



Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: [www.elsevier.com/locate/jasrep](http://www.elsevier.com/locate/jasrep)

## Turkeys on the fringe: Variable husbandry in “marginal” areas of the prehistoric American Southwest

Emily Lena Jones<sup>a,\*</sup>, Cyler Conrad<sup>a</sup>, Seth D. Newsome<sup>b</sup>, Brian M. Kemp<sup>c,d</sup>, Jacqueline Marie Kocer<sup>a</sup>

<sup>a</sup> Department of Anthropology, University of New Mexico, MSC01-1040, Anthropology 1, Albuquerque, NM 87131, USA

<sup>b</sup> Department of Biology, University of New Mexico, MSC03-2020, 167 Castetter Hall, Albuquerque, NM 87131, USA

<sup>c</sup> Department of Anthropology, Washington State University, Pullman, WA 99164, USA

<sup>d</sup> School of Biological Sciences, Washington State University, Pullman, WA 99164, USA

### ARTICLE INFO

#### Article history:

Received 2 September 2015

Received in revised form 21 March 2016

Accepted 20 May 2016

Available online xxxx

#### Keywords:

Tijeras Pueblo

Chamisal Pueblo

Gallina

Rattlesnake Ridge

Cuchillo

Sandia mountains

Stable isotopes

Turkey domestication

Ancient DNA (aDNA)

Mitochondrial DNA (mtDNA)

### ABSTRACT

Previous research reporting stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope values of prehistoric turkey (*Meleagris gallopavo*) remains from the American Southwest indicates that these birds were husbanded in consistent ways: the majority of samples suggest a diet dominated by maize, a domesticate that uses the  $\text{C}_4$  photosynthetic pathway. However, most of these studies have focused on turkey remains from locations where maize would likely have been readily available. Here we present isotope and mitochondrial DNA (mtDNA) haplotype data from turkey remains from the relatively high-elevation site of Tijeras Pueblo (LA 581), a location where maize production may have been marginal. The Tijeras Pueblo turkeys display a unique carbon isotope pattern in both bone collagen and bone apatite, with half the samples indicating a predominately  $\text{C}_3$  diet (a signature characteristic of modern wild turkeys) and the other half predominately  $\text{C}_4$ , even though the majority of samples belong to the Southwestern domestic turkey mtDNA lineage identified by Speller et al. (2010). Comparative collagen samples from the Albuquerque Basin and the Gallina region do not follow this pattern. Apatite-collagen  $\delta^{13}\text{C}$  spacing in the Tijeras turkeys suggests these birds were acquiring carbohydrates and protein from a mixture of  $\text{C}_3$ - and  $\text{C}_4$ -based resources. We propose that the  $\text{C}_3$  Tijeras turkeys were free-ranged, and that the presence of two distinct turkey husbandry regimes at Tijeras Pueblo may reflect Tijeras' geographic location on a cultural boundary between the Plains and Pueblo regions.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

### 1. Introduction

The nature of the human–turkey (*Meleagris gallopavo*) relationship in the prehistoric American Southwest has long been a matter of debate. Were turkeys domestic or wild (Beacham and Durand, 2007; Grimstead et al., 2014)? If domestic, were they domesticated independently (McKusick, 1986) or imported from domestic flocks maintained by prehistoric Mesoamericans? Did Ancestral Puebloans use turkeys for food or for ritual purposes, and did this use change through time (Badenhorst and Driver, 2009; Lipe et al., 2016; McKusick, 2001)? In recent years, ancient DNA (aDNA) research has addressed some of these questions, establishing the presence of a distinct turkey lineage – separate from both the Mexican domestic turkey and the local wild Merriam's turkey (*M. gallopavo merriami*) – in the American Southwest as far back as the Basketmaker period (A.D. 1; Speller et al., 2010). Isotope-based studies (Kellner et al., 2010; McCaffery et al., 2014; Rawlings and Driver, 2010; also see Grimstead et al., 2014 for a different approach) provide further support for domestication: these studies

have established a remarkably consistent picture of turkey husbandry in the prehistoric Southwest, with the vast majority of turkey samples having  $\delta^{13}\text{C}$  values indicative of diets dominated by  $\text{C}_4$  plants (presumably maize), a few individuals showing values in the  $\text{C}_3$  range, and no turkeys with the intermediate  $\delta^{13}\text{C}$  values that would be consistent with a diet of mixed  $\text{C}_3$  and  $\text{C}_4$  resources (Fig. 2; Kellner et al., 2010; McCaffery et al., 2014; Rawlings and Driver, 2010). Turkeys with  $\delta^{13}\text{C}$  values indicative of a  $\text{C}_4$ -based diet match those of contemporaneous humans, suggesting that these turkeys were eating diets similar to those consumed by the people who husbanded them (e.g., Coltrain and Janetski, 2013). The few turkeys with  $\delta^{13}\text{C}$  values indicative of a  $\text{C}_3$ -based diet have been interpreted as reflecting the occasional presence of local wild Merriam's turkey, a reasonable argument given that isotopic studies of wild turkeys indicate a diet dominated by  $\text{C}_3$  resources (e.g., Stearns, 2010).

However, many questions about turkey husbandry in the American Southwest remain. One such question involves the cost of maintaining domestic turkeys in areas with variable or low agricultural productivity. Maize was the staple food for prehistoric people as well as for domestic turkeys (Coltrain et al., 2007; Cordell and McBrinn, 2012; Geib, 2011; Matson and Chisholm, 1991). If maize availability was restricted in a

\* Corresponding author.

E-mail address: [elj@unm.edu](mailto:elj@unm.edu) (E.L. Jones).

particular year, turkey growers would have faced a choice: feed people or feed turkeys. This problem would likely have been a relatively common one in areas where maize production was marginal due to a shorter growing season; it may also have been an issue in areas where people invested less in maize production for cultural and/or historical reasons.

Most of the previous isotopic studies were conducted with samples derived from sites in core areas of the American Southwest, places where maize would have been a relatively stable resource (Hayes and Caperton, 1981; Kohler et al., 2012). Because turkeys from sites in areas where the growing season was short and/or in which the material culture suggests a difference from these core areas have yet to be analyzed, it may be that we have underestimated the heterogeneity in prehistoric Southwestern turkey husbandry practices.

Environmentally marginal locations in the Southwest include high-elevation sites such as Tijeras Pueblo (Fig. 1; 2,150 m). Maize typically requires 120 frost-free days for good production (Mackey, 1985), but Tijeras is located in a pass in the Sandia Mountains (elevation range: 1,800–3,255 m), and the number of frost-free days at this site is often closer to 100 (Cordell, 1980b; Cordell et al., 1984; Julyan, 2006; Julyan

and Stuever, 2005). Dendroarchaeological records suggests climate was particularly variable between 1300 and 1425 A.D., when Tijeras Pueblo was occupied (Cordell, 1980a; Van West and Cordell, 2013).

Despite this, the inhabitants of Tijeras Pueblo were, like other Ancestral Puebloan peoples, maize farmers (Cordell, 1980b), and the archaeofaunal remains from this site are rich in turkey (Young, 1980). Previous interpretations have assumed turkeys were husbanded here in ways similar to elsewhere in the Southwest region. Given the challenges inherent in growing maize in the Sandia Mountains coupled with the suitability of the local habitat for wild turkeys, however, it may be that the prehistoric inhabitants of Tijeras Pueblo exploited wild turkeys, which are common in this area today (Julyan and Stuever, 2005), rather than investing in domestic turkeys. Alternatively, if they did keep domestic turkeys, these turkeys may have been allowed to free-range for wild plants and insects, a strategy documented ethnographically among Eastern Puebloan peoples (Lang and Harris, 1984).

In this paper, we explore this question using stable isotope ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) and aDNA data from the turkeys of Tijeras Pueblo. We compare our findings to isotope data from modern wild turkeys and from archaeological turkeys from two other eastern locations (the Albuquerque

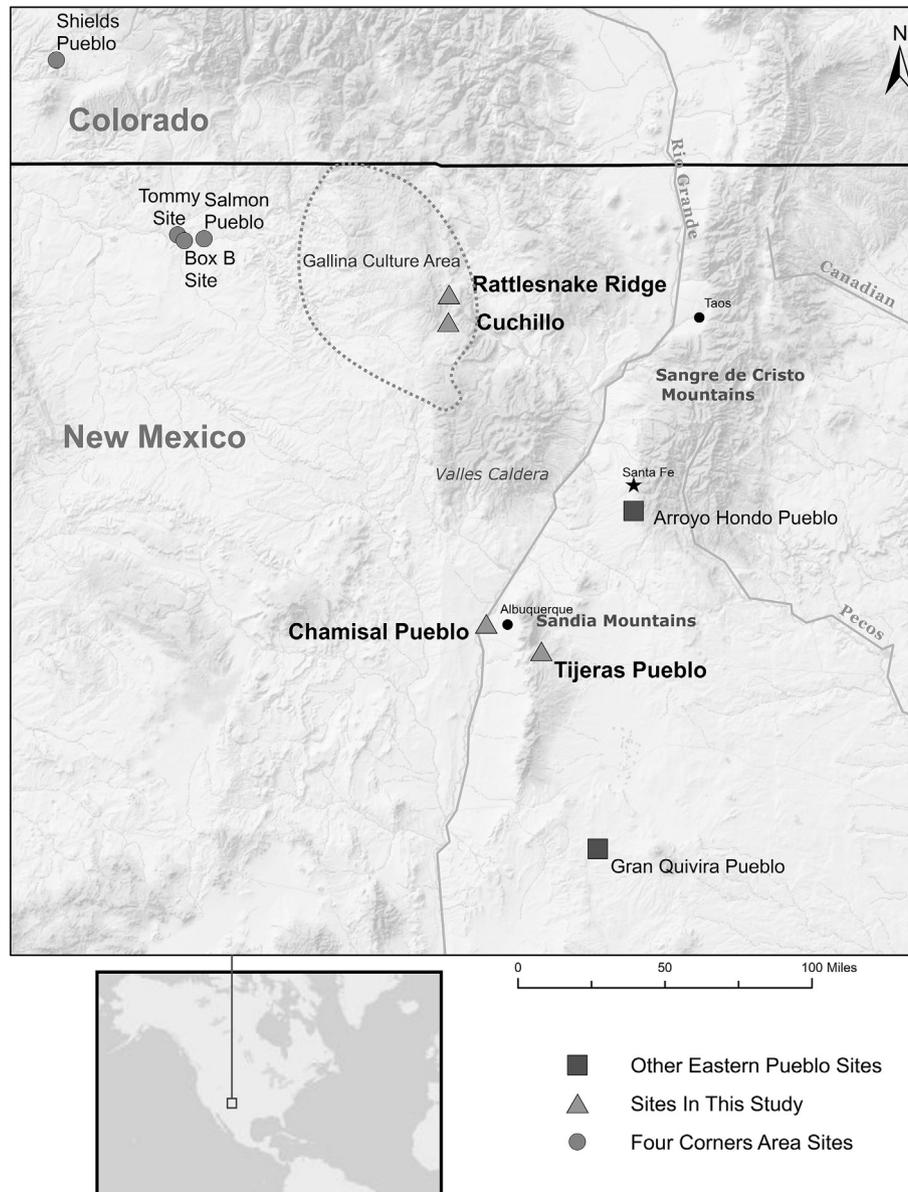


Fig. 1. Location of sites discussed in this study.

Basin and the Gallina region), as well as to the results of other studies that have examined these questions in other areas of the American Southwest (Conrad et al., this volume; Kellner et al., 2010; Lipe et al., 2016; McCaffery et al., 2014; Rawlings and Driver, 2010).

## 2. Background

### 2.1. The Sandias and Tijeras Pueblo

Tijeras Pueblo could be considered a marginal location for a maize agriculture-dependent settlement, as the relatively short growing season and higher climatic variability would make a subsistence strategy focused on maize challenging (Anderson and Oakes, 1980). Despite this, this site is a multi-story roomblock similar to other Pueblo IV period habitations (Cordell, 1980b). The bulk of its occupation occurred between A.D. 1300 and 1425, and multiple lines of evidence, including macrobotanical and geochronological data, suggest maize was the basis of the diet for humans at this site, just as it was in other Southwestern sites during this period (Cordell, 1980a; Garber, 1980).

Archaeological excavations at Tijeras Pueblo conducted in the 1970s resulted in a rich faunal assemblage (Jones and Gabe, 2015; Young, 1980), including a substantial number of turkey specimens (NISP = 151, or 12% of total vertebrate NISP). While turkey pens were not identified at Tijeras, other lines of evidence – including a concentration of turkey dung in several rooms and significant recovery of eggshell (Judy Vredenburg, personal communication) – suggest turkeys were a significant part of life at this site.

The Tijeras turkeys thus represent an ideal assemblage with which to test for heterogeneity in prehistoric turkey husbandry—one on the fringe of the Southwest core area but where turkeys were nonetheless maintained as a significant resource. We sampled 31 turkey specimens from Tijeras Pueblo recovered from a variety of contexts and spanning the full occupation of the site; detailed contextual information is available in the supplemental data.

### 2.2. Comparative samples

We hypothesize that turkeys from marginal locations should be more likely to have been procured in ways different than the typical Southwestern pattern (Kellner et al., 2010; McCaffery et al., 2014; Rawlings and Driver, 2010; see  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  data in Fig. 2). This might include (1) eschewing domestic turkeys altogether and using wild turkeys in their place; (2) a husbandry practice in which domestic turkeys were allowed to free-range; or (3) using a combination of wild, domestic, and/or free-ranged turkeys. Testing these hypotheses

requires data on the isotopic signature of wild turkeys. For this reason, we analyzed bone collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  and bone apatite  $\delta^{13}\text{C}$  collected from the wild in relatively high-elevation locations in New Mexico and Texas that are archived at the UNM Museum of Southwest Biology (Table 1).

In addition, we analyzed prehistoric turkey samples from two other areas (Fig. 1): the Gallina region ( $n = 1$  from Rattlesnake Ridge, LA 35648 at 2317 m;  $n = 2$  from Cuchillo, LA 22861 at 2091 m; and four unprovenienced specimens that are likely from Cuchillo) and the Albuquerque Basin ( $n = 11$  from Chamisal Pueblo, LA 22765 at 1518 m). The Gallina sites date to an earlier period (ca. A.D. 1100) than Tijeras Pueblo but may represent locations that are both culturally and environmentally marginal. Gallina sites have a distinct archaeological record (for example, pointed-bottom pots and architecture featuring masonry towers) and are widely assumed to represent a different cultural adaptation than contemporaneous Southwestern sites (Ellis, 1988). In addition, like Tijeras Pueblo, the Gallina region is high elevation (both sites sampled here are at elevations over 2000 m) and could be considered marginal for maize production. The median number of frost-free days in the Gallina region is less than 98 (Constan, 2011), well short of the optimal 120. As at Tijeras, there is strong evidence for turkey husbandry in the Gallina sites, with abundant turkey remains and documented turkey pens (Constan, 2011).

While the Albuquerque Basin is more climatically favorable for maize agriculture than high-elevation Tijeras or the Gallina region, this region has an archaeological record suggesting that it was likely culturally distinct from many other parts of the Southwest. Analyses of prehistoric social networks based on architecture and ceramics indicate a different pattern than that seen elsewhere (e.g., Cordell and McBrinn, 2012; Eckert and Cordell, 2004; Schaafsma, 2007). Puebloan settlement appears to have been relatively sparse in this area prior to A.D. 1200, with population growth occurring later than it did in the Four Corners region (Eckert and Cordell, 2004; Marshall and Walt, 1984). The earliest known turkey pens in the Albuquerque Basin date to the Late Developmental/Early Pueblo I period (e.g., Cordero and Dicks, 2010), at least 500 years after they are documented in the Four Corners (Rawlings and Driver, 2010). If cultural difference, rather than environmental marginality, is driving heterogeneity in turkey husbandry, we might expect to see a different pattern of turkey management in the Albuquerque Basin. Chamisal Pueblo, from which we drew our turkey sample, dates between A.D. 1300 and 1600, making it roughly contemporaneous with Tijeras Pueblo.

## 3. Methods

We measured turkey bone collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from the samples described above and compared them to previously published data from Shields Pueblo (5MT3807; Rawlings and Driver, 2010), the Tommy Site (LA 126581; McCaffery et al., 2014), Salmon Pueblo (LA 8846; McCaffery et al., 2014), the Box B Site (LA 16660; McCaffery et al., 2014), Arroyo Hondo Pueblo (LA 12; Conrad et al., this volume), and Gran Quivira (LA 120; Kellner et al., 2010) (Fig. 1), as well as to wild turkey collagen isotope data reported by Lipe et al. (2016). In addition, we measured bone apatite  $\delta^{13}\text{C}$  from the Tijeras turkeys and the comparative wild turkeys, and we calculated the spacing in  $\delta^{13}\text{C}$  values between bone apatite and collagen ( $\Delta^{13}\text{C}_{\text{apatite-collagen}}$ ).

Finally, 13 turkey specimens from Tijeras Pueblo underwent genetic analysis. Our goal in this was to identify whether turkeys exploited at Tijeras were wild Merriam's turkeys, Southwestern domesticate turkeys, or members of some other genetic lineage(s).

### 3.1. Bone collagen preparation

For bone collagen analysis, 50–100 mg of bone was sub-sampled from each element. Bone samples were demineralized in 0.5 N hydrochloric acid at  $\sim 5^\circ\text{C}$  for  $\sim 24$  h. Samples were then rinsed to neutrality in deionized water. We extracted lipids from both modern and ancient

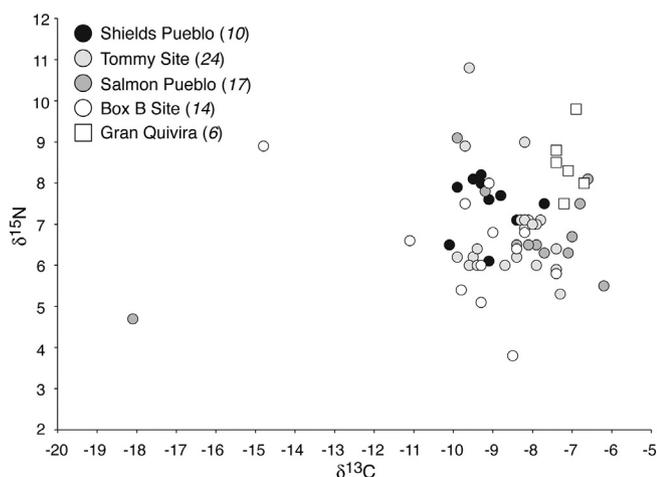


Fig. 2. Collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from previous Southwestern turkey isotope studies (Kellner et al., 2010; McCaffery et al., 2014; Rawlings and Driver, 2010).

**Table 1**  
Modern turkey samples analyzed in this study. “MSB” indicates specimens from the Museum of Southwest Biology; “Private” specimens were donated by Gwyneth Duncan. C:N ratios are weight percent.

Sample ID	Species	Element	Side	Sex	Provenience	$\delta^{13}\text{C}_{\text{collagen}}$	Seuss corr.	$\delta^{15}\text{N}$	C:N	$\delta^{13}\text{C}_{\text{apatite}}$
MSB:Bird:11007	<i>Meleagris gallopavo merriami</i>	Femur	R	unk.	Unknown	−20.4	−20.4	6.1	2.8	−13.4
MSB:Bird:11006	<i>Meleagris gallopavo merriami</i>	Femur	R	F	Colorado	−19.9	−19.9	5.6	2.8	−13.9
MSB:Bird:9002	<i>Meleagris gallopavo intermedia</i>	Femur	R	F	Ft. Stockton, TX	−20.5	−20.5	7.1	2.9	−14.5
MSB:Bird:9001	<i>Meleagris gallopavo intermedia</i>	Femur	R	F	Ft. Stockton, TX	−16.7	−16.7	8.3	2.8	−12.0
MSB:Bird:6682	<i>Meleagris gallopavo</i>	Femur	R	F	Pleasanton, NM	−16.6	−16.6	5.6	2.8	−11.1
MSB:Bird:560	<i>Meleagris gallopavo</i>	Femur	R	M	Mt. Taylor, NM	−16.8	−16.8	6.7	2.8	−11.6
Private:1	<i>Meleagris gallopavo</i>	Tibiotarsus	R	M	Vermejo Park, NM	−19.8	−19.8	6.4	2.8	−12.9
Private:2	<i>Meleagris gallopavo</i>	Tibiotarsus	R	F	Vermejo Park, NM	−20.8	−20.9	3.9	2.8	−14.4

bone collagen samples; while lipid extraction is typically not needed for ancient samples, we chose to treat modern and ancient samples in a similar fashion prior to isotope analysis. Lipids were extracted via three sequential 24 h soaks in a 2:1 chloroform:methanol solvent solution; samples were then rinsed to neutrality in deionized water before being lyophilized. Approximately 0.5–0.6 mg of dried sample was weighed into tin capsules.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values were measured on a Costech 4010 elemental analyzer (Valencia, CA) coupled to a Thermo Scientific Delta V isotope ratio mass spectrometer (Bremen, Germany) at the University of New Mexico Center for Stable Isotopes (UNM–CSI; Albuquerque, NM). Isotope values are reported in delta ( $\delta$ ) notation:  $[(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$ , where  $R_{\text{sample}}$  and  $R_{\text{standard}}$  are the  $^{13}\text{C}/^{12}\text{C}$  or  $^{15}\text{N}/^{14}\text{N}$  ratios of the unknown samples and standard, respectively. The internationally accepted standards for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  are Vienna Pee Dee Belemnite (V-PDB) and atmospheric  $\text{N}_2$ , respectively. The units for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values are parts per thousand (‰) or per mil. We also measured the weight percent carbon and nitrogen concentrations of all turkey bone collagen samples, which ranged between 2.7 and 2.9 indicative of intact collagen containing minimal amounts of contaminants (Ambrose, 1990; see supplemental data). Within-run analytical precision (SD) was  $\leq 0.2\%$  for both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values.

To directly compare modern and ancient turkey isotope data, we accounted for the historic decrease in the  $\delta^{13}\text{C}$  value of atmospheric  $\text{CO}_2$  (i.e., Suess effect) by applying a correction value of  $-0.005\%$ /year for turkeys collected between 1930 and 1960 and  $-0.022\%$ /year for turkeys collected since 1960 (Francey et al., 1999; Indermuhle et al., 1999; Leuenberger et al., 1992).

### 3.2. Apatite preparation

To prepare bone apatite, ~50–100 mg of bone was drilled from each bone element to produce a homogenized powder. Each sample was placed into a bath of 3% hydrogen peroxide for 24 h to remove all organics and then rinsed and centrifuged 5 times to remove all hydrogen peroxide. The prepared samples were placed in a bath of 0.1 M buffered acetic acid for 30 min to remove labile diagenetic carbonate (Coltrain and Janetski, 2013). After 15 min, the samples were vortexed to ensure that all powdered bone reacted with the acetic acid. The samples were rinsed three times to neutrality and air-dried under a fume hood for 24 h. Approximately 0.5–0.6 mg of apatite was weighed into glass Exetainer vials and reacted with phosphoric acid at 50 °C for 6 h. The  $\text{CO}_2$  produced from this reaction was measured on a Thermo Scientific GasBench (Bremen, Germany) coupled to a Delta V isotope ratio mass spectrometer at UNM–CSI. Delta values and units are reported as described above for  $\delta^{13}\text{C}$  measurement of bone collagen samples (Section 3.1). Within-run analytical precision was 0.1‰ for apatite  $\delta^{13}\text{C}$ .

McCaffery et al. (2014) predict that apatite  $\delta^{13}\text{C}$  values for 100 percent maize-fed turkeys will fall between  $-2.7\%$  and  $+4.0\%$ , while values for turkeys with a wholly  $\text{C}_3$  diet should be between  $-21.0\%$  and  $-7.9\%$  and those for turkeys with a mixed diet will range between

$-7.8\%$  and  $-2.8\%$ . We use these values to guide our interpretations of apatite  $\delta^{13}\text{C}$ .

### 3.3. Apatite-collagen $\delta^{13}\text{C}$ spacing

Bone apatite  $\delta^{13}\text{C}$  values represent bulk diet, which for largely herbivorous species such as turkeys is dominated by carbohydrates, while bone collagen  $\delta^{13}\text{C}$  values largely represent dietary protein (Ambrose and Norr, 1992; Kellner and Schoeninger, 2007). The spacing in  $\delta^{13}\text{C}$  values between bone apatite and collagen ( $\Delta^{13}\text{C}_{\text{apatite-collagen}}$ ) can be used to assess trophic level (e.g., herbivore, omnivore, or carnivore) and differentiate between dietary sources of carbohydrates and protein for both modern and ancient animals (Lee-Thorp et al., 1989). Kellner and Schoeninger (2007; also see McCaffery et al., 2014) used  $\Delta^{13}\text{C}_{\text{apatite-collagen}}$  to model diets, finding that animals that ate  $\text{C}_3$ -based protein fit the line  $y = 1.74x + 21.4$  ( $r^2 = 0.95$ ), while those eating  $\text{C}_4$ -based protein best fit the line  $y = 1.71x + 10.6$  ( $r^2 = 0.80$ ). We use these protein regression lines to identify the  $\delta^{13}\text{C}$  of dietary protein consumed by archaeological and modern turkeys (Fig. 4) and to interpret whether the turkeys in our sample had predominately  $\text{C}_4$ , predominately  $\text{C}_3$ , or mixed diets.

### 3.4. Ancient DNA

Thirteen turkey specimens from Tijeras Pueblo were sent to the Laboratory of Molecular Anthropology and Ancient DNA at Washington State University (WSU) for genetic analysis. Approximately 38–55 mg of bone (Table 2) was sub-sampled from the whole specimens and submerged in 6% sodium hypochlorite for 4 min to remove possible surface contamination (Barta et al., 2013). The bleach was poured off and the samples were rinsed twice by submersion in DNA-free water. DNA was extracted following the WSU method described by Cui et al. (2013) (this method is referred to as extraction method 1 in Table 2). The DNA extracts were first tested for the presence of PCR inhibitors and treated accordingly with repeat silica extractions, following Kemp et al. (2014). Attempts were made to sequence nucleotide positions (nps) 15554–16013 of the mitochondrial genome (relative to GenBank accession number EF153719) in 3 or 4 amplicons following the WSU methods described by Speller et al. (2010). Note that in Table S5 of Speller et al. (2010) there is a mistake in the description of their forward primer for the D-Loop 1 and 1A (primer T15533F), which actually spans nps 15533–15553. Larger portions of the two samples (sample 14: 112 mg, sample 21: 166 mg) that failed to yield analyzable DNA using these methods were decontaminated as described above and extracted according to the modified Kemp et al. (2007) method described by Moss et al. (2014) (this method is referred to as extraction method 2 in Table 2). Portions of the mitochondrial genome were sequenced as just described. Sequences were aligned to a turkey mtDNA reference (GenBank accession number EF153719) in Sequencher (version 4.8). Any novel mutations observed over those previously recorded by Speller et al. (2010) were confirmed by sequencing multiple independent amplicons

**Table 2**

Methods employed for DNA extraction, mtDNA sequences, and haplotypes for the Tijeras Pueblo turkeys sent for aDNA analysis.

Sample ID	mg.	Extraction method	No. repeat silica extractions	Sequence read*	Mutations*	Haplotype
11	45	1	0	15554–16013	15735C, 15808C, 15953C	aHap1
12	55	1	0	15554–16013	15735C, 15808C, 15953C	aHap1
13	44	1	0	15634–16013	15677C, 15679T, 15782T, 15791G, 15793T, 15808C, 15845T, 15953C	aHap2? <sup>§</sup>
14	54	1	0	No DNA	N/A	N/A
	112	2	1	No DNA	N/A	N/A
15	46	1	0	15634–16013	15735C, 15808C, 15953C	aHap1? <sup>†</sup>
16	49	1	0	15554–16013	15735C, 15808C, 15953C	aHap1
17	54	1	1	15730–16013	15735C, 15808C, 15953C	aHap1? <sup>†</sup>
18	39	1	0	15554–16013	15735C, 15808C, 15953C	aHap1
19	38	1	1	15634–16013	15735C, 15808C, 15953C	aHap1? <sup>†</sup>
20	51	1	0	15554–16013	15735C, 15808C, 15953C	aHap1
21	48	1	0	No DNA	N/A	N/A
	166	2	0	15554–16013	15735C, 15808C, 15953C	aHap1
22	46	1	1	15554–16013	15735C, 15808C, 15953C	aHap1
23	52	1	1	15554–16013	15735C, 15808C, 15953C	aHap1

\* Relative to GenBank accession number EF153719.

† While the “incomplete” mtDNA of these individuals exhibit the core mutations of the aHap1 haplotype (i.e., 15735C, 15808C, and 15953C), the eventual resolution of the missing sequence data may reveal them to belong to one or more lineages derived from the aHap1 haplotype, thus leaving them defined as aHap1.

§ While the “incomplete” mtDNA of this individual exhibits the core mutations of the aHap2 haplotype, it is derived at np 15791 by an A&gt;G transition, and eventual resolution of the missing sequence data may reveal additional derived mutations placing it one or more mutational steps away from aHap2, thus leaving this lineage defined as aHap2.

in order to guard against recording “mutations” that, in fact, represent nucleotides that have been damaged post-mortem (Winters et al., 2011).

## 4. Results

### 4.1. Bone collagen

Tijeras turkey bone collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values produced a pattern (Fig. 3a) distinct from that seen elsewhere in the Southwest (Fig. 2). While approximately half ( $n = 17$ ) of the Tijeras sample showed  $\delta^{13}\text{C}$  values consistent with a  $\text{C}_4$ -rich diet, the other half ( $n = 14$ ) suggest a diet dominated by  $\text{C}_3$  resources (Tables 3 and 4). The difference between these groups is statistically significant (Welch's  $t$ -test:  $t_{\text{welch}} = -26.14$ ,  $p < 0.01$ ). The  $\delta^{15}\text{N}$  values also show a less-marked but still clear trend: turkeys with  $\delta^{13}\text{C}$  values indicative of  $\text{C}_3$ -based diets have lower  $\delta^{15}\text{N}$  than do those with  $\delta^{13}\text{C}$  values indicative of  $\text{C}_4$ -based ones ( $t_{\text{welch}} = -5.85$ ,  $p < 0.01$ ).

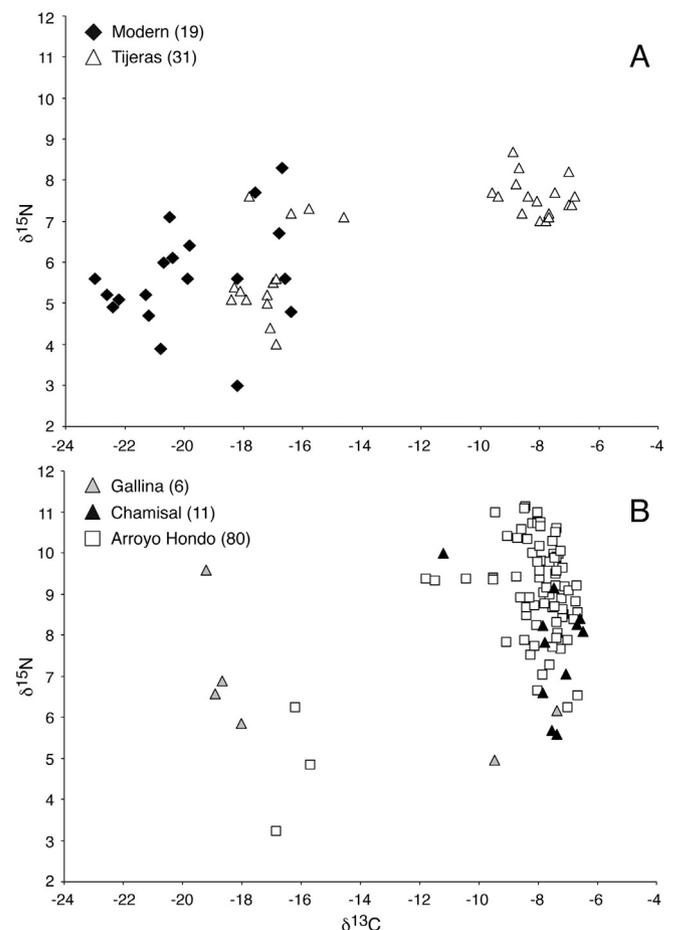
The Tijeras turkeys with a  $\text{C}_3$ -based diet also differ significantly in  $\delta^{13}\text{C}$  values from modern wild specimens. Bone collagen from the modern wild turkeys sampled as part of this study (Tables 1 and 4; also see supplemental data) and from those sampled by Lipe et al. (2016) have lower  $\delta^{13}\text{C}$  values than do the Tijeras turkeys with a  $\text{C}_3$ -based diet ( $t_{\text{welch}} = -4.58$ ,  $p < 0.01$ ), although  $\delta^{15}\text{N}$  values are similar between these two groups ( $t_{\text{welch}} = -0.10$ ,  $p = 0.92$ ). In addition, modern turkey  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values differ significantly from those of the Tijeras birds with  $\text{C}_4$ -based diets ( $\delta^{13}\text{C}$ :  $t_{\text{welch}} = -21.32$ ,  $p = 0.00$ ;  $\delta^{15}\text{N}$ :  $t_{\text{welch}} = -6.26$ ,  $p = 0.00$ ).

The Albuquerque Basin and Gallina samples produced divergent results (Table 4). The 11 Chamisal turkeys all suggest a  $\text{C}_4$  diet (Fig. 3b) and are statistically indistinguishable from the Tijeras turkeys with a  $\text{C}_4$ -based diet ( $t_{\text{welch}} = -0.99$ ,  $p = 0.33$ ); the Chamisal turkeys also have  $\delta^{13}\text{C}$  values similar to those analyzed in previous studies (Fig. 2). Chamisal turkey  $\delta^{15}\text{N}$  values are similar to those with  $\text{C}_4$ -based diets in the Tijeras sample ( $t_{\text{welch}} = -0.37$ ,  $p = 0.71$ ; Table 4).

By contrast, the majority of Gallina samples ( $n = 5$ ) suggest a  $\text{C}_3$ -based diet (Fig. 3b). While two of these specimens did have a  $\delta^{13}\text{C}$  values indicative of  $\text{C}_4$ -based diets, these two specimens may represent a single individual (see supplemental data). In addition,  $\delta^{15}\text{N}$  values from these turkeys are similar to modern wild turkeys ( $t_{\text{welch}} = -0.46$ ,  $p = 0.66$ ) and to the Tijeras turkeys with  $\text{C}_3$ -based diets ( $t_{\text{welch}} = -1.38$ ,  $p = 0.21$ ; Table 4).

### 4.2. Bone apatite

Bone apatite  $\delta^{13}\text{C}$  results from the Tijeras turkeys concur with the collagen results (Tables 3 and 4), with apatite  $\delta^{13}\text{C}$  values again



**Fig. 3.** Collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from (A) the Tijeras Pueblo (this study) and modern wild turkeys (this study and Lipe et al., 2016) and (B) the Arroyo Hondo (Conrad et al., this volume), Chamisal Pueblo, and Gallina region turkeys.

**Table 3**  
Tijeras Pueblo turkey isotope and aDNA results; n.d. indicates context is undated. C:N ratios are weight percent.

Sample ID	Context	Occupation	$\delta^{13}\text{C}_{\text{collagen}}$	$\delta^{15}\text{N}$	C:N ratio	$\delta^{13}\text{C}_{\text{apatite}}$	Haplotype
11	Room 139	n.d.	-8.1	7.5	2.7	-0.8	aHap1
12	Room 139	n.d.	-7.7	7.2	2.7	-0.5	aHap1
13	Room 40	Late	-16.9	4.0	2.7	-6.6	aHap2?
14	Midden 1	n.d.	-15.8	7.3	2.8	-5.5	N/A
15	Midden 2	n.d.	-18.1	5.3	2.8	-7.0	aHap1
16	Midden 2	n.d.	-18.3	5.4	2.8	-5.3	aHap1?
17	Room 116	Early	-7.5	7.7	2.7	0.0	aHap1
18	Room 116	Early	-18.4	5.1	2.8	-8.5	aHap1?
19	Room 116	Early	-8.7	8.3	2.7	-0.5	aHap1?
20	Room 116	Early	-6.9	7.4	2.7	-0.6	aHap1
21	Room 116	Early	-8.9	8.7	2.8	-1.4	aHap1
22	Room 85	n.d.	-6.8	7.6	2.7	0.3	aHap1
23	Plaza 1	n.d.	-17.2	5.2	2.8	-9.8	aHap1
24	Midden 2	n.d.	-14.6	7.1	2.8	-9.1	-
25	Room 33	n.d.	-16.4	7.2	2.8	-10.2	-
26	Midden 2	n.d.	-17.0	5.5	2.8	-9.5	-
27	Plaza 1	n.d.	-17.8	7.6	2.8	-8.0	-
28	Room 30	n.d.	-17.9	5.1	2.8	-9.9	-
29	Room 81	n.d.	-17.1	4.4	2.8	-10.7	-
30	Room 132	n.d.	-7.0	7.4	2.8	-0.3	-
31	Room 5	Late	-16.9	5.6	2.8	-6.6	-
32	Room 106	n.d.	-7.7	7.1	2.8	-1.0	-
33	Midden 1	n.d.	-8.0	7.0	2.8	-1.3	-
34	Room 111	Late	-7.0	8.2	2.9	-0.3	-
35	Room 126	n.d.	-9.6	7.7	2.8	-1.0	-
36	Plaza 1	n.d.	-8.6	7.2	2.8	-4.8	-
37	Midden 3	n.d.	-7.8	7.0	2.8	-0.6	-
38	Room 115	Late	-8.4	7.6	2.8	-1.5	-
39	Room 115	Late	-8.8	7.9	2.8	-2.3	-
40	Room 81	n.d.	-9.4	7.6	2.8	-0.9	-
41	Room 141	n.d.	-17.2	5.0	2.8	-6.6	-

separating into two clear groups ( $t_{\text{welch}} = 12.61, p = 0.00$ ). The specimens identified as having  $\text{C}_3$ -based diets from bone collagen had lower apatite  $\delta^{13}\text{C}$  values than the others; the majority ( $n = 9$ ) fell between  $-21.0\%$  and  $-7.9\%$ , that is, within the range predicted by McCaffery et al. for turkeys with a  $\text{C}_3$ -based diet (2014). The remaining five specimens identified as having  $\text{C}_3$ -based diets from bone collagen had apatite  $\delta^{13}\text{C}$  values between  $-7.0\%$  and  $-5.3\%$ , placing them in McCaffery et al.'s "mixed" diet group. Apatite  $\delta^{13}\text{C}$  values of the modern wild turkeys ranged between  $-12.9\%$  and  $-11.1\%$ , suggesting a  $\text{C}_3$ -based diet for all specimens (Tables 1 and 4). Although the modern and Tijeras  $\text{C}_3$  turkeys with a  $\text{C}_3$ -based diet clearly are closer to each other than either is to the Tijeras turkeys with a  $\text{C}_4$ -based diet, these two groups also differ from each other (Fig. 4): apatite  $\delta^{13}\text{C}$  values are lower for the modern wild turkeys than the Tijeras  $\text{C}_3$  group ( $t_{\text{welch}} = -7.31, p = 0.00$ ).

#### 4.3. Apatite-collagen spacing

$\Delta^{13}\text{C}_{\text{apatite-collagen}}$  values support the hypothesis that at least some of the Tijeras turkeys with  $\delta^{13}\text{C}$  values indicating a  $\text{C}_3$ -based diet had a

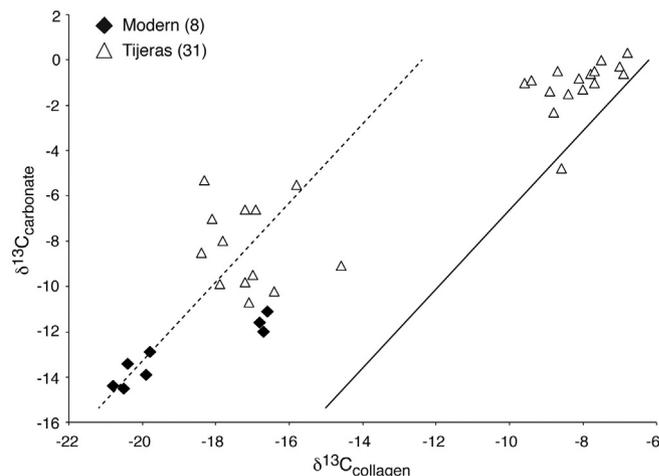
**Table 4**  
Means and standard deviations (SD) of bone collagen and apatite stable isotope values for the turkeys discussed in this study.

		Gallina Sites	Chamisal Pueblo	Arroyo Hondo Pueblo	Tijeras Pueblo		Modern
					$\text{C}_3$ diet	$\text{C}_4$ diet	
$\delta^{15}\text{N}$	Mean	6.8	7.7	9.0	5.7	7.6	6.2
	SD	1.5	1.4	1.4	1.1	0.5	1.3
$\delta^{13}\text{C}_{\text{collagen}}$	Mean	-15.7	-7.6	-8.2	-17.1	-8.1	-18.9
	SD	5.1	1.3	1.8	1.0	0.9	1.9
$\delta^{13}\text{C}_{\text{apatite}}$	Mean	-	-	-1.8	-8.1	-1.0	-13.0
	SD	-	-	1.7	1.8	1.1	1.3
$\Delta^{13}\text{C}_{\text{apatite-collagen}}$	Mean	-	-	6.4	9.0	7.0	6.0
	SD	-	-	0.7	2.2	1.1	0.8

mixed diet with inputs from both wild resources and from maize (Fig. 4). Not only do the Tijeras turkeys with collagen  $\delta^{13}\text{C}$  values indicative of a  $\text{C}_3$ -based diet have higher mean  $\Delta^{13}\text{C}_{\text{apatite-collagen}}$  than either the  $\text{C}_4$  group or the modern wild specimens (Welch's  $F$ -test:  $F = 11.55, p = 0.004$ ), there is also significantly more variation in  $\Delta^{13}\text{C}_{\text{apatite-collagen}}$  values in this group (Table 4).

#### 4.4. Ancient DNA

Of the 15 extractions performed on the 13 samples, five required a repeat silica extraction to sufficiently remove inhibitors (Kemp et al., 2014; Table 2). Eight of the 13 samples (specimen numbers 11, 12, 16, 18, 20, 21, 22, and 23) yielded "complete" mtDNA sequences spanning



**Fig. 4.** Collagen and apatite  $\delta^{13}\text{C}$  of the Tijeras Pueblo and modern wild turkeys (this study), with  $\text{C}_3$  and  $\text{C}_4$  protein lines following Kellner and Schoeninger (2007) and McCaffery et al. (2014).  $\text{C}_3$  protein:  $y = 1.74x + 21.4$  (dotted line);  $\text{C}_4$  protein:  $y = 1.71x + 10.6$  (solid line).

nps 15554–16013, all exhibiting the aHap1 haplotype (Speller et al., 2010). “Incomplete” sequences spanning nps 15634–16013 or 15730–16013 were obtained from four samples. Specimen numbers 15, 17, and 19 exhibit the core mutations of the aHap1 haplotype (i.e., 15735C, 15808C, and 15953C); however, the eventual resolution of the missing sequence data may reveal them to belong to one or more lineages derived from the aHap1 haplotype. The incomplete sequence of specimen number 13 reveals a unique form of turkey mitochondrial DNA, one that is derived by an A>G transition at nucleotide position (np) 15791 from the aHap2 haplotype (Speller et al., 2010). A BLAST search of GenBank (conducted on August 25, 2015) revealed no complete matches to this haplotype, confirming its uniqueness—it has yet to be observed in any other modern or ancient turkey. The mutation (15791G) that makes this lineage unique was confirmed by sequencing from two independent amplifications. Repeated observations of an identical sequence effectively rules out these results as having been influenced by post-mortem nucleotide damage (Winters et al., 2011). Specimen number 14 yielded no analyzable DNA using the methods employed in this study.

## 5. Discussion

The results presented here clearly support the hypothesis that there was variability in turkey husbandry in the prehistoric American Southwest. At Tijeras Pueblo, approximately half ( $n = 14$ ) of the turkeys sampled had collagen  $\delta^{13}\text{C}$  values suggesting a diet intermediate between wild turkeys and domestic ones. The remaining Tijeras Pueblo turkeys ( $n = 17$ ) produced collagen  $\delta^{13}\text{C}$  values suggesting a diet dominated by  $\text{C}_4$  resources—in this case, likely maize (Rawlings and Driver, 2010). The apatite  $\delta^{13}\text{C}$  data further support this finding.  $\delta^{15}\text{N}$  data suggest Tijeras turkeys with a  $\text{C}_3$ -based diet and modern turkeys occupied a similar trophic level—one different from the turkeys with a  $\text{C}_4$ -based diet. As discussed earlier, ethnographic data suggest that among Eastern Puebloan groups, domestic turkeys were sometimes “free-ranged” and/or brought to cornfields to assist in insect control (Lang and Harris, 1984). The Tijeras turkeys with a  $\text{C}_3$ -based diet may represent turkeys husbanded in this way.

$\Delta^{13}\text{C}_{\text{apatite-collagen}}$  patterns provide further support for a group of free-ranging turkeys at Tijeras. Mean  $\Delta^{13}\text{C}_{\text{apatite-collagen}}$  for the Tijeras turkeys with a predominantly  $\text{C}_4$  diet ( $+7.0 \pm 1.1\%$ ) is similar to that previously reported for turkeys from the Four Corners region that had  $\text{C}_4$ -based diets ( $+6.8 \pm 2.3\%$ ; McCaffery et al., 2014) and to our sample of modern turkeys ( $+6.0 \pm 0.8\%$ ) with a  $\text{C}_3$ -based diet. Smaller  $\Delta^{13}\text{C}_{\text{apatite-collagen}}$  spacing suggests that both the carbohydrate and protein components of diet are derived from either  $\text{C}_4$  or  $\text{C}_3$  resources, but not a combination of the two. This appears to have been the case for both the modern wild turkeys and the Tijeras turkeys with a  $\text{C}_4$ -based diet.

In contrast, Tijeras turkeys with apatite and collagen  $\delta^{13}\text{C}$  values indicative of a diet rich in  $\text{C}_3$  resources have significantly larger  $\Delta^{13}\text{C}_{\text{apatite-collagen}}$  spacing ( $+9.0 \pm 2.8\%$ ), suggesting that the ultimate source of protein and carbohydrates for these birds included a combination of  $\text{C}_3$  and  $\text{C}_4$  resources. Such a pattern could arise if turkeys were used for insect control in agricultural fields where they had access to protein sources that were largely  $\text{C}_3$ -based while also being fed  $\text{C}_4$  carbohydrates (i.e., maize). Comparison of our data with the protein regression lines developed by Kellner and Schoeninger (2007) supports this hypothesis. The  $\text{C}_3$  Tijeras turkeys plot separately from the modern ones but largely cluster along the  $\text{C}_3$  protein regression line (Fig. 4). Our data therefore suggest the Tijeras turkeys with a  $\text{C}_3$ -based diet may have been free-ranged—the first documentation of this ethnographically reported pattern in the archaeological record.

These data thus indicate two distinct turkey husbandry regimes at Tijeras Pueblo: one in which turkeys were likely fed maize and another in which turkeys were free-ranged. While fine-grained chronological data are not available for these samples, the relatively short occupation range of Tijeras (~125 years) suggests that temporal shifts in husbandry

practice are not responsible for the variation in  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  patterns among these turkeys. What chronological data are available show no discernable temporal trend (Table 3).

The Tijeras turkeys therefore represent a departure from previously identified husbandry practice in the prehistoric Southwest in two ways: the practice of maintaining free-ranging birds, and the presence of two distinct husbandry patterns (Kellner et al., 2010; McCaffery et al., 2014; Rawlings and Driver, 2010). But why is Tijeras different? While we do not have sufficient evidence at this point to definitively answer this question, our comparative data (Fig. 3b) in combination with data from previous studies (Fig. 2) are suggestive.

Earlier, we suggested that turkeys from marginal locations – whether the marginality was due to environmentally posed challenges involved with maize production and/or to cultural differences – would be more likely to have been husbanded in variable ways. While our study did identify variability, we did not find evidence clearly supporting the marginality hypothesis. All of the Chamisal Pueblo turkeys ( $n = 11$ ) indicated a  $\text{C}_4$ -dominated diet, while most ( $n = 5$ ) of the Gallina samples produced values consistent with a  $\text{C}_3$ -based wild diet. While at first glance this might seem to support the environmental marginality hypothesis, as both the Gallina region and Tijeras are high-elevation while Chamisal is located along the Rio Grande,  $\delta^{13}\text{C}$  data from turkeys of Arroyo Hondo Pueblo (Fig. 3b; Conrad et al., this volume) suggest otherwise. Arroyo Hondo Pueblo is also located at a high elevation (2,161 m) and like Tijeras Pueblo and the Gallina sites would have been subject to variability in the length of the growing season (Lang and Harris, 1984; Wetterstrom et al., 1986). Despite this,  $\delta^{13}\text{C}$  values of Arroyo Hondo turkeys are consistent with a  $\text{C}_4$ -based diet. Environmental marginality may have played a role in why some of the Tijeras turkeys consumed a  $\text{C}_3$ -based diet, but it does not seem to be the only driver of this pattern.

However, the location of Tijeras Pueblo may still be important in understanding the turkey isotope data. Tijeras lies along a pass through a mountain range that divides the Eastern Pueblo cultural region from that of the Plains (Fig. 1), and thus along a travel route that may have been an important conduit of Plains–Pueblo exchange (e.g., Speth, 1991; Spielmann, 1991; Wilcox, 1991). Indeed, other aspects of the Tijeras assemblage, such as the presence of buffalo (*Bison bison*) and pronghorn (*Antilocapra americana*), provide evidence of such contact (Cordell, 1980b; Jones and Gabe, 2015). Perhaps the variability in turkey husbandry observed at Tijeras relates to its location on a cultural boundary—whether through the import of turkeys from other regions and/or different clan or family groups with distinct traditions of turkey husbandry. That we also identified turkeys with a  $\text{C}_3$ -based diet in the Gallina region provides some support for the cultural boundary interpretation, as Gallina peoples also inhabited a cultural boundary, albeit a very different one (e.g., Constan, 2011).

A final point of discussion concerns the combined isotope and aDNA results. Our  $\delta^{13}\text{C}$  data show two distinct groups with no overlap. Initially, we assumed that in such a situation, a turkey with a  $\delta^{13}\text{C}$  value indicative of a  $\text{C}_4$ -based diet would reliably identify a member of the southwest domestic lineage, and conversely, turkeys with  $\delta^{13}\text{C}$  values suggesting a  $\text{C}_3$ -based diet would signify wild Merriam's turkeys. The aDNA data presented here falsify this hypothesis. The majority of turkeys with a  $\text{C}_3$ -based diet sampled for aDNA ( $n = 4$ ) were members of the most common southwest domestic lineage (aHap1). While one sample had an aHap2 lineage, and thus is a member of the less frequently observed mitochondrial haplogroup H2, there is little reason to believe that these turkeys were wild based on DNA alone (Lipe et al., 2016). This specimen had  $\delta^{13}\text{C}$  values similar to the other Tijeras turkeys with a  $\text{C}_3$ -based diet.

The aDNA findings are significant in part because they suggest  $\delta^{13}\text{C}$  data cannot be used as a proxy for a turkey's mitochondrial DNA lineage, at least not among Southwestern turkeys, without significant additional data. However, these data also open up larger questions: if the Tijeras turkeys that consumed a  $\text{C}_3$ -based diet but were genetically domestic

were “free-range,” why were only some turkeys raised in this way? Why has this practice only been recorded at Tijeras Pueblo? Does the variability in apatite  $\delta^{13}\text{C}$  and  $\Delta^{13}\text{C}_{\text{apatite-collagen}}$  in this sample indicate that some turkeys were free-ranged and others more feral? More research is required to understand variability in turkey husbandry practices in the prehistoric Southwest.

## 6. Conclusions

The data presented here demonstrate that there was heterogeneity in turkey husbandry practices in the prehistoric American Southwest. Our sample from Tijeras Pueblo produced two groups with distinct  $\delta^{13}\text{C}$  values, and this pattern cannot be adequately explained by time. Neither is the pattern explained by membership in one or another mitochondrial DNA lineage: all but one of the specimens sampled for aDNA were identified as members of the most common southwestern domestic turkey lineage (aHap1, Speller et al., 2010). Our comparative samples from other potentially marginal locations add to this heterogeneity: turkeys from Chamisal Pueblo adhered to the previously established turkey husbandry pattern (i.e., Fig. 2) with all samples indicating a C<sub>4</sub>-based diet, while the turkeys from the Gallina region had a C<sub>3</sub>-based diet.

Although our study does indicate heterogeneity in turkey husbandry, the factors driving this variability remain uncertain. Marginality may play some role, but this hypothesis is not well-supported by the data presented here and in Conrad et al. (this volume). Site location along cultural boundaries seems a more likely driver, but why this should be important remains unresolved. In short, more data are needed to fully answer the questions we have raised here. We can conclude with certainty, however, that turkey husbandry practices *did* vary in the prehistoric American Southwest.

## Acknowledgments

We thank Andrew Johnson and Christopher Witt of the Museum of Southwest Biology and Gwyneth Duncan for access to modern turkey samples; Robin Cordero, Alex Kurota, Dave Phillips and the Maxwell Museum, Jeremy Kulishek and the Cibola National Forest, and the Pueblo of Isleta for access to archaeological samples; Viorel Atudorei and Laura Burkemper of UNM–CSI for analytical assistance; and Allyson Richins, Mauriel Rodriguez-Curras, and Taylor Readyhough at UNM and Cara Monroe at WSU for lab assistance. Thanks also to R. Kyle Bocinsky, Joan Coltrain, Robin Cordero, David Hurley, Bill Lipe, Sherry Nelson, Madeline Scheintaub, Judy Vredenburg, and the Friends of Tijeras Pueblo for help along the way. The research presented here was supported in part by a UNM Research Allocations Committee Grant and by a School for Advanced Research Arroyo Hondo Grant. Finally, this project would never have begun without the encouragement of the late Linda Cordell—thank you, Linda.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.jasrep.2016.05.051>.

## References

- Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *J. Archaeol. Sci.* 17, 431–451.
- Ambrose, S.H., Norr, L., 1992. On stable isotopic data and prehistoric subsistence in the Soconusco Region. *Curr. Anthropol.* 33, 401–404.
- Anderson, D., Oakes, Y., 1980. A world view of agriculture. In: Cordell, L.S. (Ed.), *Tijeras Canyon: Analyses of the Past*. University of New Mexico Press, Albuquerque, NM, pp. 12–40.
- Badenhorst, S., Driver, J.C., 2009. Faunal changes in farming communities from Basketmaker II to Pueblo III (AD 1–1300) in the San Juan Basin of the American Southwest. *J. Archaeol. Sci.* 36, 1832–1841.
- Barta, J.L., Monroe, C., Kemp, B.M., 2013. Further evaluation of the efficacy of contamination removal from bone surfaces. *Forensic Sci. Int.* 231.
- Beacham, E.B., Durand, S.R., 2007. Eggshell and the archaeological record: new insights into turkey husbandry in the American Southwest. *J. Archaeol. Sci.* 34, 1610–1621.
- Coltrain, J.B., Janetski, J.C., 2013. The stable and radio-isotope chemistry of southeastern Utah Basketmaker II burials: dietary analysis using the linear mixing model SISUS, age and sex patterning, geolocation and temporal patterning. *J. Archaeol. Sci.* 40, 4711–4730.
- Coltrain, J.B., Janetski, J.C., Carlyle, S.W., 2007. The stable- and radio-isotope chemistry of Western Basketmaker Burials: implications for early Puebloan diets and origins. *Am. Antiq.* 72, 301–321.
- Conrad, C., Jones, E.L., Newsome, S.D., Schwartz, D.W., 2016. Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo. *J. Archaeol. Sci. Rep.* (this volume).
- Constan, C., 2011. Ceramic Resource Selection and Social Violence in the Gallina Area of the American Southwest. University of New Mexico, Albuquerque, NM.
- Cordell, L.S., 1980a. Prehistoric climate and agriculture. In: Cordell, L.S. (Ed.), *Tijeras Canyon: Analyses of the Past*. University of New Mexico Press, Albuquerque, NM, pp. 60–70.
- Cordell, L.S., 1980b. *Tijeras Canyon: analyses of the past*. University of New Mexico Press, Albuquerque, NM.
- Cordell, L.S., McBrinn, M.E., 2012. *Archaeology of the Southwest*, 3rd edition ed. Left Coast Press, Walnut Creek, CA.
- Cordell, L.S., Earls, A., Binford, M., 1984. Subsistence systems in the mountainous regions of the Rio Grande Valley. In: Fish, S., Fish, P. (Eds.), *Prehistoric agricultural strategies in the Southwest*. Arizona State University Research Papers, Tempe, AZ, pp. 233–243.
- Cordero, R.M., Dicks, A.M., 2010. LA 25862 data recovery. In: Gerow, P.A. (Ed.), *The MAPL Western Expansion Project. Volume 3: Data Recovery along Segment 9, Sandoval County, New Mexico*. Office of Contract Archeology, University of New Mexico, Albuquerque, NM.
- Cui, Y., Lindo, J., Hughes, C.E., Johnson, J.W., Hernandez, A.G., Kemp, B.M., Ma, J., Cunningham, R., Petzelt, B., Mitchell, J., Archer, D., Cybulski, J.S., Malhi, R.S., Gilbert, M.T.P., 2013. Ancient DNA analysis of mid-Holocene individuals from the northwest coast of North America reveals different evolutionary paths for mitogenomes. *PLoS One* 8, e66948.
- Eckert, S.L., Cordell, L.S., 2004. Pueblo IV community formation in the Central Rio Grande Valley. In: Adams, E.C., Duff, A.I. (Eds.), *The Protohistoric Pueblo World, A.D. 1275–1400*. University of Arizona Press, Tucson, AZ, pp. 35–42.
- Ellis, F.H., 1988. *From Drought to Drought: An Archaeological Record of Life Patterns as Developed by the Gallina Indians of North Central New Mexico (A.D. 1050 to 1300)*. Florence Hawley Ellis Museum of Anthropology, Santa Fe, NM.
- Francey, R.J., Allison, C.E., Etheridge, D.M., Trudinger, C.M., Enting, I.G., Leuenberger, M., Langenfelds, R.L., Michel, E., Steele, L.P., 1999. A 1000-year high precision record of  $\delta^{13}\text{C}$  in atmospheric  $\text{CO}_2$ . *Tellus B* 51, 170–193.
- Garber, E., 1980. Analysis of plant remains. In: Cordell, L.S. (Ed.), *Tijeras Canyon: Analyses of the Past*. University of New Mexico Press, Albuquerque, NM, pp. 71–87.
- Geib, P.R., 2011. *Foragers and Farmers of the Northern Kayenta Region*. University of Utah Press, Salt Lake City.
- Grimstead, D.N., Reynolds, A.C., Hudson, A.M., Akins, N.J., Betancourt, J.L., 2014. Reduced population variance in strontium isotope ratios informs domesticated turkey use at Chaco Canyon, New Mexico, USA. *J. Archaeol. Method Theory* 1–23.
- Hayes, A.C., Caperton, T.J., 1981. Contributions to Gran Quivira archeology, Gran Quivira National Monument, New Mexico, National Park Service. U.S. Dept. of the Interior, Washington, D.C.
- Indermuhle, A., Stocker, T.F., Joos, F., Fischer, H., Smith, H.J., Wahlen, M., Deck, B., Mastroianni, D., Tschumi, J., Blunier, T., Meyer, R., Stauffer, B., 1999. Holocene carbon-cycle dynamics based on  $\text{CO}_2$  trapped in ice at Taylor Dome, Antarctica. *Nature* 398, 121–126.
- Jones, E.L., Gabe, C., 2015. The promise and peril of older collections: meta-analyses in the American Southwest. *Open Quat.* 1, 1–13.
- Julyan, R., 2006. *The Mountains of New Mexico*. University of New Mexico Press, Albuquerque.
- Julyan, R., Stuever, M., 2005. *Field Guide to the Sandia Mountains*. University of New Mexico Press, Albuquerque.
- Kellner, C.M., Schoeninger, M.J., 2007. A simple carbon isotope model for reconstructing prehistoric human diet. *Am. J. Phys. Anthropol.* 133, 1112–1127.
- Kellner, C.M., Schoeninger, M.J., Spielmann, K.A., Moore, K., 2010. Stable isotope data show temporal stability in diet at Pecos Pueblo and diet variation among southwest pueblos. In: Morgan, M.E. (Ed.), *Pecos Pueblo Revisited: The Biological and Social Context*. Harvard University Press, Cambridge, MA, pp. 79–92.
- Kemp, B.M., Malhi, R.S., McDonough, J., Bolnick, D.A., Eshleman, J.A., Rickards, O., Martinez-Labarga, C., Johnson, J.R., Lorenz, J.G., Dixon, E.J., Fifield, T.E., Heaton, T.H., Worl, R., Smith, D.G., 2007. Genetic analysis of early Holocene skeletal remains from Alaska and its implications for the settlement of the Americas. *Am. J. Phys. Anthropol.* 132, 605–621.
- Kemp, B.M., Monroe, C., Judd, K.G., Reams, E., Grier, C., 2014. Evaluation of methods that subdue the effects of polymerase chain reaction inhibitors in the study of ancient and degraded DNA. *J. Archaeol. Sci.* 42.
- Kohler, T.A., Bocinsky, R.K., Cockburn, D., Crabtree, S.A., Varien, M.D., Kolm, K.E., Smith, S., Ortman, S.G., Kobitz, Z., 2012. Modelling prehispanic Pueblo societies in their ecosystems. *Ecol. Model.* 241, 30–41.
- Lang, R.W., Harris, A.H., 1984. *The Faunal Remains from Arroyo Hondo Pueblo, New Mexico: A Study in Short-Term Subsistence Change*. School of American Research Press, Santa Fe, NM.
- Lee-Thorp, J.A., Sealy, J.C., van der Merwe, N.J., 1989. Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *J. Archaeol. Sci.* 16, 585–599.
- Leuenberger, M., Siegenthaler, U., Langway, C., 1992. Carbon isotope composition of atmospheric  $\text{CO}_2$  during the last ice age from an Antarctic ice core. *Nature* 357, 488–490.

- Lipe, W.D., Bocinsky, R.K., Chisholm, B.S., Matson, R.G., Jarvis, E., Lyle, R., Dove, D.M., Judd, K., Kemp, B.M., 2016. Cultural and genetic contexts for early turkey domestication in the Northern Southwest. *Am. Antiq.* 81, 97–113.
- Mackey, J.C., 1985. A thirteenth century A.D. example of the successful use of archaeological corn collections for paleoenvironmental reconstruction: a reply to Benz. *Plains Anthropol.* 30, 149–159.
- Marshall, M.P., Walt, H.J., 1984. Rio Abajo: Prehistory and History of a Rio Grande Province. New Mexico Historic Preservation Program, Santa Fe, NM.
- Matson, R.G., Chisholm, B., 1991. Basketmaker II subsistence: carbon isotopes and other dietary indicators from Cedar Mesa, Utah. *Am. Antiq.* 56, 444–459.
- McCaffery, H., Tykot, R.H., Gore, K.D., DeBoer, B.R., 2014. Stable isotope analysis of turkey (*Meleagris gallopavo*) diet from Pueblo II and Pueblo III sites, Middle San Juan Region, Northwest New Mexico. *Am. Antiq.* 79, 337–352.
- McKusick, C.R., 1986. Southwest Indian Turkeys: Prehistory and Comparative Osteology. Southwest Bird Laboratory, Globe, Ariz.
- McKusick, C.R., 2001. Southwest Birds of Sacrifice. Arizona Archaeological Society, Tucson, AZ.
- Moss, M.L., Judd, K.G., Kemp, B.M., 2014. Can salmonids (*Oncorhynchus* spp.) be identified to species using vertebral morphometrics? A test using ancient DNA from Coffman Cove, Alaska. *J. Archaeol. Sci.* 41, 879–889.
- Rawlings, T.A., Driver, J.C., 2010. Paleodiet of domestic turkey, Shields Pueblo (5MT3807), Colorado: isotopic analysis and its implications for care of a household domesticate. *J. Archaeol. Sci.* 37, 2433–2441.
- Schaafsma, P., 2007. New Perspectives on Pottery Mound Pueblo. University of New Mexico Press, Albuquerque.
- Speller, C.F., Kemp, B.M., Wyatt, S.D., Monroe, C., Lipe, W.D., Arndt, U.M., Yang, D.Y., 2010. Ancient mitochondrial DNA analysis reveals complexity of indigenous North American turkey domestication. *Proc. Natl. Acad. Sci.* 107, 2807–2812.
- Speth, J.D., 1991. Some unexplored aspects of mutualistic Plains–Pueblo exchange. In: Spielmann, K.A. (Ed.), *Farmers, Hunters, and Colonists: Interaction between the Southwest and the Southern Plains*. University of Arizona Press, Tucson, pp. 18–35.
- Spielmann, K.A., 1991. Coercion or cooperation? Plains–Pueblo interaction in the protohistoric period. In: Spielmann, K.A. (Ed.), *Farmers, Hunters, and Colonists: Interaction between the Southwest and the Southern Plains*. University of Arizona Press, Tucson, pp. 36–50.
- Stearns, B.D., 2010. Diet Reconstruction of Wild Rio-Grande Turkey of Central Utah Using Stable Isotope Analysis. Brigham Young University, Provo, UT.
- Van West, C.R., Cordell, L.S., 2013. Using tree-ring data to explore community formation at Tijeras Pueblo. Hibben Center, University of New Mexico, Albuquerque, Tijeras Pueblo Workshop.
- Wetterstrom, W., Bohrer, V.L., Lang, R.W., 1986. Food, diet, and population at prehistoric Arroyo Hondo Pueblo, New Mexico. School of American Research Press, Santa Fe, NM.
- Wilcox, D.R., 1991. Changing contexts of Pueblo adaptations, 1250–1600. In: Spielmann, K.A. (Ed.), *Farmers, Hunters, and Colonists: Interaction between the Southwest and the Southern Plains*. University of Arizona Press, Tucson, pp. 107–127.
- Winters, M., Barta, J.L., Monroe, C., Kemp, B.M., Gilbert, M.T.P., 2011. To clone or not to clone: method analysis for retrieving consensus sequences in ancient DNA samples. *PLoS One* 6, e21247.
- Young, C., 1980. Analysis of faunal remains. In: Cordell, L.S. (Ed.), *Tijeras Canyon: Analyses of the Past*. University of New Mexico Press, Albuquerque, NM, pp. 88–120.