Archaeological and Anthropological Sciences (2024) 16:36
https://doi.org/10.1007/s12520-024-01937-2

RESEARCH

Turkey domestication and provisioning in the Mesa Verde Region (US Southwest), Pueblo I to Pueblo III (725–1280 CE): C, Sr, and O isotope analyses

Jacques Burlot[1,2] · **Joan Brenner Coltrain**[3] · **Virginie Renson**[1] · **Karen Gust Schollmeyer**[4] · **Amanda Werlein**[1,5] · **Jeffrey R. Ferguson**[1,6]

Received: 13 March 2023 / Accepted: 9 January 2024

Abstract

From the Pueblo I to the Late Pueblo III periods (725–1280 CE), in the Mesa Verde and McElmo Dome regions of the American Southwest, turkey use continuously increased, then declined during the final period of widespread residential occupation in the region. Increasing aridity in the Late PIII period may have limited agricultural productivity, and consequently, the ability to provision turkeys. In this paper, we use C, Sr, and O isotope analyses of turkey bone ($n=95$) from archaeological contexts to investigate whether the turkey diets and the locations where they were raised changed over time as a consequence of demographic and social changes in the region. Our results show that almost all turkeys were raised by Puebloan maize farmers in or in the vicinity of the McElmo Dome region and fed a C_4-based diet, presumably dominated by maize, during the whole period under study. However, it seems that they were fed less maize during the late thirteenth century. Perhaps facing lower yield harvests, maize was prioritized for human consumption, which resulted in less intensified turkey production efforts and reduced investment in maize-provisioned flocks. Our results also attest to the occasional use of local (likely wild) turkeys not provisioned with maize, and one wild turkey brought in from a more distant area.

Keywords Strontium isotopes · Oxygen isotopes · Carbon isotopes · Turkey · Domestication · American Southwest

Introduction

Changes in the availability of large game in the US Southwest provide a useful window into larger processes affecting the social-natural setting in which ancient groups lived. Although the majority of calories in ancient Southwestern farmers' diets came from maize (Wetterstrom 1986; Decker and Tieszen 1989; Hegmon 1989; Spielmann et al. 1990; Little and Little 1997; Martin 1999; Coltrain and Leavitt 2002; Coltrain and Janetski 2013), meat was an important source of fat, protein, and other essential nutrients either not abundant or not easily digestible in maize (Spielmann and Angstadt-Leto 1996; Nelson and Schollmeyer 2003; Schollmeyer 2011). Access to animals would also have been socially important, as they were linked to ritual and prestige in the ancient Southwest to an extent that may have outweighed their food value (Driver 1997; Potter 1997, 2000; Grimstead and Bayham 2010; Schollmeyer 2011).

Substantial settlement changes over the Pueblo I through Pueblo III periods (725–1280 CE) took place in the Mesa Verde area, due to increasing anthropogenic effects on the resource base and growing population aggregation (Lipe 1995). Although changes in access to deer (*Odocoileus hemionus*) and turkeys (*Meleagris gallopavo*) may not have meant a failure to gain adequate calories, declining animal protein intake confronted prehistoric maize farmers as populations grew, affecting settlement patterns and resource acquisition

✉ Jacques Burlot
jacques.burlot@hotmail.fr

[1] Archaeometry Laboratory, Research Reactor Center, University of Missouri, 1513 Research Park Drive, Columbia, MO 65211, USA

[2] MONARIS-UMR 8233, Sorbonne Université, 4 Place Jussieu, Tour 53 Couloir 43-53, 75252 Paris, France

[3] Department of Anthropology, University of Utah, 260 Central Campus Drive, Salt Lake City, UT 84112, USA

[4] Archaeology Southwest, 300 North Ash Alley, Tucson, AZ 85701, USA

[5] Department of Chemistry, University of Missouri, 125 Chemistry Building, Columbia, MO 65211, USA

[6] Department of Anthropology, University of Missouri, 112 Swallow Hall, Columbia, MO 65211, USA

practices (Driver 2002; Kuckelman 2010; Schollmeyer and Driver 2013; Badenhorst et al. 2019).

The Mesa Verde region provides the context for a case study addressing how changes in faunal availability over time relate to dramatic episodes of social change and resource stress. Previous work in the area has demonstrated a series of changes in the use of faunal resources from 725 to 1280 CE (Driver 2002; Muir and Driver 2002; Schollmeyer and Driver 2013). Excavations by the Dolores Archaeological Project and Crow Canyon Archaeological Center have facilitated fine-grained dating based on dendrochronology and ceramics allowing assemblages to be dated within 40- to 80-year time intervals (Ortman et al. 2007), and intense archaeological survey allows accurate population estimates (Varien et al. 2007; Schwindt et al. 2016). Examining these intervals reveals an interesting record of declining artiodactyl (deer, elk, and pronghorn) representation coupled with increased turkey use (Schollmeyer and Driver 2013). Artiodactyls' proportional contribution to assemblages shows a statistically significant decrease in every time interval from 725 to 1225 CE. In contrast, the contribution of turkeys shows a significant increase in every time interval from 725 to 1280 CE, then decreases during the last period of residential occupation. Lagomorph (jackrabbit and cottontail) ratios remain relatively stable over the entire time period.

Here, we use C, Sr, and O isotope analyses of turkey bones from the Mesa Verde region to investigate, first, whether changes occurred in the diet of these animals as a consequence of social pressures during later time periods. Second, based on the strontium isotopic baseline of the study area (Burlot et al. 2022), we examine whether the initial dramatic increase in turkey use came from increased local production, involved inter-village transport of turkeys, or was perhaps due to the mixed use of managed birds provisioned with maize and birds hunted in the wild.

Population aggregation, turkey domestication and provisioning in the Mesa Verde region

The Mesa Verde region encompasses southwest Colorado and portions of adjoining states (Fig. 1a). This study area combines a long-term record of human occupation with dating precision allowing us to identify both short-term variation and broader trends. Farmers inhabited the region from about 500 BCE to 1280 CE (Martin 1999; Coltrain et al. 2007; Coltrain and Janetski 2013), relying on maize agriculture supplemented with wild plants and animals and, late in the sequence, domesticated turkeys.

The earliest evidence of sedentary farmers is from the Basketmaker III period (Varien et al. 2007; Schwindt et al. 2016; Cates 2020; Diederichs 2020). Turkeys were already being provisioned by people before this time period, but appear to have been used primarily as a source of feathers (Lipe et al. 2016, 2020; Cates 2020). Until the Late Pueblo II period (discussed below), their remains are generally encountered as articulated deposits rather than as household refuse and do not show evidence of processing for food. After this time, turkey remains appear much more commonly in archaeological sites and especially in household refuse and are heavily provisioned with maize (Rawlings and Driver 2010). This change in turkey use has been argued to be a response to declines in artiodactyl availability in the area that also began in the Late Pueblo II period, a shift that would have made the effort to provision these animals worthwhile as farmers sought to gain additional protein and fat resources to replace those once more readily available from large game animals (Spielmann and Angstadt-Leto 1996; Badenhorst and Driver 2009; Schollmeyer and Driver 2023). Studies of turkey aDNA and isotopic signals of these birds' diets indicate that turkey remains in archaeological sites throughout the temporal sequence discussed here include those of both genetically domesticated and wild turkeys, and that individuals from either category often consumed enough C_4 plants to indicate they were provisioned with maize (Rawlings and Driver 2010; Speller et al. 2010; McCaffery et al. 2014; Lipe et al. 2016; Kemp et al. 2017).

Our study begins with the Pueblo I period (750–900 CE), when some settlements first coalesced into substantial villages of 100 households or more (Johnson et al. 2005). These villages were short-lived, with occupations of 40 years or less, and by 880 CE, a large-scale emigration reduced human populations in the region (Judge 1989; Wilshusen 1999). Turkeys are thought to have been primarily a source of feathers—used in making blankets and other items—rather than food at this time, even though most were maize-provisioned birds (Munro 1994, 2011; Rawlings and Driver 2010; Lipe et al. 2020), and genetic evidence indicates that some were domesticated (Speller et al. 2010). Until the Pueblo II period, turkey remains are relatively rare, and where they do occur, they are largely purposeful deposits of articulated animals with no evidence of butchery (Munro 1994; Muir and Driver 2002; Badenhorst and Driver 2009). Turkey remains are much less common in Pueblo I assemblages than in any subsequent period (Schollmeyer and Driver 2013).

The Pueblo II period (900–1140 CE) began with an interval of low human population and widely dispersed households, some of which were loosely clustered into spatially dispersed communities (Lipe and Varien 1999a; Varien et al. 2007). Despite these relatively small, scattered populations, artiodactyl abundance declined significantly relative to lagomorphs when compared to Pueblo I, suggesting early human impacts on the encounter rate of large animals (Schollmeyer and Driver 2013). At the same time, the ratio of turkeys to lagomorphs increased, suggesting that managed and domesticated birds may have provided a newly important source of meat as large game became harder to acquire (Spielmann and Angstadt-Leto 1996; Schollmeyer and Driver 2013). In the second half of this period (1060–1140 CE), immigration increased the area's population, and settlements became increasingly aggregated in community centers built in the style of, and likely socially or politically connected to, Chacoan communities to the south (Lipe and Varien 1999a). The ratio of artiodactyls to lagomorphs again declines substantially from that of the previous period, and the ratio of turkeys—of which the vast majority seemed to have consumed a diet high in C_4 plants (Rawlings and Driver 2010)—to lagomorphs increases even more substantially (Schollmeyer and Driver 2013). Simulation modeling echoes archaeological findings, indicating that hunting at any reasonable level by Pueblo II populations would have substantially reduced deer populations supporting the use of managed, maize-provisioned turkey flocks as a replacement meat source (e.g., Bocinsky et al. 2012; Kohler et al. 2012).

Turkeys are thought to have been largely maize fed in this time period and also during Pueblo III based on carbon isotope analysis of Pueblo II–III samples from Shields Pueblo (5MT3807) and a small sample of other sites in the region (Rawlings and Driver 2010; McCaffery et al. 2014; Grimstead et al. 2016). Another study combining the analysis of coprolites, aDNA, and N and C isotopes confirmed this finding at several sites including Champagne Spring, located ca. 40 km northwest of our study area (Lipe et al. 2016) (Fig. 1a).

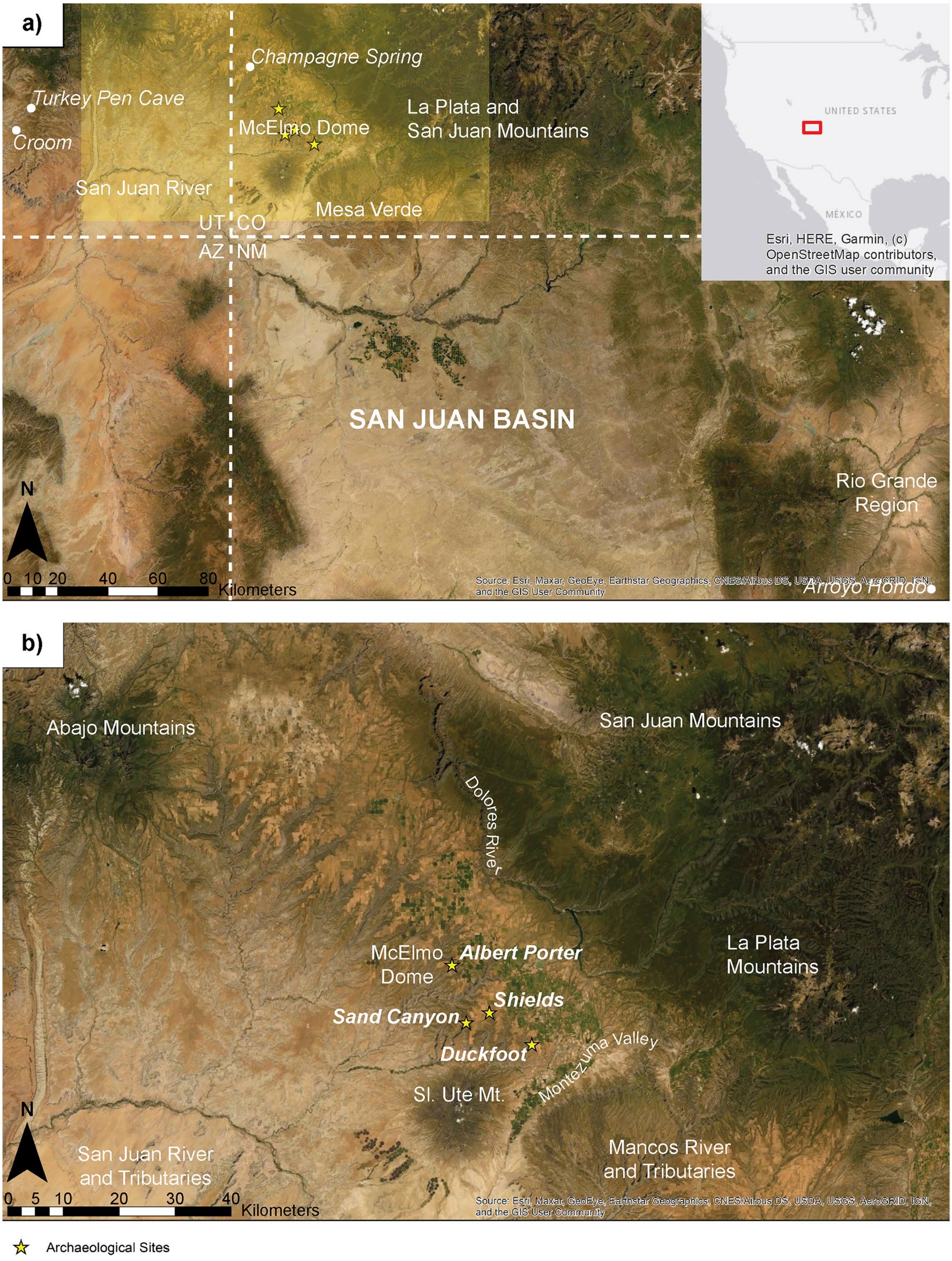
Several decades of drought ushered in the early Pueblo III period (1140–1225 CE), but the end of the drought around 1180 CE coincided with another period of rapid population growth and increasingly aggregated clustering of residential communities on mesa tops (Lipe and Varien 1999b). The late Pueblo III period (1225–1300 CE) saw continued population growth, with peak populations around 1260 CE (Varien et al. 2007). Interestingly, the ratio of turkeys to lagomorphs declines at this time (Schollmeyer and Driver 2013), perhaps due to problems feeding turkeys as human populations grew and demand for maize increased relative to agricultural productivity.

The end of the Pueblo III period (terminal Pueblo III, 1260–1280 + CE) encompassed a number of rapid social and environmental changes, including the "great drought" of 1276–1299 CE and shorter growing seasons associated with the onset of the Little Ice Age, as well as increased evidence of violent conflict (Crown et al. 1994; Wilcox and Haas 1994; Ahlstrom et al. 1995; Lipe and Varien 1999b; Lightfoot and Kuckelman 2001; Kuckelman 2010). In particular, Kuckelman links the decades of climatic downturn to a dramatic change in resource acquisition patterns and accompanying interpersonal violence (Kuckelman 2010). She argues that the inhabitants of Sand Canyon Pueblo reverted to an emphasis on hunting and gathering during the last decades before abandonment of the village. At this time, turkeys decline in frequency in deposits at the site and wild game increases, shifts likely tied to repeated maize crop failures that forced people to stop provisioning turkey flocks and to forage farther afield for wild plants and animals. Ellyson et al. (2019) recorded a particularly low proportion of adult male turkeys in these Terminal Pueblo III contexts, which might indicate that they were culled as juveniles. Assuming that males and females reproduced at the same rate, and yet a greater proportion of females survived to adulthood, led them to suggest that raising males to maturity became too costly in terms of maize consumption versus protein gains (Ellyson et al. 2019). It might also indicate reduced importance of feathers vs meat.

Munro proposed that farmers who left the Mesa Verde region at the end of the Pueblo III period, moving into the northern and central Rio Grande region, likely brought turkeys with them given an increase during Pueblo IV in the frequency of turkey remains at these Rio Grande sites (Munro 2011). This finding suggests groups from Mesa Verde introduced their breeding turkeys into the area (Conrad et al. 2016; Ortman 2016). More recently, ancient mitochondrial DNA (mtDNA) analyses of turkey samples found in pre-1280 CE contexts in the McElmo Dome region and in pre- and post-1280 CE contexts in the Northern Rio Grande region (Fig. 1a) support Munro's hypothesis, demonstrating that pre-1280 CE turkeys in the Northern Rio Grande area are genetically distinct from those of Mesa Verde and post-1280 CE Northern Rio Grande contexts (Munro 2011), whereas the latter two are similar (Kemp et al. 2017). In other words, populations from Mesa Verde moved with their turkey flocks.

Previous stable isotope analyses in turkey studies in the Mesa Verde Region

The modern wild turkey has a varied omnivorous diet, mainly composed of C_3 plants (fruits, shrubs, nuts, flowers, and some fatty invertebrates), but also C_4 plants like maize when available (Thornton et al. 2016; McCaffery et al. 2021). In the Southwest, because they are obligate drinkers, wild turkeys generally live in forested areas near running water typically in upland regions (Grimstead et al. 2016). A substantial amount of household labor was necessary to raise turkeys, since they had to be fed and watered regularly, protected from predators, and in some cases penned in confined spaces that needed to be maintained and cleaned (Badenhorst et al. 2019; Conrad 2022).


a)
Champagne Spring
Turkey Pen Cave
Croom
McElmo Dome
La Plata and
San Juan Mountains
San Juan River
Mesa Verde
UT
CO
AZ
NM
UNITED STATES
MÉXICO
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
SAN JUAN BASIN
Rio Grande Region
N
0 10 20 40 60 80 Kilometers
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Arroyo Hondo
b)
Abajo Mountains
San Juan Mountains
Dolores River
McElmo Dome
Albert Porter
La Plata Mountains
Shields
Sand Canyon
Duckfoot
Montezuma Valley
Sl. Ute Mt.
N
San Juan River and Tributaries
Mancos River and Tributaries
0 5 10 20 30 40 Kilometers
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Archaeological Sites

◂**Fig. 1** **A** Map showing the archaeological sites and the regions mentioned in the text. The yellow highlighted zone corresponds to the study area. **b** Enlarged study area showing the four archaeological sites on the McElmo Dome. Basemap sources: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, and the GIS User Community

Observation of turkey coprolites as well as N and C isotope analyses of turkey bone samples from Turkey Pen Cave (42SA3714) and the Croom site (42SA3701) on Cedar Mesa—two sites located west of the Central Mesa Verde region—and from Champagne Spring (5DL2333) located ca. 40 km northwest (Fig. 1a) shows that turkeys subsisted primarily on maize from Basketmaker II (1–500 CE) to the early Pueblo II period (Lipe et al. 2016). Carbon isotope analysis of turkey samples selected in other early Pueblo contexts from several sites in northwestern New Mexico and southwestern Colorado confirms these results reporting that turkeys subsisted on 60–89% C_4 plants (McCaffery et al. 2021). This was also the case for the turkeys found at Shields Pueblo in later contexts, dating to Pueblo II and III (Rawlings and Driver 2010). Little variability was present in either C or N isotope values over time, suggesting that little change took place in general turkey provisioning over this window of time. The same observation can be made with Pueblo II–III turkeys from Arroyo Hondo (Conrad et al. 2016) as well as several sites in the Middle San Juan Region (McCaffery et al. 2014) (Fig. 1a). In both cases, turkeys exhibited high C_4 diets during Pueblo II and III. Yet, a few turkey samples showed lower $\delta^{13}C$ values attesting to a C_3 plant-based diet, indicating the occasional capture of a wild bird (Jones et al. 2016).

Questions and sampling

Objectives

Despite relatively uniform results from the above-cited studies, small sample sizes in some cases and the absence of high-resolution temporal control limit our ability to examine short-term variation in maize provisioning over time and space. Shifts in the use of turkey from a feather to a meat source between the Pueblo I and II periods, as well as shifts in settlement location and aggregation over time, are likely to have influenced the amount of maize available for animal fodder and the locations where turkeys could productively be raised.

Our first question concerns the evolution of turkey production and investigates in particular whether turkey diets changed over time. Farmers may have faced problems provisioning turkeys in some villages and time periods, particularly during the last decades of occupation at sites like Sand Canyon. We use $\delta^{13}C$ values to observe whether there is a trend within late Pueblo III assemblages which contributes to a better understanding of the abandonment of the region and what the effects of deteriorating climate and social upheaval had on turkey diets.

Our second question focuses on potential temporal changes in locations where turkeys were raised. Domesticated and provisioned turkeys were present in the sites considered here, but we do not know whether they were exchanged between local villages or on a larger regional scale. Based on environmental strontium and oxygen isotopic baselines with distinct signatures for several regions in the study area (Burlot et al. 2022), we will use these data to examine areas of production.

Villages included in this study and sample selection

Our study focuses on faunal assemblages from four multicomponent villages—Shields Pueblo, Duckfoot (5MT3868), Albert Porter (5MT123), and Sand Canyon (5MT765)—spanning the Pueblo I through late Pueblo III periods (Fig. 1b), all of which were excavated by Crow Canyon Archaeological Center and are curated at Canyons of the Ancients Visitor Center and Museum. Shields Pueblo was inhabited in the Pueblo I period and (after a brief hiatus) continuously from Early Pueblo II through Late Pueblo III (Rawlings 2006), providing samples from every time period of interest in our study. The Duckfoot site contributes complementary data from the Pueblo I period (Walker 1993). Albert Porter Pueblo was occupied during the late Pueblo II through late Pueblo III periods (Badenhorst 2008), and Sand Canyon Pueblo provides additional data from the late Pueblo III period, including an assemblage representing the last few years of that era (Muir 1999; Kuckelman 2010) (Table 1).

Although many assemblages in the area can be dated within 40-year time periods (Ortman et al. 2007; Varien et al. 2007), we have chosen a broader temporal classification in this study (Table 1) to reflect a reasonable balance between analytical costs, sample destruction, and sample size. Thus, where possible, we chose ten turkey samples by time/site category (Table 1) for a total of 95 samples analyzed, 85 of which consist of leg bones (femur, tibiotarsus, fibula, or tarsometatarsus). Femora were chosen whenever possible, with tibiotarsi selected if too few spatially dispersed femora were available, followed by other leg elements, and then other elements. We removed 0.25 g from each selected specimen, and the remainder of each specimen remains in the collection. Samples were chosen from different structures and widely dispersed locations in midden deposits in order to minimize the chance of sampling the same individual animal multiple times, choosing securely

Table 1 Number of turkey samples selected by period and site

Time period	Archaeological sites	Number of samples
Pueblo I (725–920 CE)	Duckfoot	4
	Shields	9
Early Pueblo II (920–1060 CE)	Shields	11
Late Pueblo II (1060–1140 CE)	Shields	10
	Albert Porter	10
Early Pueblo III (1140–1225 CE)	Shields	10
	Albert Porter	9
Late Pueblo III (1225–1280 CE)	Shields	7
	Albert Porter	8
	Sand Canyon	7
Terminal Pueblo III (ca. 1280 CE)	Sand Canyon	10

dated contexts from each site. The only available securely dated contexts for Terminal Pueblo III samples were from kiva deposits at Sand Canyon Pueblo (Kuckelman 2010), where samples were selected from surface contact or fill below roof fall contexts. Late Pueblo III samples from Sand Canyon were all chosen from midden layers securely dated to that time period (Kuckelman 2010). No turkey burials (whole articulated turkeys purposely placed in pits, with or without accompanying items) were sampled.

Analytical methods

Carbonate C and O isotope analysis

Hydroxyapatite analysis yields the carbon isotope data necessary for the examination of maize consumption while providing oxygen isotope data useful in determining spatial (primarily elevational) origins of fauna. Bone hydroxyapatite (apatite) is a calcium phosphate mineral containing carbonate ions (CO_3^{2-}) substituted in the phosphate (PO_4^{3-}) position or adsorbed into the crystal hydration layer. During isotope analysis, the adsorbed (or labile) carbonate ions subject to exchange are removed, preserving in vivo $\delta^{13}C$ and $\delta^{18}O$ signals (Bryant et al. 1996).

Bone apatite carbon isotope values ($\delta^{13}C$) reflect dietary choices and are used here to estimate the contribution of maize to the diets of turkeys, an indication of managed animals versus exploitation of hunted wild birds. Bone apatite $\delta^{13}C$ values reflect the weighted average $\delta^{13}C$ value of carbon intake metabolized for energy. Virtually all ingested carbon used in the production of energy leaves the body in the form of CO_2 produced by mitochondrial respiration. Respired CO_2 is in equilibrium with blood bicarbonates (HCO_3^-) from which the carbonates ($CaCO_3$) in bone apatite precipitate. The relative abundance of carbon-13 to carbon-12 in bone apatite is diagnostic of diet because $^{13}C/^{12}C$ ratios covary with one of three plant types identified by their photosynthetic pathway (Farquhar et al. 1989; Ehleringer and Monson 1993), two of which are pertinent here. During photosynthesis, C_3 plants discriminate heavily against metabolism of $^{13}CO_2$ (Cerling et al. 1998), expressing a modern, mean $\delta^{13}C$ value of ~ −26.5‰, being ^{13}C depleted relative to atmosphere (−8‰). Trees, temperate season grasses, and most forbs use C_3 photosynthesis. In contrast, the C_4 photosynthetic pathway discriminates less against ^{13}C as an adaptation to reduced atmospheric CO_2 concentrations and increased seasonality (Cerling et al. 1997). C_4 plants are thus characterized by more positive $\delta^{13}C$ values (~ −13 to −10‰) (Ehleringer et al. 1997). A subset of forbs and sedges, as well as warm season grasses (including the domesticate maize), are C_4 plants. A faunal diet comprised entirely of C_4 resources with a mean $\delta^{13}C$ value −10‰ would result in bone apatite $\delta^{13}C$ values > 0‰ given an additional ca. +12‰ diet to tissue isotopic offset (Cerling and Harris 1999; Kellner and Schoeninger 2007).

Bone apatite $\delta^{18}O$ values covary with the oxygen isotope chemistry of meteoric water, which fractionates with increases in elevation, distance from a coastline, and the seasonality or temperature of precipitation. As water vapor masses move upslope, $H_2{}^{18}O$ preferentially rains out, accelerated by declines in temperature. $H_2{}^{18}O$ also rains out as water vapor masses move inland progressively depleting inland $\delta^{18}O$ values relative to coastal moisture, although this effect is less marked in warm versus cold precipitation events (Fricke et al. 1995; Fricke and O'Neil 1999; Daux et al. 2005). Among faunal taxa that are obligate drinkers (including turkeys), skeletal $\delta^{18}O$ values record the oxygen isotope chemistry of drinking water sources (Fricke et al. 1995; Hoppe 2006). The high topographic relief (< 1500– > 3700 m above msl) and localized rainfall patterns in the study area may allow oxygen isotopic data to discern small-scale spatial differences independently or in combination with the strontium isotopic data.

Sample preparation for plant and bone hydroxyapatite $\delta^{18}O$ was conducted at the Archaeological Center Research Facility for Stable Isotope Chemistry at the University of Utah. Samples of faunal bone were pre-treated as follows: 100 mg of powdered bone was soaked 24 h in 3% hydrogen peroxide to remove organics, rinsed to neutrality, and dried. Samples were then treated 30 min in 0.1 M buffered acetic acid to remove labile carbonates, again rinsed to neutrality, and dried. Stable carbon and oxygen isotopic values were determined relative to VPDB on a Thermo Gasbench coupled to a Thermo Finnigan Delta Plus XL IRMS at the University of Wyoming Stable Isotope Facility. QA normalized standard uncertainty was 0.2‰ (ref material UWSIF17 [GS-1]). QC standard uncertainty was 0.3‰ (ref material UWSIF19 [rock] and 0.1‰ (ref material UWSIF06 [$CaCo_3$]. We report $\delta^{18}O_{VPDB}$ values in VSMOW converted using the following equation (Coplen et al. 1983): $\delta^{18}O_{VSMOW} = 1.03091\ \delta^{18}O_{VPDB} + 30.91$.

Sr isotope analysis

Previous studies have demonstrated the utility of strontium isotopic analyses of prehistoric faunal specimens for assessing the mobility of animals (see Bentley 2006). Strontium is an alkali earth metal that has four stable isotopes (^{88}Sr, ^{87}Sr, ^{86}Sr, and ^{84}Sr) and only one, ^{87}Sr, that derives from the radioactive decay of ^{87}Rb. Strontium is present in the geological substrate and transfers from rocks to soils, water, plants, and animals and moves through the food chain without isotopic fractionation. Strontium is chemically similar to calcium, which enables the replacement of calcium by strontium in the hydroxyapatite structure of bones and teeth. In bones, strontium undergoes continuous replacement and its isotopic composition reflects time-averaged information from the last years of the animal's life. Because the underlying geology is not the only factor that determines the isotopic signature of strontium that enters the bone or tooth tissues through the food chain, mobility studies often require the establishment of a baseline for the isotopic signature of biogenic strontium for the region of interest. Such a baseline has recently been established for the Mesa Verde region in the southwestern US (Burlot et al. 2022) and will be used for comparison with data obtained from skeletal elements of turkey recovered from prehistoric contexts.

The samples were cleaned using a nylon brush and cut with a diamond disk to isolate a fragment of approximately 20–40 mg. The samples were then sonicated for 30 min in mQ 18MΩ water, for 20 min in 5% acetic acid, and for 5 min in 5% acetic acid. Between these steps, the samples were rinsed three times using mQ 18 MΩ water. The samples were then soaked in 5% acetic acid for 7 h. They were then rinsed and sonicated for 5 min in mQ 18 MΩ water, and dried overnight. The samples were digested in 2 ml of 7 N HNO_3 (Optima Grade) at 125 °C for about 12 h. The Sr extraction was done using EiChrom Sr-spec""TM resin and a protocol adapted from De Muynck et al. for Ca-rich matrices (Muynck et al. 2009). The Sr eluates were evaporated at 90 °C and the dry residues re-dissolved in 0.05 N HNO^3. The Sr isotope analyses were conducted on the Nu Plasma II MC-ICP-MS (Nu Instruments) in operation at MURR. Samples were run in alternation with a solution of the SRM987 certified material. Both the sample and standard solutions were prepared to obtain ~ 150 ppb Sr and were corrected for mass fractionation and mass interferences of ^{87}Rb and ^{86}Kr and ^{84}Kr. The sample values were finally corrected by standard bracketing using the value published by Thirlwall for the ^{87}Sr/^{86}Sr ratio (0.710248) (Thirlwall 1991). The values obtained for the SRM987 were 0.71027 ± 0.00004 ($n = 57$). To examine the reproducibility of the entire protocol, the SRM1400 (Bone Ash) was analyzed and values obtained were 0.71311 ± 0.00003 (2SD) ($n = 6$). These values are in agreement with the range of 0.71312 ± 0.00004 (2SD) previously obtained by De Muynck et al. (2009). In addition, two replicates (i.e., second analysis of the same solution) were run (Table 2).

Results

Apatite δ^{13}C results

Ninety-five turkeys were sampled for bone apatite δ^{13}C. All but two yielded carbon isotope values between − 6 and − 0.5‰. Two outliers, MVSrB002 from the Albert Porter site and MVSrB174 from Shields Pueblo, yielded bioapatite values of − 11.2‰ and − 10.9‰, respectively (Table 2, Fig. 2), indicating diets comprised nearly entirely of C_3 forage with limited intake of C_4 plant materials and herbivorous insects as would be expected in wild caught birds (McCaffery et al. 2014). They represent the whole wild caught population of the present study and are thus not included in the following discussion.

Average δ^{13}C values for the Duckfoot (− 2.2 ± 1.5‰) ($n = 4$), Shields (− 2.2 ± 0.8‰) ($n = 46$), and Albert Porter (− 2.3 ± 1.3‰) ($n = 26$) sites are statistically indistinguishable (two-sample *t* test assuming unequal variance), whereas the Sand Canyon average is less positive (− 3.1 ± 1.0‰) ($n = 17$) (Table 3). The mean difference between the latter two sites and Sand Canyon δ^{13}C is significant ($p \leq 0.05$), but significance is not reached in Duckfoot carbon data due to small sample size (Table 3). Turkeys from Sand Canyon date only to the latter two Puebloan periods suggesting that less positive apatite δ^{13}C values reflect less investment in turkey provisioning during a period of turmoil and recession. This finding seems to be confirmed when we observe turkey assemblages by period. Average turkey apatite δ^{13}C values for assemblages dating to Pueblo I to early Pueblo III vary between − 2.4‰ and − 1.8‰, while averages for samples dating to both the Late and Terminal Pueblo III are − 3.1‰ (Table 3). Moreover, average δ^{13}C values for three of the first four periods in our study (P I, LP II, EP III) are significantly more positive ($p < 0.05$) that those of the latter two, Late and Terminal Pueblo III. Early Pueblo II is the exception with $p = 0.07$ (LPIII) and $p = 0.06$ (TPIII), approaching but not reaching significance.

Percent C_4 intake is calculated using a C_3 preindustrial, endmember value of − 24.5‰, C_4 endmember of − 10.5‰ (CO_2 $\delta^{13}C = -6.3$‰ [(Coltrain and Janetski 2013; Cotton et al. 2016; McCaffery et al. 2021)]), and an estimated + 12‰ $\delta^{13}C_{apt}$ fractionation offset. This offset is estimated based on a wild turkey mean $\delta^{13}C_{apt}$ value of − 11.0‰ (see MVSrB002 and MVSrB174) under the assumption that

Table 2 Description, location, and Sr, C, and O isotope data for turkeys from the Mesa Verde region (*replicate)

Sample ID	Element	Time Period	$^{87}Sr/^{86}Sr$	*2se*	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VSMOW}$
Duckfoot—site number: 5MT3868—site elevation: 1936 m						
MVSrB273	Scapula, distal end	P I			−0.9	22.6
MVSrB284	Long bone shaft possibly femur	P I			−1.8	24.7
MVSrB293	Tarsometatarusus, distal	P I			−1.7	27.0
MVSrB294	Tibiotarsus, distal end	P I			−4.3	24.0
Shields—site number: 5MT3807—site elevation: 2052 m						
MVSrB066	Humerus shaft	P I			−1.7	21.6
MVSrB067	Tibiotarsus, distal end	P I	0.70942	0.00001	−1.7	23.4
MVSrB068	Tibiotarsus, distal end	P I	0.70945	0.00001	−2.4	22.2
MVSrB071	Humerus shaft	P I			−1.9	21.5
MVSrB079	Humerus shaft	P I			−0.7	22.1
MVSrB080	Ulna, proximal	P I			−1.4	22.2
MVSrB081	Fibula, proximal	P I	0.70936	0.00001	−1.9	21.8
MVSrB107	Tibiotarsus distal end and shaft	P I			−2.4	22.7
MVSrB112	Vertebra	P I			−0.5	21.3
MVSrB174	Tibiotarsus shaft	EP II	0.71009	0.00002	−10.9	23.0
MVSrB132	Humerus, proximal	EP II			−1.8	20.5
MVSrB133	Tibiotarsus shaft	EP II			−2.3	22.4
MVSrB142	Humerus shaft	EP II	0.70941	0.00002	−1.4	21.8
MVSrB143	Humerus, proximal	EP II			−1.8	20.6
MVSrB149	Tibiotarsus shaft	EP II	0.70947	0.00002	−2.1	26.2
MVSrB153	Fibula shaft	EP II			−3.4	23.9
MVSrB154	Fibula shaft	EP II			−2.8	23.0
MVSrB155	Fibula shaft	EP II			−3.0	22.8
MVSrB181	Femur, no epiphyses	EP II	0.70950	0.00002	−2.5	24.5
MVSrB183	Tarsometatarsus shaft	EP II	0.70947	0.00002	−3.4	26.4
MVSrB088	Metapodial, distal/femur shaft	LP II			−1.4	21.9
MVSrB097	Tibiotarsus distal end and shaft	LP II			−2.5	21.5
MVSrB105	Femur shaft	LP II			−1.7	22.5
MVSrB110	Femur shaft	LP II	0.70942	0.00001	−2.4	24.1
MVSrB118	Femur shaft	LP II	0.70947	0.00001	−1.6	21.2
MVSrB146	Femur	LP II			−2.6	23.8
MVSrB147	Femur, proximal	LP II			−2.4	20.8
MVSrB160	Femur, proximal	LP II			−2.9	21.0
MVSrB196	Femur, proximal	LP II			−1.7	24.1
MVSrB198	Innominate fragment	LP II			−3.2	21.6
MVSrB085	Femur shaft	EP III	0.70946	0.00002	−2.6	21.6
MVSrB095	Femur shaft	EP III			−1.8	22.3
MVSrB123	Femur, distal	EP III	0.70947	0.00002	−2.2	20.3
MVSrB129	Femur, proximal	EP III			−2.0	23.1
MVSrB137	Femur, proximal	EP III	0.70916	0.00002	−0.6	21.3
MVSrB140	Femur shaft	EP III			−3.2	19.1
MVSrB141	Femur, distal	EP III			−1.5	21.7
MVSrB157	Femur, distal	EP III			−1.5	23.6
MVSrB161	Femur shaft	EP III			−2.5	26.1
MVSrB171	Femur shaft	EP III			−1.6	23.4
MVSrB075	Tibiotarsus shaft	LP III			−3.5	22.0
MVSrB090	Tibiotarsus shaft	LP III			−2.4	21.4
MVSrB104	Femur shaft	LP III			−2.5	22.0
MVSrB114	Tibiotarsus distal end	LP III			−2.5	22.1
MVSrB182	Tibiotarsus shaft	LP III	0.70946	0.00001	−2.1	25.8

Table 2 (continued)

Sample ID	Element	Time Period	$^{87}Sr/^{86}Sr$	*2se*	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VSMOW}$
MVSrB197	Tibiotarsus, distal end	LP III	0.70926	0.00001	− 2.7	19.9
MVSrB199	Tibiotarsus, distal end	LP III	0.70953	0.00001	− 5.0	21.3
Albert Porter—site number: 5MT123—site elevation: 2053 m						
MVSrB016	Tibiotarsus distal end	LP II			− 3.3	21.7
MVSrB020	Tibiotarsus distal end and shaft	LP II	0.70947	0.00001	− 1.0	21.6
MVSrB024	Tibiotarsus distal end and shaft	LP II			− 0.8	21.5
MVSrB041	Tibiotarsus distal end and shaft	LP II			− 2.2	22.1
MVSrB042	Femur, proximal	LP II	0.70953	0.00001	− 0.6	21.3
MVSrB043	Tibiotarsus shaft	LP II	0.70952	0.00001	− 3.7	22.3
MVSrB051	Tibiotarsus distal end	LP II			− 2.3	21.9
MVSrB056	Femur, distal	LP II			− 0.7	20.9
MVSrB061	Femur, distal	LP II	0.70952	0.00001	− 2.2	21.4
MVSrB259	Femur, distal	LP II			− 2.3	24.6
MVSrB002	Femur, distal	EP III	0.70955	0.00002	− 11.2	21.3
MVSrB003	Femur shaft	EP III			− 2.5	21.4
MVSrB006	Femur, distal	EP III			− 2.7	22.3
MVSrB017	Femur shaft	EP III			− 1.7	20.9
MVSrB033	Femur, distal	EP III	0.70951	0.00001	− 1.6	18.0
MVSrB040	Femur shaft	EP III	0.70939	0.00002	− 1.9	24.6
MVSrB040*			0.70938	0.00001		
MVSrB054	Femur shaft	EP III			− 0.8	22.9
MVSrB057	Femur, proximal	EP III			− 1.1	20.9
MVSrB267	Femur shaft	EP III			− 2.2	21.8
MVSrB004	Tibiotarsus distal end and shaft	LP III			− 0.5	22.3
MVSrB010	Tibiotarsus distal end	LP III	0.70949	0.00001	− 4.3	19.0
MVSrB010*			0.70949	0.00001		
MVSrB011	Tibiotarsus shaft	LP III			− 3.5	17.8
MVSrB027	Tibiotarsus distal end and shaft	LP III			− 2.8	22.0
MVSrB028	Tibiotarsus shaft	LP III			− 2.3	21.0
MVSrB029	Tibiotarsus shaft	LP III			− 2.9	21.6
MVSrB030	Tibiotarsus distal end	LP III	0.70941	0.00001	− 6.0	18.1
MVSrB037	Femur shaft	LP III			− 2.5	24.2
Sand Canyon—site number: 5MT765—site elevation: 2090 m						
MVSrB209	Tibiotarsus, distal end	LP III			− 3.6	25.0
MVSrB218	Tibiotarsus shaft	LP III			− 3.0	23.6
MVSrB222	Tibiotarsus, distal end	LP III	0.70941	0.00001	− 1.6	22.4
MVSrB224	Femur shaft	LP III			− 3.0	23.6
MVSrB225	Femur shaft	LP III			− 3.8	22.6
MVSrB237	Tibiotarsus shaft	LP III	0.70943	0.00001	− 3.8	25.5
MVSrB239	Tibiotarsus, distal end	LP III	0.70949	0.00002	− 3.0	27.8
MVSrB243	Tibiotarsus shaft	TP III	0.70936	0.00001	− 2.1	25.6
MVSrB246	Femur, proximal	TP III	0.70941	0.00001	− 2.7	27.0
MVSrB226	Tibiotarsus shaft	TP III			− 2.7	22.7
MVSrB227	Tibiotarsus, distal end	TP III			− 4.6	21.4
MVSrB228	Tibiotarsus, distal end	TP III			− 2.8	23.0
MVSrB229	Tibiotarsus, distal end	TP III			− 3.0	22.1
MVSrB230	Tibiotarsus shaft	TP III			− 2.9	24.5
MVSrB233	Tibiotarsus, distal end	TP III	0.70945	0.00002	− 5.5	21.2
MVSrB235	Tibiotarsus, distal end	TP III	0.70958	0.00001	− 1.7	25.7
MVSrB236	Tibiotarsus, distal end	TP III			− 3.0	20.8

although non-human managed, wild-caught birds subsisted primarily on C_3 forage (~24.5‰), slight enrichment likely resulted from occasional intake of wild C_4 and/or CAM plants such as *Amaranthus* sp. or *Opuntia* spp., respectively (Martin 1999:Table 1). This offset is in good accord with turkey mean apatite-collagen spacing averaging $+7.0 \pm 0.5$‰ ($n = 155$), reported in several studies (Conrad et al. 2016; Table 2; McCaffery et al. 2014; Table 2; Thornton et al. 2016; Table 1). Thus, a 100% C_4 diet would yield a bone apatite $\delta^{13}C$ value of +3‰.

McCaffery et al. (2014) report a mean bone apatite $\delta^{13}C$ value of -2.0 ± 1.2‰ on 48 turkeys from P II–III sites in northwest New Mexico. Whereas, 80 turkeys from Arroyo Hondo Pueblo in central New Mexico (~1300–1425 CE) exhibited a $\delta^{13}C_{apt}$ value of -1.5 ± 0.7‰ (Conrad et al. 2016). Finally, Thornton et al. (2016) report an average Mayan turkey Pre- to Postclassic turkey value of −4.8‰ ($n = 27$) (Thornton et al. 2016). Mesa Verde $\delta^{13}C_{apt}$ values by site fall within this range. In all three cases, maize provisioning was clearly evident with C_4 intake making up 65–70% of reported turkey diets; indicating that approximately a third of these turkeys' diet consisted of other components such as C_3 forage (fats, nuts, seeds, flowers) and invertebrates (Thornton et al. 2016; McCaffery et al. 2021). In accord with these results, maize comprised an average ~61 ± 4% of Mesa Verde turkey diets (Table 3), well within the range of comparable human diets (e.g., Coltrain et al. 2007:Table 2; Coltrain and Janetski 2013:Table 4; Martin 1999:Table 2; Spielmann et al. 1990:Table 2). The most positive Mesa Verde $\delta^{13}C_{apt}$ values (−0.5‰) from both Shields Pueblo and Albert Porter indicate 75% maize intake while the least positive (−6.0‰) also from Albert Porter reflects 36% reliance on maize. Maize provisioning declines, both within and across sites during Late Pueblo III and Terminal Pueblo III with intake dropping by ca. 15%. Pre-Late Pueblo III reliance on maize averages 64%, whereas maize intake during later periods averages 56%, again reflecting pressure on the Mesa Verde resource base likely due to human population demands and a period of drought that negatively impacted maize yields.

$^{87}Sr/^{86}Sr$ results

A subset of thirty-two turkeys was analyzed for $^{87}Sr/^{86}Sr$. These samples were selected to cover the range of $\delta^{13}C$ values and to represent every time period. Samples from Albert Porter ($n = 9$) fall within the range 0.70939–0.70955; those from Sand Canyon ($n = 7$) exhibit a similar range between 0.70936 and 0.70958. In contrast, samples from Shields ($n = 16$) cover a wider range of values 0.70916–0.71009 including one sample with a much higher Sr value (MVSrB174 0.71009), and two samples with the lowest values in our dataset (MVSrB137 and MVSrB197 at 0.70916 and 0.70926, respectively) (Table 2, Fig. 3). Increased variation in Shields Pueblo Sr values is due in part to sampling; 48% of turkeys sampled in the study derive from Shields; 50% of the reported Sr values are on Shields' turkeys, and occupation of the site covers nearly the full temporal range of the study, Pueblo I to Late Pueblo III. Thus, Shields Pueblo Sr data are likely representative of spatiotemporal variation in turkey procurement across the study area, suggesting that, with few exceptions, turkeys found in sampled Mesa Verde faunal assemblages were raised locally. In contrast, MVSrB174, with a Sr values of 0.71009, was both not acquired locally and a not from a managed, maize-provisioned flock given a $\delta^{13}C_{apt}$ value of −10.9‰.

Figure 3 shows also that, with the exception of Shields Pueblo outliers, no temporal trends are present in our Sr data whether within or across sites.

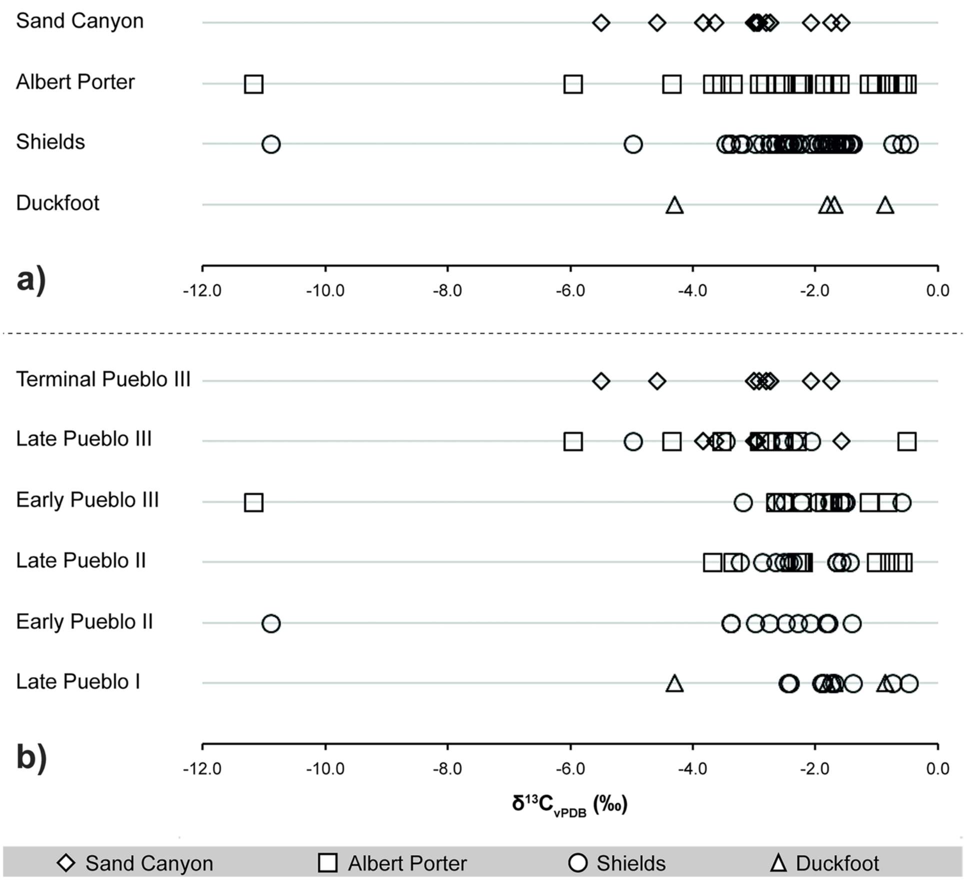
All turkey samples, except the three outliers noted above, express $^{87}Sr/^{86}Sr$ values that fall within the "McElmo Dome Interval," namely the local range plus or minus standard error as defined in Burlot et al. (2022) (Table 2, Fig. 3: red band; see Appendix 1 for a more detailed description of the isotopic baseline).

Two samples recovered at Shields have lower Sr isotopic ratios: MVSrB137 and MVSrB197, 0.70916 and 0.70926, respectively (Figs. 3 and 4a). These low $^{87}Sr/^{86}Sr$ values can correspond to several zones in the region, including all those adjacent to the "local" one (Fig. 4a–c). Benson et al. (2009) analyzed synthetic soil-waters from the McElmo Dome, reporting a $^{87}Sr/^{86}Sr$ range of 0.70925–0.70971. Given these comparative data, sample MVSrB197 $^{87}Sr/^{86}Sr$ may be considered local and was clearly raised in a provisioned flock with a $\delta^{13}C$ value of −2.7‰. Furthermore, such low Sr isotopic ratios exclude the mountainous regions to the east and northeast (zones 5 and 6), as well as the region south of the Sleeping Ute Mountain, the Montezuma Valley (zone 10), and the area near Mancos River and its tributaries (zone 8) (Fig. 4b). The southern part of zone 11, located along the San Juan River and its tributaries, may be excluded as well. Samples from our isotopic baseline collected in this area are in agreement with Benson's Sr data.

Among the two samples whose Sr isotope ratios are higher than those of zone 1, MVSrB235 features a $^{87}Sr/^{86}Sr$ value of 0.70958, 0.00002 more positive than those of the McElmo Dome Interval but within both standard error and the range of values reported by Benson et al. (2009) (Figs. 3 and 4a). Although this value falls within ranges determined for adjacent zones to the east (zones 3 and 4), namely along the Dolores River and to the south (zone 2) and west (zone 11) (Fig. 4d), the bird was clearly maize fed given a $\delta^{13}C$ value of −1.7‰, and we consider it local.

Conversely, sample MVSrB174 from Shields Pueblo exhibits a Sr isotopic ratio of 0.71009, well above the McElmo Dome Interval (Figs. 3 and 4a). According to the

Fig. 2 δ^{13}C$_{apt}$ of turkeys from the Mesa Verde region classified by **a)** site and **b)** period



strontium isotopic baseline defined for the study area, this value falls into only two regions, zones 4 and 5 located in the San Juan Mountains several tens of kilometers northeast of the archaeological sites under study (Fig. 4e). With a δ^{13}C value of – 10.9‰, this turkey was clearly wild caught at some distance from Shields Pueblo and transported to the site for consumption.

δ^{18}O results

δ^{18}O$_{VSMOW}$ values for all turkey samples ranged from 17.8 to 27.8‰ with a mean of 22.5 ± 1.9‰ (Table 2 and 3). The Duckfoot site (1926 masl), mean is 24.6 ± 1.8‰, range 24.0–27.0‰. At Sand Canyon (2019 masl), turkey samples average 23.8 ± 2.1‰, range 21.2–27.8‰. Albert Porter (2053 masl) average δ ^{18}O is 21.5 ± 1.7‰, range 17.8–24.6‰. Shields Pueblo (2052 masl) δ^{18}O averages 22.4 ± 1.6‰, range 19.1–26.4‰. The Duckfoot mean is significantly enriched relative to Albert Porter ($p = 0.03$, $t = 3.16$, $df = 4$), and the Shields Pueblo mean is significantly different from both Sand Canyon ($p = 0.02$, $t = -2.44$, $df = 24$) and Albert Porter ($p = 0.02$, $t = 2.41$, $df = 52$).

Local populations drinking from the same water source typically exhibit a ~ 2–4‰ range of bulk bone or enamel oxygen isotope values (White et al. 2004; Evans et al. 2006; Coltrain and Janetski 2013) consistent with a 2.4‰ range reported for a local suite of modern domesticated animals. Whereas the range of oxygen values from Duckfoot is 3‰, well within an expected value for animals drinking from the same water source (although not likely to be representative given small sample size), the range of values from the remaining three sites is wider than expected averaging 6.9 ± 0.4‰. Further, among the six turkeys exhibiting δ^{18}O values lower than 20‰, all date late in the sequence, to the Early Pueblo III or Late Pueblo III; five also expressed δ ^{13}C lower than their site means, suggesting that these birds ranged more widely and were less well provisioned than their counterparts. Among these six birds, three expressed Sr values within site ranges; two were not sampled for Sr, whereas MVSrB197 was one of two turkeys with a Sr value (0.70926) below the range for samples from Shields Pueblo. Eighteen turkeys exhibited δ^{18}O values more positive than 24‰, spanning the temporal range of the study. Higher oxygen values are likely the consequence of drinking from highly evaporated standing pools or containers of water as would be expected among penned birds. Standing water typically exhibits higher evaporation rates than flowing water sources or water sources replenished frequency by precipitation, increasing δ^{18}O. Finally, the Duckfoot site

Table 3 Turkey $\delta^{13}C_{apt}$ and $\delta^{18}O_{vSMOW}$ averages, standard deviations (Stdev), and ranges (‰) calculated by period for each site

Site	masl	Era	*n*	$\delta^{13}C_{apt}$			% C_4	$\delta^{18}O_{vSMOW}$		
				Average	Stdev	‰ Range		Average	Stdev	Range
Duckfoot	1926	**Site Avg**	**4**	**−2.2**	**1.5**	**3.4**	**62.9**	**24.6**	**1.8**	**22.6–27.0**
		P I	4	−2.2	1.5	3.4	62.9	24.6	1.8	22.6–27.0
Shields	2052	**Site Avg**	**46**	***−2.2***	***0.8***	**4.5**	**62.9**	**22.4**	**1.6**	**19.1–26.4**
		P I	9	−1.6	0.7	1.9	67.1	22.1	0.7	21.3–23.4
		EP II	10	*−2.4*	*0.7*	2.0	61.4	23.2	2.0	20.5–26.4
		LP II	10	−2.2	0.6	1.8	62.9	22.3	1.3	20.8–24.1
		EP III	10	−2.0	0.7	2.6	64.3	22.3	2.0	19.1–26.1
		LP III	7	−3.0	1.0	2.9	57.1	22.1	1.8	19.9–25.8
Albert Porter	2053	**Site Avg**	**26**	***−2.3***	*1.3*	**5.5**	**62.1**	**21.5**	**1.7**	**17.8–24.6**
		LP II	10	−1.9	1.1	3.1	65.0	21.9	1.0	20.9–24.6
		EP III	8	*−1.8*	*0.6*	1.9	65.7	21.6	1.8	18.0–24.6
		LP III	8	−3.1	1.6	5.5	56.4	20.8	2.2	17.8–24.2
Sand Canyon	2019	**Site Avg**	**17**	**−3.1**	**1.0**	**3.4**	**56.4**	**23.8**	**2.1**	**21.2–27.8**
		LP III	7	−3.1	0.8	2.2	56.4	24.4	1.9	22.4–27.8
		TP III	10	−3.1	1.1	3.8	56.4	23.4	2.2	20.8–27.0
Period			*n*							
Pueblo I			13	−1.8	1.0	3.8	65.7	22.9	1.6	21.3–27.0
Early Pueblo II			10	−2.4	0.7	2.0	61.4	23.2	2.0	20.5–26.4
Late Pueblo II			20	−2.1	0.9	3.1	63.6	22.1	1.2	20.8–24.6
Early Pueblo III			18	−1.9	0.7	2.6	65.0	22.0	1.9	18.0–26.1
Late Pueblo III			22	−3.1	1.1	5.5	56.4	22.3	2.4	17.8–27.8
Terminal Pueblo III			10	−3.1	1.1	3.8	56.4	23.4	2.2	20.8–27.0

Italicized values correspond to those from which the mean and standard deviations were calculated after the subtraction of samples MVSrB002 and MVSrB174 from the sites Albert Porter and Shields, respectively

is approximately 100 m lower in elevation than the other three sites, and although few in number, Duckfoot samples express the most positive mean $\delta^{18}O$ value in keeping with both elevation/temperature-mediated precipitation values and evaporative increase in $\delta^{18}O$ (Fricke and O'Neil 1996, 1999; Daux et al. 2005).

Discussion

The combination of McElmo Dome isotopic data presented here illustrates a shift in turkey management during the social and environmental changes occurring at the end of the Pueblo III period in the Mesa Verde area. The fine-grained dating obtained for sites under study allows us to distinguish subperiods within the Puebloan era, facilitating documentation of trends in turkey management over time.

Changes in turkey diet during the Late Pueblo III period

With the exception of two samples, MVSrB002 and MVSrB174, bone apatite $\delta^{13}C$ data attest that turkeys were fed a C_4-based diet, presumably dominated by maize, with moderate input from C_3 resources (Fig. 2) until Late Pueblo and Terminal Pueblo III. Maize-based diets have been reported at Shields Pueblo (Rawlings and Driver 2010) and other Puebloan sites in the northern Southwest (McCaffery et al. 2014, 2021; Conrad et al. 2016). However, no measurable changes in diet over time were reported, and intake of maize was estimated to average 65–70%. Our estimate is slightly lower for earlier periods in the study, and even lower for post-1225 CE, given endmember and fractionation factors cited above. These findings are not surprising given that average $\delta\ ^{13}C$ values for Mesa Verde turkeys were less positive than those reported by Conrad et al. (2016) and McCaffery et al. (2014), and our dataset can be partitioned into discrete temporal windows. It is clear that from perhaps as early as the Basketmaker III period (post-600 CE) (McCaffery et al. 2021), managed turkey flocks were maintained across the greater Southwest. The birds were provisioned with maize and allowed to forage to varying degrees for invertebrates and C_3 plants.

The carbon isotope chemistry of samples MVSrB002 and MVSrB174 (Table 2) is in contrast with that of managed birds, showing diets comprised virtually entirely of C_3 forage, comparable to values measured on modern, wild turkey

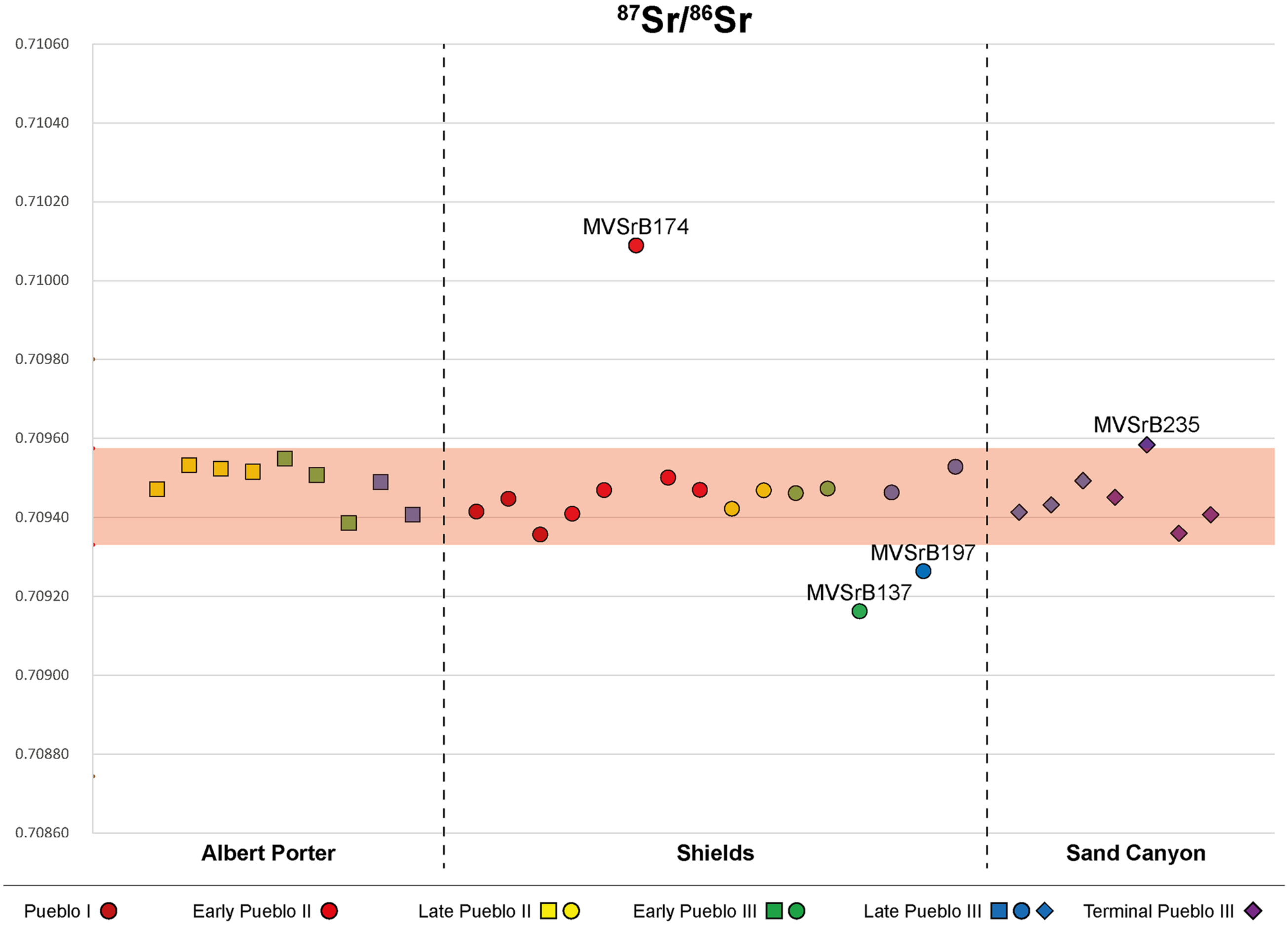


Fig. 3 ^{87}Sr/^{86}Sr measurements of turkeys from the Mesa Verde region classified by site and period. The red band corresponds to the Zone 1 ^{87}Sr/.^{86}Sr interval (+2σ)

from the region (Jones et al. 2016). Despite the presence of managed maize-provisioned flocks, wild turkeys were at least occasionally harvested and returned to Puebloan sites for consumption.

It is interesting to note that turkey maize consumption did not change significantly over time in the study area until Late and Terminal Pueblo III. Turkey production (as inferred from the proportion of turkey to lagomorph bone in assemblages in the study area) increased substantially in the Late Pueblo II and Early Pueblo III periods (Schollmeyer and Driver 2013), but this shift was not accompanied by a significant change in turkey maize consumption in our study sample.

During the late thirteenth century, with increasing aridity in the McElmo Dome region, turkeys were fed less maize. Perhaps as people faced lower yield harvests, maize was prioritized for human consumption. Resource stress is further documented at McElmo Dome sites by a decline in lagomorph and artiodactyl NISP during the Terminal Pueblo III (Ellyson et al. 2019). Kuckelman argues that raising turkey during the late Puebloan period required too great an investment in vital maize stores necessitating less intensified breeding efforts and reduced investment in managed and provisioned flocks (Kuckelman 2010). Our data support this assessment.

Zones of turkey production

All but two Shields Pueblo turkeys, MVSrB137 and MVSrB174, feature ^{87}Sr/^{86}Sr within the local isotopic signature defined by both our isotopic baseline (Burlot et al. 2022) and the Sr isotope values of soil samples collected in the McElmo Dome region (Benson et al. 2009). This finding is consistent with the understanding that turkeys were managed by Puebloan maize farmers using locally grown maize, as further attested by the discovery of pens and enclosures at several sites in the region (Munro 2011; Conrad 2022). Among the two samples with ^{87}Sr/^{86}Sr values that deviate from the McElmo Dome range, MVSrB137 Sr values match those of adjacent areas such as zone 2 (Fig. 4b, c). Because this bird also featured a higher $\delta^{13}C_{apt}$ and a local $\delta^{18}O$ signature, we suggest it was raised near sites under study

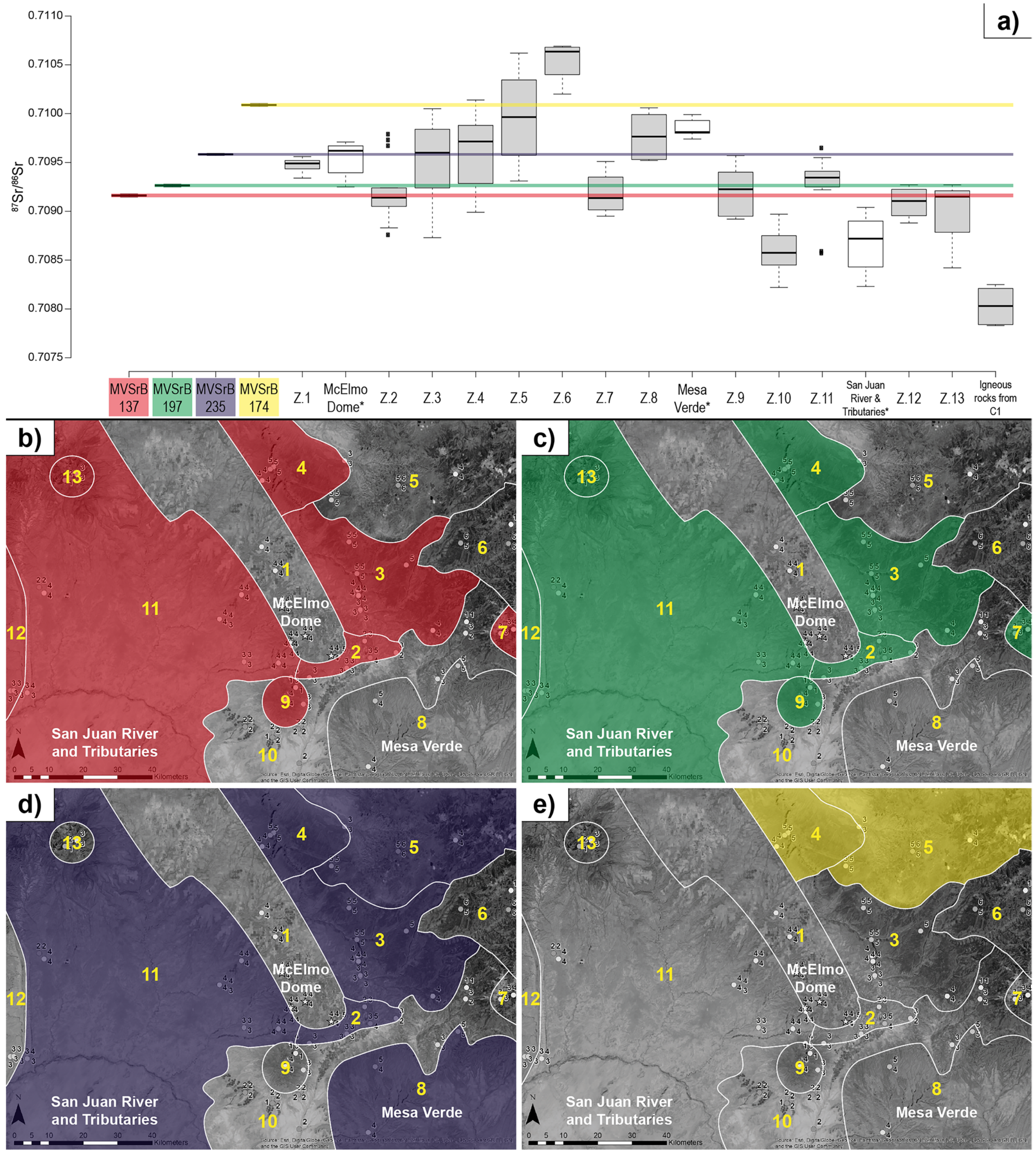


Fig. 4 **a)** ^{87}Sr/^{86}Sr ranges from Mesa Verde' main zones (grey boxplots represent data from Burlot et al. 2022; white boxplots and * represent data from Benson et al. 2009). **b)** Potential zones, in red, from which sample MVSrB137 might have come according to its ^{87}Sr/^{86}Sr. **c)** Potential zones, in green, from which sample MVSrB197 might have come according to its ^{87}Sr/^{86}Sr. **d)** Potential zones, in blue, from which sample MVSrB235 might have come according to its ^{87}Sr/^{86}Sr. **e)** Potential zones, in yellow, from which sample MVSrB174 might have come according to its ^{87}Sr/^{86}Sr

and perhaps brought or traded into McElmo Dome sites for consumption. In contrast, MVSrB174 was clearly wild caught at some distance from McElmo Dome given a significantly less positive $\delta^{13}C_{apt}$ value (– 10.9‰) and Sr signature consistent with the San Juan mountainous region 40 km to the northeast of the study area (Fig. 4e). We hypothesize that this turkey was likely encountered during an upland hunting trip and returned to Shields Pueblo for consumption (Benson et al. 2009).

Having argued for the possibility that provisioned birds moved between sites in the region, it is important to note that empirically determining the movement of turkeys across McElmo Dome sites in Mesa Verde is not possible. Because the interval of turkey Sr isotope values is very narrow and completely overlaps for all sites in the study, we cannot differentiate turkey production areas over time and space. Inter-village exchanges that may well have taken place during this period cannot be traced with present Sr data.

As noted above, average site $\delta^{18}O$ values fell within a narrow local range of 21.5–24.6‰, but the range of within-site oxygen isotope values varied more widely as might be expected of penned birds drinking from standing water sources variably affected by evapotranspiration. Lower elevation sites, Sand Canyon and Duckfoot, exhibited slightly more positive average $\delta^{18}O$ values relative to Albert Porter and Shields Pueblo as expected.

Conclusions

Reported isotope data echo previous studies across the greater Southwest in supporting substantial turkey provisioning with maize, and reveal interesting additional temporal variability. Likely domesticated by the Basketmaker III period (Lipe et al. 2016), turkeys were initially raised to provide feathers for making blankets and other items rather than for meat. During the Puebloan period, while continuing to be valued for their feathers, they also became a source of animal protein (Bocinsky 2011). Isotopic data in our study support this interpretation, indicating substantial turkey provisioning with locally grown maize across this time interval. Our study also indicates a shift in Late Pueblo III turkey diets and provisioning, with turkeys receiving measurably less maize as social and environmental conditions for food production became more challenging in the decades before the residential abandonment of this region. Isotopic evidence for occasional use of local (likely wild) turkeys not provisioned with maize, and one non-provisioned turkey brought in from a more distant area. also support the interpretation that turkey use and turkey management were flexible strategies and that people readily shifted their practices to suit changing opportunities and conditions. This is consistent with the high degree of variability evident in turkey penning and tethering practices (Conrad 2022),

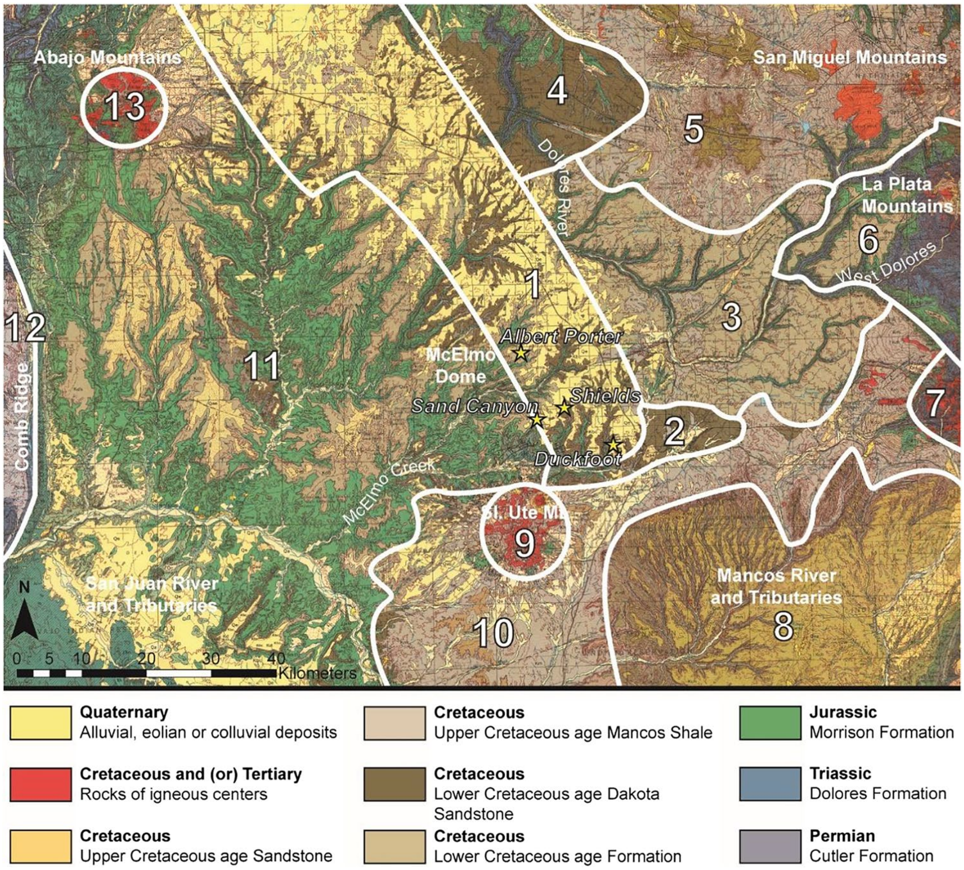


Fig. 5 Map of the Mesa Verde region showing the thirteen main geologic and geographical zones (basemap source: Department of the Interior, United States Geological Survey). Legend simplified from the original map

and indicates that we still have much to learn about how ancient people managed their flocks in the Southwest.

Appendix 1: isotopic baseline of the Mesa Verde Region (US Southwest)

Based on analysis of 55 rodents and 94 plants, Burlot et al. (2022) defined 13 zones in the Mesa Verde region delimited by their geography and geology (Fig. 5). Zone 1, whose geology includes primarily Pleistocene aeolian deposits with exposures of Cretaceous Dakota Sandstone and Upper Jurassic Morrison formation sandstone and mudstone, is the zone in which sites under study are located. Baseline faunal and plant samples collected in this zone feature a strontium isotopic range between 0.70934–0.70956. Called the "McElmo Dome Interval", it distinguishes Zone 1 from other zones in study area. Zone 6, corresponding to the La Plata Mountains, presents higher $^{87}Sr/^{86}Sr$ values and, conversely, Zone 10, located to the south, has lower $^{87}Sr/^{86}Sr$ values (Burlot et al. 2022).

Acknowledgements We thank Bridget Ambler and the staff of the Canyons of the Ancients Visitor Center and Museum for their assistance with the archaeological sample collection. We also thank Bruce Bradley, David Dove, and Four Corners Research and the staff of Crow Canyon Archaeological Center for their assistance with additional samples.

Author contribution Jacques Burlot: conceptualization, formal analysis, investigation, writing—original draft, writing—review and editing, visualization, and supervision; Joan Brenner-Coltrain: conceptualization, methodology, validation, formal analysis, investigation, writing—original draft, writing—review and editing, and funding acquisition; Virginie Renson: conceptualization, methodology, validation, investigation, writing—review and editing, and funding acquisition; Karen Schollmeyer: conceptualization, resources, writing—review and editing, and funding acquisition; Amanda Werlein: investigation; Jeffrey R. Ferguson: conceptualization, resources, writing—review and editing, project administration, and funding acquisition.

Funding This project is funded by a National Science Foundation grant (BCS-1460436) to Jeffrey R. Ferguson and Karen Schollmeyer. The acquisition of the Nu Plasma II MC-ICP-MS was funded by the National Science Foundation (grant BCS-0922374). The Archaeometry Laboratory is supported by the National Science Foundation (grant BCS-1912776).

Data Availability All isotopic data presented in this article are accessible in Table 2. As for those used to define the isotopic baseline of the studied area, they are accessible via Table 1 of the article by Burlot et al. (2022).

Declarations

Competing interests The authors declare no competing interests.

References

Ahlstrom RVN, Van West CR, Dean JS (1995) Environmental and chronological factors in the Mesa Verde-Northern Rio Grande migration. J Anthropol Archaeol 14:125–142. https://doi.org/10.1006/jaar.1995.1007

Badenhorst S, Driver JC (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. https://doi.org/10.1016/j.jas.2009.04.006

Badenhorst S, Driver JC, Ryan SC (2019) Desirable meat: the social context of meat procurement at Albert Porter Pueblo, a Great House Community in the Central Mesa Verde Region. Kiva 85:191–213. https://doi.org/10.1080/00231940.2019.1579442

Benson LV, Stein JR, Taylor HE (2009) Possible sources of archaeological maize found in Chaco Canyon and Aztec Ruin, New Mexico. J Archaeol Sci 36:387–407. https://doi.org/10.1016/j.jas.2008.09.023

Bentley RA (2006) Strontium isotopes from the earth to the archaeological skeleton: a review. J Archaeol Method Theory 13(3):135–187. https://doi.org/10.1007/s10816-006-9009-x

Bocinsky RK (2011) Is a Bird in the Hand Really Worth Two in the Bush? Models of Turkey Domestication on the Colorado Plateau. Unpublished M.A, Thesis, Department of AnthropologyWashington State University

Bocinsky RK, Jason AC, Timothy AK, Johnson CD (2012) How Hunting Changes the VEP World, and How the VEP World Changes Hunting. In: Kohler TA, Varien MD (eds) Emergence and Collapse of Early Villages: Models of Central Mesa Verde Archaeology. University of California Press, Berkeley, pp 145–152

Bryant JD, Koch PL, Froelich PN et al (1996) Oxygen isotope partitioning between phosphate and carbonate in mammalian apatite. Geochim Cosmochim Acta 60:5145–5148

Burlot J, Schollmeyer K, Renson V et al (2022) Defining isotopic signatures of potential procurement sources: A case study in the Mesa Verde region of the US Southwest. J Archaeol Sci Rep 41:103334. https://doi.org/10.1016/j.jasrep.2021.103334

Cerling TE, Harris JM (1999) Carbon isotope fractionation between diet and bioapatite in ungulate mammals an implications for ecological and paleoecological studies. Oecologia 120:347–363

Cerling TE, Harris JM, MacFadden BJ et al (1997) Global vegetation change through the Miocene/Pliocene boundary. Nature 389:153–158. https://doi.org/10.1038/38229

Cerling TE, Ehleringer JR, Harris JM (1998) Carbon dioxide starvation, the development of C4 ecosystems, and mammalian evolution. Philos Trans R Soc Lond B Biol Sci 353:159–171. https://doi.org/10.1098/rstb.1998.0198

Coltrain JB, Janetski JC (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. https://doi.org/10.1016/j.jas.2013.07.012

Coltrain JB, Leavitt SW (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. https://doi.org/10.2307/1593822

Coltrain JB, Janetski JC, Carlyle SW (2007) The stable- and radio-isotope chemistry of western basketmaker burials: implications for early Puebloan diets and origins. Am Antiq 72:301–321. https://doi.org/10.2307/40035815

Conrad C (2022) Contextualizing Ancestral Pueblo Turkey (Meleagris gallopavo spp.) Management. J Archaeol Method Theory 29:624–665. https://doi.org/10.1007/s10816-021-09531-9

Conrad C, Jones EL, Newsome SD, Schwartz DW (2016) Bone isotopes, eggshell and turkey husbandry at Arroyo Hondo Pueblo. J Archaeol Sci Rep 10:566–574. https://doi.org/10.1016/j.jasrep.2016.06.016

Coplen TB, Kendall C, Hopple J (1983) Comparison of stable isotope reference samples. Nature 302:236–238. https://doi.org/10.1038/302236a0

Cotton JM, Cerling TE, Hoppe KA et al (2016) Climate, CO2, and the history of North American grasses since the Last Glacial Maximum. Sci Adv 2:e1501346. https://doi.org/10.1126/sciadv.1501346

Daux V, Lécuyer C, Adam F et al (2005) Oxygen isotope composition of human teeth and the record of climate changes in France (Lorraine) during the last 1700 years. Clim Change 70:445–464. https://doi.org/10.1007/s10584-005-5385-6

Decker KW, Tieszen LL (1989) Isotopic Reconstruction of Mesa Verde Diet from Basketmaker III to Pueblo III. Kiva 55:33–47. https://doi.org/10.1080/00231940.1989.11758135

Driver JC (1997) Zooarchaeology and Social Organization in Non-State Societies. Anthropozoologica 25–26:79–84

Driver JC (2002) Faunal Variation and Change in the Northern San Juan Region. In: Varien MD, Wilshusen RH (eds) Seeking the Center Place: Archaeology and Ancient Communities in the Mesa Verde Region. University of Utah Press, Salt Lake City, pp 143–160

Ehleringer JR, Monson RK (1993) Evolutionary and ecological aspects of photosynthetic pathway variation. Evol Ecol Asp Photosynthetic Pathway Var 24:411–439. https://doi.org/10.1146/annurev.es.24.110193.002211

Ehleringer JR, Cerling TE, Helliker BR (1997) C4 photosynthesis, atmospheric CO2, and climate. Oecologia 112:285–299. https://doi.org/10.1007/s004420050311

Ellyson LJ, Nagaoka L, Wolverton S (2019) Animal resource use related to socioenvironmental change among Mesa Verde farmers. J Anthropol Res 75:361–392. https://doi.org/10.1086/704143

Evans J, Stoodley N, Chenery C (2006) A strontium and oxygen isotope assessment of a possible fourth century immigrant population in a Hampshire cemetery, southern England. J Archaeol Sci 33:265–272. https://doi.org/10.1016/j.jas.2005.07.011

Farquhar GD, Ehleringer JR, Hubick KT (1989) Carbon isotope discrimination and photosynthesis. Annu Rev Plant Physiol Plant Mol Biol 40:503–537

Fricke HC, O'Neil JR (1996) Inter- and intra-tooth variation in the oxygen isotope composition of mammalian tooth enamel phosphate: implications for palaeoclimatological and palaeobiological research. Palaeogeogr Palaeoclimatol Palaeoecol 126:91–99. https://doi.org/10.1016/S0031-0182(96)00072-7

Fricke HC, O'Neil JR (1999) The correlation between 18O/16O ratios of meteoric water and surface temperature: its use in investigating terrestrial climate change over geologic time. Earth Planet Sci Lett 170:181–196. https://doi.org/10.1016/S0012-821X(99)00105-3

Fricke HC, O'Neil JR, Lynnerup N (1995) Oxygen isotope composition of human tooth enamel from medieval Greenland: linking climate and society. Geology 23:869–872. https://doi.org/10.1130/0091-7613(1995)023%3c0869:SROICO%3e2.3.CO;2

Grimstead DN, Bayham FE (2010) Evolutionary ecology, elite feasting, and the Hohokam: a case study from a Southern Arizona Platform Mound. Am Antiq 75:841–864. https://doi.org/10.7183/0002-7316.75.4.841

Grimstead DN, Reynolds AC, Hudson AM et al (2016) Reduced Population Variance in Strontium Isotope Ratios Informs Domesticated Turkey Use at Chaco Canyon, New Mexico, USA. J Archaeol Method Theory 23:127–149. https://doi.org/10.1007/s10816-014-9228-5

Hegmon M (1989) Risk reduction and variation in agricultural economies: a computer simulation of Hopi agriculture. Res Econ Anthropol 11:89–121

Hoppe KA (2006) Correlation between the oxygen isotope ratio of North American bison teeth and local waters: Implication for paleoclimatic reconstructions. Earth Planet Sci Lett 244:408–417. https://doi.org/10.1016/j.epsl.2006.01.062

Johnson CD, Kohler TA, Cowan J (2005) Modeling historical ecology, thinking about contemporary systems. Am Anthropol 107:96–107. https://doi.org/10.1525/aa.2005.107.1.096

Jones EL, Conrad C, Newsome SD et al (2016) Turkeys on the fringe: variable husbandry in "marginal" areas of the prehistoric American Southwest. J Archaeol Sci Rep 10:575–583. https://doi.org/10.1016/j.jasrep.2016.05.051

Judge J (1989) Chaco Canyon - San Juan Basin. In: Cordell LS, Gumerman GJ (eds) Dynamics of Southwest Prehistory. Smithsonian Institution Press, Washington D.C., pp 209–262

Kellner CM, Schoeninger MJ (2007) A simple carbon isotope model for reconstructing prehistoric human diet. Am J Phys Anthropol 133:1112–1127

Kemp BM, Judd K, Monroe C et al (2017) Prehistoric mitochondrial DNA of domesticate animals supports a 13th century exodus from the northern US southwest. PLoS ONE 12:e0178882. https://doi.org/10.1371/journal.pone.0178882

Kohler TA, Bocinsky RK, Cockburn D et al (2012) Modelling prehispanic Pueblo societies in their ecosystems. Ecol Model 241:30–41. https://doi.org/10.1016/j.ecolmodel.2012.01.002

Kuckelman KA (2010) The depopulation of Sand Canyon Pueblo, a large ancestral Pueblo village in Southwestern Colorado. Am Antiq 75:497–525

Lightfoot RR, Kuckelman KA (2001) A Case of Warfare in the Mesa Verde Region. In: LeBlanc SA, Rice GE (eds) Deadly landscapes: case studies in Prehistoric Southwestern Warfare. University of Utah Press, Salt Lake City, pp 51–64

Lipe WD (1995) The depopulation of the Northern San Juan: conditions in the turbulent 1200s. J Anthropol Archaeol 14:143–169. https://doi.org/10.1006/jaar.1995.1008

Lipe WD, Bocinsky RK, Chisholm BS et al (2016) Cultural and genetic contexts for early Turkey domestication in the Northern Southwest. Am Antiq 81:97–113. https://doi.org/10.7183/0002-7316.81.1.97

Lipe WD, Tushingham S, Blinman E et al (2020) Staying warm in the upland southwest: a "supply side" view of turkey feather blanket production. J Archaeol Sci Rep 34:102604. https://doi.org/10.1016/j.jasrep.2020.102604

Little JDC, Little EA (1997) Analysing prehistoric diets by linear programming. J Archaeol Sci 24:741–747. https://doi.org/10.1006/jasc.1996.0155

Martin SL (1999) Virgin Anasazi diet as demonstrated through the analysis of stable carbon and nitrogen isotopes. Kiva 64:495–514. https://doi.org/10.1080/00231940.1999.11758395

McCaffery H, Tykot RH, Gore KD, DeBoer BR (2014) Stable isotope analysis of turkey (Meleagriscc Gallopavo) diet from Pueblo II and Pueblo III sites, Middle San Juan Region, Northwest New Mexico. Am Antiq 79:337–352. https://doi.org/10.7183/0002-7316.79.2.337

McCaffery H, Miller K, Tykot RH (2021) Paleodiet of Turkeys (Meleagris gallopavo) in the Early Pueblo Period of the Northern Southwest. Kiva 87:129–151. https://doi.org/10.1080/00231940.2021.1891713

Muir RJ, Driver JC (2002) Scale of analysis and zooarchaeological interpretation: Pueblo III faunal variation in the Northern San Juan Region. J Anthropol Archaeol 21:165–199. https://doi.org/10.1006/jaar.2001.0392

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

Munro ND (2011) Chapter 22: Domestication of the Turkey in the American Southwest. In: Smith BD (ed) The Subsistence Economies of Indigenous North American Societies: A Handbook. Smithsonian Institution Scholarly Press, Washington D.C., pp 543–555

Muynck DD, Huelga-Suarez G, Heghe LV et al (2009) Systematic evaluation of a strontium-specific extraction chromatographic resin for obtaining a purified Sr fraction with quantitative recovery from complex and Ca-rich matrices. J Anal at Spectrom 24:1498–1510. https://doi.org/10.1039/B908645E

Nelson MC, Schollmeyer KG (2003) Game Resources, Social Interaction, and the Ecological Footprint in Southwest New Mexico. J Archaeol Method Theory 10:69–110. https://doi.org/10.1023/A:1024525428186

Ortman SG (2016) Uniform Probability Density Analysis and Population History in the Northern Rio Grande. J Archaeol Method Theory 23:95–126. https://doi.org/10.1007/s10816-014-9227-6

Ortman SG, Varien MD, Gripp TL (2007) Empirical Bayesian methods for archaeological survey data: an application from the Mesa Verde region. Am Antiq 72:241–272. https://doi.org/10.2307/40035813

Potter JM (1997) Communal ritual and faunal remains: an example from the Dolores Anasazi. J Field Archaeol 24:353–364. https://doi.org/10.1179/009346997792208140

Potter JM (2000) Pots, parties, and politics: communal feasting in the American Southwest. Am Antiq 65:471–492. https://doi.org/10.2307/2694531

Rawlings TA, Driver JC (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. https://doi.org/10.1016/j.jas.2010.05.004

Schollmeyer KG (2011) Large game, agricultural land, and settlement pattern change in the eastern Mimbres area, southwest New Mexico. J Anthropol Archaeol 30:402–415. https://doi.org/10.1016/j.jaa.2011.04.004

Schollmeyer KG, Driver JC (2013) Settlement patterns, source–sink dynamics, and artiodactyl hunting in the Prehistoric U.S. Southwest J Archaeol Method Theory 20:448–478. https://doi.org/10.1007/s10816-012-9160-5

Schollmeyer KG, Driver JC (2023) Fine-grained chronology reveals human impacts on animal populations in the Mesa Verde Region of the American Southwest. In: Ryan S (ed) Research, Education, and American Indian Partnerships at the Crow Canyon Archaeological Center. University Press of Colorado, Boulder, pp 335–346

Schwindt DM, Bocinsky RK, Ortman SG et al (2016) The social consequences of climate change in the Central Mesa Verde Region. Am Antiq 81:74–96

Speller CF, Kemp BM, Wyatt SD et al (2010) Ancient mitochondrial DNA analysis reveals complexity of indigenous North American turkey domestication. PNAS 107:2807–2812. https://doi.org/10.1073/pnas.0909724107

Spielmann KA, Schoeninger MJ, Moore K (1990) Plains-Pueblo interdependence and human diet at Pecos Pueblo, New Mexico. Am Antiq 55:745–765. https://doi.org/10.2307/281248

Thirlwall MF (1991) Long-term reproducibility of multicollector Sr and Nd isotope ratio analysis. Chem Geol 94:85–104. https://doi.org/10.1016/0168-9622(91)90002-E

Thornton E, Emery KF, Speller C (2016) Ancient Maya turkey husbandry: testing theories through stable isotope analysis. J Archaeol Sci Rep 10:584–595. https://doi.org/10.1016/j.jasrep.2016.05.011

Varien MD, Ortman SG, Kohler TA et al (2007) Historical ecology in the Mesa Verde Region: results from the Village Ecodynamics Project. Am Antiq 72:273–299. https://doi.org/10.2307/40035814

Walker DN (1993) Faunal Remains. In: Lightfoot RR, Etzkorn MC (eds) The Duckfoot Site, vol 1. Descriptive Archaeology. Crow Canyon Archaeological Center, Cortez, pp 239–252

Wetterstrom W (1986) Food, Diet, and Population at Prehistoric Arroyo Hondo Pueblo. School of American Research Press, Santa Fe, New Mexico

White C, Longstaffe FJ, Law KR (2004) Exploring the effects of environment, physiology and diet on oxygen isotope ratios in ancient Nubian bones and teeth. J Archaeol Sci 31:233–250. https://doi.org/10.1016/j.jas.2003.08.007

Wilcox DR, Haas J (1994) The Scream of the Butterfly: Competition and Conflict in the Prehistoric Southwest. In: Gumerman GJ (ed) Themes in Southwest Prehistory. School of American Research Press, Santa Fe, pp 211–238

Badenhorst S (2008) The Zooarchaeology of Great House Sites in the San Juan Basin of the American Southwest. Unpublished Ph.D. Thesis, Simon Fraser University, Department of Archaeology

Cates KM (2020) Faunal Remains. In: Diederichs SR (ed) The Basketmaker Communities Project. Electronic document. pp 513–584

Crown PL, Orcutt J, Kohler TA (1994) Pueblo cultures in transition: The Northern Rio Grande. In: Adler M (ed) The Prehistoric Pueblo World: A.D. 1150–1350. University of Arizona Press, Tucson, pp 188–204

Diederichs SR (2020) The Basketmaker Communities Project

Lipe WD, Varien MD (1999a) Pueblo II (A.D. 900–1150). In: Lipe WD, Varien MD, Wilshusen RH (eds) Colorado prehistory: a context for the Southern Colorado River Basin. Colorado Council of Professional Archaeologists, Denver, pp 242–289

Lipe WD, Varien MD (1999b) Pueblo III (A.D. 1150–1300). In: Lipe WD, Varien MD, Wilshusen RH (eds) Colorado prehistory: a context for the Southern Colorado River Basin. Colorado Council of Professional Archaeologists, Denver, pp 290–385

Muir RJ (1999) Zooarchaeology of Sand Canyon Pueblo, Colorado. Unpublished Ph.D. Thesis, Simon Fraser University, Department of Archaeology

Rawlings TA (2006) Faunal analysis and meat procurement: reconstructing the sexual division of labor at Shields Pueblo, Colorado. Unpublished Ph.D. Thesis, Simon Fraser University, Department of Archaeology

Spielmann KA, Angstadt-Leto E (1996) Hunting, Gathering and Health in the Prehistoric Southwest. In: Tainter J, Tainter BB (eds) Evolving Complexity and Environmental Risk in the Prehistoric Southwest. Santa Fe Institute Studies in Complexity. Addison-Wesley, Reading, pp 79–106

Wilshusen RH (1999) Pueblo I (A.D. 750–900). In: Lipe WD, Varien MD, Wilshusen RH (eds) Colorado Prehistory: A Context for the Southern Colorado River Basin. Colorado Council of Professional Archaeologists, Denver, pp 196–241

Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH (“Springer Nature”).

Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users (“Users”), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use (“Terms”). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval , sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com