Journal of Archaeological Science: Reports xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo

Cyler Conrad [a,*], Emily Lena Jones [a], Seth D. Newsome [b], Douglas W. Schwartz [c]

[a] Department of Anthropology, MSC01-1040, Anthropology 1, University of New Mexico, Albuquerque, NM 87131, United States
[b] Department of Biology, MSC03-2020, 167 Castetter Hall, University of New Mexico, Albuquerque, NM 87131, United States
[c] School for Advanced Research, PO Box 2188, Santa Fe, NM 87504, United States

ARTICLE INFO

Article history:
Received 1 September 2015
Received in revised form 24 March 2016
Accepted 9 June 2016
Available online xxxx

Keywords:
Arroyo Hondo Pueblo
LA 12
New Mexico
Turkey
Stable isotopes
Eggshell
Embryogenesis
Scanning electron microscope

ABSTRACT

Studies of archaeofaunal turkey and eggshell remains have identified a clear and consistent pattern of turkey husbandry across the prehistoric Southwest. Domestic turkeys appear to have been penned, fed maize, and kept genetically isolated from wild turkey populations. In this study we use carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope values, scanning electron microscopy of eggshells, and quantitative analysis of turkey remains from Arroyo Hondo Pueblo (LA 12) to explore how turkey husbandry at this Pueblo IV site fits into the overall regional pattern. We find that although turkeys seem to have played a minor role in the overall faunal subsistence at Arroyo Hondo, they were nevertheless carefully husbanded, even during periods of climatic stress and human demographic fluctuation.

1. Introduction

Bone and eggshell from turkey (*Meleagris gallopavo*) are frequently identified in prehistoric archaeological contexts from the American Southwest (e.g., Akins, 1985; Badenhorst and Driver, 2009; Beacham and Durand, 2007). These data, combined with a rich ethnographic and ethnohistoric record, indicate that turkey eggs, feathers and meat held significant economic and ceremonial value to indigenous groups in this region (Beidleman, 1956; Durand, 2003; Lange, 1950; Reed, 1951; Schroeder, 1968). Evidence for the consumption of turkey meat appears in Spanish documents and also in the archaeological record: individual specimens displaying cut marks and burning as well as the presence of turkey remains within refuse middens, rooms and plazas at archaeological sites show that prehistoric Southwesterners ate turkey meat (Akins, 1985; Durand and Durand, 2008; Munro, 1994).

Although likewise recorded in historic documents (Dunn, 1968:108; Fewkes, 1900:691; Hough, 1900:468; cf. Judd, 1954:66; Lange, 1950; White, 1932:130–131), egg use is less well understood archaeologically. One study of archaeological eggshell focuses on Salmon Ruin, New Mexico (Fig. 1). Using scanning electron microscopy (SEM) of the mammillary cone structure, this work found that only between the late Pueblo II and early Pueblo III periods were poults hatched at Salmon Ruin; at this time, there was also evidence for increased use of turkey meat as food (Beacham and Durand, 2007). These findings match a larger regional trend of increasing relative abundance of turkey in archaeofaunas from the Four Corners region around the Pueblo III period (see discussion in Badenhorst and Driver, 2009). The reasons for this change in turkey use are debated, but some have argued that during Basketmaker and Pueblo I the domestic turkey's primary role was a producer of eggs and/or feathers for ritual (Beacham and Durand, 2007; Windes, 1977). In contrast, by the late Pueblo II (1100s C.E.) period, turkeys may have been used primarily as food (Badenhorst and Driver, 2009; Beacham and Durand, 2007; Windes, 1987). In this scenario, as human populations grew and wild meat sources were depleted, Southwestern peoples decreased their use of freshly-laid eggs and instead focused on hatching those eggs to produce turkey flocks. When populations moved from the Mesa Verde region to the Northern Rio Grande at the end of the 13th century, it seems likely they would have brought their methods of turkey management – including reliance on turkeys for food, and investment in the maintenance and growth of turkey flocks to this new region (see discussions in Hegmon et al., 2008 and Ortman, 2014).

In this paper, we test the hypothesis of economic reliance on turkeys in the Pueblo IV Northern Rio Grande (C.E. 1300–1600) with a case study from Arroyo Hondo Pueblo (LA 12) (Fig. 1). We combine carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis of bones with scanning electron microscopy of turkey eggshells and measures of archaeofaunal

* Corresponding author.
E-mail address: cylerc@unm.edu (C. Conrad).

http://dx.doi.org/10.1016/j.jasrep.2016.06.016
2352-409X/

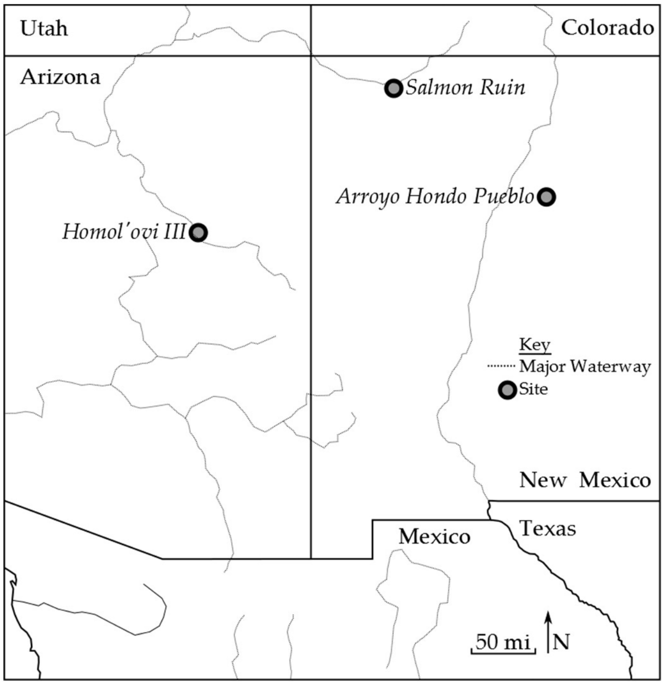

Fig. 1. Map of sites discussed in the text.

relative abundance, taxonomic evenness and the ratio of eggshell fragments/mass to identify how the Arroyo Hondo turkeys were husbanded.

2. Turkeys and eggs at Arroyo Hondo Pueblo

Arroyo Hondo Pueblo was founded in ~1300 C.E. and occupied intermittently until its abandonment around 1425 C.E. (Creamer, 1993). The site was excavated between 1971 and 1974 by the School of American Research (see Shapiro, 2005). Site excavators identified two general periods of occupation (Creamer, 1993), with Component I spanning approximately 1300–1370 C.E. and Component II 1370–1425 C.E. (Fig. 2).

The faunal assemblage recovered at Arroyo Hondo comprised 91 taxa and a NISP (number of identified specimens) of 24,589 including a significant number of turkey specimens (N = 1134 or 4.61% of total NISP; Lang and Harris, 1984). In addition, the excavations recovered eggshell fragments both from bulk samples and from a clutch of ten individual eggs recovered in situ from Plaza K during excavation (Fig. 3; Creamer, 1993). The Plaza K clutch broke during the recovery process and is now fragmented. The combination of abundant turkey and eggshell remains from a well-documented site makes this assemblage an ideal test case with which to explore hypotheses about turkey husbandry in the Pueblo IV Northern Rio Grande.

3. Methods

We examined turkey eggshell and bone from both Component I and II contexts (Fig. 2) at Arroyo Hondo. All scanning electron micrographs and source code for analyses conducted in R (3.1.1) and RStudio (0.98.1028) are available in the University of New Mexico's digital electronic repository (http://repository.unm.edu; Conrad et al., 2015). We used the R package *vegan* for diversity analyses (Oksanen et al., 2015). Measured stable isotope values, provenience, and turkey skeletal information are included with this paper as Supplemental data.

Fig. 2. Map of Arroyo Hondo Pueblo plazas and room blocks during Component I (A) and Component II (B). Drawing by Richard W. Lang and courtesy of the School for Advanced Research.

Fig. 3. Eggs recovered in-situ from Plaza K (LA12-K-2-IV-I). Photograph by Michael P. Marshall (Photo AH4-MPM-8) and courtesy of the School for Advanced Research.

3.1 Turkey bone analyses

We calculated the relative abundance of turkey (NISP turkey specimens/total NISP*100) using the NISP values published by Lang and Harris (1984) to assess the overall role of turkeys in the Arroyo Hondo Pueblo subsistence system. While faunal taxonomic abundance cannot be directly translated into numbers of individual animals consumed at a site (Grayson, 1984; Lyman, 2008), this metric provides a general estimate of a resource's relative economic importance when considered through time. If Arroyo Hondo follows the pattern of turkey exploitation identified throughout the Southwest during the Pueblo IV period, then we would expect relatively high abundance of this species during both Component I (1300–1370 C.E.) and Component II (1370–1425 C.E.) periods.

In addition, we calculated the taxonomic evenness of the Arroyo Hondo faunal assemblage. Evenness is a measure of diversity that focuses on the degree to which specimens are equally distributed across taxa (Magurran, 2004; Jones, 2016; Lyman, 2008). In conjunction with relative abundance, evenness can help to identify periods when a particular taxon may have been more significant in the diet. For example, if the relative abundance of turkeys is high and evenness is low in the Arroyo Hondo fauna, this pattern would suggest a situation where turkeys comprised a large component of the faunal assemblage. To measure evenness, we used the reciprocal of Simpson's index, or 1/D (Magurran, 2004) calculated with the R package *vegan* (Oksanen et al., 2015). 1/D is widely used in zooarchaeological studies because it is less influenced by sample size than some other evenness measures; however, it is not constrained between 0 and 1 like other measures making the assessment of an assemblage's overall evenness challenging. Here, we interpret faunas as being even when 1/D is greater than or equal to 5 (Jones, 2004).

Finally, we used bone collagen carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis to assess the diets of turkeys from Arroyo Hondo. Stable isotope analysis provides insight into diet because the isotopic composition of an animal's tissues mirrors that of their food sources (Ambrose and Norr, 1993; DeNiro, 1987; Schoeninger and DeNiro, 1984; Schoeninger and Moore, 1992). In the American Southwest wild turkey (*Meleagris gallopavo merriami*) diets are dominated by plants that utilize the C_3 photosynthetic pathway and thus have $\delta^{13}C$ values averaging near −25‰ (Jones et al., in this volume; Lipe et al., 2016; Stearns, 2010). Because maize (*Zea mays*) utilizes the C_4 photosynthetic pathway that produces $\delta^{13}C$ values of approximately −10‰ (Coltrain and Leavitt, 2002), turkeys eating a maize-dominated diet should have higher bone collagen and apatite $\delta^{13}C$ values than their wild counterparts (McCaffery et al., 2014; Rawlings and Driver, 2010). Previous stable isotope work on turkeys from archaeological contexts in the Southwest shows that most ancient turkeys have C_4 values consistent with a maize-based diet (Grimstead et al., 2014; Kellner et al., 2010; McCaffery et al., 2014; Lipe et al., 2016; Rawlings and Driver, 2010; but see Jones et al., in this volume). We analyzed bone collagen and apatite from 80 Arroyo Hondo turkey specimens. We selected samples based on provenience and on element completeness, using the latter as a proxy for collagen preservation (as in Rawlings and Driver, 2010). Our sample includes 62 from Component I and 18 from Component II contexts (see Supplemental data).

3.1.2 Bone collagen preparation

From each element we sub-sampled a ~50–100 mg bone fragment, which were demineralized in 0.5 N hydrochloric (HCl) acid for 24 h at ~5 °C. Each sample was rinsed to neutrality three times with deionized water, and then lipid-extracted by soaking them three times in a solvent solution of 2:1 chloroform/methanol for 24 h. Samples were then lyophilized and ~0.5–0.6 mg was weighed into a tin capsule for isotope analysis. $\delta^{13}C$ and $\delta^{15}N$ values were measured on a Costech (4010) elemental analyzer coupled to a Thermo Scientific Delta V isotope ratio mass spectrometer at the University of New Mexico Center for Stable Isotopes (UNM–CSI). Isotope data are expressed in delta (δ) notation which for $\delta^{13}C$ and $\delta^{15}N = [(R_{sample} / R_{standard}) - 1] \times 1000$, where R_{sample} or $R_{standard}$ are the $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios in the sample or standard for carbon and nitrogen. Internationally accepted standards are Vienna Pee Dee Belemnite (V-PDB) limestone and atmospheric N_2 for $\delta^{13}C$ and $\delta^{15}N$, respectively. Units for δ values are parts per thousand (‰) or per mil. We also measured the weight percent carbon to nitrogen concentrations ratios of all bone collagen samples, which ranged between 2.7 and 3.0 (see Supplemental data), indicating that collagen is unaltered (Ambrose, 1990). Analytical precision (SD) was assessed by analysis of internal reference standards and was measured to be <0.2‰ for collagen $\delta^{13}C$ and $\delta^{15}N$ values.

3.1.3 Bone apatite preparation

For apatite $\delta^{13}C$ analysis we drilled ~50–100 mg of bone to produce a homogenized powder. To remove organics, powdered samples were placed in a bath of 3% hydrogen peroxide for 24 h. Each sample was then centrifuged three times in deionized water. Next, these samples were treated for 30 min with 0.1 m buffered acetic acid to remove labile diagenetic carbonate (Coltrain and Janetski, 2013). All samples were vortexed after 15 min to ensure complete bone reaction with the acetic acid. Following this acid bath, the samples were again centrifuged three times in deionized water and then were air-dried for 24 h under a fume hood. Approximately 0.5–0.6 mg of homogenized apatite powder was weighed into glass exetainer vials and treated with phosphoric acid at 50 °C for 6 h to produce CO_2. $\delta^{13}C$ values were measured on a Thermo Scientific GasBench coupled to a Delta V isotope ratio mass spectrometer at UNM–CSI; delta calculations are similar to those for bone collagen described above. Analytical precision (SD) was assessed by analysis of internal reference standards and was measured to be <0.1‰ for apatite $\delta^{13}C$ values.

3.2 Eggshell analyses

We considered all eggshell fragments recovered from the Arroyo Hondo archaeological excavations (Table 1). Each fragment was counted and its mass recorded by provenience prior to analysis. To understand the fragmentation of eggshells at Arroyo Hondo, we quantified the relationship between number of eggshell fragments (NISP) and total mass. Since whole turkey eggshells have a relatively consistent mass (~7.25 g) it may be possible to determine how many eggs are represented in a sample based on the relationship between number of eggshell fragments and mass (Windes, 1977, 1987, 1993; Munro, 1994). Because we know how many eggs were initially recovered in Plaza K, we can compare the eggshell NISP/mass ratio to the known number of

Please cite this article as: Conrad, C., et al., Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo, J. Archaeol. Sci. Rep. (2016), http://dx.doi.org/10.1016/j.jasrep.2016.06.016

Table 1
All eggshell samples collected during the Arroyo Hondo Pueblo excavations based on component, provenience, NISP, mass (grams) and the ratio of identified eggshell fragments to mass. NS denotes the eggshell was not sampled in this study for SEM analysis.

SEM sample ID	Component	Provenience	NISP	Mass (g)	Ratio (NISP/mass)
AHE1	I	Roomblock 6, room 101B, object 2	107	1.88	56.91
AHE2	I	Plaza K, room 12, level II	3	0.16	18.75
AHE3	I	Plaza K, room 3, level III, object 3	3	0.06	50.00
AHE5	I	Plaza K, room 16, level III and IV	4	0.13	30.77
NS1	I	Plaza G, room 25A, level II	1	0.04	25.00
AHE8	I	Plaza K, room 12, level III	2	0.09	22.22
AHE9	I	Plaza K, room 4, level IV	4	0.20	20.00
AHE10	I	Plaza K, room 15, level IV	8	0.25	32.00
AHE11	I	Plaza K, room 2, level IV	51	1.56	32.69
AHE12	I	Plaza K, room 16, level II	2	0.10	20.00
NS2	I	Plaza K, room 12, level I	1	0.05	20.00
AHE14	I	Plaza K, room 6, level IV	2	0.08	25.00
AHE15	I	Plaza K, room 4, level IV, object 1	56	4.54	12.33
AHE16	I	Plaza K, room 4, level IV, object 1	28	3.03	9.24
AHE17	I	Plaza K, room 4, level IV, object 1	15	2.84	5.28
AHE18	I	Plaza K, room 4, level IV, object 1	9	1.53	5.88
AHE19	I	Plaza K, room 4, level IV, object 1	25	3.30	7.58
AHE20	I	Plaza K, room 4, level IV, object 1	32	3.65	8.77
AHE21	I	Plaza K, room 4, level IV, object 1	28	4.56	6.14
AHE22	I	Plaza K, room 4, level IV, object 1	75	6.99	10.73
AHE23	I	Plaza K, room 4, level IV, object 1	52	3.98	13.07
AHE24	I	Plaza K, room 4, level IV, object 1	54	5.00	10.80
AHE25	I	Plaza K, room 4, level IV, object 1	90	4.37	20.59
NS3	I	Plaza K, room 4, level IV, object 1	232	15.60	14.87
NS4	II	Plaza C, room A, level 16	1	0.06	16.67
NS5	II	Plaza C, room A12, level 1, object 21	1	0.02	50.00
Total			886	64.07	13.83

eggs, which allows us to test hypotheses about eggshell mass as a proxy for total number of eggs.

To ensure that individual eggs were not analyzed more than once, we selected a single eggshell fragment for scanning electron microscope (SEM) analysis from each provenience at Arroyo Hondo. We did not conduct analysis on eggshell from proveniences with an eggshell NISP of 1; we also excluded a bag of mixed fragments from Plaza K. This left us with a total sample of 21 eggshell fragments for SEM analysis (Table 1).

Sample preparation for SEM analysis followed Beacham and Durand (2007) with one exception. To preserve the organic portion of the eggshells, we rinsed each sample in deionized water instead of washing it in bleach. A bleach rinse preserves the mammillary cone morphology while cleansing the inner eggshell surface of organics, but it completely destroys the membrane layer. The membrane layer separates the albumen from the shell and is comprised of woven protein fibers articulated to the mammillary cones (Beacham, 2006; Beacham and Durand, 2007; Sidell, 1993). This layer is often preserved in archaeological shell samples (Sidell, 1993) and must be removed to identify the mammillary cone morphology (Beacham and Durand, 2007; Lapham et al., this volume). Since several contexts at Arroyo Hondo have low abundances of eggshell, we chose to limit organic destruction. This lowered the number of samples that had visible mammillary cones to 14, but preserved a reasonable sample for future analyses.

After samples were air-dried, the fragments were attached to specimen mounting stubs using double-sided tape. A small stroke of graphite conductive adhesive was brushed on the eggshell fragment and the mounting stub to increase the conductivity of the sample. Samples were carbon coated on an EMITECH K950X carbon vacuum evaporator using graphite rods, providing a 15–20 nanometer thick layer of carbon film to increase the conductivity and visual resolution of the sample under the SEM. For SEM analysis, samples were placed into a JEOL 5800LV SEM and run under the high vacuum mode for optimal resolution. We used a working distance of 15 mm at approximately $\times 200$ magnification with 20 kV accelerating voltage. To age the eggshells, we photographed the samples and compared them to a morphological ageing guide (Beacham and Durand, 2007).

4. Results

4.1 Turkey bone analyses

Both turkey relative abundance and overall taxonomic evenness show little change through time (Fig. 4). Turkeys comprise a modest but stable portion of the faunal assemblage, ranging between 2% (152 out of 6400) and 13% (317 out of 2414) of total NISP, with a mean value of $6 \pm 3.8\%$ (Fig. 4). Taxonomic evenness values are high, ranging between 7.0 and 10.8 with a mean value of 9.2 ± 1.3.

Stable isotope results suggest that the majority of the Arroyo Hondo turkeys consumed a C_4-based diet (Figs. 5 and 6; see also Supplemental data). Of the 80 turkeys sampled in this study, 77 fall within the range of a C_4 diet and only three have $\delta^{13}C$ values consistent with a wild C_3-based diet (Table 2; see also Jones et al., in this volume; Lipe et al., 2016; McCaffery et al., 2014; Stearns, 2010). Overall, our results are in agreement with patterns identified elsewhere in the northern Southwest: the majority of turkeys appear to have been husbanded and fed a C_4-based diet presumably dominated by maize, while a small number had a wild diet (Kellner et al., 2010; McCaffery et al., 2014; Rawlings and Driver, 2010).

4.2 Eggshell analyses

We identified 886 turkey eggshell fragments with a total mass of 64.1 g in the Arroyo Hondo assemblage (Table 1). The majority of these samples were fragments recovered from bulk samples during excavation, but in addition ten individual eggs were recovered in situ from Plaza K (Fig. 3). In most cases, few specimens were recovered per context and this resulted in high NISP/mass ratios, indicating high fragmentation (Table 1). For example, three eggshell fragments were recovered from Plaza K, Room 3, Level III (SEM sample AHE3) with a total mass of 0.06 g. The NISP/mass ratio for this context is 50.0. In contrast, the 107 fragments recovered from Roomblock 6, Room 101B (SEM sample AHE1) produced a total mass of 1.88 g; the NISP/mass ratio for this sample is 56.9. While these ratios are similar, they derive from different abundances and mass.

Please cite this article as: Conrad, C., et al., Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo, J. Archaeol. Sci. Rep. (2016), http://dx.doi.org/10.1016/j.jasrep.2016.06.016

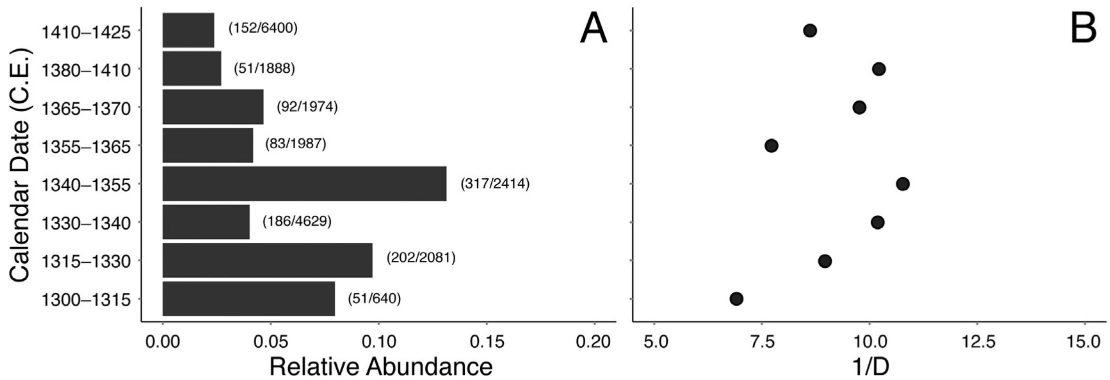

Fig. 4. (A) Relative abundance of turkey specimens and (B) overall faunal taxonomic evenness (reciprocal of Simpson's index), based on values from Lang and Harris (1984). The transition between Component I and II at Arroyo Hondo falls at 1370 C.E. Relative abundance values represent the number of turkeys compared to total NISP values for each context.

In the clutch of eggs from Plaza K (SEM samples AHE15–25) where there is a known association between individual eggs and eggshell fragments, we found high fragmentation rates in some samples but not others: the NISP/mass values here range between 5.2 and 20.6 (Table 1). Furthermore, in this sample the ten individual eggs have a total mass of 59.39 g. If we use 7.25 g (following Windes, 1977, 1987, 1993) as our control for the whole weight of turkey eggshell (for a single egg), then this indicates 8.2 eggs present in Plaza K instead of 10. While this test provides some support for using eggshell mass as a proxy for whole-egg abundance, the variability in fragmentation identified in other parts of the site suggests this measure should be used with caution.

Of the 21 eggshell samples selected for SEM analysis, 14 lacked an organic membrane layer and could be successfully aged (Tables 3 and 4). Of these, five eggshells had no or very minor reabsorption of the mammillary cone, suggesting that the incubation cycle never began or was stopped within days of the eggs being laid. These specimens (Table 3; Fig. 7) were aged to between 0 and 18 days in the embryonic cycle but are labeled as NR (no reabsorption) following Beacham and Durand (2007) and Lapham et al. (this volume). In contrast, the clutch of ten eggs from Plaza K shows a different pattern (Table 4). Of the nine age-able eggs, six aged to very late in the embryonic cycle (24 days or later) while three suggested a late age, or minimal reabsorption (MR), near 18 days (Fig. 8). We also identified immature turkey bones (embryo fragments) within the sample containers of nine of the ten eggs from the Plaza K clutch. In addition, some eggs appear to have almost hatched while others did not. This suggests the Plaza K clutch formed with eggs from multiple hens that were laid within a multi-day period.

5. Discussion

Previous zooarchaeological research suggests that Southwestern turkey husbandry began to shift towards increased economic use during Pueblo III in the Four Corners region (Akins, 1985; Badenhorst and Driver, 2009; Beacham and Durand, 2007; Windes, 1977). We tested whether these patterns of use were also present in the Pueblo IV Northern Rio Grande using bones and eggshells from Arroyo Hondo Pueblo. Given previous stable isotope and SEM analyses, we expected that eggshell would indicate eggs were hatched and $\delta^{13}C$ values would suggest a diet dominated by C_4 resources. While the isotope data presented here do conform to the larger Southwestern pattern, the eggshell analysis did not meet our predictions. Given the limitations of our sample we are unable to determine a cause for the unexpected eggshell results, but we review four possible drivers – ceremonial activity, turkey subsistence, human subsistence and recovery/sampling biases – in light of two questions: (a) how does turkey stable isotope and abundance data match larger patterns in the Southwest? and (b) what potential processes drove the use of eggs, including the anomalous Plaza K sample?

5.1 Turkey stability and stable isotopes

The collagen and apatite $\delta^{13}C$ values of the Arroyo Hondo turkey bones are similar to those identified in other Southwestern studies and suggest that the majority of turkeys at this site ate a C_4-based diet with little or no input from C_3 resources. At Arroyo Hondo there is

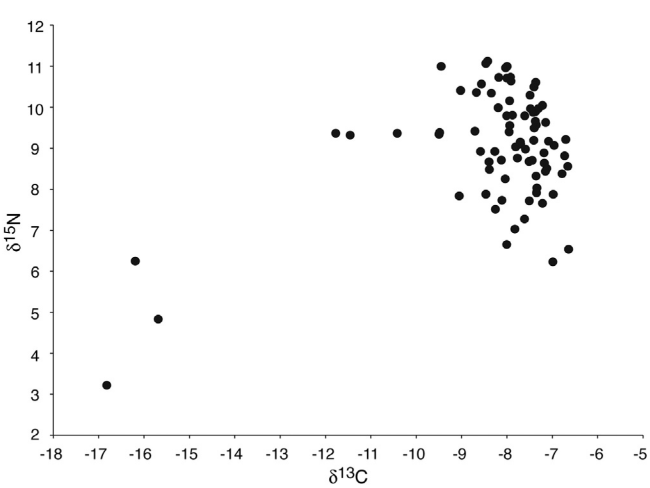

Fig. 5. Bivariate plot of turkey bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values from Arroyo Hondo Pueblo.

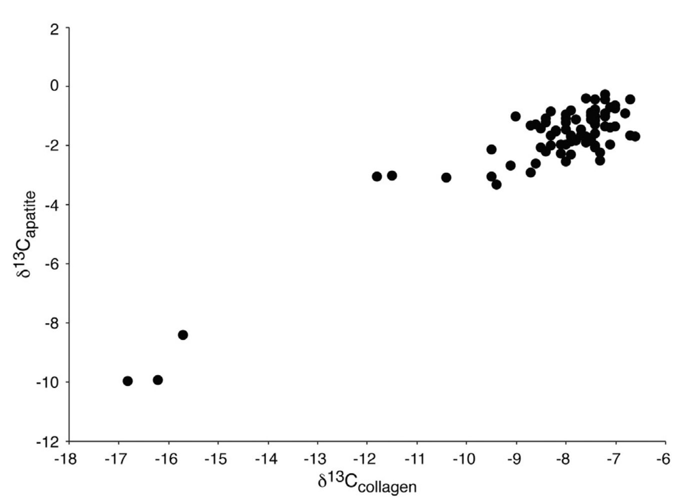

Fig. 6. Bivariate plot of turkey bone collagen and apatite $\delta^{13}C$ isotope values.

Please cite this article as: Conrad, C., et al., Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo, J. Archaeol. Sci. Rep. (2016), http://dx.doi.org/10.1016/j.jasrep.2016.06.016

Table 2
Mean (±SD) bone collagen $\delta^{13}C$ and $\delta^{15}N$ and apatite $\delta^{13}C$ values of turkeys from Arroyo Hondo Pueblo.

	$\delta^{13}C_{collagen}$	$\delta^{15}N$	$\delta^{13}C_{apatite}$
C_4 diet (n = 77)	−7.9 ± 0.9	9.2 ± 1.1	−1.5 ± 0.7
C_3 diet (n = 3)	−16.2 ± 0.6	4.7 ± 1.5	−9.4 ± 0.9

strong evidence for maize production (Wetterstrom, 1986); given this and other isotope studies from this region (e.g., Coltrain et al., 2007; Coltrain and Janetski, 2013; Jones et al., in this volume; Kellner et al., 2010; Lipe et al., 2016; McCaffery et al., 2014; Rawlings and Driver, 2010) it is likely that these turkeys were fed maize. The relative abundance of turkeys is low but steady throughout the 14th century, with no evidence of increasing intensification (Fig. 4). Dendroarchaeological, paleoecological, and human skeletal analyses all suggest that the occupants of Arroyo Hondo suffered periods of significant stress (Palkovich, 1983, 2008, 2012; Rose et al., 1983; Wetterstrom, 1986). Despite this, the prehistoric inhabitants of Arroyo Hondo appear to have devoted some portion of an apparently precarious maize crop to feed turkeys, even when they themselves were under dietary stress.

These results highlight the distinctiveness of the Arroyo Hondo faunal assemblage, and, perhaps, differences between the Four Corners region and the Northern Rio Grande. Research in the Mesa Verde region of the northern Southwest indicates that turkey exploitation intensified during the late Pueblo II and the Pueblo III periods (Badenhorst and Driver, 2009; Driver, 2002; Muir and Driver, 2002; Windes, 1987). In contrast, turkey exploitation appears to have remained stable through time at Arroyo Hondo. The consistent C_4-based diet suggests a high level of investment, a pattern that is striking and aids our understanding of variability in turkey husbandry practice across the prehistoric Southwest (e.g., Jones et al., in this volume).

5.2 Using eggs at Arroyo Hondo Pueblo

Our expectation was that turkeys would have been hatched at Arroyo Hondo Pueblo, but instead our results suggest that the eggs we examined were taken soon after they were laid. If this pattern accurately reflects egg use at Arroyo Hondo, it would match the pattern identified by Beacham and Durand (2007) at Salmon Ruin (Pueblo III period) where only 1 egg (out of 30) had significant reabsorption indicative of hatching. Given our relatively small sample size (n = 14), it is impossible to conclusively assess whether this pattern is representative of egg use at Arroyo Hondo as a whole; we therefore review four non-mutually exclusive explanations for this pattern below.

One possible explanation involves the use of eggs in ceremony. Ethnographic records from the American Southwest describe the use of egg tempera by Puebloan societies in ceremonial activities, such as the production of masks and other ritual objects (Dunn, 1968; Fewkes, 1900; Hough, 1900; Judd, 1954; White, 1932). Egg tempera production would result in eggshell fragments from eggs taken early in the embryonic cycle. It is possible that the unhatched eggs in our sample reflect the use of egg tempera. Unfortunately, our sample consists of only 14 total fragments. In addition, equifinality is also an issue as we have no way to distinguish between ceremonial use and several other possibilities, including eggs as a source of food for humans or turkeys (see below). Ceremonial use remains a hypothesis, but one that is not possible to test with available data, and would be difficult to test in any situation without a special contextual deposit (e.g., Lapham et al., this volume), such as the Plaza K clutch described earlier.

Special contextual deposits containing turkeys and their eggs vary in composition. For example, at the Mitla Fortress site in Oaxaca, Mexico, unhatched turkey eggs and juvenile birds were placed as ritual offerings (Lapham et al., this volume). In the Southwest, a similar offering of eggs was recorded at the Pueblo IV Alameda School Site near Albuquerque, New Mexico (Cordero, 2013). However, neither of these cases closely resembles the Plaza K clutch; both the Mitla Fortress and Alameda eggs have other indicators (such as red ochre) suggesting ceremonial activity, while the Plaza K eggs from Arroyo Hondo do not.

A special deposit more similar to the Plaza K eggs comes from Homol'ovi III, a site in northeastern Arizona (~1275–1400C.E.). At Homol'ovi III, a deposit of seven whole eggs in association with the remains of a female turkey suggests that the mother died and the eggs quickly perished due to lack of care (Senior and Pierce, 1984:247). The Homol'ovi III deposit thus seems to represent a natural event rather than a ceremonial one, a scenario that could also explain the evidence from the Plaza K clutch. However, unlike the Homol'ovi III eggs, the Plaza K eggs differ in age (Table 4), as one egg did not have fragmented embryonic remains while the other nine did, and some eggs appear to have almost hatched while others did not. This does not rule out a natural death, but it does suggest a difference from the situation at Homol'ovi III. In summary, the evidence for ceremonial use of eggs at Arroyo Hondo Pueblo is inconclusive in both the bulk eggshell samples and the Plaza K clutch.

A potential non-ceremonial explanation for the lack of hatched eggshell fragments is turkey diet. Female turkeys sometimes consume eggshell fragments after poults have hatched to recover calcium lost during the laying and incubation cycle (Mollie Streuver, cited in Windes, 1977). If this occurred at Arroyo Hondo Pueblo, any hatched eggs would have been eaten, which would explain why we did not identify any of them in our sample. While we cannot dismiss this possibility, we did identify eggshell with low levels of reabsorption from several proveniences, including contexts identified as pens. If turkeys were eating eggshell, they would do so regardless of the age of the egg. Consumption of shell thus seems an unlikely explanation for the frequency of eggs taken early in their embryonic cycle at the site.

While turkey diet may not be responsible for the lack of hatched eggshell fragments, human diet may explain this pattern. Humans also eat turkey eggs, and the eggs they eat are usually taken early in the embryonic cycle. Perhaps the abundance of eggs taken earlier in their developmental cycle reflects human subsistence choices: a focus on turkey eggs rather than turkey meat. One way to identify human consumption of

Table 3
Turkey eggshell ageing results based on mammillary cone morphology for eggshell from bulk sample proveniences. "Membrane present" indicates the sample could not be aged. NR = no reabsorption. See Beacham and Durand (2007) and Lapham et al. (this volume) for age criteria.

SEM sample ID	Component	Provenience	Age (days)	Embryonic fragments?
AHE1	I	Roomblock 6, room 101B, object 2	NR 0-18	Y
AHE2	I	Plaza K, room 12, level II	Membrane present	N
AHE3	I	Plaza K, room 3, level III, object 3	Membrane present	N
AHE5	I	Plaza K, room 16, level III and IV	NR 0-18	N
AHE8	I	Plaza K, room 12, level III	Membrane present	N
AHE9	I	Plaza K, room 4, level IV	NR 0-18	N
AHE10	I	Plaza K, room 15, level IV	NR 0-18	N
AHE11	I	Plaza K, room 2, level IV	NR 0-18	N
AHE12	I	Plaza K, room 16, level II	Membrane present	N
AHE14	I	Plaza K, room 6, level IV	Membrane present	N

Please cite this article as: Conrad, C., et al., Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo, J. Archaeol. Sci. Rep. (2016), http://dx.doi.org/10.1016/j.jasrep.2016.06.016

Table 4
Turkey eggshell ageing results based on mammillary cone morphology for the Plaza K clutch of eggs (Plaza K, Room 4, Level IV, Object 1). "Membrane present" indicates the sample could not be aged. MR = minimal reabsorption. See Beacham and Durand (2007) and Lapham et al. (this volume) for age criteria.

SEM sample ID	Component	Provenience	Age (days)	Embryonic fragments?
AHE15	I	Plaza K, room 4, level IV, object 1	Membrane present	N
AHE16	I	Plaza K, room 4, level IV, object 1	MR 0-18	Y
AHE17	I	Plaza K, room 4, level IV, object 1	MR 0-18	Y
AHE18	I	Plaza K, room 4, level IV, object 1	MR 0-18	Y
AHE19	I	Plaza K, room 4, level IV, object 1	18-22	Y
AHE20	I	Plaza K, room 4, level IV, object 1	24-hatched	Y
AHE21	I	Plaza K, room 4, level IV, object 1	24-hatched	Y
AHE22	I	Plaza K, room 4, level IV, object 1	24-hatched	Y
AHE23	I	Plaza K, room 4, level IV, object 1	24-hatched	Y
AHE24	I	Plaza K, room 4, level IV, object 1	24-hatched	Y
AHE25	I	Plaza K, room 4, level IV, object 1	Membrane present	Y

eggs is through the presence of eggshell fragments in trash middens (Beacham and Durand, 2007; Durand and Durand, 2008; Munro, 1994; Windes, 1977, 1987, 1993). At Arroyo Hondo, however, the eggshells are almost entirely derived from plaza contexts, with only one sample from a room block (Table 1). Thus, we can neither refute nor support this hypothesis with the eggshell sample from Arroyo Hondo.

Another potential driver for the eggshell pattern results from sampling and recovery biases. There is a wealth of literature on the impact of screen size and sampling on archaeological recovery in general and on eggshells in particular (Beacham and Durand, 2007; Jones and Gabe, 2015; Keepax, 1981; Nagaoka, 2005; Stahl, 1996; Stewart et al., 2013). Controlled experiments in eggshell recovery indicate that smaller sized screens recover significantly more eggshell fragments (Durand and Durand, 2008). The excavators at Arroyo Hondo Pueblo used

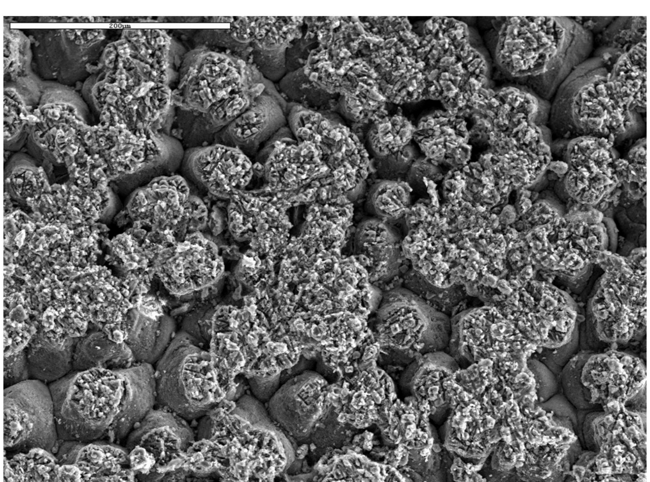

Fig. 7. Scanning electron micrograph of Arroyo Hondo Pueblo eggshell sample AHE5 (LA12-K-16-III + IV). Scale bar is 200 μm. Approximate age is between 0 and 18 days old, but the extremely low level of mammillary cone reabsorption indicates that the incubation cycle of this egg ended very quickly after being laid.

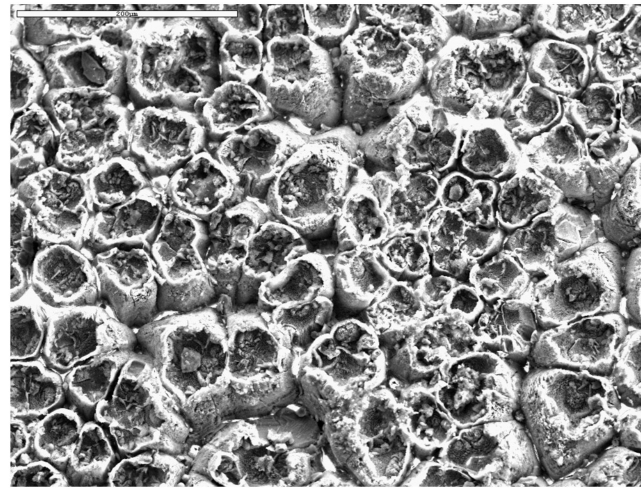

Fig. 8. Scanning electron micrograph of Arroyo Hondo Pueblo eggshell sample AHE21 (LA12-K-4-IV-I). Scale bar is 200 μm. Approximate age is around 24 days in the embryonic cycle, or hatched.

relatively large 0.75-inch (19.05 mm) mesh, which almost certainly reduced the number of eggshell fragments recovered.

In addition, while we are unaware of any studies that describe the differential fragmentation of eggshells from turkeys that were taken early in their embryonic cycle versus being hatched, it is plausible that hatched turkey eggshells are more fragile. Birds absorb nutrients (e.g., calcium) from eggshells during the embryonic cycle (Carey, 1983; Carpenter et al., 1994; Reynolds et al., 2004), as such hatched turkey eggshells would likely be more fragile due to their lower concentration of calcium and other shell-matrix binding elements. Therefore, the lack of hatched eggshell in our bulk sample contexts (Table 3) may reflect the combination of increased fragility of eggs and the large screens used in the Arroyo Hondo Pueblo excavations.

Our sample was already small due to these recovery issues, but we reduced the sample even further, limiting our analysis to 21 samples of which only 14 produced results. While our results are suggestive, increasing the sample size could very well alter the pattern seen here (e.g., Grayson, 1981, 1984; Lyman, 2008). Recovery and sampling thus seem likely candidates to explain the eggshell pattern at Arroyo Hondo Pueblo. This hypothesis could be tested with additional sampling of the site using 1/8″ or smaller screens, while targeting midden and roomblock contexts to provide a less plaza-focused sample (Table 1).

6. Conclusions

Puebloan occupants of Arroyo Hondo exploited both the turkey and the egg, but to differing degrees and in different ways. Turkey eggs were used as a resource in their own right, but whether the apparent predominance of this activity suggested by our results reflects ceremonial activities, turkey or human subsistence, or recovery/sampling biases remains unclear. On the other hand, both isotope values and turkey abundance suggest domestic turkeys were carefully husbanded; the stability of this activity during periods of climatic and dietary stress is surprising, and suggests that turkeys were significant for reasons beyond their economic value. However, there are still many questions to be answered about both the Arroyo Hondo assemblage and the role of turkeys in the Pueblo IV period: how did the prehistoric inhabitants of Arroyo Hondo use eggs? How does turkey use at Arroyo Hondo relate to earlier turkey use in the Four Corners region? And why were turkeys so important to be worth investment in times of stress? These questions can only be answered through continued work on the turkeys of the prehistoric American Southwest.

Please cite this article as: Conrad, C., et al., Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo, J. Archaeol. Sci. Rep. (2016), http://dx.doi.org/10.1016/j.jasrep.2016.06.016

Acknowledgements

We thank Lisa Barrera, Jennifer Day, Laura Elliff, Cynthia Geoghegan, Nicole Taylor (SAR) and Dave Phillips (Maxwell Museum) for loan and grant assistance; Heather Edgar, Sherry Nelson, and Michael Spilde at the University of New Mexico for laboratory access; Nicu-Viorel Atudorei and Laura Burkemper for analytical assistance; Brad Beacham, Leigh Cominiello, Kathy Durand-Gore, Brenna Lissoway, Ben Marwick, and Gavin Simpson for help along the way; and two anonymous reviewers for extremely helpful comments on a previous draft of this manuscript. We are grateful for financial support from the School for Advanced Research Arroyo Hondo Grants Program. Finally, thanks to Patricia Crown for a number of egg-cellent conversations which inspired this research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2016.06.016.

References

Akins, N.J., 1985. Prehistoric faunal utilization in Chaco Canyon: Basketmaker III through Pueblo III. In: Mathien, F.J. (Ed.)Environment and Subsistence of Chaco Canyon New Mexico. National Park Service, Albuquerque.

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., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert, J.B., Gisela, G. (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, Berlin.

Badenhorst, S., Driver, J.C., 2009. Faunal changes in farming communities from Basketmaker II to Pueblo III (A.D. 1-1300) in the San Juan Basin of the American Southwest. J. Archaeol. Sci. 36, 1832–1841.

Beacham, E.B., 2006. Eggshell and the Archaeological Record: A Developmental Study of Prehistoric Eggshell (M.A. thesis). Department of Anthropology and Applied Archaeology, Eastern New Mexico University, Portales, NM.

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.

Beidleman, R.G., 1956. Ethnozoology of the Pueblo Indians in historic times: part II: birds. Colorado Archaeological Society XXII. 2, pp. 17–28.

Carey, C., 1983. Structure and function of avian eggs. In: Johnston, R.F. (Ed.), Current Ornithology 1. Plenum Press, New York, pp. 69–103.

Carpenter, K., Hirsch, K.F., Horner, J.R., 1994. Dinosaur Eggs and Babies. Cambridge University Press, Cambridge.

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., Leavitt, S.W., 2002. Climate and diet in fremont prehistory: economic variability and abandonment of maize agriculture in the Great Salt Lake Basin. Am. Antiq. 67, 453–485.

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 (2), 301–321.

Conrad, C., Jones, E.L., Newsome, S.D., Schwartz, D.W., 2015. Arroyo Hondo Pueblo Turkey Analysis and Scanning Electron Microscope Data. University of New Mexicohttp://hdl.handle.net/1928/29606.

Cordero, R.M., 2013. Final Report on Excavations of the Alameda School Site (LA 421): A Classic Period Pueblo of the Tiguex Province. Report prepared for Albuquerque Public Schools, Albuquerque, New Mexico by the Office of Contract Archaeology, Albuquerque, New Mexico. OCA/UNM Report Number: 185-969.

Creamer, W., 1993. The architecture of Arroyo Hondo Pueblo, New Mexico. Arroyo Hondo Archaeological Series vol. 7. School of American Research Press, Santa Fe.

DeNiro, M.J., 1987. Stable isotopy and archaeology. Am. Sci. 75 (2), 182–191.

Driver, J.C., 2002. Faunal variation and change in the Northern San Juan region. In: Varien, M.D., Wilshusen, R.H. (Eds.), Seeking the Center Place: Archaeology and Ancient Communities in the Mesa Verde Region. University of Utah Press, Salt Lake City.

Dunn, D., 1968. American Indian Painting of the Southwest and Plains Areas. University of New Mexico Press, Albuquerque.

Durand, K.R., 2003. Function of Chaco-era great houses. Kiva 69 (2), 141–169.

Durand, K.R., Durand, S.R., 2008. Animal bone from salmon ruins and other great houses: faunal exploitation in the Chaco world. In: Reed, P. (Ed.), Chaco's Northern Prodigies: Salmon, Aztec, and the Ascendancy of the Middle San Juan Region after A.D. 1100. University of Utah Press, Salt Lake City.

Fewkes, J.W., 1900. Property-right in eagles among the Hopi. Am. Anthropol. 2 (4), 690–707.

Grayson, D.K., 1981. The effects of sample size on some derived measures in vertebrate faunal analysis. J. Archaeol. Sci. 8, 77–88.

Grayson, D.K., 1984. Quantitative Zooarchaeology: Topics in the Analysis of Archaeological Faunas. Academic Press, Orlando.

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 http://dx.doi.org/10.1007/s10816-014-9228-5.

Hegmon, M., Peeples, M.A., Kinzig, A.P., Kulow, S., Meegan, C.M., Nelson, M.C., 2008. Social transformation and its human costs in the prehispanic U.S. southwest. Am. Anthropol. 110, 313–324.

Hough, W., 1900. A collection of Hopi ceremonial pigments. National Museum Annual Report XXIII, pp. 463–471.

Jones, E.L., 2004. Dietary evenness, prey choice, and human-environment interactions. J. Archaeol. Sci. 31, 307–317.

Jones, E.L., 2016. In Search of the Broad Spectrum Revolution in Paleolithic Southwest Europe. Springer International, New York.

Jones, E.L., Gabe, C., 2015. The promise and peril of older collections: meta-analyses and the zooarchaeology of late prehistoric/early historic New Mexico. Open Quat. 1 (6), 1–13.

Jones, E.L., Conrad, C., Newsome, S.D., Kemp, B.M., Kocer, J.K., Turkeys on the fringe: variable husbandry in “marginal” areas of the prehistoric American Southwest, J. Archaeol. Sci.: Rep., http://dx.doi.org/10.1016/j.jasrep.2016.05.051 (in this volume).

Judd, N.M., 1954. The Material Culture of Pueblo Bonito. The Smithsonian Institution, Washington, D.C.

Keepax, C.A., 1981. Avian egg-shell from archaeological sites. J. Archaeol. Sci. 8, 315–335.

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, pp. 79–92.

Lang, R.W., Harris, A.H., 1984. The faunal remains from Arroyo Hondo Pueblo, New Mexico. Arroyo Hondo Archaeological Series vol. 5. School of American Research Press, Santa Fe.

Lange, C.H., 1950. Notes on the use of turkeys by Pueblo Indians. El Palacio 57 (7), 204–210.

Lapham, H.A., Feinman, G.M., Nicholas, L.M. Turkey husbandry and use in Oaxaca, Mexico: a contextual study of turkey remains and SEM analysis of eggshell from the Mitla Fortress, J. Archaeol. Sci.: Rep., (this volume).

Lipe, W.D., Bocinsky, R.K., Chisholm, B.S., Lyle, R., Dove, D.M., Matson, R.G., Jarvis, E., Judd, K., Kemp, B.M., 2016. Cultural and genetic contexts for early turkey domestication in the Northern Southwest. Am. Antiq. 81, 97–113.

Lyman, R.L., 2008. Quantitative Paleozoology. University of Cambridge Press, Cambridge.

Magurran, A.E., 2004. Measuring Biological Diversity. Blackwell, Malden.

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 (2), 337–352.

Muir, R.J., Driver, J.C., 2002. Scale of analysis and zooarchaeological interpretation: pueblo III faunal variation in the northern San Juan region. J. Anthropol. Archaeol. 21, 165–199.

Munro, N.D., 1994. An Investigation of Anasazi Turkey Production in Southwestern Colorado (M.A. Thesis). Department of Archaeology, Simon Fraser University, Burnaby.

Nagaoka, L., 2005. Differential recovery of Pacific Island fish remains. J. Archaeol. Sci. 32, 941–955.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Wagner, H., 2015. Vegan: Community Ecology Package, R Package Version 2. p. 3-0 (http://CRAN.R-project.org/package=vegan).

Ortman, S., 2014. Uniform probability density analysis and population history in the northern Rio Grande. J. Archaeol. Method Theory 1–32.

Palkovich, A.M., 1983. Pueblo population and society: the Arroyo Hondo skeletal and mortuary remains. Arroyo Hondo Archaeological Series vol. 3. School of American Research Press, Santa Fe.

Palkovich, A.M., 2008. Rickets, community dynamics, and gender relations at Arroyo Hondo, a fourteenth century ancestral Pueblo. In: Stodder, A.L.W. (Ed.), Reanalysis and Reinterpretation in Southwestern Bioarchaeology, Arizona State University Anthropological Papers No. 59. Arizona State University, Tempe, pp. 143–150.

Palkovich, A.M., 2012. Community violence and everyday life: death at Arroyo Hondo. In: Martin, D.L., Harrod, R.P., Pérez, V.R. (Eds.), The Bioarchaeology of Violence. University Press of Florida, Gainesville, pp. 111–120.

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.

Reed, E.K., 1951. Turkeys in southwestern archaeology. El Palacio 58 (7), 195–205.

Reynolds, S.J., Mänd, R., Tilgar, V., 2004. Calcium supplementation of breeding birds: directions for future research. Ibis 146, 601–614.

Rose, M.R., Dean, J.S., Robinson, W.P., 1983. The past climate of Arroyo Hondo, New Mexico, reconstructed from tree rings. Arroyo Hondo Archaeological Series vol. 4. School of American Research Press, Santa Fe.

Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochim. Cosmochim. Acta 48, 625–639.

Schoeninger, M.J., Moore, K., 1992. Bone stable isotope studies in archaeology. J. World Prehist. 6 (2), 247–296.

Schroeder, A., 1968. Birds and feathers in documents relating to Indians of the southwest. In: Schroeder, A. (Ed.), Collected Papers in Honor of Lyndon Lane Hargrave. Museum of New Mexico Press, Santa Fe.

Senior, L.M., Pierce, L.J., 1984. Turkeys and domestication in the southwest: implications from Homol'ovi III. Kiva 54 (3), 245–259.

Shapiro, J.S., 2005. A Space Syntax Analysis of Arroyo Hondo Pueblo, New Mexico: Community Formation in the Northern Rio Grade. School of American Research Press, Santa Fe.

Sidell, E.J., 1993. A methodology for the identification of archaeological eggshell. Supplement to Volume 10, Museum Applied Science Center for Archaeology. The University Museum of Archaeology and Anthropology, University of Pennsylvania, Philadelphia.

Stahl, P.W., 1996. The recovery and interpretation of microvertebrate bone assemblages from archaeological contexts. J. Archaeol. Method Theory 3 (1), 31–75.

Stearns, B.D., 2010. Diet Reconstruction of Wild Rio-Grande Turkey of Central Utah Stable Isotope Analysis (M.A. Thesis). Department of Plant and Wildlife Sciences, Brigham Young University, Provo.

Stewart, J.R.M., Allen, R.B., Jones, A.K.G., Penkman, K.E.H., Collins, M.J., 2013. ZooMS: making eggshell visible in the archaeological record. J. Archaeol. Sci. 40, 1797–1804.

Wetterstrom, W., 1986. Food, diet, and population at prehistoric Arroyo Hondo Pueblo, New Mexico. Arroyo Hondo Archaeological Series vol. 6. School of American Research Press, Santa Fe.

White, L.A., 1932. The Acoma Indians: People of the Sky City, Washington, D.C., Bureau of American Ethnology Annual Report 47.

Windes, T.C., 1977. Dwellers of the Wood ("Say, Who Are Those Turkeys?") A Preliminary Eggshell Report, Manuscript on file at the National Park Service, Chaco Culture National Historical Park, Chaco C51724/Coll, 0002/042.001-56.

Windes, T.C., 1987. The use of turkeys at Pueblo Alto based on the eggshell and faunal remains. In: Mathien, F., Windes, T. (Eds.), Investigations at the Pueblo Alto Complex Chaco Canyon New Mexico 1975–1979, Volume III, Part I Artifactual and Biological Analyses, Publications in Archaeology 18E. National Park Service, Santa Fe.

Windes, T.C., 1993. Eggshells from 29SJ 629. In: Windes, T. (Ed.), The Spadefoot Toad Site: Excavations at 29SJ 629, Chaco Canyon, New Mexico: Artifactual and Biological Analyses Volume II. Branch of Cultural Research, Division of Anthropology, National Park Service, Santa Fe.

Please cite this article as: Conrad, C., et al., Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo, J. Archaeol. Sci. Rep. (2016), http://dx.doi.org/10.1016/j.jasrep.2016.06.016