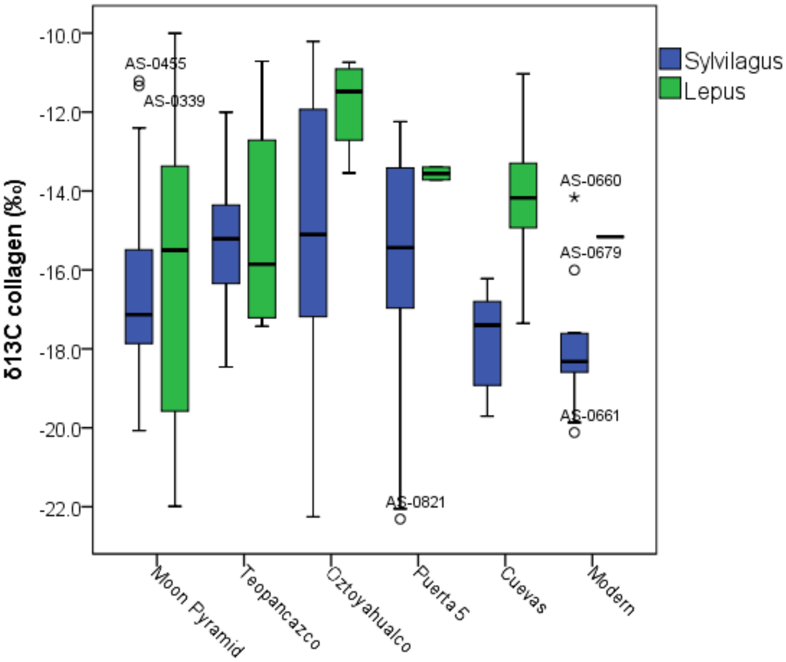

Figure 22. Box plots of stable carbon isotope values of bone collagen from each site location. Results are grouped according to genus and are arranged in rough chronological order moving from left (oldest) to right (most recent).

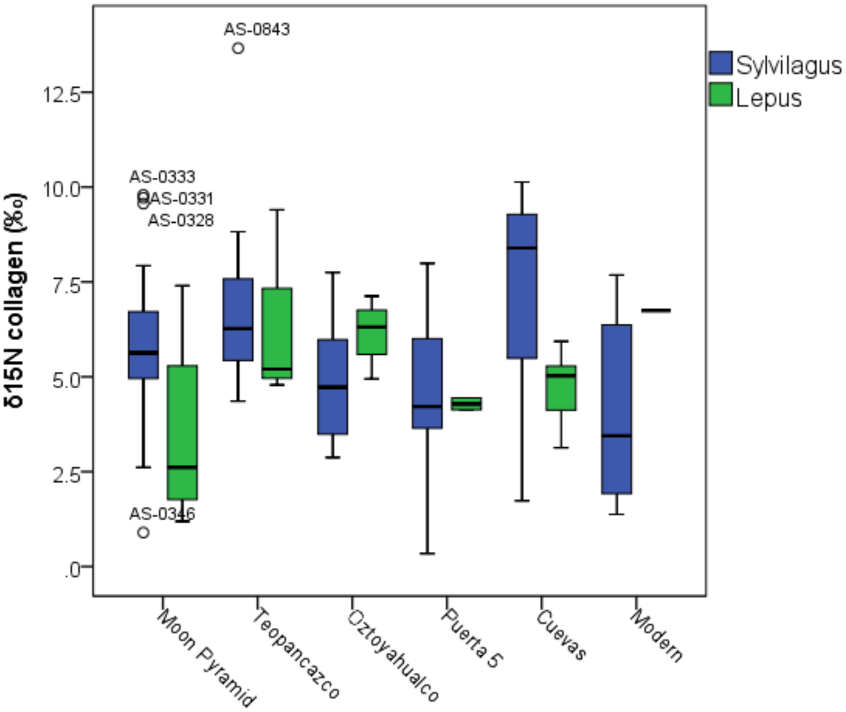

Figure 23. Box plots of stable nitrogen isotope values from each site location. Results are grouped according to genus and are arranged in rough chronological order moving from left (oldest) to right (most recent).

Exploring changes in leporid ecology through time, isotopic results were assessed according to the approximate chronological order of sampled site locations (Figures 21-23). Although all five archaeological locations represent different temporal ranges, significant overlap exists between chronologies at each site (Table 6). Moon Pyramid contexts (150 BC – AD 450) overlapped in time with both the early occupations of Teopancazco (AD 200-550) and Oztoyahualco (AD 350-550), which themselves were mostly contemporary. Additionally, although leporids from Cuevas contexts date mostly to the Aztec period (AD 1150-1500) by ceramic association, several leporids came from levels with Coyotlatelco period (AD 600-900) ceramics and thus may overlap slightly in time with Puerta 5 specimens. Nevertheless, when arranged in this rough chronological order, data demonstrated a trend of increasing leporid $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values across the Formative and Classic Periods, achieving an apex at Oztoyahualco, and then decreasing after the political and demographic collapse of the city through the Epiclassic and Postclassic periods (Figures 21 & 22). This pattern was apparent in both *Lepus* and *Sylvilagus* specimens.

Leporids from the Cuevas sample represent a reoccupation of Teotihuacan long after its political and demographic collapse. It is notable that $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values from this context were lower than all other archaeological proveniences and are closest to the modern wild samples (Figures 20-22). This suggests that after several centuries of landscape regeneration following the collapse of the city local inhabitants acquired more wild-hunted leporids from less C4/CAM dominated landscapes. The context with the second lowest $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ means is the earliest chronological sample of the site, the Moon Pyramid. Since many of these leporids predate the peak of population at the city, resulting values suggest that cottontails and jackrabbits were similarly acquired from landscapes less dominated by human-generated C4/CAM vegetation than seen at the Xolalpan period contexts of Teopancazco and Oztoyahualco.

The temporal patterns in stable carbon isotope values suggest that as the population density of the Teotihuacan Valley increased through the Classic Period and as agricultural systems expanded proportionately, leporids became increasingly integrated into the human ecological system, evidenced by their high consumption of C4/CAM plants such as maize, nopal, amaranth, or wild C4 grasses. As both *Lepus* and *Sylvilagus* are strongly attracted to agricultural fields, frequent crop raiding may have been a significant source for the high C4/CAM signal. Human clearing of nearby pine and oak forests would have opened new habitats for C4 grasses, likely serving as an additional influence on the trend of increasing bone $\delta^{13}C$ values through the Classic Period.

At Oztoyahualco, stable carbon isotope data suggest these dynamics were intensified and regularized and that the human-leporid interactions qualitatively changed during the Xolalpan period. What was once a hunter-prey relationship may have transformed into one of active management and controlled reproduction. Because both *Lepus* and *Sylvilagus* exhibited higher $\delta^{13}C$ bone apatite and collagen values in comparison to other site locations, residents of Oztoyahualco may have practiced a generalized form of animal management. Instead of concentrating on the mass production of single species, as do modern husbandry industries, leporid specialists of Teotihuacan may have managed diverse mixed-genus populations. Indeed, at least six different leporid species were discovered within the complex (Valadez 1993:730). Stable isotope data, however, do not necessitate that all leporid management occurred on site at Oztoyahualco. Social affiliates or economic partners of the compound may have kept leporids in off-site managed landscapes near agricultural fields in a manner similar to medieval European rabbit management practices (Williamson 2006). Farmers may have intentionally dedicated particular garden patches for leporid consumption, trapping individuals as needed. Indeed, similar practices have been described for modern Maya farmers of Mexico (Nations and Nigh 1980:15-19). It is possible that leporids not raised at the residential compound were brought to Oztoyahualco for butchering and processing for meat and secondary products. Additionally, several specimens exhibiting low carbon values may identify leporids originating from wild populations beyond the immediate Teotihuacan Valley. At least some scale of domestic breeding on site, however, is suggested by the presence of high phosphorous levels in certain room floors (Rooms 9 & 10) and the presence of a small room (Room 30) nestled in the corner Room 10. Regardless of the manner by which leporids were acquired, these animals appear to have been particularly important to Oztoyahualco's residents, as indicated by the presence of the unique stone sculpture of a rabbit found within a ceremonial plaza. Manzanilla (1996) has suggested that this sculpture represents the totem animal for one of the households of the residential complex. Another possible and complementary interpretation is that the stone rabbit signified the primary economic specialization of the compound's residents.

Conclusion

Stable isotope data produced in this study inform our understanding of the long-term social-environmental and human-leporid dynamics at pre-Hispanic New World city Teotihuacan. Carbon isotope data in particular provide strong evidence of Teotihuacan's growing impact on the local environment through the Classic period. Higher $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values of Teotihuacan leporids in comparison to modern specimens suggests that these animals acquired a significant portion of their diet from human-dominated social-environmental systems, which focused on the production of C4 and CAM agricultural products. Opportunistic garden hunting of leporids by Teotihuacan's human residents may have supplied many of the jackrabbit and cottontail specimens within the city. Leporid data from the compound of Oztoyahualco, however, suggest an instance of intensified interaction between humans and rabbits. Human skills of hunting, trapping or other forms of rabbit acquisition may have become formalized through time, leading to qualitative change in human-leporid relationships and an economic specialization for the Oztoyahualco complex.

Based on archaeological evidence for butchering, the high frequency of leporid remains, and the presence of a rabbit sculpture, this chapter hypothesized that leporids from Oztoyahualco would display greater evidence for incorporation into human social-environmental systems which were dominated by C4/CAM plants. Leporid $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ results are consistent with this hypothesis and provide strong support for the notion that the Oztoyahualco residential compound specialized in the management and production of leporids. Small mammal management could have served as a means to channel surplus C4/CAM agricultural products to provision captive stocks, effectively converting excess carbohydrates into high quality protein and economically valuable secondary products, such as fur, hide, glue, and bones.

Although no large-bodied terrestrial herbivores were available for domestication in Mesoamerica, inhabitants of the New World engaged in intensive relationships with many smaller and a more diverse fauna (McClung de Tapia and Sugiyama 2012; Valadez 2003), including turkeys (*Meleagris gallopavo*) (Thornton et al. 2012), turtles (*Dermatemys mawii*) (González-Porter et al. 2011), and insects such as cochineal and bees (Donkin 1977; Kent 1984). Although such relationships were not as archaeologically visible or as impactful to local environments as human-ungulate relationships in Eurasia, human-animal interactions were nevertheless important components of the emergence and organization of complex societies of ancient North America, supplying sources of high-quality protein and other economically valuable products to support dense urban populations. In sum, results of this study increase our knowledge of the long-term dynamics of the human-environmental relationship at Teotihuacan, and further our understanding of how cities of the ancient New World maintained their populations of humans and non-human animals.

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CHAPTER 5: DISCUSSION AND CONCLUSION

Results of stable isotope analyses on modern and archaeological leporid specimens of this dissertation demonstrated the utility of using these small mammals to explore long-term dynamics of social-environmental relationships through the archaeological record. Analyses of modern *Lepus* and *Sylvilagus* samples acquired from museum collections revealed significant correlations between all isotope variables and a range of local environmental conditions. Stable oxygen isotope ratios correlated with moisture variables (mean annual precipitation and relative humidity) while carbon and nitrogen stable isotope ratios correlated with temperature variables (minimum, mean, and maximum annual temperatures). However, carbon values are here considered to be most significantly influenced by the amount of local C4 grasses in the area in which the organisms lived, a variable difficult to quantify with the existing data for each site.

The influence of environmental factors on isotope ratios was further supported by comparisons of leporid isotope means from the sites of Pueblo Grande, La Ferrería, and La Quemada with expected outcomes based on the 50-year (AD 1950-2000) modern environmental data for each site. As expected, the site with the least recorded precipitation (Pueblo Grande) exhibited the highest $\delta^{18}O_{apatite}$ values, the site with highest temperatures (Pueblo Grande) exhibited the highest $\delta^{15}N_{collagen}$ values, and the site with the most grass cover (La Quemada) exhibited the highest $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values. These results demonstrate that the relative differences in environmental conditions between the sites were similar in the ancient past and that stable isotope ratios of leporid bones faithfully record such differences.

Analysis of leporid bones from the Classic period metropolis of Teotihuacan demonstrated the ability of leporid bone stable isotope values to track changes in human-animal relationships through time. The highest leporid bone carbon values of the city, seen at the apartment complex of Oztoyahualco, may indicate a qualitative change in human-leporid relations at the height of the city' occupation. Growing human populations and intensifying human-modification of the landscape may have stimulated active provisioning, care, and reproduction of rabbits to ensure a steady supply for economic and nutritional means.

An explicit question explored in Chapter 3 concerned the association between environmental conditions and social complexity in arid and semi-arid environments of North America. Testing the assumption that societies in desert environments developed during favorable environmental (i.e. wet) conditions and declined during unfavorable (i.e. dry) conditions (e.g., Armillas 1969), this chapter reported results of stable isotope analyses from three archaeological sites. A significant finding of the study was that none of the selected site locations displayed evidence for developing within exceptionally wet conditions. In particular, leporid values from La Ferrería in Durango, Mexico, indicated that Epiclassic (Ayala phase) jackrabbits lived in a more arid environment than did jackrabbits from the subsequent temporal period (Las Joyas phase), and that Ayala phase cottontails consumed more C4 vegetation than Las Joyas phase cottontails. These data indicated that, contrary to elsewhere in Mesoamerica, La Ferrería may have experienced generally wetter conditions at around AD 900, a time of widespread drought across large portions of North America. Indeed, the Las Joyas phase marked the apex of population and architectural construction at the site. These results suggested that the social and environmental history of North America was more complicated than predicted by previous models and underscored the need for more detailed studies in the region.

Future Studies

By producing stable isotope data from both bone apatite and collagen, elemental percentages of C and N, CO_3/PO_4 ratios, and IR-SF data from nearly 500 leporid bone specimens from modern and archaeological sites, this dissertation enabled a range of studies on issues beyond the primary scope of this project, but worth future investigation. Several of these areas are discussed here.

Garden Hunting

A notable secondary finding of the dissertation concerned the difference between stable carbon isotope values from archaeological leporids compared to modern specimens (Figure 24). On average, the archaeological specimens exhibited higher $\delta^{13}C_{apatite}$ and $\delta^{13}C_{collagen}$ values, than modern specimens, even after correcting modern specimens for the industrial (Seuss) effect. Although diagenetic alteration of bone values remains a possible influence that may have raised carbon values of archaeological specimens, most archaeological samples were screened for diagenesis through FTIR-ATR, C:N ratios, and collagen yields, and poorly-preserved specimens were excluded from analysis. Two factors that were presented in Chapter 3 may explain the higher stable carbon isotope values in archaeological leporids. First, all archaeological leporids likely spent their lives near human settlements in environments that had been characterized by forest clearance and the opening of new grassy landscapes. These human-dominated environments may have contributed to the spread of C4 grasses, plants that would have been incorporated into the leporids' diet and would have elevated their bone carbon values. Secondly, it is very likely that crop raiding by jackrabbits and cottontails was a common occurrence and that maize or other human-cultivated C4 plants formed a significant portion of their diet. Comparative studies (Linares 1976) and zooarchaeological research (Neusius 2008; Schollmeyer and Driver 2013) suggest that "garden hunting", the practice of hunting natural pests of agricultural fields, may have been a significant source of high-quality protein for pre-Hispanic agriculturalists of North America. Relative to the modern sample, which includes specimens from across a range of "natural" environments throughout the United States and Mexico, the consistently higher δ^{13}C values from archaeological samples were consistent with this notion. Interestingly, modern values appear to fall closer to the C4/CAM protein line than do archaeological specimens (Figure 24). If archaeological specimens were consuming protein-poor maize frequently, this may account for the generally higher overall C4/CAM consumption, but lower amounts of C4/CAM protein.

Importantly, garden hunting may have been a highly sustainable practice whereby surplus agricultural products were effectively converted into animal protein through the consumption of crop-raiding animals. This practice may have been the preferred method of animal protein acquisition, as it would have reduced energy expenditure on travel and transport during long hunting trips. Alternatively, it may have been a non-preferred "fallback" method, employed only after large game stocks had been depleted from the local environment. Future site-by-site assessments of the fauna and resulting isotope ratios will improve our understanding of the dynamics of this practice and its implications for the communities' relationship with local environments.

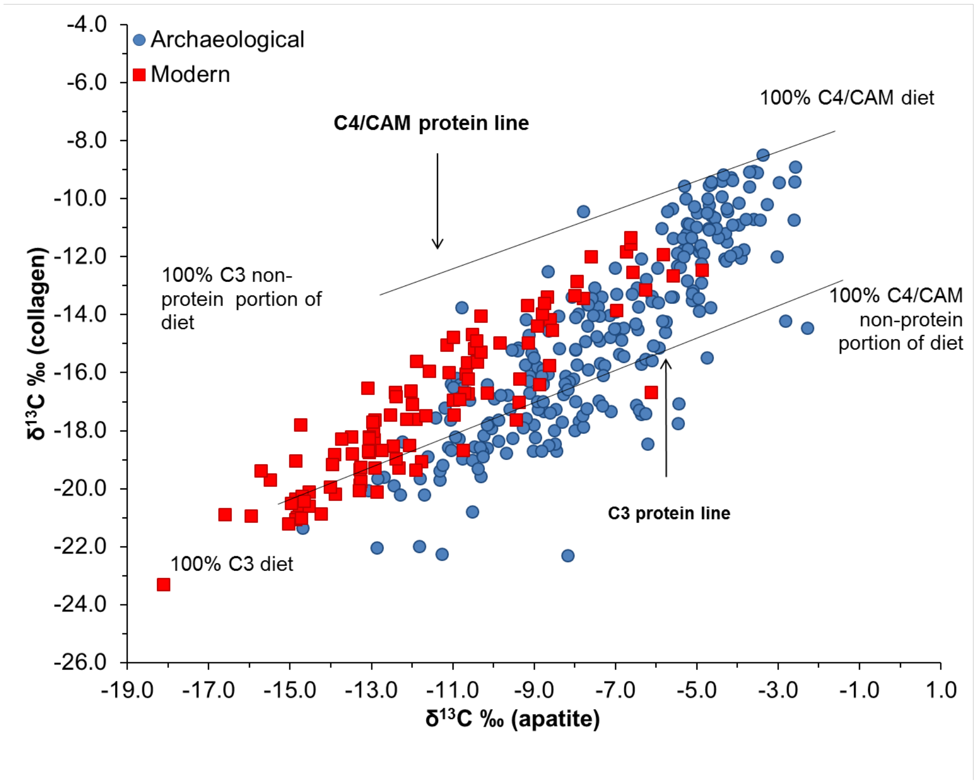

Figure 24. Scatterplot of archaeological and modern leporid stable carbon isotope values from bone apatite and collagen. Regression lines were derived from controlled feeding experiments compiled by Kellner and Schoeninger (2007) and Froehle et al. (2010). Modern specimens were corrected to archaeological values by adding up to 1.5‰ to both apatite and collagen values. The higher carbon values in archaeological specimens relative to modern specimens may be due to 'crop raiding' by archaeological leporids, a practice that would have included more C4 maize in their diets. Also, human modification to local landscapes may have opened more land for C4 grasses, which would have been consumed by leporids.

Lagomorph Index

A common measure used to explore human-environmental relations at archaeological sites is the ratio of cottontails to jackrabbits (*Sylvilagus/*(*Sylvilagus+Lepus)*. As briefly introduced in Chapter 3, this "Lagomorph Index" assumes that sites exhibiting lower values, i.e. more jackrabbits relative to cottontails, characterize environments that were more open, arid, or impacted by human activities (Driver and Woiderski 2008). Future studies using both the lagomorph index and stable isotope analyses of jackrabbit and cottontail bones will help refine our understanding of how each method reflects aspects of past environmental landscapes. Assessments of leporids from the Pueblo Grande site analyzed in Chapter 3, for example, can assess changes in the lagomorph index through time and compare these values to changes in stable isotope ratios. Indeed, previous studies have calculated the lagomorph index for the site from contexts spanning hundreds of years (James 1994). Exploring these data alongside the isotopic results of this dissertation will provide a more detailed picture of past social-environmental changes to the landscape.

Baseline correlations

A limitation of the baseline study in Chapter 2 was the interpolated climate/environmental data used to characterize leporid site locations. Because 50 year average values of moisture and temperature variables were used, and because the data were interpolated (estimated), actual environmental conditions present during the 1-2 average years of a leporid's life may have been quite different. This study, therefore, likely underestimated the actual strength of the observed correlations. Future studies may refine the regression analyses by acquiring leporid specimens from contexts with better-characterized local environmental conditions. Additionally, future multivariate assessments of stable isotope data, such as cluster analysis and discriminant function analysis, will improve our ability to predict past environmental characteristics from available isotopic data.

Conclusion

Through stable isotope analyses of jackrabbit and cottontail bones, this dissertation presented an in-depth assessment of the human-leporid relationship as a link between social and environmental systems. Resulting data were explored across multiple temporal and geographic scales, spanning BC 150 to the present day, and ranging from the continental scale to the level of an individual apartment compound. By demonstrating the utility of leporid bones to monitor past environmental conditions, this project added a new method of environmental reconstruction to the archaeological toolkit, and the application of the method to several archaeological case studies increased our understanding of social complexity and aridity in pre-Hispanic North America. Ultimately, this dissertation shed new light on the entangled relationships humans have formed with plants and animals of their local environments and how these dynamic interactions have contributed to social organization and change through time.

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APPENDECIES

APPENDIX I. List of modern bone specimens and their proveniences.

Lab #	Spec #	Bone element	Museum[1]	Genus/species	Country	State	Locus
AS-0213	28233	vertebra	LACNHM	Lepus californicus deserticola	USA	California	Randsburg, 8.5 mi N, 3 mi W
AS-0214	28236	vertebra	LACNHM	Lepus californicus deserticola	USA	California	Deep Springs, 8 mi S, 4 mi W; Deep Springs Lake
AS-0215	29049	mandible	LACNHM	Lepus californicus deserticola	USA	California	Randsburg, 10 mi N, 8 mi W
AS-0216	29050	mandible	LACNHM	Sylvilagus audubonii arizonae	USA	California	Randsburg, 10 mi N, 8 mi W
AS-0217	32360	mandible	LACNHM	Sylvilagus audubonii audubonii	USA	California	Cima, 6.5 mi S, 6 mi E
AS-0218	32361	mandible	LACNHM	Sylvilagus audubonii audubonii	USA	California	Cima, 8 mi E, 1 mi S; Howe Spring
AS-0219	32362	vertebra	LACNHM	Sylvilagus audubonii audubonii	USA	California	Cima, 8 mi E, 1 mi S; Howe Spring
AS-0220	32363	vertebra	LACNHM	Sylvilagus audubonii audubonii	USA	California	Cima, 8 mi E, 1 mi S; Howe Spring
AS-0221	34331	mandible	LACNHM	Lepus californicus	Mexico	Zacatecas	Banon
AS-0222	34332	occipital	LACNHM	Lepus californicus	Mexico	Zacatecas	Pinos, 7 mi S
AS-0223	34337	mandible	LACNHM	Lepus californicus	Mexico	Zacatecas	Banon
AS-0224	34338	nasal?	LACNHM	Lepus californicus	Mexico	Zacatecas	Banon
AS-0225	34343	vertebra	LACNHM	Sylvilagus floridanus holzneri	Mexico	Zacatecas	Jalpa, 6 mi SW
AS-0226	34348	mandible	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Banon
AS-0227	34349	mandible	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Banon
AS-0228	34362	mandible	LACNHM	Sylvilagus floridanus holzneri	Mexico	Zacatecas	Jalpa, 6 mi SW
AS-0229	34363	mandible & zygomatic arch	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Pinos, 7 mi S
AS-0230	34364	mandible	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Pinos, 7 mi S
AS-0231	34365	vertebra	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Banon
AS-0232	34370	mandible	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Concepcion del Oro, 11 mi E
AS-0233	34373	mandible?	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Camacho, 13 mi SW
AS-0234	34374	occipital	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Camacho, 13 mi SW
AS-0235	35056	vertebra	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Cd. Cuauhtemoc, 3 mi N
AS-0261	35060	mandible	LACNHM	Sylvilagus floridanus holzneri	Mexico	Zacatecas	Jalpa, 10 mi W
AS-0262	35061	vert and other	LACNHM	Sylvilagus audubonii	Mexico	Zacatecas	Cd. Cuauahtemoc, 3 mi N
AS-0263	35064	scapula	LACNHM	Lepus californicus	Mexico	Zacatecas	Cd. Cuauahtemoc, 3 mi N
AS-0264	35066	vertebra	LACNHM	Lepus californicus	Mexico	Zacatecas	Cd. Cuauahtemoc, 3 mi N
AS-0265	35068	cranial frags	LACNHM	Lepus californicus	Mexico	Zacatecas	Cd. Cuauhtemoc, 3 mi N

AS-0266	44220	mandible	LACNHM	Lepus californicus deserticola	USA	California	Olancha, 2.5 mi E; Hwy 190
AS-0267	44965	vert + cranial	LACNHM	Sylvilagus audubonii	USA	California	Lucerne Valley, 20 mi NE
AS-0268	52292	vert + mandible	LACNHM	Lepus californicus deserticola	USA	California	Randsburg, 7 mi N, 3.5 mi W
AS-0271	53866	rib	LACNHM	Sylvilagus audubonii arizonae	USA	California	Borrego Springs, 2 mi S, 1 mi E
AS-0272	53868	rib	LACNHM	Sylvilagus audubonii arizonae	USA	California	Borrego Springs, 2 mi S, 1 mi E
AS-0273	53867	rib	LACNHM	Sylvilagus audubonii arizonae	USA	California	Borrego Springs, 2 mi S, 1 mi E
AS-0274	53869	rib	LACNHM	Sylvilagus audubonii arizonae	USA	California	Borrego Springs, 2 mi S, 1 mi E
AS-0275	53884	rib	LACNHM	Lepus californicus bennettii	USA	California	Borrego Springs, 2 mi S, 1 mi E
AS-0276	58787	rib	LACNHM	Sylvilagus floridanus restrictus	Mexico	Colima	Cerro Grande
AS-0277	58785	rib	LACNHM	Sylvilagus floridanus restrictus	Mexico	Colima	Cerro Grande
AS-0278	58786	mandible	LACNHM	Sylvilagus floridanus restrictus	Mexico	Colima	Cerro Grande
AS-0280	74647	vert + incisor	LACNHM	Sylvilagus floridanus alacer	USA	Texas	3 mi E Electra
AS-0281	74648	incisor + vert	LACNHM	Sylvilagus floridanus alacer	USA	Texas	3 mi E Electra
AS-0282	74649	incisor + vert	LACNHM	Sylvilagus floridanus alacer	USA	Texas	3 mi NE Electra
AS-0283	74650	mandible + teeth	LACNHM	Sylvilagus floridanus alacer	USA	Texas	2 mi NW Electra
AS-0284	88149	misc. frags	LACNHM	Lepus californicus bennettii	USA	California	Sunland, 5 mi N, 2 mi W
AS-0285	90240	misc. frags	LACNHM	Lepus californicus bennettii	USA	California	Solemint, 3 mi E
AS-0286	96630	misc. frags	LACNHM	Lepus californicus deserticola	USA	California	Beal Well, 2 km S
AS-0644	11440	femur frag	Smith	Sylvilagus floridanus yucatanicus	Mexico	Yucatan	Merida
AS-0645	20322	metapodial frags	Smith	Lepus californicus texianus	Mexico	Chihuahua	Juarez, Near Fort Bliss, Texas
AS-0646	20434	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Michoacan	Hacienda El Molino, Near Negrete
AS-0648	26598	misc. frags	Smith	Sylvilagus floridanus chapmani	Mexico	Nuevo Leon	Linares
AS-0649	27694	misc. frags	Smith	Sylvilagus floridanus chapmani	Mexico	Nuevo Leon	Linares
AS-0650	27699	misc. frags	Smith	Sylvilagus floridanus chapmani	Mexico	Tamaulipas	Mier
AS-0651	34881	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Michoacan	Patzcuaro
AS-0652	34884	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Michoacan	Patzcuaro
AS-0653	34885	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Michoacan	Patzcuaro
AS-0654	34887	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Michoacan	Patzcuaro
AS-0655	50078	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Distrito Federal	Tlalpam
AS-0656	50079	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Distrito Federal	Tlalpam
AS-0657	51111	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Distrito Federal	Tlalpam
AS-0658	55003	misc. frags	Smith	Sylvilagus floridanus connectens	Mexico	Veracruz	Jico

AS-0659	55007	misc. frags	Smith	Sylvilagus floridanus connectens	Mexico	Veracruz	Jico
AS-0660	55592	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Hidalgo	Tulancingo
AS-0661	55599	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Hidalgo	Tulancingo
AS-0663	59227	misc. frags	Smith	Lepus californicus texianus	Mexico	Sonora	Paso De Luis
AS-0664	63654	misc. frags	Smith	Sylvilagus floridanus connectens	Mexico	Veracruz	Chichicaxtle
AS-0665	63655	misc. frags	Smith	Sylvilagus floridanus connectens	Mexico	Veracruz	Chichicaxtle
AS-0666	63658	misc. frags	Smith	Sylvilagus floridanus connectens	Mexico	Veracruz	Chichicaxtle
AS-0667	63659	misc. frags	Smith	Sylvilagus floridanus connectens	Mexico	Veracruz	Chichicaxtle
AS-0668	71732	misc. frags	Smith	Lepus californicus xanti	Mexico	Baja California Sur	Cape San Lucas
AS-0669	73439	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Oaxaca	Huilotepec
AS-0670	73440	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Oaxaca	Huilotepec
AS-0671	73442	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Oaxaca	Huilotepec
AS-0672	73456	mand frags, zygo arch frag	Smith	Sylvilagus floridanus aztecus	Mexico	Oaxaca	San Mateo Del Mar
AS-0673	75952	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Chiapas	San Cristobal
AS-0674	76235	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Chiapas	San Cristobal
AS-0675	76236	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Chiapas	San Cristobal
AS-0676	76237	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Chiapas	San Cristobal
AS-0677	78468	nasal frags	Smith	Lepus californicus texianus	Mexico	Queretaro	Tesquisquiapam
AS-0678	81463	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Hidalgo	Zimapan
AS-0679	81528	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Hidalgo	Zimapan
AS-0680	90964	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Zacatecas	Hacienda San Juan Capistrano
AS-0681	90965	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Zacatecas	Hacienda San Juan Capistrano
AS-0682	92981	misc. frags	Smith	Lepus californicus melanotis	Mexico	Tamaulipas	Alta Mira
AS-0683	92982	misc. frags	Smith	Lepus californicus melanotis	Mexico	Tamaulipas	Alta Mira
AS-0684	93692	misc. frags	Smith	Lepus californicus melanotis	Mexico	Tamaulipas	Alta Mira
AS-0685	98258	misc. frags	Smith	Sylvilagus floridanus holzneri	Mexico	Chihuahua	Colonia Garcia
AS-0686	98259	misc. frags	Smith	Sylvilagus floridanus holzneri	Mexico	Chihuahua	Colonia Garcia
AS-0687	100505	misc. frags	Smith	Sylvilagus floridanus yucatanicus	Mexico	Campeche	Campeche
AS-0688	108184	misc. frags	Smith	Sylvilagus floridanus	Mexico	Yucatan	Progreso

				yucatanicus			
AS-0689	108187	misc. frags	Smith	Sylvilagus floridanus yucatanicus	Mexico	Yucatan	Progreso
AS-0690	116553	misc. frags	Smith	Sylvilagus floridanus chapmani	Mexico	Tamaulipas	Matamoras
AS-0691	116565	zygo arch	Smith	Sylvilagus floridanus chapmani	Mexico	Tamaulipas	Soto La Marina
AS-0692	138667	misc. frags	Smith	Lepus californicus californicus	Mexico	Baja California	Rancho Viejo, 15 Mi W Of Alamos
AS-0693	138669	misc. frags	Smith	Lepus californicus californicus	Mexico	Baja California	Rancho Viejo, 15 Mi W Of Alamos
AS-0694	138670	misc. frags	Smith	Lepus californicus californicus	Mexico	Baja California	Rancho Viejo, 15 Mi W Of Alamos
AS-0695	139047	misc. frags	Smith	Lepus californicus californicus	Mexico	Baja California	San Quintin
AS-0696	139049	misc. frags	Smith	Lepus californicus californicus	Mexico	Baja California	San Quintin
AS-0697	139052	misc. frags	Smith	Lepus californicus californicus	Mexico	Baja California	San Quintin
AS-0698	146579	misc. frags	Smith	Lepus californicus xanti	Mexico	Baja California Sur	Cape Saint Lucas
AS-0699	146580	misc. frags	Smith	Lepus californicus xanti	Mexico	Baja California Sur	Cape Saint Lucas
AS-0700	146582	misc. frags	Smith	Lepus californicus xanti	Mexico	Baja California Sur	Cape Saint Lucas
AS-0701	147707	misc. frags	Smith	Lepus californicus texianus	Mexico	Sonora	Hermajillo
AS-0702	329624	mandible frag	Smith	Sylvilagus floridanus chapmani	Mexico	Nuevo Leon	El Potosi
AS-0703	329628	misc. frags	Smith	Sylvilagus floridanus chapmani	Mexico	Nuevo Leon	El Potosi
AS-0704	510816	femur frag	Smith	Sylvilagus floridanus orizabae	Mexico	Puebla	San Baltazar Tetela
AS-0705	540914	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Puebla	San Baltazar Tetela
AS-0706	540914	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Puebla	San Baltazar Tetela
AS-0707	540915	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Puebla	San Baltazar Tetela
AS-0708	540915	misc. frags	Smith	Sylvilagus floridanus orizabae	Mexico	Puebla	San Baltazar Tetela
AS-0709	540916	ribs	Smith	Sylvilagus floridanus	Mexico	Puebla	Malinche Volcano, S Slope
AS-0710	560048	rib	Smith	Lepus californicus texianus	Mexico	San Luis Potosi	San Luis Potosi, 31 Mi WNW, Cerro Blanco, Hwy 49
AS-0711	560051	misc. frags	Smith	Lepus californicus texianus	Mexico	Jalisco	Lagos De Moreno, 9.8 Mi SW, Hwy 80
AS-0712	A1418	misc. frags	Smith	Sylvilagus floridanus chapmani	Mexico	Tamaulipas	Matamoras
AS-0713	A1523	misc. frags	Smith	Sylvilagus floridanus chapmani	Mexico	Tamaulipas	Matamoras
AS-0714	A13470	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Oaxaca	Tehuantepec
AS-0715	A13862	misc. frags	Smith	Sylvilagus floridanus aztecus	Mexico	Oaxaca	Tehuantepec
AS-0716	L27	calcaneous	UTSA	Lepus	USA		Far W. Crockett Co. Ft Lancaster
AS-0717	L28	calcaneous	UTSA	Lepus	USA		Mills County
AS-0718	L29	tibia	UTSA	Lepus	USA		Gillespie Co. 1.5 miles E of Fredericksburg

AS-0719	L73	metapodial	UTSA	Lepus	USA		Hayes Co. 7 miles W of Dripping Springs HWY 290
AS-0720	L74	misc. frags	UTSA	Lepus	USA		W Kerr Co. Mountain Home
AS-0721	L201	misc. frags	UTSA	Lepus	USA		Kerr Co. 3 miles E of Center Point on HWY 27
AS-0722	L471	misc. frags	UTSA	Lepus	USA		East Fort Bliss
AS-0723	L472	misc. frags	UTSA	Lepus	USA		East Fort Bliss
AS-0724	L473	misc. frags	UTSA	Lepus	USA		Northern Tularosa
AS-0725	L474	misc. frags	UTSA	Lepus	USA	Arizona	Arizona Uplands
AS-0726	L475	misc. frags	UTSA	Lepus	USA	Arizona	Arizona Uplands
AS-0727	L476	misc. frags	UTSA	Lepus	USA		Mesilla Valley
AS-0728	L477	misc. frags	UTSA	Lepus	USA		Sonoran Desert
AS-0729	L478	misc. frags	UTSA	Lepus	USA		Deming NM
AS-0730	L479	misc. frags	UTSA	Lepus	USA		East Fort Bliss
AS-0731	L480	misc. frags	UTSA	Lepus	USA		East Fort Bliss
AS-0732	L481	misc. frags	UTSA	Lepus	USA		East Fort Bliss
AS-0733	L482	misc. frags	UTSA	Lepus	USA		East Fort Bliss
AS-0734	L483	misc. frags	UTSA	Lepus	USA		East Fort Bliss

1. LACNHM = Los Angeles County Natural History Museum. Smith = Smithsonian Institution’s National Museum of Natural History. UTSA = University of Texas, San Antonio’s Center for Archaeological Research.

APPENDIX II. Environmental profiles of modern site locations.

Lab #	Ecosystem	Biome	Elev. (m)	AVG TEMP (°C)	MIN TEMP (°C)	MAX TEMP (°C)	MAP (mm)	RH (%)
AS-0213	Mojave Desert	Deserts and Xeric Shrublands	1067	19.1	8.8	24.0	145	36.1
AS-0214	Great Basin	Deserts and Xeric Shrublands	1558	11.8	3.0	20.5	150	46.3
AS-0215	Mojave Desert	Deserts and Xeric Shrublands	914	16.3	8.6	24.1	149	36.1
AS-0216	Mojave Desert	Deserts and Xeric Shrublands	914	16.3	8.6	24.1	165	36.1
AS-0217	Sonoran Desert	Deserts and Xeric Shrublands	1605	14.1	7.8	20.4	281	34.9
AS-0218	Sonoran Desert	Deserts and Xeric Shrublands	520	13.2	6.8	19.6	297	34.9
AS-0219	Sonoran Desert	Deserts and Xeric Shrublands	520	13.2	6.8	19.6	267	34.9
AS-0220	Sonoran Desert	Deserts and Xeric Shrublands	520	13.2	6.8	19.6	267	34.9
AS-0221	Chihuahuan Desert	Deserts and Xeric Shrublands	1951	17.4	7.8	27.0	403	54.3
AS-0222	Central Mexican Matorral	Deserts and Xeric Shrublands	2073	16.3	8.2	24.5	421	60.4
AS-0223	Chihuahuan Desert	Deserts and Xeric Shrublands	1951	17.4	7.8	27.0	403	54.3
AS-0224	Chihuahuan Desert	Deserts and Xeric Shrublands	1951	17.4	7.8	27.0	403	54.3
AS-0225	Central Mexican Matorral	Deserts and Xeric Shrublands	1554	20.9	11.4	30.5	680	55.8
AS-0226	Chihuahuan Desert	Deserts and Xeric Shrublands	1951	17.4	7.8	27.0	403	54.3
AS-0227	Chihuahuan Desert	Deserts and Xeric Shrublands	1951	17.4	7.8	27.0	403	54.3
AS-0228	Central Mexican Matorral	Deserts and Xeric Shrublands	1554	20.9	11.4	30.5	680	55.8
AS-0229	Central Mexican Matorral	Deserts and Xeric Shrublands	2073	16.3	8.2	24.5	421	60.4
AS-0230	Central Mexican Matorral	Deserts and Xeric Shrublands	2073	16.3	8.2	24.5	421	60.4
AS-0231	Chihuahuan Desert	Deserts and Xeric Shrublands	1951	17.0	7.8	27.0	403	54.3
AS-0232	Chihuahuan Desert	Deserts and Xeric Shrublands	1615	19.4	10.3	28.5	401	57.1
AS-0233	Sierra Madre Occidental pine-oak forests	Tropical and Subtropical Coniferous Forests	1768	16.8	8.6	25.1	641	56.0
AS-0234	Sierra Madre Occidental pine-oak forests	Tropical and Subtropical Coniferous Forests	1768	16.8	8.6	25.1	641	56.0
AS-0235	Central Mexican Matorral	Deserts and Xeric Shrublands	2012	16.9	8.0	25.9	451	55.7
AS-0261	Central Mexican Matorral	Deserts and Xeric Shrublands	1859	20.9	11.7	31.0	655	55.8
AS-0262	Central Mexican Matorral	Deserts and Xeric Shrublands	2012	16.9	8.0	25.9	451	55.7
AS-0263	Central Mexican Matorral	Deserts and Xeric Shrublands	2012	16.9	8.0	25.9	451	55.7
AS-0264	Central Mexican Matorral	Deserts and Xeric Shrublands	2012	16.9	8.0	25.9	451	55.7
AS-0265	Central Mexican Matorral	Deserts and Xeric Shrublands	2012	16.9	8.0	25.9	451	55.7
AS-0266	Mojave Desert	Deserts and Xeric Shrublands	1100	15.2	7.5	23.4	190	38.2

AS-0267	Mojave Desert	Deserts and Xeric Shrublands	1206	15.1	7.0	23.1	266	35.3
AS-0268	Mojave Desert	Deserts and Xeric Shrublands	914	16.3	8.8	24.0	145	36.1
AS-0271	Sonoran Desert	Deserts and Xeric Shrublands	318	20.8	12.2	29.3	196	37.8
AS-0272	Sonoran Desert	Deserts and Xeric Shrublands	318	20.8	12.2	29.3	196	37.8
AS-0273	Sonoran Desert	Deserts and Xeric Shrublands	318	20.8	12.2	29.3	196	37.8
AS-0274	Sonoran Desert	Deserts and Xeric Shrublands	318	20.8	12.2	29.3	196	37.8
AS-0275	Sonoran Desert	Deserts and Xeric Shrublands	318	20.8	12.2	29.3	196	37.8
AS-0276	Jalisco dry forests	Tropical and Subtropical Dry Broadleaf Forests	2377	16.3	9.5	23.2	935	61.3
AS-0277	Jalisco dry forests	Tropical and Subtropical Dry Broadleaf Forests	2377	16.3	9.5	23.2	935	61.3
AS-0278	Jalisco dry forests	Tropical and Subtropical Dry Broadleaf Forests	2377	16.3	9.5	23.2	935	61.3
AS-0280	Central Mixed-Grass Prarie	Temperate Grasslands, Savannas and Shrublands	349	16.9	9.6	24.2	706	66.4
AS-0281	Central Mixed-Grass Prarie	Temperate Grasslands, Savannas and Shrublands	349	16.9	9.6	24.2	706	66.4
AS-0282	Central Mixed-Grass Prarie	Temperate Grasslands, Savannas and Shrublands	349	16.9	9.6	24.2	706	66.4
AS-0283	Central Mixed-Grass Prarie	Temperate Grasslands, Savannas and Shrublands	349	16.9	9.6	24.2	706	66.4
AS-0284	California South Coast	Mediterranean Forests, Woodlands and Scrub	876	15.0	8.2	21.9	465	40.1
AS-0285	California South Coast	Mediterranean Forests, Woodlands and Scrub	560	16.2	8.7	23.8	441	40.1
AS-0286	Mojave Desert	Deserts and Xeric Shrublands	501	20.8	13.2	28.6	110	34.2
AS-0644	Yucatan dry forests	Tropical and Subtropical Dry Broadleaf Forests	12	25.8	20.7	30.9	950	71.4
AS-0645	Chihuahuan Desert	Deserts and Xeric Shrublands	1139	17.4	9.0	25.9	220	46.2
AS-0646	Bajio dry forests	Tropical and Subtropical Dry Broadleaf Forests	1536	19.9	12.1	27.7	786	57.3
AS-0648	Tamaulipan Thorn Scrub	Deserts and Xeric Shrublands	358	22.6	15.8	29.6	790	68.8
AS-0649	Tamaulipan Thorn Scrub	Deserts and Xeric Shrublands	358	22.6	15.8	29.6	790	68.8
AS-0650	Tamaulipan Thorn Scrub	Deserts and Xeric Shrublands	63	23.2	16.9	29.6	538	69.2
AS-0651	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2134	15.8	8.1	23.5	1045	60.5
AS-0652	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2134	15.8	8.1	23.5	1045	60.5
AS-0653	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2134	15.8	8.1	23.5	1045	60.5
AS-0654	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2134	15.8	8.1	23.5	1045	60.5
AS-0655	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2438	14.8	6.4	23.3	941	62.2
AS-0656	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2316	14.8	6.4	23.3	941	62.2
AS-0657	Trans-Mexican Volcanic Belt pine-	Tropical and Subtropical Coniferous Forests	2316	14.8	6.4	23.3	941	62.2

	oak forests							
AS-0658	Oaxan Montane Forests	Tropical and Subtropical Moist Broadleaf Forests	1463	17.9	12.7	23.1	1914	76.4
AS-0659	Oaxan Montane Forests	Tropical and Subtropical Moist Broadleaf Forests	1463	17.9	12.7	23.1	1914	76.4
AS-0660	Meseta Central matorral	Deserts and Xeric Shrublands	2393	14.3	7.5	22.3	610	70.6
AS-0661	Meseta Central matorral	Deserts and Xeric Shrublands	2591	14.3	7.5	22.3	610	70.6
AS-0663	Sonoran Desert	Deserts and Xeric Shrublands	1163	22.8	9.1	25.7	219	34.5
AS-0664	Veracruz dry forests	Tropical and Subtropical Dry Broadleaf Forests	110	26.4	19.9	30.8	1081	74.0
AS-0665	Veracruz dry forests	Tropical and Subtropical Dry Broadleaf Forests	110	26.4	19.9	30.8	1081	74.0
AS-0666	Veracruz dry forests	Tropical and Subtropical Dry Broadleaf Forests	110	26.4	19.9	30.8	1081	74.0
AS-0667	Veracruz dry forests	Tropical and Subtropical Dry Broadleaf Forests	110	26.4	19.9	30.8	1081	74.0
AS-0668	San Lucan xeric scrub	Deserts and Xeric Shrublands	25	23.9	18.1	29.6	199	69.9
AS-0669	Southern Pacific dry forests	Tropical and Subtropical Broadleaf Forests	30	27.5	22.4	32.7	944	71.0
AS-0670	Southern Pacific dry forests	Tropical and Subtropical Broadleaf Forests	30	27.5	22.4	32.7	944	71.0
AS-0671	Southern Pacific dry forests	Tropical and Subtropical Broadleaf Forests	30	27.5	22.4	32.7	944	71.0
AS-0672	Southern Pacific dry forests	Tropical and Subtropical Dry Broadleaf Forests	8	27.5	22.5	32.5	1050	69.4
AS-0673	Tropical and Subtropical Coniferous Forests	Tropical and Subtropical Coniferous Forests	2499	13.8	7.4	20.1	1250	70.6
AS-0674	Tropical and Subtropical Coniferous Forests	Tropical and Subtropical Coniferous Forests	2499	13.8	7.4	20.1	1250	70.6
AS-0675	Tropical and Subtropical Coniferous Forests	Tropical and Subtropical Coniferous Forests	2499	13.8	7.4	20.1	1250	70.6
AS-0676	Tropical and Subtropical Coniferous Forests	Tropical and Subtropical Coniferous Forests	2499	13.8	7.4	20.1	1250	70.6
AS-0677	Central Mexican Matorral	Deserts and Xeric Shrublands	1981	17.5	9.0	26.0	521	65.9
AS-0678	Sierra Madre Oriental pine-oak forests	Tropical and Subtropical Coniferous Forests	1890	17.0	9.2	24.8	673	65.9
AS-0679	Sierra Madre Oriental pine-oak forests	Tropical and Subtropical Coniferous Forests	1890	17.0	9.2	24.8	673	65.9
AS-0680	Meseta Central matorral	Deserts and Xeric Shrublands	1128	21.4	13.5	29.2	489	57.3
AS-0681	Meseta Central matorral	Deserts and Xeric Shrublands	1128	21.4	13.5	29.2	489	57.3
AS-0682	Veracruz moist forests	Tropical and Subtropical Moist Broadleaf Forests	23	24.0	19.7	28.3	1006	74.2
AS-0683	Veracruz moist forests	Tropical and Subtropical Moist Broadleaf Forests	23	24.0	19.7	28.3	1006	74.2
AS-0684	Veracruz moist forests	Tropical and Subtropical Moist Broadleaf Forests	23	24.0	19.7	28.3	1006	74.2
AS-0685	Sierra Madre Occidental pine-oak forests	Tropical and Subtropical Coniferous Forests	1951	12.5	3.9	21.0	412	44.5
AS-0686	Sierra Madre Occidental pine-oak forests	Tropical and Subtropical Coniferous Forests	1951	12.5	3.9	21.0	412	44.5
AS-0687	Yucatan dry forests	Tropical and Subtropical Dry Broadleaf Forests	10	26.4	21.6	31.2	1045	69.3

AS-0688	Mesoamerican Gulf-Caribbean mangroves	Mangroves	1	25.5	21.8	29.2	488	73.0
AS-0689	Mesoamerican Gulf-Caribbean mangroves	Mangroves	1	25.5	21.8	29.2	488	73.0
AS-0690	Gulf Coast Praries and Marshes	Tropical and Subtropical Grasslands, Savannas and Shrublands	10	23.3	18.2	28.5	724	74.6
AS-0691	Veracruz moist forests	Tropical and Subtropical Moist Broadleaf Forests	12	24.4	18.0	30.9	587	71.9
AS-0692	California South Coast	Mediterranean Forests, Woodlands and Scrub	213	16.5	10.1	22.3	282	45.4
AS-0693	California South Coast	Mediterranean Forests, Woodlands and Scrub	213	16.5	10.1	22.3	282	45.4
AS-0694	California South Coast	Mediterranean Forests, Woodlands and Scrub	213	16.5	10.1	22.3	282	45.4
AS-0695	California South Coast	Mediterreanean Forests, Woodlands and Scrub	8	19.1	11.1	27.0	173	62.4
AS-0696	California South Coast	Mediterreanean Forests, Woodlands and Scrub	8	19.1	11.1	27.0	173	62.4
AS-0697	California South Coast	Mediterreanean Forests, Woodlands and Scrub	8	19.1	11.1	27.0	173	62.4
AS-0698	San Lucan xeric scrub	Deserts and Xeric Shrublands	25	23.9	18.1	29.6	199	69.9
AS-0699	San Lucan xeric scrub	Deserts and Xeric Shrublands	25	23.9	18.1	29.6	199	69.9
AS-0700	San Lucan xeric scrub	Deserts and Xeric Shrublands	25	23.9	18.1	29.6	199	69.9
AS-0701	Sonoran Desert	Deserts and Xeric Shrublands	258	24.1	16.1	31.8	299	40.3
AS-0702	Sierra Madre Oriental pine-oak forests	Tropical and Subtropical Coniferous Forests	2591	13.2	5.8	20.6	588	63.7
AS-0703	Sierra Madre Oriental pine-oak forests	Tropical and Subtropical Coniferous Forests	2591	13.2	5.8	20.6	588	63.7
AS-0704	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2075	17.7	9.5	25.9	805	61.8
AS-0705	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2075	17.7	9.5	25.9	805	61.8
AS-0706	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2075	17.7	9.5	25.9	805	61.8
AS-0707	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2075	17.7	9.5	25.9	805	61.8
AS-0708	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	2075	17.7	9.5	25.9	805	61.8
AS-0709	Trans-Mexican Volcanic Belt pine-oak forests	Tropical and Subtropical Coniferous Forests	3454	7.4	2.7	17.9	1036	66.5
AS-0710	Central Mexican Matorral	Deserts and Xeric Shrublands	2291	16.5	8.1	24.8	373	60.4
AS-0711	Central Mexican Matorral	Deserts and Xeric Shrublands	1910	18.3	9.8	26.7	654	55.4
AS-0712	Gulf Coast Praries and Marshes	Tropical and Subtropical Grasslands, Savannas and Shrublands	5	23.3	18.8	28.5	725	74.6
AS-0713	Gulf Coast Praries and Marshes	Tropical and Subtropical Grasslands, Savannas and Shrublands	5	23.3	18.8	28.5	725	74.6
AS-0714	Tropical and Subtropical Coniferous Forests	Tropical and Subtropical Coniferous Forests	2499	27.6	7.4	20.1	1250	70.6
AS-0715	Tropical and Subtropical	Tropical and Subtropical Coniferous Forests	2499	27.6	7.4	20.1	1250	70.6

	Coniferous Forests								
AS-0716	Chihuahuan Desert	Deserts and Xeric Shrublands	663	18.8	11.1	26.4	394	65.8
AS-0717	Edwards Plateau	Temperate Grasslands, Savannas and Shrublands	334	18.9	11.9	25.9	734	71.1
AS-0718	Edwards Plateau	Temperate Grasslands, Savannas and Shrublands	513	20.9	11.7	25.3	769	71.1
AS-0719	Edwards Plateau	Temperate Grasslands, Savannas and Shrublands	399	18.8	12.4	25.2	854	71.1
AS-0720	Edwards Plateau	Temperate Grasslands, Savannas and Shrublands	398	18.8	12.1	25.5	839	71.1
AS-0721	Edwards Plateau	Temperate Grasslands, Savannas and Shrublands	500	19.0	12.2	25.7	762	71.9
AS-0722	Chihuahuan Desert	Deserts and Xeric Shrublands	1231	17.1	9.1	25.1	221	46.2
AS-0723	Chihuahuan Desert	Deserts and Xeric Shrublands	1231	14.7	5.8	23.6	286	45.8
AS-0724	Chihuahuan Desert	Deserts and Xeric Shrublands	1466	14.6	6.2	23.0	296	48.7
AS-0725	Colorado Plateau	Deserts and Xeric Shrublands	1858	10.6	3.6	18.1	204	43.5
AS-0726	Colorado Plateau	Deserts and Xeric Shrublands	1654	12.2	3.7	20.4	321	43.2
AS-0727	Chihuahuan Desert	Deserts and Xeric Shrublands	1324	14.6	5.5	24.4	264	45.8
AS-0728	Sonoran Desert	Deserts and Xeric Shrublands	655	19.7	11.9	27.5	406	39.2
AS-0729	Chihuahuan Desert	Deserts and Xeric Shrublands	655	15.3	6.0	24.6	257	45.8
AS-0730	Chihuahuan Desert	Deserts and Xeric Shrublands	1231	17.1	9.1	25.1	221	46.2
AS-0731	Chihuahuan Desert	Deserts and Xeric Shrublands	1231	17.1	9.1	25.1	221	46.2
AS-0732	Chihuahuan Desert	Deserts and Xeric Shrublands	1231	17.1	9.1	25.1	221	46.2
AS-0733	Chihuahuan Desert	Deserts and Xeric Shrublands	1231	17.1	9.1	25.1	221	46.2
AS-0734	Chihuahuan Desert	Deserts and Xeric Shrublands	1231	17.1	9.1	25.1	221	46.2

APPENDIX III. Stable isotope results of modern leporids.

LAB NUM	δ^{13}C col	δ^{13}C col	C:N	δ^{13}C ap	δ^{18}O ap	δ^{13}C col (corrected)	δ^{13}C ap (corrected)
AS-0213	-21.4	6.0	3.5	-15.3	27.6	-22.1	-16.0
AS-0214	-20.1	6.7	3.5	-14.0	28.4	-20.8	-14.8
AS-0215	-19.9	5.3	3.4	-14.7	30.2	-20.7	-15.5
AS-0216				-16.3	30.5		-17.1
AS-0217	-21.8	4.9	3.5	-15.5	31.0	-22.5	-16.2
AS-0218	-20.7	5.7	3.6	-14.8	31.0	-21.5	-15.5
AS-0219	-20.5	3.1	3.6	-14.0	32.2	-21.3	-14.8
AS-0220	-15.5	4.8	3.5	-11.7	31.7	-16.3	-12.5
AS-0221	-16.4	8.0	3.4	-11.1	28.7	-17.1	-11.9
AS-0222	-13.9	8.0	3.4	-7.0	27.9	-14.7	-7.8
AS-0223	-15.3	7.6	3.5	-9.3	30.4	-16.0	-10.1
AS-0224	-18.4	6.5	3.4	-10.2	29.1	-19.1	-10.9
AS-0225	-18.2	2.9	4.1	-12.4	32.0	-19.0	-13.2
AS-0226	-15.7	7.2	3.5	-10.6	32.4	-16.5	-11.3
AS-0227	-14.7	7.1	3.5	-9.5	28.3	-15.5	-10.3
AS-0228	-16.7	2.0	3.4	-12.3	28.3	-17.4	-13.1
AS-0229	-13.2	7.2	3.7	-5.6	26.4	-14.0	-6.4
AS-0230	-17.0	13.3	3.6	-10.1	27.4	-17.7	-10.9
AS-0231	-15.4	5.9	3.4	-11.3	32.3	-16.2	-12.0
AS-0232	-19.0	9.0	3.5	-13.8	31.0	-19.8	-14.6
AS-0233	-17.4	10.3	3.6	-13.2	30.2	-18.2	-13.9
AS-0234	-17.2	8.7	4.1	-9.6	30.9	-17.9	-10.4
AS-0235	-17.8	3.2	3.6	-10.1	29.1	-18.5	-10.9
AS-0261	-18.2	3.0	3.3	-13.3	24.8	-19.0	-14.0
AS-0262	-17.7	6.0	3.6	-11.6	26.4	-18.4	-12.3
AS-0263	-18.2	5.8	3.4	-11.7	29.0	-19.0	-12.5
AS-0264	-20.0	2.8	3.7	-13.7		-20.8	-14.4
AS-0265	-17.0	5.7	3.4	-11.4	23.1	-17.7	-12.1
AS-0266	-16.1	10.8	3.3	-11.1	24.9	-16.8	-11.8
AS-0267	-17.5	5.8	3.5	-11.5	33.6	-18.2	-12.2
AS-0268	-21.2	6.0	3.3	-15.4	28.6	-21.9	-16.2
AS-0271	-19.0	7.7	3.3	-13.8	29.2	-19.7	-14.6
AS-0272				-14.1	30.4		-14.9
AS-0273				-16.1	30.6		-16.9
AS-0274	-19.0	8.7	3.5	-14.5	31.3	-19.8	-15.2
AS-0275	-12.1	5.9	3.4	-7.4	28.1	-12.9	-8.1
AS-0276		1.1	3.4	-19.2	24.2		-20.0

AS-0277	-24.1	1.3	3.7	-18.9	24.2	-24.8	-19.6
AS-0278	-20.1	3.9	3.5	-16.5	27.2	-20.9	-17.2
AS-0280	-21.0	5.7	3.4	-15.5	25.2	-21.8	-16.2
AS-0281	-19.7	5.2	3.5	-13.1	27.0	-20.5	-13.9
AS-0282	-17.3	7.6	3.3	-13.8	27.6	-18.0	-14.6
AS-0283	-19.8	6.2	3.5	-15.6	26.0	-20.5	-16.4
AS-0284	-22.1	3.9	3.4			-22.9	
AS-0285	-21.0	4.1	3.4			-21.7	
AS-0286	-19.6	4.4	3.5	-14.3	31.5	-19.6	-14.3
AS-0644	-20.8	5.1	3.2	-14.8	25.8	-22.3	-16.3
AS-0645	-18.3	8.3	3.2	-12.9	31.9	-19.8	-14.4
AS-0646	-18.0	10.2	3.2	-12.9	25.0	-19.5	-14.4
AS-0648				-16.7	26.3		-18.2
AS-0649	-16.7	8.2	3.05	-6.1	29.4	-18.2	-7.6
AS-0650	-17.0	9.0	3.19	-11.0	27.8	-18.5	-12.5
AS-0651	-18.8	4.7	3.20	-13.5	24.1	-20.3	-15.0
AS-0652	-20.2	5.9	3.18	-13.9	23.6	-21.7	-15.4
AS-0653	-18.7	8.4	3.22	-10.7	24.0	-20.2	-12.2
AS-0654	-21.0	2.1	3.24	-14.8	25.6	-22.5	-16.3
AS-0655	-17.6	5.2	3.27	-11.9	26.7	-19.1	-13.4
AS-0656				-13.9	24.6		-15.4
AS-0657	-18.7	7.3	3.29	-13.0	24.7	-20.2	-14.5
AS-0658	-19.1	2.7	3.29	-11.8	19.9	-20.6	-13.3
AS-0659	-16.7	3.5	3.35	-10.6	21.7	-18.2	-12.1
AS-0660	-14.2	5.5	3.18	-8.6	25.5	-15.7	-10.1
AS-0661	-20.1	2.3	3.22	-14.5	23.4	-21.6	-16.0
AS-0663	-15.0	7.9	3.21	-11.1	30.9	-16.5	-12.6
AS-0664	-11.8	9.4	3.23	-6.7	24.5	-13.3	-8.2
AS-0665	-16.1	7.4	3.21	-10.7	24.4	-17.6	-12.2
AS-0666	-14.4	9.1	3.21	-8.9	24.6	-15.9	-10.4
AS-0667	-18.5	6.8	3.36	-12.1	23.5	-20.0	-13.6
AS-0668	-11.9	10.9	3.30	-5.8	26.8	-13.4	-7.3
AS-0669	-15.7	5.2	3.30	-10.6	26.8	-17.2	-12.1
AS-0670				-9.4	23.6		-10.9
AS-0671				-9.7	27.6		-11.2
AS-0672	-19.9	11.2	3.27	-13.3	23.4	-21.4	-14.8
AS-0673				-12.9	21.9		-14.4
AS-0674				-15.8	20.5		-17.3
AS-0675				-13.4	20.7		-14.9
AS-0676				-13.5	19.3		-15.0

AS-0677	-15.2	6.7	3.31	-10.5	27.5	-16.7	-12.0
AS-0678	-17.6	7.7	3.38	-12.1	27.0	-19.1	-13.6
AS-0679	-16.0	7.3	3.35	-11.1	26.5	-17.5	-12.6
AS-0680	-13.4	5.7	3.32	-7.8	27.2	-14.9	-9.3
AS-0681				-8.9	27.8		-10.4
AS-0682				-5.0	23.7		-6.5
AS-0683				-6.2	25.9		-7.7
AS-0684	-12.9	7.0	3.30	-7.9	25.7	-14.4	-9.4
AS-0685	-19.7	1.0	3.37	-15.5	24.2	-21.2	-17.0
AS-0686	-17.6	1.1	3.29	-12.9	27.8	-19.1	-14.4
AS-0687				-13.0	25.1		-14.5
AS-0688	-19.3	6.1	3.30	-12.3	25.4	-20.8	-13.8
AS-0689				-7.8	26.1		-9.3
AS-0690				-11.5	23.0		-13.0
AS-0691	-18.2	6.8	3.32	-13.5	24.2	-19.7	-15.0
AS-0692	-20.9	4.9	3.35	-14.2	29.4	-22.4	-15.7
AS-0693	-21.1	4.0	3.45	-14.9	29.6	-22.6	-16.4
AS-0694	-21.2	3.5	3.49	-15.0	28.4	-22.7	-16.5
AS-0695	-18.7	10.2	3.30	-13.1	28.7	-20.2	-14.6
AS-0696	-17.1	11.4	3.58	-12.0	28.2	-18.6	-13.5
AS-0697	-18.5	9.3	3.37	-12.5	26.6	-20.0	-14.0
AS-0698				-8.7	26.6		-10.2
AS-0699	-11.6	9.3	3.26	-6.6	29.0	-13.1	-8.1
AS-0700	-13.4	13.3	3.33	-8.0	23.5	-14.9	-9.5
AS-0701	-20.1	11.1	3.33	-12.9	27.7	-21.6	-14.4
AS-0702	-21.7	2.1	3.25	-17.3	26.6	-22.4	-18.1
AS-0703	-21.7	2.4	3.25	-16.7	27.9	-22.4	-17.5
AS-0704							
AS-0705	-19.6	1.5	3.28	-14.6	26.1	-20.3	-15.4
AS-0706	-19.4	1.4	3.27	-13.5	25.6	-20.2	-14.2
AS-0707	-19.7	3.4	3.37	-13.7	27.9	-19.7	-13.7
AS-0708	-19.6	2.7	3.38	-13.3	28.2	-19.6	-13.3
AS-0709	-21.1	1.4	3.32	-15.6	25.3	-21.9	-16.4
AS-0710	-14.7	6.6	3.23	-9.9	28.7	-14.9	-10.2
AS-0711	-12.8	5.6	3.22	-8.3	24.5	-13.0	-8.6
AS-0712	-18.3	6.8	3.29	-12.7	26.7	-18.3	-12.7
AS-0713	-18.6	6.8	3.41	-11.9	26.6	-18.6	-11.9
AS-0714	-22.4	5.4	3.31	-14.8	25.3	-22.4	-14.8
AS-0715	-22.0	5.5	3.37	-16.3	26.2	-22.0	-16.3
AS-0716	-19.2	5.6	3.47	-14.5	25.9	-19.2	-14.5

AS-0717	-19.3	6.8	3.34	-16.2	22.0	-19.3	-16.2
AS-0718	-16.5	3.5	3.40	-10.6	21.9	-16.5	-10.6
AS-0719	-14.1	4.0	3.37	-8.1	25.0	-14.1	-8.1
AS-0720	-15.2	7.0	3.43	-10.7	22.5	-15.2	-10.7
AS-0721	-15.4	6.2	3.51	-8.5	24.5	-15.4	-8.5
AS-0722	-17.5	4.3	3.63	-10.9	25.7	-17.7	-11.2
AS-0723	-17.4	4.9	3.36	-12.8	28.7	-17.6	-13.0
AS-0724	-13.4	6.2	3.41	-6.3	27.1	-13.7	-6.6
AS-0725	-20.8	1.7	3.35	-14.0	27.7	-21.1	-14.3
AS-0726	-17.6	3.3	3.27	-13.1	24.2	-17.8	-13.4
AS-0727	-16.5	3.4	3.36	-9.4	26.3	-16.8	-9.6
AS-0728	-21.3	3.7	3.31	-15.7	28.0	-21.5	-16.0
AS-0729	-20.1	4.5	3.86	-12.6	26.1	-20.4	-12.9
AS-0730	-16.3	6.5	3.24	-12.6	27.3	-16.6	-12.9
AS-0731	-14.8	6.6	3.24	-11.1	28.8	-15.1	-11.3
AS-0732	-15.7	5.3	3.25	-11.2	25.7	-15.9	-11.4
AS-0733	-14.4	7.3	3.25	-9.5	27.9	-14.6	-9.7
AS-0734	-20.0	6.5	3.42	-14.0	27.8	-20.3	-14.3

APPENDIX IV. Stable Isotope Results from Pueblo Grande, La Ferreria, and La Quemada

Lab #	Spec #	Site[1]	Unit	Prov A	Phase	Gen[2]	δ^{13}C ap	δ^{18}O ap	δ^{13}C col	δ^{15}N col	CN	CP	IR-SF
AS-0374		LF	10		Ayala (600-800)	Lep	-4.3	23.9	-12.2	5.7	3.3	0.24	2.87
AS-0375		LF	10		Ayala (600-800)	Lep			-11.4	6.7	3.3	0.26	7.60
AS-0376		LF	10		Ayala (600-800)	Lep	-3.9	24.7	-12.1	5.8	3.3	0.17	2.03
AS-0377		LF	1	unit 1	Las Joyas (800-950)	Syl	-8.8	25.1				0.16	4.03
AS-0378		LF	10		Ayala (600-800)	Lep	-7.1	26.8				0.22	2.84
AS-0379		LF	1	Terrace in front of N. wall	Las Joyas (800-950)	Lep			-14.0	5.3	3.3	0.22	1.62
AS-0380		LF	1	E. Trench wall	Las Joyas (800-950)	Syl	-11.7	23.6	-20.2	5.1	3.3	0.21	2.88
AS-0381		LF	1	E. Trench Wall	Las Joyas (800-950)	Lep	-4.3	20.7				0.21	2.64
AS-0382		LF	1	E. Trench wall	Las Joyas (800-950)	Syl	-10.1	27.2	-16.4	3.1	3.3	0.37	2.91
AS-0383		LF	1	E. Trench wall	Las Joyas (800-950)	Lep	-6.0	25.8				0.22	2.56
AS-0384		LF	1	E. Trench wall	Las Joyas (800-950)	Syl						0.26	1.63
AS-0385		LF	1	E. Trench wall	Las Joyas (800-950)	Syl	-9.1	26.9	-15.3	7.3	3.3	0.24	2.76
AS-0386		LF	1	E. Trench wall	Las Joyas (800-950)	Syl	-8.5	25.9	-17.3	3.4	3.3	0.22	2.62
AS-0387		LF	1	Area in front of N. Wall	Las Joyas (800-950)	Lep	-5.2	27.6	-10.9	5.5	3.3	0.24	2.42
AS-0388		LF	1		Las Joyas (800-950)	Lep	-4.2	25.1	-10.4	7.7	3.3	0.20	2.33
AS-0389		LF	7		Ayala (600-800)	Syl	-7.4	24.4				0.23	1.97
AS-0390		LF	7		Ayala (600-800)	Syl	-7.4	23.2				0.30	2.17
AS-0391		LF	7		Ayala (600-800)	Syl	-10.4	22.9				0.24	2.22
AS-0392		LF	7		Ayala (600-800)	Lep	-11.5	26.2				0.35	2.60
AS-0393		LF	7		Ayala (600-800)	Syl	-3.1	26.8				0.16	2.54
AS-0394		LF	7		Ayala (600-800)	Syl	-9.6	24.1	-16.8	5.1	3.3	0.31	2.17
AS-0395		LF	7		Ayala (600-800)	Lep	-4.5	23.5				0.21	2.03
AS-0396		LF	7		Ayala (600-800)	Lep	-4.9	28.6				0.21	2.01
AS-0397		LF	7		Ayala (600-800)	Lep	-6.1	26.7				0.25	2.04
AS-0398		LF	7		Ayala (600-800)	Lep	-5.5	26.6	-12.3	5.9	3.2	0.33	3.14
AS-0399		LF	7		Ayala (600-800)	Lep	-4.7	30.9				0.16	3.18
AS-0400		LF	7		Ayala (600-800)	Lep	-5.2	28.3	-10.9	12.5	3.3	0.22	2.88
AS-0401		LF	7		Ayala (600-800)	Syl	-7.1	28.2	-14.0	2.9	3.2	0.38	2.87

AS-0402		LF	7		Ayala (600-800)	Syl	-7.9	28.3	-14.0	7.2	3.2	0.34	2.85
AS-0403		LF	7	unit 5	Ayala (600-800)	Lep	-4.6	27.6	-10.6	6.4	3.2	0.20	3.19
AS-0404		LF	7	unit 5	Ayala (600-800)	Lep	-4.0	23.8	-10.1	5.6	3.2	0.16	3.28
AS-0405		LF	2		Ayala (600-800)	Syl	-7.4	27.9	-15.7	7.3	3.3	0.29	3.30
AS-0406		LF	2		Ayala (600-800)	Syl	-5.3	27.1	-10.0	6.7	3.2	0.23	2.82
AS-0407		LF	2	N. quad. Tr W of Terr W.1	Ayala (600-800)	Syl	-7.5	26.7	-13.1	5.8	3.3	0.21	2.87
AS-0408		LF	2		Ayala (600-800)	Lep	-4.3	27.9	-12.1	6.1	3.2	0.23	3.00
AS-0409		LF	4			Lep	-4.9	27.7	-12.9	5.7	3.3	0.20	3.04
AS-0410		LF	4			Syl	-6.5	24.3			2.7	0.31	2.91
AS-0411		LF	4			Lep	-4.4	22.8				0.22	3.58
AS-0412		LF	1		Las Joyas (800-950)	Lep	-5.2	22.4	-11.2	6.0	3.2	0.21	3.11
AS-0413		LF	1		Las Joyas (800-950)	Lep	-3.7	21.3				0.25	2.80
AS-0414		LF	1	Lower E. Wall	Las Joyas (800-950)	Lep	-4.6	23.6	-9.5	6.0	3.3	0.29	3.07
AS-0415		LF	1	Terrace in front of N. wall	Las Joyas (800-950)	Lep	-5.6	22.1	-10.3	7.0	3.3	0.23	2.92
AS-0416		LF	7	unit 5	Ayala (600-800)	Lep	-4.4	27.5	-9.9	1.2	3.2	0.21	3.10
AS-0417		LF	7	unit 5	Ayala (600-800)	Lep	-4.9	27.4	-11.8	4.6	3.2	0.22	3.14
AS-0418		LF	7	unit 5	Ayala (600-800)	Lep	-4.7	21.2	-11.0	5.4	3.2	0.17	3.24
AS-0419		LF	7	unit 5	Ayala (600-800)	Lep	-5.6	26.5	-11.4	5.0	3.2	0.25	3.03
AS-0420		LF	7	unit 5	Ayala (600-800)	Syl	-5.3	27.1	-11.8	6.6	3.2	0.26	3.09
AS-0421		LF	5	unit 10	Las Joyas (800-950)	Lep	-3.6	22.6	-10.7	5.2	3.3	0.22	2.89
AS-0422		LF	5	unit 2	Las Joyas (800-950)	Syl	-6.5	24.2	-14.5	7.4	3.3	0.20	3.24
AS-0423	1:T1:B101	PG		TM1	Santa Cruz	Syl						0.29	2.09
AS-0424	1:T1:B172	PG	TM1	1	Gilla Butte	Lep	-10.9	27.2	-16.2	11.0	3.2	0.22	3.27
AS-0425	1:T1:B229	PG	TM1	1		Lep	-10.5	31.7	-18.6	7.6	3.3	0.21	2.59
AS-0426	1:T1:B245	PG	TM1	1	Gilla Butte	Lep	-7.5	31.7				0.25	2.48
AS-0427	1:T1:B26	PG	TM1	1	Santa Cruz	Lep	-9.4	32.1	-15.1	8.0	3.4	0.22	2.73
AS-0428	1:T1:B262	PG	TM1	1	Santa Cruz	Lep	-10.8	28.7	-16.4	8.4	3.3	0.24	2.70
AS-0429	1:T1:B285	PG	TM1	1	Santa Cruz	Lep	-7.6	29.3	-13.4	4.9	3.3	0.20	2.98
AS-0430	1:T1:B28	PG	TM1	1	Santa Cruz	Lep	-11.4	34.2	-17.6	9.7	3.3	0.20	2.81

	6												
AS-0431	1:T1:B287	PG	TM1	1	Santa Cruz	Lep	-7.7	29.9	-13.7	7.0	3.4	0.22	2.50
AS-0432	1:T1:B298	PG	TM1	1	Santa Cruz	Lep	-7.0	33.9	-12.4	7.4	3.3	0.22	2.57
AS-0433	1:T1:B333	PG	TM1	1	Gilla Butte	Lep	-4.9	26.0	-11.6	5.6	3.4		
AS-0434	1:T1:B357	PG	TM1	1	Gilla Butte	Lep	-10.8	31.0	-16.8	7.7	3.3		
AS-0435	1:T1:B377	PG	TM1	1	Gilla Butte	Syl	-8.3	27.9				0.25	2.43
AS-0436	1:T1:B381	PG	TM1	1	Gilla Butte	Lep	-10.2	31.2	-18.2	7.1	3.3	0.20	3.35
AS-0437	1:T1:B424	PG	TM1	1	Santa Cruz	Lep	-9.1	35.3	-16.7	7.3	3.3	0.18	2.78
AS-0438	1:T1:B430	PG	TM1	1	Santa Cruz	Lep	-8.5	35.5	-18.0	7.3	3.3	0.22	2.53
AS-0439	1:T1:B434	PG	TM1	1	Snaketown	Syl						0.40	1.91
AS-0440	1:T1:B462	PG	TM1	1	Gilla Butte	Lep	-8.0	31.6	-15.2	10.7	3.4	0.19	2.40
AS-0441	1:T1:B476	PG	TM1	1	Santa Cruz	Syl	-11.8	30.9	-19.7	6.8	3.4	0.37	2.12
AS-0442	1:T1:B494	PG	TM1	1	Gilla Butte	Syl	-7.3	31.5					
AS-0443	1:T1:B530	PG	TM1	1		Syl	-7.0	32.8				0.17	2.74
AS-0444	1:T1:B564	PG	TM1	1	Gilla Butte	Syl	-11.6	28.7	-18.9	8.8	3.3	0.21	2.40
AS-0445	1:T1:B578	PG	TM1	1	Gilla Butte	Syl sp.	-12.2	31.0	-18.4	6.0	3.3	0.17	2.42
AS-0446	1:T1:B581	PG	TM1	1	Gilla Butte	Syl sp.	-11.1	30.2	-18.6	8.8	3.3	0.21	2.27
AS-0447	1:T1:B59	PG	TM1	1	Santa Cruz	Lep	-8.1	30.9	-13.4	9.0	3.3	0.25	2.57
AS-0448	1:T1:B595A	PG	TM1	1	Sacaton	Lep	-8.9	32.4	-15.8	6.3	3.3		
AS-0449	1:T1:B596A	PG	TM1	1	Sacaton	Lep	-10.8	31.0	-13.8	7.1	3.3		
AS-0450	1:T1:B602C	PG	TM1	1	Sacaton	Lep	-9.4	26.8	-15.2	5.4	3.3	0.26	2.52
AS-0451	1:T1:B603B	PG	TM1	1	Sacaton	Lep	-10.8	27.6	-18.3	6.2	3.3	0.24	2.41
AS-0452	1:T1:B606C	PG	TM1	1	Gilla Butte	Lep	-7.9	27.7	-17.7	7.8	3.3		

AS-0453	1:T1:B921	PG	TM1	1	Sacaton	Lep			-18.3	7.0	3.3	0.38	5.00
AS-0454	1:T1:B98	PG	TM1	1	Santa Cruz	Lep	-8.0	26.1	-17.0	8.1	3.3	0.20	3.13
AS-0457	1996.17.B1055	PG		Unit 3, HA 2, SW 1/4, level 1	Civano	Lep	-5.7	28.7	-10.4	7.3	3.2		
AS-0458	1996.17.B1055	PG		Unit 3, HA 2, SW 1/4, level 1	Civano	Lep	-8.0	21.7	-14.1	8.6	3.2	0.21	3.03
AS-0459	1996.17.B1053	PG		Unit 3, HA 2, fill	Soho Early Classic	Lep	-8.5	20.5	-18.5	8.7	3.2	0.24	2.82
AS-0460	1996.17.B1054	PG		Unit 4, HA 5, NE 1/4, level 2	Polvoron	Lep	-5.1	27.7				0.31	2.95
AS-0461	1996.17.B1054	PG		Unit 4, HA 5, SW 1/4, floor, PL 79	Polvoron	Lep	-5.0	24.6	-11.0	9.6	3.3	0.22	3.02
AS-0462	1996.17.B1056	PG		Unit 3, HA 2, rec unit 2, level 1	Soho Late	Lep	-8.4	30.0	-15.2	10.7	3.2	0.21	2.56
AS-0463	1996.17.B1054	PG		Unit 4, HA 5, C 8, entry, level 2, floor 185	Civano	Lep	-9.2	30.9	-15.7	8.7	3.3	0.20	2.91
AS-0464	1996.17.B1054	PG		Unit 4, HA 5, C 5, SE 1/4, level 3	Civano	Syl	-8.4	31.1	-18.7	6.0	3.3		
AS-0465	1996.17.B1054	PG	pit	Unit 4, HA 5, fill	Polvoron	Lep	-9.0	29.6	-18.7	6.2	3.3	0.29	2.76
AS-0466	1996.17.B1055	PG	trash pit	Unit 3, HA 2, level 1	Soho Early	Lep	-10.0		-17.9	7.0	3.2	0.22	3.62
AS-0467	1996.17.B1056	PG	pit	Unit 3, ha 7, level 1	Soho Early Classic	Syl	-7.4	25.6				0.24	2.98
AS-0468	1996.17.B1056	PG	pit	Unit 3, HA7, BA5, level 2, SS 12	Polvoron Late Classic	Syl	-8.2	22.9	-16.1	5.3	3.4	0.28	3.18
AS-0469	1996.17.B1055	PG		Unit 3, HA 2, SE 1/4, level 1	Polvoron	Syl	-8.8	27.8	-16.0	7.9	3.3	0.27	3.04
AS-0470	1996.17.B1053	PG		Unit 3, HA 2, S 2, level 1	Classic	Lep	-8.6	29.1	-18.5	7.7	3.3		
AS-0471	1996.17.B1055	PG		Unit 3, HA 2, W, level 1	Civano	Syl	-9.9	26.0	-18.4	7.3	3.3	0.25	2.87

AS-0472	1996.17.B1055	PG	pit	Unit 3, HA 2, SS 2, level 1	Polvoron Late Classic	Lep	-7.7	28.6	-13.7	10.5	3.2	0.23	3.03
AS-0473	1996.17.B1055	PG	trash pit	Unit 3, HA 2, level 1	Classic	Lep	-10.5	31.9	-19.0	11.0	3.3	0.28	2.92
AS-0474	1996.17.B1053	PG	trash pit	Unit 3, HA 2, N 1/2, level 2 subfloor	Soho Early	Lep	-8.8	32.9	-18.7	7.8	3.2	0.44	2.92
AS-0475	1996.17.B1055	PG	trash pit	Unit 3, HA 2, SS 9, level 2	Soho Early	Syl	-9.7	29.4	-18.8	4.0	3.3	0.44	2.85
AS-0476	1996.17.B1055	PG	trash pit	Unit 3, HA 2, SS 9, level 3	Soho Early	Syl	-9.4	32.3				0.50	3.55
AS-0477	1996.17.B1055	PG	trash pit	Unit 3, HA 2, SS 9, level 4	Soho Early	Lep	-10.9	32.2	-18.2	4.8	3.3	0.30	2.82
AS-0478	1996.17.B1055	PG	trash pit	Unit 3, HA 2, SS 9, level 4	Soho Early	Syl	-10.4	31.8	-15.3	8.2	3.3	0.29	2.84
AS-0479	1996.17.B1053	PG	pit	Unit 3, HA 2, level 3	Soho Early	Lep	-8.8	27.3	-16.4	5.2	3.3	0.39	3.11
AS-0480	1996.17.B1053	PG	pit	Unit 3, HA 2, level 3	Soho Early	Syl	-7.3	27.4	-13.4	10.6	3.2	0.29	3.20
AS-0481	1996.17.B1054	PG		Unit 4, HA 5, C 5, SW 1/4, level 1	Civano	Lep	-8.8	30.6	-17.3	9.8	3.2	0.40	2.78
AS-0482	1996.17.B1054	PG		Unit 4, HA 5, SE 1/4, level 3	Civano	Lep	-11.0	30.5	-16.4	10.8	3.2	0.25	2.74
AS-0483	1996.17.B1058	PG	trash pit	Unit 3, HA 2, W 1/2, level 1	Soho Early	Syl	-8.0	31.2	-15.2	7.2	3.2	0.41	3.15
AS-0484	1996.17.B1058	PG	trash pit	Unit 3, HA 2, W 1/2, level 3	Soho Early	Lep	-10.8	30.5	-19.0	8.5	3.2	0.28	3.07
AS-0485	1996.17.B1058	PG		Unit 4, HA 3, NE 1/4, level 2 ff	Civano	Syl	-10.3	33.1	-18.7	7.8	3.3	0.32	2.94
AS-0486	1996.17.B1054	PG		Unit 4, HA 5, rec unit 3, level 2 ff	Civano	Syl	-8.6	29.3	-14.6	8.2	3.3	0.34	3.48
AS-0487	1996.17.B1058	PG		Unit 4, HA 8, N 1/2, level 2 ff	Soho Early Classic	Lep	-7.7	32.8	-15.9	7.3	3.3	0.33	3.02
AS0488	1996.17.	PG		Unit 4, HA 4, SW	Polvoron	Lep	-5.1	31.5	-13.5	10.2	3.2	0.25	2.72

	B1054			1/4, level 1 fi									
AS-0489	1996.17.B1054	PG		Unit 4, HA 4, SW 1/4, level 1 fi	Polvoron	Syl	-5.3	28.3				0.34	3.10
AS-0490	1996.17.B1053	PG		Unit 4, HA 3, S 21, level 1	Soho Early Classic	Lep	-12.4	28.3	-19.9	8.7	3.2	0.24	2.90
AS-0491	1996.17.B1054	PG		Unit 4, HA 4, level 1 fi	Polvoron	Lep	-7.4	30.6	-14.9	8.7	3.4	0.25	2.87
As-0492	1996.17.B1054	PG		Unit 4, HA 4, SW 1/4, level 1 fi	Polvoron	Syl	-7.7	31.3	-14.4	9.0	3.3	0.37	3.05
AS-0493	1996.17.B1054	PG		Unit 4, AH 4, SE 1/4, level 2 fc, pl 3	Polvoron	Lep	-7.8	27.8	-10.5	9.1	3.4	0.25	2.80
AS-0494	1996.17.B1053	PG		Unit 4, HA 3, NW 1/4, level 1	Soho Early Classic	Lep			-11.8	9.1	3.3	0.25	4.88
AS-0495	1996.17.B1053	PG		Unit 4, HA 3, NE 1/4, level 1	Soho Early Classic	Lep			-12.8	7.6	3.4	0.25	2.90
AS-0496	1996.17.B1058	PG		Unit 4, HA 6, hand trench 1	Civano	Lep	-10.2	31.1	-18.6	10.5	3.2	0.35	3.14
AS-0497	1996.17.B1054	PG	pit	Unit 4, HA 5, level 1	Preclassic	Syl			-18.3	5.4	3.2	0.23	2.54
AS-0498	1996.17.B1053	PG	trash pit	Unit 4, HA 3, SS 37, level 2	Soho Early Classic	Lep	-9.1	31.4	-16.1	10.1	3.2	0.18	3.83
AS-0499	1996.17.B1053	PG	trash pit	Unit 4, HA 3, SS 37, level 6	Soho Early Classic	Syl	-11.0	30.0	-18.7	7.0	3.2	0.31	3.42
AS-0500	1996.17.B1059	PG	pit	Unit 4, HA 3, S 1/2, level 3	Soho Early	Lep	-6.4	30.7	-12.1	6.6	3.2	0.17	3.31
AS-0501	1996.17.B1059	PG	pit	Unit 4, HA 3, S 1/2, level 3	Soho Early	Syl	-11.4	30.6				0.22	3.41
AS-0502	1996.17.B1059	PG	pit	Unit 4, HA 3, S 1/2, level 4	Soho Early	Lep	-11.2	23.6	-17.2	7.8	3.2	0.16	3.14
AS-0503	1996.17.B1059	PG		Unit 4, HA 3, east, level 1	Civano	Lep	-7.4	30.2	-13.7	11.9	3.3	0.22	2.82
AS-0504	1996.17.B1059	PG		Unit 1, Ha 10, rec unit a, level 2 ff	Civano	Lep	-11.9	32.1				0.20	2.72

AS-0505	1996.17.B1058	PG		Unit 4, HA 4, rec unit E, level 1 ff	Polvoron	Lep	-8.3	28.9				0.23	3.89
AS-0506	1996.17.B1058	PG		Unit 4, HA 5, rec unit 4, level 2 ff	Soho Late	Syl	-12.0	30.9				0.19	3.47
AS-0507	1996.17.B1058	PG		Unit 4, HA 5, rec unit 5, level 1 fi	Soho Late	Lep	-13.1	29.2				0.19	3.61
AS-0508	1996.17.B1059	PG		Unit 4, HA 4, NE 1/4, level 1 fi	Polvoron	Lep	-7.5	30.5				0.18	3.20
AS-0509	1996.17.B1054	PG		Unit 4, HA 5, NE 1/4, level 2, From 13152	Civano	Lep	-11.0	25.2				0.20	3.42
AS-0735	178	LQ	60	0			-4.3	29.7	-11.5	8.5	3.3		
AS-0736	214	LQ	60	2			-4.1	23.9					
AS-0737	227	LQ	60	2			-4.6	19.6					
AS-0738	250	LQ	60	2		Lep	-4.2	26.1					
AS-0739	259	LQ	60	3		Lep	-6.5	23.5	-17.1	3.1	3.3		
AS-0740	333	LQ	60	5		Lep	-3.9	25.8					
AS-0741	414	LQ	60	7		Lep	-2.6	23.1	-8.9	4.5	3.3		
AS-0742	417	LQ	60	7			-9.0	23.6	-17.8	4.3	3.3		
AS-0743	438	LQ	60	8			-2.8	25.6	-14.2	3.1	3.3		
AS-0744	448	LQ	60	9		Lep	-4.2	24.6	-9.3	5.8	3.2		
AS-0745	476	LQ	60	10		Lep	-2.3	23.4	-14.5	7.2	3.3		
AS-0746	479	LQ	60	10		Lep	-4.3	24.7	-11.2	7.0	3.3		
AS-0747	545	LQ	60	11			-2.6	25.0	-10.7	6.0	3.3		
AS-0748	858	LQ	60	3		Lep	-5.1	25.7	-13.2	5.5	3.3		
AS-0749	908	LQ	60	4		Lep	-5.8	20.0	-14.6	6.5	3.3		
AS-0750	1257	LQ	60	5			-1.9	22.7					
AS-0751	1258	LQ	60	5		Lep	-5.9	25.2	-15.1	7.2	3.3		
AS-0752	1282	LQ	60	1		Lep	-3.9	21.0	-11.8	5.5	3.3		
AS-0753	1285	LQ	60	1		Lep	-4.0	21.4	-10.9	6.6	3.3		
AS-0754	1338	LQ	60	5			-4.7	19.9	-13.8	5.9	3.3		
AS-0755	1358	LQ	60	5			-3.6	22.8	-9.0	5.8	3.3		
AS-0756	1400	LQ	111	6	Early	Lep	-4.7	21.2	-9.5	7.8	3.3		
AS-	1432	LQ	111	4	Middle	Lep	-4.5	25.3	-11.3	5.4	3.4		

0757													
AS-0758	1433	LQ	111	4	Middle	Lep	-4.5	23.7	-11.0	7.4	3.2		
AS-0759	1438	LQ	111	4	Middle	Lep	-4.4	23.9				0.22	3.04
AS-0760	1534	LQ	111	3	Middle	Lep	-3.0	26.5	-9.5	5.2	3.2		
AS-0761	1542	LQ	111	3	Middle		-8.7	26.2				0.26	3.40
AS-0762	1590	LQ	111	2	Middle	Lep	-5.0	26.1	-10.5	6.0	3.3	0.21	3.14
AS-0763	1598	LQ	111	2	Middle	Lep	-3.7	22.9	-9.1	7.3	3.3	0.22	3.64
AS-0764	1697	LQ	111	2	Middle	Lep			-9.4	3.2	3.2	0.17	4.13
AS-0765	1728	LQ	111	2	Middle	Lep	-5.3	26.3	-9.6	7.5	3.2	0.19	3.61
AS-0766	1744	LQ	111	1	Middle	Lep			-9.2	5.2	3.2	0.25	4.54
AS-0767	1760	LQ	111	1	Middle	Lep	-4.6	26.7	-9.4	5.8	3.2	0.21	3.21
AS-0768	1795	LQ	111	1	Middle	Lep	-3.7	22.3	-9.6	5.4	3.2	0.21	3.36
AS-0769	1796	LQ	111	1	Middle	Lep	-5.5	20.4				0.18	3.54
AS-0770	1811	LQ	110	24	Early	Lep						0.26	6.40
AS-0771	1812	LQ	110	24	Early	Lep			-14.9	8.0	3.4	0.19	4.95
AS-0772	1818	LQ	110	24	Early							0.29	5.40
AS-0773	1821	LQ	110	23	Early	Lep	-2.6	24.3				0.29	3.18
AS-0774	1822	LQ	110	23	Early	Lep						0.36	4.80
AS-0775	1834	LQ	110	22	Early	Lep	-4.9	25.9	-11.7	7.2	3.2	0.24	3.89
AS-0776	1835	LQ	110	22	Early	Lep	-5.6	24.5				0.26	3.84
AS-0777	1836	LQ	110	22	Early		-3.9	24.4				0.36	3.24
AS-0778	1837	LQ	110	22	Early	Lep						0.20	4.35
AS-0779	1852	LQ	110	21	Middle	Lep						0.32	4.06
AS-0780	1853	LQ	110	21	Middle	Lep	-7.0	27.1				0.39	3.41
AS-0781	1867	LQ	110	20	Middle	Lep	-3.0	21.1	-12.0	5.4	3.2	0.18	3.96
AS-0782	1876	LQ	110	20	Middle	Lep						0.19	4.14
AS-0783	1935	LQ	110	19	Middle	Lep	-2.9	21.1				0.26	3.31
AS-0784	1938	LQ	110	19	Middle	Lep	-3.4	23.3				0.29	2.77
AS-0785	1949	LQ	110	19	Middle	Lep	-5.2	19.7	-11.7	8.0	3.3	0.18	3.41
AS-0786	1950	LQ	110	19	Middle	Lep	-8.7	19.4	-14.4	9.5	3.4	0.21	3.55
AS-0787	1964	LQ	110	19	Middle	Lep	-4.8	26.8				0.20	2.92
AS-0788	2036	LQ	110	18	Late	Lep						0.28	4.57
AS-0789	2038	LQ	110	18	Late	Lep	-4.6	24.7	-10.7	6.2	3.3	0.20	3.68

AS-0790	2041	LQ	110	18	Late	Lep	-4.4	21.4	-9.4	6.1	3.4	0.19	3.24
AS-0791	2073	LQ	110	18	Late	Lep	-6.5	18.2				0.20	3.39
AS-0792	2082	LQ	110	18	Late	Lep	-6.7	24.0				0.15	3.77
AS-0793	2106	LQ	110	17	Late	Lep	-5.3	24.9				0.28	2.87
AS-0794	2113	LQ	110	17	Late	Lep	-4.1	24.0	-9.4	6.5	3.3	0.24	3.03
AS-0795	2116	LQ	110	17	Late	Lep						0.28	4.07
AS-0796	2129	LQ	110	17	Late	Lep			-10.3	6.8	3.4	0.23	4.15
AS-0797	2138	LQ	110	17	Late	Lep	-5.2	24.4	-12.8	4.1	3.4	0.33	2.63
AS-0798	2147	LQ	110	17	Late	Lep	-7.9	26.9				0.37	2.14
AS-0799	2150	LQ	110	17	Late	Lep	-5.0	22.0				0.18	2.73
AS-0800	2216	LQ	110	16	Late	Lep	-11.0	24.9				0.18	2.88
AS-0801	2222	LQ	110	16	Late	Lep	-4.1	27.1	-10.9	7.4	3.4	0.15	3.00
AS-0802	2308	LQ	110	16	Late	Lep	-5.0	27.6				0.32	2.16
AS-0803	2309	LQ	110	16	Late	Lep	-4.0	23.7				0.16	2.74
AS-0804	2312	LQ	110	16	Late		-7.1	25.6				0.19	2.71
AS-0805	2313	LQ	110	16	Late		-6.1	20.7				0.31	2.24
AS-0806	2318	LQ	110	16	Late		-10.0	25.6	-16.9	9.2	3.4	0.20	2.68
AS-0807	2320	LQ	110	16	Late	Lep	-3.4	25.3	-8.5	9.6	3.5	0.18	3.12
AS-0808	2322	LQ	110	16	Late	Lep	-4.7	27.5	-10.2	5.7	3.3	0.31	2.14
AS-0809	2341	LQ	110	15	Late	Lep	-7.6	24.7				0.19	3.04
AS-0810	2344	LQ	110	15	Late	Lep	-3.5	24.3	-9.1	3.9	3.4	0.22	2.44
AS-0811	2348	LQ	110	15	Late	Lep	-3.7	21.1				0.19	2.59
AS-0812	2351	LQ	110	15	Late	Lep						0.19	2.57

1. SITES: LF = La Ferrería; PG = Pueblo Grande; LQ = La Quemada

2. GENUS: Lep = *Lepus* spp.; Syl = *Sylvilagus* spp.

APPENDIX V. Stable isotope results from Teotihuacan.

Lab #	**Spec #**	**Site**	**Phase**	**Genus**	**δ^{13}C ap**	**δ^{18}O ap**	**δ^{13}C col**	**δ^{15}N col**	**CN**	**CP**	**IR-SF**
AS-0071	11912.001	Cuevas	Azteca	Lepus	-9.2	27.8	-14.2	5.3		0.28	2.12
AS-0072	11912.002	Cuevas	Azteca	Sylvilagus			-16.2	5.0	3.3	0.26	1.98
AS-0073	21952	Cuevas	Azteca III	Sylvilagus	-11.3	21.3	-19.7	8.4	3.3	0.19	2.06
AS-0074	22715	Cuevas	Azteca III	Lepus			-13.3	5.0		0.28	1.94
AS-0075	22788	Cuevas	Azteca III	Sylvilagus	-8.6	24.7	-17.4	10.1		0.25	2.02
AS-0164	22788	Cuevas	Azteca III	Lepus	-7.7	23.2	-14.9	5.9			
AS-0165	23188	Cuevas	Mazapa Perturbado por Azteca III	Sylvilagus	-8.1	24.1	-16.3	9.2	3.3		
AS-0166	24112	Cuevas	Coyotlatelco	Sylvilagus	-12.7	28.6	-19.6	1.7	3.2		
AS-0167	25229	Cuevas	Coyotlatelco	Lepus	-7.1	26.1	-17.4	3.1	3.3		
AS-0168	22383	Cuevas	Azteca III	Sylvilagus	-9.0	30.6	-18.2	9.4	3.2		
AS-0169	11920	Cuevas	Azteca	Sylvilagus	-9.6	26.4	-17.3	6.0	3.2		
AS-0170	23402	Cuevas	Coyotlatelco tardio	Lepus	-5.9	27.8	-11.0	4.1	3.2		
AS-0655		Modern	Modern	Sylvilagus floridanus orizabae	-11.902	26.659	-17.6	5.2462	3.27044		
AS-0656		Modern	Modern	Sylvilagus floridanus orizabae	-13.892	24.577					
AS-0657		Modern	Modern	Sylvilagus floridanus orizabae	-13.048	24.66	-18.749	7.2549	3.28964		
AS-0660		Modern	Modern	Sylvilagus floridanus orizabae	-8.6096	25.527	-14.163	5.4781	3.17877		
AS-0661		Modern	Modern	Sylvilagus floridanus orizabae	-14.536	23.423	-20.118	2.3462	3.21941		
AS-0677		Modern	Modern	Lepus californicus texianus	-10.463	27.544	-15.161	6.7446	3.30667		
AS-0678		Modern		Sylvilagus floridanus orizabae	-12.137	26.968	-17.614	7.6809	3.3828	0.298246	3.36
AS-0679		Modern		Sylvilagus floridanus orizabae	-11.094	26.53	-16.004	7.3341	3.34566	0.347305	3.09
AS-0705		Modern	Modern	Sylvilagus floridanus orizabae	-13.398	26.139	-18.331	1.501	3.28099		
AS-0706		Modern	Modern	Sylvilagus floridanus orizabae	-12.247	25.641	-18.183	1.3745	3.2732		
AS-0707		Modern	Modern	Sylvilagus floridanus orizabae	-12.485	27.937	-18.433	3.4449	3.37123		
AS-0708		Modern	Modern	Sylvilagus floridanus orizabae	-12.099	28.206	-18.32	2.6507	3.37778		

AS-0709		Modern	Modern	Sylvilagus floridanus	-14.355	25.347	-19.868	1.4135	3.32211		
AS-0315	A-1224.001	Moon Pyramid	2	Lepus	-9.1	29.9					
AS-0321	A-1955.002	Moon Pyramid	1	Sylvilagus	-8.9	29.2	-17.0	7.0	3.3	0.30	2.80
AS-0322	A-1985.002	Moon Pyramid	1	Sylvilagus	-10.6	27.3			8.9	0.21	3.04
AS-0323	A-1592.001	Moon Pyramid	1	Sylvilagus	-8.8	24.8	-15.9	5.9	3.3	0.18	3.06
AS-0324	A-1917.001	Moon Pyramid	1	Lepus	-5.8	27.1	-14.2	7.4		0.15	3.17
AS-0325	A-1955.001	Moon Pyramid	1	Sylvilagus	-8.9	28.5	-17.3	6.8	3.3	0.20	3.02
AS-0326	A-1962.001	Moon Pyramid	1	Lepus	-6.4	25.4	-17.4	7.0	3.3	0.15	3.09
AS-0327	A-1962.002	Moon Pyramid	1	Sylvilagus	-9.2	26.1	-17.6	7.5	3.3	0.11	3.09
AS-0328	A-1962.003	Moon Pyramid	1	Sylvilagus	-9.9	27.6	-17.6	9.6	3.3		
AS-0329	A-1962.004	Moon Pyramid	1	Sylvilagus	-10.3	27.3	-18.6	5.0	3.3	0.20	2.78
AS-0330	A-1962.004	Moon Pyramid	1	Sylvilagus	-11.2	29.2	-19.2	7.9	3.3	0.25	2.81
AS-0331	A-1962.005	Moon Pyramid	1	Sylvilagus	-7.8	26.9	-17.9	9.7	3.3	0.13	3.08
AS-0332	A-1962.006	Moon Pyramid	1	Sylvilagus	-7.8	28.3	-17.5	6.7	3.3	0.17	2.82
AS-0333	A-1985.001	Moon Pyramid	1	Sylvilagus	-6.4	26.8	-15.7	9.8	3.3	0.15	3.05
AS-0334	A-2032.001	Moon Pyramid	1	Sylvilagus	-7.4	27.4	-17.0	6.9	3.3	0.19	2.85
AS-0335	A-1819.001	Moon Pyramid	1	Sylvilagus	-3.8	11.9				0.14	3.50
AS-0336	A-2032.002	Moon Pyramid	1	Sylvilagus	-8.7	26.3	-16.1	6.6	3.2	0.21	2.97
AS-0337	A-662.001	Moon Pyramid	2	Sylvilagus	-4.9	24.7	-13.9	5.4	3.3	0.14	3.09
AS-0338	A-915.001	Moon Pyramid	2	Sylvilagus	-6.2	29.3	-12.8	5.0	3.2	0.25	2.89
AS-0339	A-915.002	Moon Pyramid	2	Sylvilagus	-5.1	24.6	-11.3	4.3	3.3	0.20	2.91
AS-0340	A-940.001	Moon Pyramid	2	Sylvilagus						0.08	3.23

AS-0341	A-1290.001	Moon Pyramid	2	Sylvilagus	-7.5	23.7	-14.0	5.6		0.17	2.89
AS-0342	A-1296.001	Moon Pyramid	2	Sylvilagus	-8.8	25.3	-16.4	5.0		0.11	3.24
AS-0343	A-2178.001	Moon Pyramid	2	Sylvilagus	-6.0	28.4	-12.4	5.2		0.21	2.84
AS-0344	A-2366.001	Moon Pyramid	2	Lepus	-12.3	26.0	-20.2	1.8		0.23	2.82
AS-0345	A2366.002	Moon Pyramid	2	Lepus	-8.7	24.5	-12.5	6.4		0.24	2.66
AS-0346	A-520.001	Moon Pyramid	3	Sylvilagus	-10.1	24.2	-17.7	0.9	3.3	0.15	3.13
AS-0347	A-3083.001	Moon Pyramid	4	Lepus	-14.7	23.8	-21.4	1.3	3.2	0.20	2.88
AS-0348	A-3083.002	Moon Pyramid	4	Lepus	-4.7	26.4	-10.0	4.9	3.2	0.23	2.77
AS-0349	A-6394.001	Moon Pyramid	4	Sylvilagus	-11.1	28.4	-17.6	4.6	3.2	0.25	2.92
AS-0350	A-6394.002	Moon Pyramid	4	Sylvilagus	-9.0	30.2	-15.5	5.4	3.2	0.21	2.81
AS-0351	A-382.001	Moon Pyramid	5	Sylvilagus	-9.9	24.2				0.11	3.16
AS-0352	A-382.002	Moon Pyramid	5	Sylvilagus	-9.3	26.8	-17.9	6.5	3.3	0.12	3.16
AS-0353	A-382.003	Moon Pyramid	5	Sylvilagus	-8.0	23.7	-18.0	6.7	3.3	0.13	2.98
AS-0354	A-382.004	Moon Pyramid	5	Lepus	-10.8	24.7	-16.5	1.8	3.2	0.16	3.30
AS-0355	A-382.005	Moon Pyramid	5	Lepus	-11.0	25.3	-16.5	1.6	3.2	0.18	2.89
AS-0356	A-5251.001	Moon Pyramid	5	Sylvilagus	-10.1	28.3	-17.8	4.4	3.2	0.17	2.95
AS-0357	A-5279.001	Moon Pyramid	5	Lepus	-5.1	21.6	-10.3	6.1	3.2	0.16	3.51
AS-0358	H-024.002	Moon Pyramid	6	Lepus	-7.0	23.9	-14.5	2.6	3.2	0.18	2.90
AS-0359	H-107.001	Moon Pyramid	6	Lepus	-11.8	22.8	-22.0	1.2	3.2	0.17	2.59
AS-0360	H-182.001	Moon Pyramid	6	Sylvilagus	-9.1	28.4	-16.3	5.9	3.3	0.16	2.73
AS-0361	H-182.002	Moon Pyramid	6	Sylvilagus	-13.1	25.8	-20.1	2.6	3.3	0.19	2.67
AS-0362	H-305.001	Moon Pyramid	6	Lepus	-4.7	27.9	-10.5	5.3	3.2		
AS-0363	H-316.00	Moon Pyramid	6	Lepus	-4.7	25.7	-15.5	1.5	3.2		

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AS-0364	H-336.001	Moon Pyramid	6	Sylvilagus	-6.9	29.7	-15.4	6.7	3.3		
AS-0365	H-856.001	Moon Pyramid	6	Sylvilagus	-7.1	25.9	-14.8	5.6	3.2		
AS-0366	K-246.001	Moon Pyramid	4	Sylvilagus	-10.3	24.1	-18.9	5.6	3.3		
AS-0367	F-307.001	Moon Pyramid	6 o 7?	Sylvilagus	-10.9	27.6				0.10	3.16
AS-0368	F307.002	Moon Pyramid	6 o 7?	Lepus	-7.4	22.6	-14.0	1.8	3.3	0.14	3.21
AS-0369	F-312.002	Moon Pyramid	7	Lepus			-20.8	2.6	3.2	0.24	5.64
AS-0370	F-312.001	Moon Pyramid	7	Lepus			-13.4	3.3	3.2	0.34	0.56
AS-0371	K-317.001	Moon Pyramid	4	Lepus	-10.3	24.7	-19.6	4.5	3.3	0.17	2.67
AS-0372	F-610.001	Moon Pyramid	7	Sylvilagus	-12.8	25.6	-19.7	3.1	3.2	0.14	4.18
AS-0373	F-970.001	Moon Pyramid	6 o 7?	Sylvilagus	-11.3	24.4	-19.4	3.8	3.2	0.14	3.74
AS-0455	H-913.001	Moon Pyramid	6	Sylvilagus			-11.2	5.7	3.2	0.23	2.94
AS-0456	H-024.001	Moon Pyramid	6	Sylvilagus			-17.1	4.1	3.3	0.26	2.39
AS-0068	OZT.012	Oztoyahualco	Xolalpan	Sylvilagus	-6.0	24.3	-13.6	2.9	3.3	0.24	2.06
AS-0069	OZT.013	Oztoyahualco	Xolalpan	Sylvilagus	-7.9	21.8	-15.7	4.9	3.4	0.20	2.22
AS-0070	OZT.015	Oztoyahualco	Xolalpan	Sylvilagus	-4.0	20.9				0.22	2.30
AS-0171	OZT.010	Oztoyahualco	Xolalpan	Sylvilagus			-11.4	4.9	3.3		
AS-0172	OZT.005	Oztoyahualco	Xolalpan	Lepus	-3.4	24.7	-10.7	6.4	3.3	0.26	2.83
AS-0173	OZT.008	Oztoyahualco	Xolalpan	Leporidae quizas Sylvilagus cunicularis	-3.3	27.2	-10.2	7.7	3.2	0.26	2.73
AS-0174	OZT.009	Oztoyahualco	Xolalpan	Sylvilagus	-6.4	26.8	-17.3	7.2	3.2	0.34	2.56
AS-0175	OZT.016	Oztoyahualco	Xolalpan	Sylvilagus	-11.3	24.9	-22.3	2.9	3.2	0.22	3.08
AS-0176	OZT.011	Oztoyahualco	Xolalpan	Lepus?	-5.4	24.8	-17.1	4.3	3.6	0.15	3.18
AS-0177	OZT.014	Oztoyahualco	Xolalpan	Sylvilagus	-5.5	24.7	-17.8	4.0	3.4	0.21	2.84
AS-0260	OZT.017	Oztoyahualco	Xolalpan	Lepus			-11.1	7.1		0.25	4.30
AS-0853	OZT.001	Oztoyahualco	Xolalpan	Lepus	-5.5	29.4	-11.9	6.2	3.2		
AS-0854	OZT.002	Oztoyahualco	Xolalpan	Sylvilagus	-4.2	27.4	-12.0	5.1	3.3		
AS-0855	OZT.003	Oztoyahualco	Xolalpan	Sylvilagus	-6.8	22.5	-14.5	6.9	3.4		

AS-0856	OZT.004	Oztoyahualco	Xolalpan	Lepus	-6.1	27.0	-13.5	4.9	3.4		
AS-0857	OZT.006	Oztoyahualco	Xolalpan	Sylvilagus	-8.2	27.1	-16.4	4.6	3.2		
AS-0858	OZT.007	Oztoyahualco	Xolalpan	Sylvilagus	-4.8	26.8	-11.9	3.0	3.4		
AS-0814	25625.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-5.4	26.0	-12.4	3.6	3.2	0.23	3.10
AS-0815	25666.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-7.3	22.8	-15.8	4.8	3.3	0.33	3.18
AS-0816	25698.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus			-13.4	7.7	3.3	0.33	3.59
AS-0817	25714.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-8.8	24.3	-16.1	5.2	3.3	0.34	3.24
AS-0818	26505.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-12.9	23.3	-22.1	0.3	3.3	0.29	3.04
AS-0819	26542.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-6.8	24.5				0.13	3.33
AS-0820	26549.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-8.3	26.6	-16.7	4.1	3.3	0.25	3.18
AS-0821	26612.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-8.2	24.2	-22.3	1.7	3.4	0.16	3.31
AS-0822	26749.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-5.7	23.9				0.13	3.56
AS-0823	27519.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-5.6	22.9	-13.4	4.9	3.4	0.11	3.70
AS-0824	27521.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-10.4	23.7	-19.3	2.7	3.3	0.19	3.33
AS-0825	27541.001	Puerta 5	Coyotlatelco/ Metepec				-14.3	7.3	3.3	0.13	4.12
AS-0826	27541.002	Puerta 5	Coyotlatelco/ Metepec				-18.1	3.7	3.3	0.07	3.69
AS-0827	27541.003	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus						0.07	4.16
AS-0828	27541.004	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-4.9	25.9	-12.2	7.8	3.3	0.14	3.47
AS-0829	28192.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-5.0	24.3				0.10	3.74
AS-0830	28197.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus						0.07	3.63
AS-0831	28199.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-6.8	23.8	-15.4	3.6	3.4	0.11	3.80
AS-0832	28200.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus			-13.3	4.2	3.4	0.09	3.82
AS-0833	28200.002	Puerta 5	Coyotlatelco/ Metepec	Lepus						0.08	3.79
AS-0834	28200.003	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-6.6	26.5				0.11	3.74
AS-0835	29004.001	Puerta 5	Coyotlatelco/ Metepec	Lepus	-6.7	26.1				0.11	3.91
AS-0836	29914.001	Puerta 5	Coyotlatelco/ Metepec	Lepus	-5.6	23.5	-13.4	4.4	3.3	0.15	3.37
AS-0837	30431.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus			-17.1	3.7	3.3	0.37	3.63
AS-0838	35214.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-7.0	21.5	-13.9	8.0	3.3	0.14	3.63
AS-0839	35222.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-9.8	24.0	-16.8	5.1	3.3	0.17	3.41
AS-0840	35269.001	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus	-6.5	25.5	-14.3	3.7	3.3	0.13	3.58
AS-0841	35273.001	Puerta 5	Coyotlatelco/ Metepec	Lepus			-13.7	4.1	3.3	0.18	3.40
AS-0842	27541.005	Puerta 5	Coyotlatelco/ Metepec	Sylvilagus			-12.7	6.8	3.2	0.15	3.61
AS-0178	43036.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-7.7	27.0	-17.2	5.7	3.2	0.22	2.93

AS-0179	58208.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-7.0	29.6	-14.5	4.4	3.2	0.40	2.61
AS-0180	3126.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-8.3	28.6	-17.7	8.5	3.3	0.40	2.58
AS-0181	55878.002	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-6.1	26.1	-15.1	4.5	3.2	0.42	2.97
AS-0182	35127.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-5.8	28.4	-14.2	5.5	3.2	0.46	2.64
AS-0183	66717.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-6.2	23.7	-18.5	7.0	3.3	0.29	2.60
AS-0184	7786.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-6.3	25.7	-15.5	8.1	3.3		
AS-0185	55935.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-6.4	28.6	-13.7	5.9	3.2		
AS-0186	14206.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-7.3	27.4	-16.1	6.3	3.2		
AS-0187	51541.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-6.1	29.3	-15.6	5.4	3.2		
AS-0843	43320.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus			-12.0	13.7	3.0	0.23	3.95
AS-0844	43375.002	Teopancazco	Tlamimilolpa - Xolalpan	Lepus	-6.3	25.4	-17.4	5.1	3.3	0.14	4.49
AS-0845	43375.001	Teopancazco	Tlamimilolpa - Xolalpan	Lepus	-9.1	28.0	-14.7	9.4	3.1		
AS-0846	44296.001	Teopancazco	Tlamimilolpa - Xolalpan	Lepus	-8.8	27.2	-17.0	4.8	3.3		
AS-0847	44373.001	Teopancazco	Tlamimilolpa - Xolalpan	Lepus	-5.8	25.8					
AS-0848	47376.001	Teopancazco	Tlamimilolpa - Xolalpan	Lepus	-3.8	26.9	-10.7	5.3	3.2		
AS-0849	51506.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-9.5	26.4	-15.2	5.3	3.3		
AS-0850	55878.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-6.6	28.8	-13.3	6.3	3.3		
AS-0851	58982.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-7.5	27.5	-14.8	6.3	3.3		
AS-0852	55988.001	Teopancazco	Tlamimilolpa - Xolalpan	Sylvilagus	-8.2	28.3	-16.6	8.8	3.3		