

Climate-Driven Dietary Change on the Colorado Plateau, USA, and Implications for Gender-Specific Foraging Patterns

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Complementary archaeological and paleoenvironmental datasets from North Creek Shelter (Colorado Plateau, Utah, USA) are analyzed using the diet breadth model, revealing human dietary patterns during the early and middle Holocene. Abundance indices are derived from botanical and faunal datasets and, along with stone tools, are used to test the prediction that increasing aridity caused the decline of high-return resources. This prediction appears valid with respect to botanical resources, given that high-ranked plants drop out of the diet after 9800 cal BP and are replaced with low-ranked, small seeds. The prediction is not met, however, with respect to faunal resources: high-ranked artiodactyls are consistently abundant in the diet. The effects of climate change on dietary choices are also examined. Findings show that increased aridity coincides with greater use of small seeds and ground stone tools but not with increases in low-ranked fauna, such as leporids. The patterns observed from the North Creek Shelter botanical and faunal datasets may reflect different foraging strategies between men and women. This would explain why low-ranked plant resources became increasingly abundant in the diet without a corresponding decrease in abundance of high-ranked artiodactyls. If so, then archaeological records with similar datasets should be reexamined with this perspective.

Keywords: diet breadth model, broad spectrum diets, sexual division of labor, abundance indexes, macrobotanical remains, starch granules, tubers, ground stone tools, North Creek Shelter, Holocene

Se analizan, series de datos complementarios arqueológicos y paleo ambientales de la región norte, North Creek Shelter (Meseta del Colorado, Utah, Estados Unidos de America), utilizando el modelo de amplitud de la dieta alimentaria que revela el comportamiento alimenticio humano durante el Holoceno temprano y medio. Abundantes índices de datos botánicos y de fauna, así como de herramientas de piedra, comprueban la hipótesis de que el aumento de la aridez en la zona provocó la disminución de los recursos alimenticios de alto rendimiento. Esta predicción pareciera válida en relación a los recursos botánicos, ya que las plantas de alto rendimiento se eliminan de la dieta después de 9800 cal aP y son reemplazadas por semillas pequeñas de bajo rendimiento. Sin embargo, la predicción no se cumple con respecto a los recursos derivados de la fauna: los artiodáctilos de alto rendimiento son consistentemente abundantes en la dieta. También se examinan los efectos del cambio climático en las elecciones dietéticas, encontrando que el aumento de la aridez coincide con un mayor uso de semillas pequeñas y herramientas de piedra para moler, pero no con aumentos en la fauna de bajo rendimiento, como los leporidos. Los patrones observados en las series de datos botánicos y de fauna de North Creek Shelter pueden reflejar diferentes formas de recolección de alimentos entre hombres y mujeres, lo que explica la discrepancia de que los recursos vegetales de bajo rendimiento se volvieron cada vez más abundantes en la dieta sin una disminución correspondiente en la abundancia de artiodáctilos de alto rendimiento. Basados en esta perspectiva, los hallazgos arqueológicos con series de datos similares deberían de reexaminarse.

Palabras clave: modelo de amplitud de la dieta, dietas de amplio espectro, división de labor por genero, índices de abundancia, residuos macrobotánicos, gránulos de almidón, tubérculos, herramientas de piedra para moler, North Creek Shelter, Holoceno

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The ecology of broad spectrum diets has long been an issue in the prehistory of arid western North America. Broad spectrum diets have been described as energetically expensive, incurring high caloric costs in harvesting, processing, and preparing food materials for human consumption (Flannery 1969). Such diets included seed, insect, and small mammal components that required different technologies and social structures to provide sufficient caloric yields. This “broad spectrum revolution” of subsistence modification occurs around 9000 cal BP in the Great Basin and Colorado Plateau and is associated with the intensive incorporation of small seed processing, basketry, and grinding stone technologies (Geib and Jolie 2018; Rhode et al. 2006; Simms 2008).

The hypothesis that has been most often proposed to explain this dietary pattern is drawn from optimal foraging theory, which suggests that people in general only resorted to low-return small seeds after calorically higher-return resources and high-quality resource patches diminished in abundance (O’Connell et al. 1982). Based on the principles of the diet breadth (or prey choice) model (Stephens and Krebs 1986), food resources are ranked based on their expected post-encounter energetic return rates (kcal/hr) relative to other resources in the diet. Small seeds and other expensive plant resources are typically ranked low compared to large-bodied animals because of their high handling costs relative to energetic yields (Table 1). The diet breadth model predicts that foragers will always pursue higher-ranked resources on encounter and take lower-ranked resources only when encounter rates with higher-ranked resources decline (Schoener 1971). An increase in the abundance of lower-ranked resources in the diet therefore indicates a decline in the availability of high-ranked resources and an overall reduction in foraging efficiency (Bayham 1979; Broughton and Grayson 1993; Kelly 1995a; Winterhalder and Smith 1992).

This hypothesis, however, assumes an “average” or “undifferentiated” forager. It does not take into account differentiated and specialized roles in foraging strategies, such as age or gender, nor does it account for other hunting technologies (Hawkes and O’Connell 1992:64;

Jochim 1988:130; Kelly 2014; Sassaman 1992; Wood et al. 2021). These assumptions are important because the costs and benefits associated with reproductive fitness can differ between men and women (O’Connell et al. 1999). A more nuanced hypothesis (Elston and Zeanah 2002) suggests gender-specific foraging patterns across the Great Basin and Colorado Plateau during the early and middle Holocene. Whereas women foraged in local and reliable resource patches, accumulating low-return resources and investing heavily in plant-processing tools, men pursued fluctuating but highly mobile, large-bodied animals at some distance. It has also been suggested that variability in acquiring large game would lead to women foraging for lower-ranked resources (Elston et al. 2014).

Increasing aridity and vegetation responses have been offered as the ecosystem drivers of global changes in dietary patterns (e.g., Edwards and O’Connell 1995; O’Connell and Hawkes 1981, 1984; O’Connell et al. 1982; Rhode et al. 2006). In the Great Basin and Colorado Plateau specifically, dietary changes have been attributed to intense aridification that began at about 9500 cal BP (e.g., Grayson 2000, 2011; Louderback et al. 2020; O’Connell et al. 1982; Schmitt and Lupo 2012; Simms 2008). However, this paradigm of increasing aridity and dietary response has never been tested quantitatively using multiple lines of evidence from a single site. The current study applies the diet breadth model to understand human dietary patterns through time using the North Creek Shelter (NCS) faunal, botanical, stone tool, and climate datasets.

Although there are several types of measurable parameters used to examine diet breadth and foraging efficiency (e.g., evenness/richness, skeletal representation, age/sex ratio of faunal remains, climate, technology/tools, etc.), this study relies on abundance indexes constructed over time for faunal and botanical resources at NCS. These indexes, along with one for stone tools, are used to test the assumption that increasing aridity during the early to middle Holocene caused the decline of high-return resources and, therefore, led to the incorporation of low-return resources into the diets of the NCS occupants. To determine if diet breadth changes and/or a shift to low-return resources are coincident with

Table 1. Post-encounter Return Rates and Relative Rank of Dietary Resources at North Creek Shelter.

Category	Type	Post-encounter Return Rate (kcal/hr)	Rank
large mammal	deer, pronghorn, bighorn sheep	15,725–31,450	A (high-rank)
small mammal	hares, cottontail rabbits	8,983–15,400	B
tuber (USO) plants	tuber starch granules	50–3,831	C
large seeds and nuts	pinyon seed coats, acorn nuts	69–1,408	D
small seeds	<i>Chenopodium</i> and various small seeds	92–1,307	E (low-rank)

Note: Return-rate values come from the published literature (e.g., Broughton et al. 2011; Couture et al. 1986; Diehl and Waters 2006; Gremillion 2004; Kelly 1995a; Rhode and Rhode 2015; Simms 1987; Smith and Martin 2001; Smith and McNees 2005; Ugan and Rosenthal 2016).



Figure 1. Location of North Creek Shelter (NCS) in Escalante on the Colorado Plateau in southern Utah (indicated by yellow star). Inset map shows the physiographic boundaries of the Great Basin (green) and Colorado Plateau (orange), and the yellow star is the approximate location of NCS.

climate change, an increase in leporids, small seeds, and ground stone tools should be positively correlated with warmer/drier climates. If the patterns do not conform, then alternative hypotheses must be examined.

Site Setting and Stratigraphy

NCS lies at the base (1,900 m asl) of a south-facing sandstone cliff (Straight Cliffs Formation)

overlooking Escalante Valley in southern Utah (Figure 1). The stratigraphic sequence is more than 4 m deep and contains many archaeological features—such as hearths and pits—as well as abundant stone tools, faunal assemblages, and botanical remains (Figure 2). The finds were recovered from cultural strata deposited between 11,300 cal BP and 300 cal BP, and they are defined as Paleoarchaic (Strata II, III, and IV; 11,300–10,200 cal BP), Early Archaic (Stratum

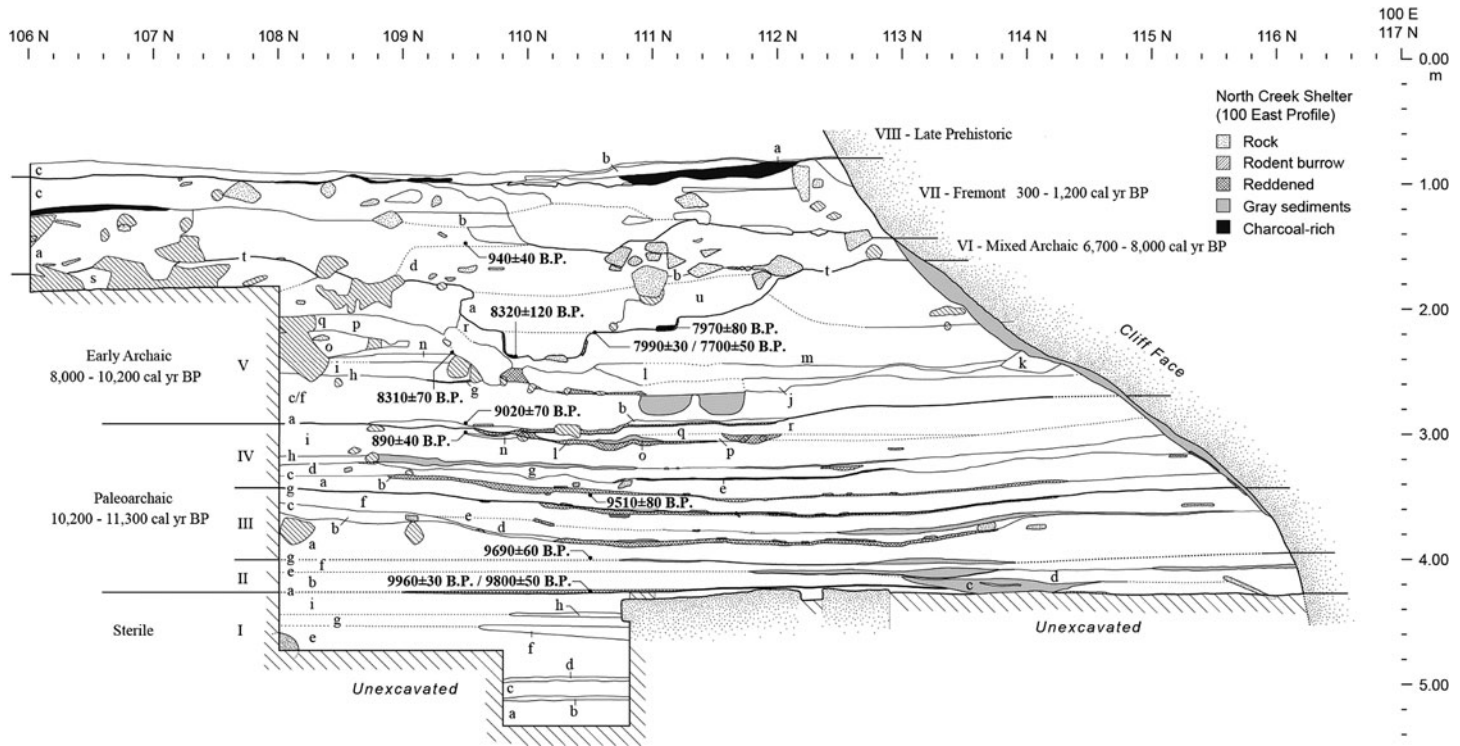


Figure 2. Stratigraphic profile of North Creek Shelter (adapted from Janetski et al. 2012).

V; 10,200–8000 cal BP), Mixed Archaic (Stratum VI; 8000–6700 cal BP), Fremont (Stratum VII; 1200–300 cal BP), and Late Prehistoric (Stratum VIII; Figure 2). The strata were further subdivided into 68 substrata (Va, Vb, Vc, etc.) based on observable changes in the sediments, with some substrata interpreted as short-term living/use surfaces (see Janetski et al. 2012).

The assumption that these use surfaces represent human activity areas and therefore behavioral patterns over time comes from several criteria that Janetski and colleagues (2012) describe. For example, compacted and reddened sediments underlie several use surfaces throughout strata II–V. Artifacts as well as pit and hearth features lie flat and originate from the same surface, measuring just a few centimeters from the reddened sediments. The patterned distribution of artifacts and features (especially those from strata II–V) were sealed rapidly by depositional events during the early Holocene (see Janetski et al. 2012; Louderback et al. 2020). Furthermore, refitting efforts have found that matches occur within these discrete use surfaces.

For this study, dietary faunal and botanical remains are examined from cultural strata II–VI in order to capture the major climatic and vegetation changes (see Louderback et al. 2020) that might affect dietary choices during the early and middle Holocene and therefore reflect patterns in the diet breadth analyses. Stone tool abundances are also examined during this time period to determine if ground stone technology was developed at the same time as low-return resources were incorporated into the diet to maximize overall caloric returns. The chronological framework used by Louderback and colleagues (2020) is also used here. Radiocarbon ages for particular substrata (IIa, IIe, IIg, IIIa, IIIb, IIIe, Va, Vh, Vm, Vt, and VI) were calibrated using OxCal (Bronk-Ramsey and Lee 2013) and then averaged for substrata that did not have an associated radiocarbon age (Supplemental Figure 1; Supplemental Table 1).

Methods

Faunal Dietary Patterns

Faunal remains were recovered from a total of 53 substrata across strata II–VI. Descriptive

summaries of the NCS mammalian fauna can be found in Janetski and colleagues (2012), Newbold (2009), and Johannson (2013). Previous evaluations of NCS faunal remains did not properly account for taphonomy, thereby potentially including noncultural taxa (e.g., carnivores and rodents) in analyses of diet breadth. This was avoided by using the annotated data records and segregating specimens into human and non-human accumulations based on burning and cut marks as cultural markers (see Louderback 2014:Appendices B and D). Additionally, relative abundance indexes had been previously calculated for cultural periods (e.g., Paleoarchaic and Early Archaic) rather than for individual substrata (e.g., Va, Vb, Vc, etc.), thereby blurring any quantitative changes that may have occurred. Consequently, relative abundances were recalculated for individual substrata rather than cultural periods. Applying a more rigorous assessment to faunal cultural markers and reexamining the NCS faunal remains by individual substrata resulted in a dietary dataset different from the ones previously published (Janetski et al. 2012; Newbold 2009). This new assessment excludes carnivores and rodents as dietary taxa (both of which lacked cultural markers) but keeps artiodactyls and leporids (Supplemental Table 2). Taxa were included using the lowest taxonomic category that could be assigned with confidence. Taxa represented by a single specimen in any given substratum were excluded in order to minimize the effects of an accidental movement of specimens across strata (Grayson 1991). The same means of counting taxa and/or specimens was applied consistently across all assemblages. The number of individual specimens (NISP) for dietary faunal remains are provided in Supplemental Table 2 and are archived in Dryad (<https://datadryad.org/stash/dataset/doi:10.5061/dryad.w9ghx3fq3>).

Relative Abundance and Ubiquity. Relative abundance for each dietary faunal taxon was calculated using the following formula: $(\sum \text{NISP}_{\text{taxon}} / \sum \text{NISP}_{\text{all faunal taxa}}) \times 100$. It was used to measure changing abundances of a particular taxon over time, and it can inform about the importance of that taxon to past human diets. Relative abundance was calculated for both dietary faunal and botanical datasets.

The ubiquity index (expressed as a percentage) describes the occurrence of a taxon based on number of features or stratigraphic units in which that resource is recovered: $\% \text{ of taxon}_i = (N \text{ of substrata with taxon}_i / \Sigma N \text{ substrata}) \times 100$ (Popper 1988). Higher percentages indicate more pervasive use over time, which therefore has implications for the stability of resource availability as well as cultural importance. This was calculated for both faunal and botanical datasets.

Botanical Dietary Patterns

Macrobotanical remains (e.g., seeds, seed coats, fruits) were recovered by flotation analysis from hearth features ($n = 156$) excavated from 38 substrata spanning all cultural strata (II–VI) (Louderback 2014; Supplemental Table 2). Because these remains come from discrete hearth features (versus general cultural fill), they are considered human subsistence refuse if there is evidence of charring.

Identification of certain families is made possible by their diagnostic characteristics—such as the thick, ovoid, and large seed coats of Pinaceae or the angular, elongated, and small achenes of Asteraceae. Certain genera are also identified in this way; *Chenopodium* spp., for example, has lenticular, beaked, and rimmed seeds. *C. berlandieri* was isolated from all other *Chenopodium* spp. seeds because it has a distinctive reticulate pericarp and seed-coat patterning (Holmgren et al. 2012). *Rhus* sp. (sumac) seeds are ovoid with a radicle bulge (these specimens are distinctively striated, perhaps due to pericarp impression). In three cases, plant remains are identified to species: *Atriplex confertifolia* (shadscale) by its two-winged fruits, *Achnatherum hymenoides* (Indian ricegrass) by its distinctive flask-shaped achene, and *Solanum jamesii* (Four Corners potato) by its distinctive starch granules (Louderback and Pavlik 2017). Unidentified and indeterminate seeds and fruit are not included in the dietary analyses. The lowest possible taxonomic level was determined by using contemporary reference material from herbaria, seed reference collections, and plant specimens gathered at the study site itself. Local and regional floras are also used (e.g., Heil et al. 2013; Welsh et al. 2015). Nomenclature conforms to USDA GRIN (<https://www.ars-grin.gov/>).

Ninety-four ground stone tools spanning strata V and VI were analyzed for starch granules. The majority of tools were made from sandstone (88%), with quartzite (6%), volcanics (5%), and granite (1%) comprising the remainder. The weight of the tools varied from 4 g to approximately 13.5 kg (see Louderback [2014] for ground stone inventory and data). Starch granules were extracted following the protocols outlined in Louderback (2014) and Louderback et alia (2015), and granules were identified using the approach outlined in Louderback et alia (2017). Only starch granules with eccentric hila have been positively identified (Louderback and Pavlik 2017).

Because there is no way to determine an absolute count of starch granules, NISP is based on the number of ground stone tools that yielded identifiable granules in each substratum. For example, in substratum Vt, three of the 20 ground stone tools bore granules assigned to *Solanum jamesii*. Therefore, the NISP value for *S. jamesii* in substratum Vt is three. The NISP for dietary botanical remains are provided in Supplemental Table 2 and are archived in Dryad (<https://datadryad.org/stash/dataset/doi:10.5061/dryad.w9ghx3fq3>).

Relative Abundance and Ubiquity. Relative abundances and the ubiquity index were also calculated for dietary plant remains, using the same formulas mentioned above.

Abundance Indexes

The abundances of both higher- and lower-return resources are often used in archaeological studies to detect a broadening of the diet (e.g., Broughton 2002; Broughton et al. 2011; Codding et al. 2010). Abundance indexes express variability in foraging efficiency by calculating the ratio of higher-return prey relative to lower-return prey, where 1.0 indicates the sample is composed entirely of higher-return prey and 0.0 indicates the sample is composed entirely of lower-return prey (Bayham 1979; Broughton 2002; Codding et al. 2010; Grayson and Cannon 1999; Nagaoka 2001).

Artiodactyl Index. Bones of artiodactyls and leporids, the two most abundant dietary remains in the NCS faunal assemblage, were used to calculate an artiodactyl index: $(\text{NISP}_{\text{Artiodactyls}} /$

($NISP_{Artiodactyls} + NISP_{Leporids}$). Artiodactyls are typically ranked higher than leporids due to their large body size (e.g., Bayham 1979, Broughton et al. 2011), but recent research suggests that high risks (i.e., failed pursuits) are often not taken into account (Bird et al. 2009; Codding et al. 2010). Furthermore, leporids have been found to be low risk and a reliable resource, thereby increasing their overall return rates (Lupo et al. 2020; Morin et al. 2020). This study uses body size as the primary measure of prey rank and therefore supports the suggestion that artiodactyls are ranked higher than leporids.

High-Return Plant Index. A high-return plant index was calculated and used to detect a broadening of the diet (e.g., Weiss et al. 2004). This index is the ratio of higher-return plant-part remains (i.e., Pinaceae large seeds, *Quercus* nuts, *S. jamesii* tubers) relative to lower-return plant-part remains (i.e., small seeds), where 1.0 indicates the sample is entirely higher-return and 0.0 indicates the sample is entirely lower-return.

The return rates of geophytes from western North America can range widely from 50 kcal/hr to up to 4,000 kcal/hr (Couture et al. 1986; Ugan and Rosenthal 2016). The tubers included in this study come from *Solanum jamesii*, a wild potato that grows across the Four Corners region (Kinder et al. 2017; Louderback and Pavlik 2017). A small population of *S. jamesii* is located approximately 150 m from NCS. Although return rate data are not yet available, this highly nutritious and productive perennial would have provided a reliable source of carbohydrates and minerals throughout the year. Handling costs would most likely have been minimal because its tubers are often found just below the litter layer in oak and conifer stands. Furthermore, *S. jamesii* tubers do not necessarily need to be cooked or roasted in order to be consumed. Various cooking and processing techniques for the tubers include drying, storing in a pit, and grinding into flour to make a bread (Castetter and Opler 1936). Given this information, *S. jamesii* tubers probably rank highly among geophytes with respect to post-encounter return rates.

Chipped Stone Tool Index. A chipped stone tool index was applied to determine when ground

stone tools were employed at NCS. It is the ratio of chipped stone tools (i.e., projectile points) relative to ground stone tools (i.e., manos and metates), where 1.0 indicates the sample is composed entirely of chipped stone tools and 0.0 indicates the sample is composed entirely of ground stone tools. The NISP for chipped and ground stone tools are provided in Supplemental Table 2 and are archived in Dryad (<https://datadryad.org/stash/dataset/doi:10.5061/dryad.w9ghx3fq3>).

Climate Index. A climate index is calculated using the ratio between conifer and Amaranthaceae pollen analyzed from NCS sediments (Supplemental Table 2 and Dryad <https://datadryad.org/stash/dataset/doi:10.5061/dryad.w9ghx3fq3>), where 1.0 indicates the sample is composed entirely of conifer pollen (*Abies*, *Picea*, *Pseudotsuga*, *Pinus*, indicating cool conditions) and 0.0 indicates the sample is composed entirely of Amaranthaceae pollen (arid conditions; Louderback et al. 2020). Other climate indexes could have been used in this study, including the cool-adapted/warm-adapted conifer ratio based on NCS plant macrofossils (Louderback et al. 2020) or regional pollen and plant macrofossil records, such as Anderson and colleagues (1999), Betancourt (1984), Withers and Mead (1993), or Coats and colleagues (2008). All of these regional records corroborate the Holocene vegetation shifts and increasing aridity observed at NCS.

Temporal Sequencing. The artiodactyl and high-return plant indexes along with the chipped stone tool and climate indexes are plotted through time. A generalized linear model (GLM) of the binomial family (with quasi-likelihood estimation) and a “logit” link function was applied (McCullagh and Nelder 1989) and plotted using the R Programming Language (R Core Team 2019). The R code is published at Zenodo (<https://doi.org/10.5281/zenodo.5123350>). The quasibinomial GLM applies to proportional data and is therefore used for all indexes in this study.

Effects of Climate on Dietary Choices

Artiodactyl, chipped stone tool, and high-return plant indexes were regressed against the climate index to determine the effects of climate on dietary choices. If diet breadth and/or a shift to more expensive technology and low-return resources

are coincident with climate change, then negative relationships should be apparent. A quasibinomial GLM with a “logit” link function was applied to each plot using the R Programming Language (R Core Team 2019). The R code is published at Zenodo (<https://doi.org/10.5281/zenodo.5123350>).

Results

Faunal Dietary Patterns

NISP and NTAFA for dietary faunal remains are presented in Supplemental Table 2. Six different dietary taxa were identified in the NCS faunal remains. High-ranked fauna include *Antilocapra americana* (pronghorn), *Cervus elaphus* (elk), *Odocoileus hemionus* (mule deer), and *Ovis canadensis* (bighorn sheep). Low-ranked fauna include *Lepus* sp. (hares) and *Sylvilagus* sp. (cottontail rabbits).

Relative Abundance and Ubiquity. Abundances of dietary faunal remains vary through time, ranging from one to over 350 bones in a single substratum. The lowest abundances occur throughout strata IV (10,500–10,000 cal BP) and VI (~7400–6700 cal BP). Higher abundances occur in strata II, III (11,300–10,500 cal BP), and V (9800–7600 cal BP). Deer make up 76% of the assemblage, regardless of when

they were deposited, making this dietary resource both abundant and ubiquitous (87%; Figure 3). In contrast, *Sylvilagus*, *Lepus*, and *Ovis* bones are ubiquitous (85%, 66%, and 47%, respectively) but not very abundant (16%, 4%, and 4%, respectively). This suggests constant but low-level use. Other dietary faunal taxa (*Antilocapra* and *Cervus*) are neither abundant (totaling less than 0.7%) nor ubiquitous (11% and 8%, respectively), suggesting opportunistic or ephemeral use.

Botanical Dietary Patterns

A total of 21 types of dietary plant taxa were recovered from 156 hearth features at NCS. This includes 17 families, 12 genera, and three that were identified to species level. Several potentially important dietary items are absent or rare, such as roots, tubers, berries, and other plants that lack dense, easily preserved parts. Some of these, such as tubers, may not show up in the macrobotanical record simply for reasons of differential preservation, but they do show up in the form of starch granules preserved in the cracks and crevices of ground stone tools. One such tuber, *Solanum jamesii*, was identified and included in dietary analyses for this study (see Louderback and Pavlik 2017).

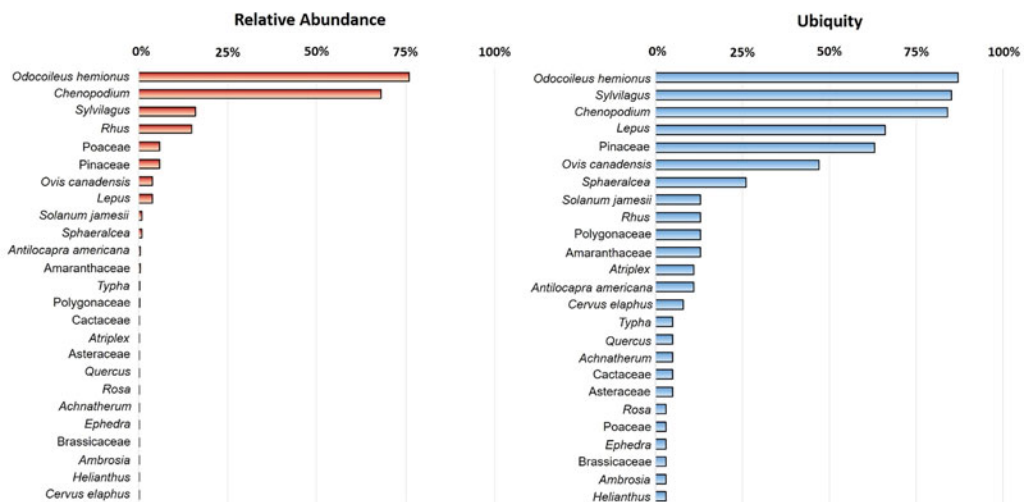


Figure 3. Relative abundance and ubiquity (frequency of occurrence) for dietary faunal and botanical datasets at NCS. Relative abundances for faunal and botanical taxa were calculated separately ($\Sigma\text{NISP}_{\text{faunal}} = 2,871$ and $\Sigma\text{NISP}_{\text{botanical}} = 1,568$). Ubiquity was also calculated separately ($\Sigma\text{substrata}_{\text{faunal}} = 53$, $\Sigma\text{substrata}_{\text{botanical}} = 38$).

Relative Abundance and Ubiquity Index. Abundances of dietary macrobotanical remains fluctuate through time, ranging from one to more than 280 seeds, seed coats, fruits, and fragments in a single substratum. The lowest abundances occur throughout strata II and IV (11,300–10,000 cal BP). These plant materials tend to be Pinaceae seeds. Higher abundances of dietary plant remains occur in substrata IIIc and IIIe (10,800–10,600 cal BP) as well as throughout strata V and VI (10,000–6700 cal BP). Remains of *Chenopodium* seeds and fruits are dominant in these deposits, although they are matched in abundance by *Rhus* sp. seeds in substrata Vh and Vi (9300–9100 cal BP). Overall, there is a progressive increase in dietary plant remains after substratum Va (~10,000 cal BP).

Chenopodium seeds make up 68% of the assemblage, regardless of when they were deposited, making this dietary resource both abundant and ubiquitous (84%; Figure 3). In contrast, Pinaceae seed coats and *Sphaeralcea* sp. seeds are ubiquitous (63% and 26%, respectively) but not very abundant (5% and 1%, respectively). This suggests constant but low-level use. *Rhus* sp. seeds, which are the second most abundant plant remains (15%), occur in only 13% of all strata.

Most other dietary plant taxa are neither abundant nor ubiquitous, suggesting opportunistic or ephemeral use. It is noteworthy that members of Chenopodiaceae and Amaranthaceae have a total ubiquity index of 97%, therefore dominating the diet through a considerable period of time.

Abundance Indexes

Artiodactyl Index. Artiodactyl index values (Figure 4) are lowest throughout stratum IV (10,500–10,000 cal BP) as well as in substrata Vt, VIa, and VIId (~8100–7000 cal BP). Values are highest in strata II and III (11,300–10,600 cal BP) as well as in substrata Vf–Vs (9400–8130 cal BP). Overall, the NCS assemblage is dominated by artiodactyls that, relative to leporids, do not decline significantly over time ($p = 0.78$; Supplemental Table 3).

High-Return Plant Index. High-return plant index values (Figure 4) are highest in substrata IIa, IIc, IIe, IIIg, and Vb, which date from 11,300 to 9800 cal BP and then significantly decline ($p < 0.01$) as small seeds increase in abundance during the early and middle Holocene (~10,000–7000 cal BP; Supplemental Table 3). It is important to note, however, that tubers of *S. jamesii* were also collected between 8100

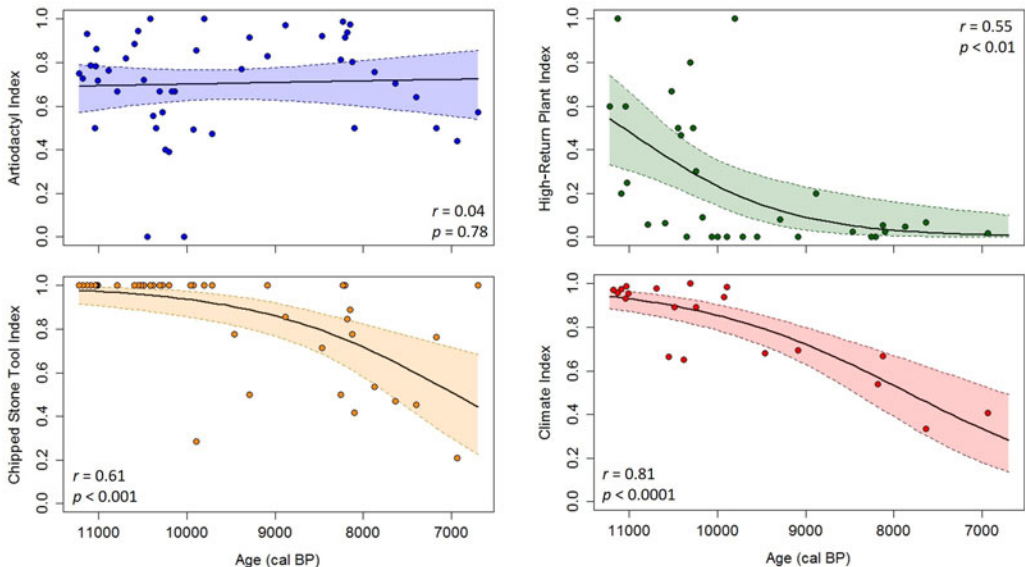


Figure 4. Artiodactyl, high-return plant, chipped stone tool, and climate indexes plotted against time using datasets from NCS. Dashed lines represent 95% confidence intervals around the GLMs (quasibinomial with a “logit” link function). Correlation coefficient (r) and probabilities (P) of the GLM are indicated.

and 7600 cal BP (substrata Vt, Vu, VIa) and processed on ground stone tools.

Chipped Stone Tool Index. Chipped stone tool index values (Figure 4) are highest in strata II, III, and IV, which date from 11,300 to 10,000 cal BP. Ground stone tools first appear in substratum Va (9900 cal BP) and steadily increase in abundance ($p < 0.001$) until 6700 cal BP (Supplemental Table 3). This increase in ground stone tool use correlates with the increased abundance of all small seeds ($r = +0.60$, $p < 0.0001$; see Louderback 2014).

Climate Index. Climate index values (Figure 4) are highest in strata II, III, IV, and Va (11,300–9900 cal BP), indicating cool/moist conditions. But they begin to decline significantly in substrata Vf, Vi, Vq, Vs, VIa, and Vid (9500–6700 cal BP) when conditions become more arid ($p < 0.0001$; Louderback et al. 2020; Supplemental Table 3).

Effects of Climate on Dietary Choices

There is no significant relationship between the abundance of higher-ranked faunal resources and climate ($p = 0.87$), but negative relationships, albeit nonsignificant, exist between the chipped stone tools and climate ($p = 0.12$) as well as the high-return plant resources and climate ($p = 0.14$; Figure 5; Supplemental Table 3). In other words, as climate gets warmer, the abundances of ground stone tools and small seeds increase.

Discussion

The diet breadth model (Stephens and Krebs 1986) predicts that decreasing encounters with high-ranked resources should result in increasing use of lower-ranked resources, therefore reflecting adjustments in human foraging behavior. At North Creek Shelter, this prediction appears valid with respect to botanical resources because high-ranked plants such as pine nuts and acorns drop out of the diet after 9800 cal BP and are replaced with low-ranked, small seeds. The prediction is not met, however, with respect to the faunal resources where high-ranked artiodactyls are consistently abundant in the diet throughout the Holocene and are not replaced with low-ranked leporids for any sustained amount of time.

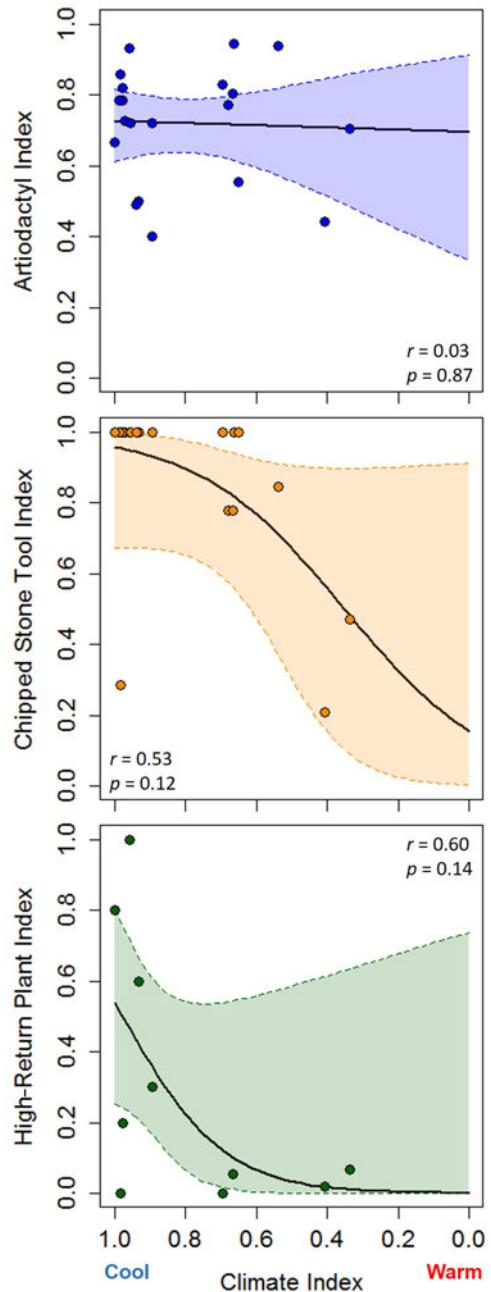


Figure 5. Artiodactyl, chipped stone tool, and high-return plant indexes plotted against the climate index to determine the effects of climate on dietary choices. Dashed lines represent 95% confidence intervals around the GLMs (quasibinomial with a “logit” link function). Correlation coefficient (r) and probabilities (P) of the GLM are indicated.

In arid regions on a global basis, increasing aridity and resultant changes in vegetation composition are offered as the ecosystem drivers of changes in dietary patterns (e.g., Edwards and O'Connell 1995; O'Connell and Hawkes 1981, 1984; O'Connell et al. 1982; Rhode and Louderback 2007; Rhode et al. 2006). Increasing aridity at NCS began by 10,200 cal BP and progressed significantly by 9300 cal BP, which was indicated by a shift in vegetation from a mixed conifer forest of cool-adapted species to a semiarid woodland and shrub mosaic (Louderback et al. 2020). This increased aridity coincides with greater use of small seeds and ground stone tools but not with corresponding increases in leporid abundances.

The NCS dataset contains fundamental lines of evidence encompassing diet and climate over time from a single site, which therefore allows for a true test of predictions of the diet breadth model. Other sites in the arid West that contain faunal, botanical, and stone tool datasets (e.g., Danger Cave, Bonneville Estates Rockshelter, Cowboy Cave, Sudden Shelter) were not analyzed specifically to test diet breadth predictions. Instead, they examined for differences between Paleoarchaic and Archaic subsistence patterns (Geib and Jolie 2018; Madsen 2007; Rhode and Louderback 2007; Rhode et al. 2006). In examining these patterns, generalizations regarding diet breadth between Paleoarchaic and Archaic foragers were not quantitatively tested and were primarily based on a single line of evidence (e.g., ground stone tool abundance) rather than multiple indicators. In addition, some of those lines of evidence come from very different places and probably from different groups of people experiencing very different resource landscapes across time.

Two major questions arise from the current study:

- (1) *Why did high-ranked faunal resources not decline in the deposits of NCS when there was clear development of aridity and changes in regional vegetation?* Faunal records from Great Basin archaeological sites during the late Pleistocene / early Holocene tend to be characterized by a diverse array of smaller, low-ranked prey such as

birds, lagomorphs, fish, and insects (Grayson 1988; Hockett 2015; Hockett et al. 2017; Pinson 2007). Artiodactyls do not become abundant in those deposits until the middle Holocene (e.g., Hockett 2015; Pinson 2007), and they increase even more during the late Holocene (Broughton et al. 2008, 2011; Hockett 2015). At NCS, artiodactyls are as abundant during the early Holocene at 11,000 cal BP (substratum II, NISP = 181) as they are during the middle Holocene at 7900 cal BP (substratum Vu, NISP = 136), although abundances vary throughout these time periods. Perhaps local depletion of deer populations was regularly mitigated by immigration from distant sources. Unlike the Great Basin, the landscapes of the northern Colorado Plateau consist of nearly continuous and large areas of upland that may have provided corridors for constantly reestablishing herds in the vicinity of NCS, regardless of climate-driven vegetation change. In southern Utah, deer are now ubiquitous, occupying and moving between essentially all vegetation zones, from subalpine forests to desert scrub (Durrant 1952). That they would be present during the climatic shift to aridity between the early and middle Holocene is, therefore, not surprising. This has been suggested for other faunal patterns in the region (e.g., Sudden Shelter; Broughton et al. 2011; Byers and Broughton 2004).

Another hypothesis for large game hunting throughout the Holocene is based on costly signaling and "showing off" rather than foraging efficiency (Hildebrandt and McGuire 2002). The show-off hypothesis suggests that male hunters gain higher fitness by choosing "risky" resources that can be shared widely. Although this might explain the consistent or increased abundance of large game resources in archaeological sites, it has been refuted by many researchers on the basis of empirical, theoretical, and methodological evidence (Broughton and Bayham 2003; Byers and Broughton 2004; Codding and Jones 2007; Fisher 2015; Grimstead 2010; Gurven and Hill 2009). More importantly, it has also been suggested that the

show-off hypothesis may not result in the highest fitness-related benefits (Hawkes 1990, 1991).

- (2) *What is the driver for broadening of diets at NCS if not a decline in high-ranked faunal resources?* The patterns observed from the NCS faunal and botanical datasets may reflect different foraging strategies between men and women, which would explain why low-ranked plant resources became increasingly abundant in the diet without a corresponding decrease in the abundance of high-ranked artiodactyls. Gender-specific foraging in the archaeological record is something that has been explored before, and in the case of the Carson Desert in Nevada, it has been modeled and tested using archaeological data (e.g., Elston and Zeanah 2002; Kelly 1995b, 1997; Larsen and Hutchinson 1999; Larsen and Kelly 1995; Larsen et al. 1995; Rhode 2003; Schoeninger 1995, 1999; Zeanah 2004). The prevailing consensus from those studies suggests that men and women had different goals: women stayed near home base to forage in productive lowland patches, whereas men forayed into the uplands for large-game resources (Zeanah 2004). More recent research (Coddling et al. 2010; Elston et al. 2014) elaborates on those findings by suggesting that some undefined level of variability in acquiring large game would lead to women simultaneously foraging for more reliable but lower-ranked resources. Likewise, the lack of ground stone tools in archaeological sites prior to 10,000 cal BP (Grayson 2011; Madsen 2007) suggests that gender-specific foraging patterns were more “convergent” (sensu Coddling et al. 2010; Elston et al. 2014) because foragers would not have stayed in one location long enough for women to invest in that technology. Sometime after 10,000 cal BP, foraging patterns of men and women would have “diverged” if acquiring game was more unpredictable and foragers were staying in one place for longer periods of time.

These predictions regarding gender-specific foraging patterns are drawn from

ethnographic studies of modern foragers. For example, gender and age differences in foraging patterns have been investigated among the Aché and the Hadza. The Aché are indigenous hunter-gatherers who live in the tropical forests of eastern Paraguay, and the Hadza are traditional foragers who inhabit the arid savannah woodland of northern Tanzania. Based on ethnographic studies, both of these groups defy diet breadth expectations that foragers will maximize their mean energetic rates because reproductive fitness costs and benefits may be different for men and women (O’Connell et al. 1999). Aché men and women, for example, have different foraging strategies based on their goals (Coddling et al. 2011; Hawkes 1990; Hawkes et al. 1991; Hill et al. 1987; Hurtado et al. 1985). Aché women tend to be risk averse due to family provisioning. Consequently, they forage in more reliable resource patches, accumulating more low-return resources, heavily investing in plant-processing tools, and keeping the food for themselves and their children (Hawkes 1991). Aché men pursue fluctuating but highly mobile large-bodied animals, and when they are successful, their prey is shared widely (Hawkes 1991). Ethnographic studies also indicate that women’s foraging strategies are good indicators of diet breadth due to risk-averse foraging goals as well as climate change, whereas men’s are not (Hurtado et al. 1985; O’Connell and Hawkes 1984; O’Connell et al. 1999). In the case of the Hadza foragers, children are able to collect their own plant resources (i.e., fruits) during the wet season. But with increases in aridity and seasonality, those plant resources may not be available for children. Therefore, Hadza women provision with resources that tend to have high handling costs (such as small seeds and tubers; Hawkes et al. 1997; O’Connell et al. 1999; Wood et al. 2021). This is exactly what may be registered with the NCS record, and it is probably the best explanation for the differing patterns observed in the faunal and botanical assemblages at NCS.

At NCS, complementary faunal and botanical assemblages provide an opportunity to identify gender-specific foraging patterns across a long arc of time and environmental change. The current study posits that prior to 10,500 cal BP, variability in acquiring artiodactyls was low (coefficient of variation [CV] for artiodactyl index strata II = 0.18 and III = 0.13) compared to after (CV for strata IV = 0.54, V = 0.19 and VI = 0.19). This means that when NCS was surrounded in cool-adapted conifers, women were not staying in one place collecting small seeds and using ground stone tools to process them. Instead, they may have been participating in hunts and/or opportunistically collecting high-return plant food resources, such as large-seeded pine nuts. Gender-specific foraging patterns at NCS prior to 10,500 cal BP therefore seem to align with convergent patterns of labor division (Coddling et al. 2010; Elston et al. 2014). After 10,500 cal BP, however, when conditions were becoming more arid, women apparently began collecting small seeds from various shrubby and herbaceous plants, as well as *S. jamesii* tubers (Louderback and Pavlik 2017) persisting beneath canopies and along watercourses. Ground stone tools were used to process those plant parts, thereby maximizing the overall caloric returns. Men, on the other hand, were consistently hunting artiodactyls, even though there was considerable variability in this record.

Conclusions

Although gender plays an important role in human foraging strategies (Hawkes and O'Connell 1992; Jochim 1988), it is rarely addressed during archaeological studies, especially when considering diet breadth variations through time. The NCS archaeological assemblage suggests that women and men had different foraging patterns in response to environmental change. This could be tested more widely by applying optimal foraging models to many archaeological sites in the Great Basin and on the Colorado Plateau that also have complementary faunal, botanical, stone tool, and environmental datasets.

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Data Availability Statement. Data from this project are available and archived at Dryad: <https://datadryad.org/stash/dataset/doi:10.5061/dryad.w9ghx3fq3>. R code is published at Zenodo: <https://doi.org/10.5281/zenodo.5123350>.

Supplemental Material. For supplemental material accompanying this article, visit <https://doi.org/10.1017/aaq.2021.122>.

Supplemental Figure 1. Schematic diagram showing North Creek Shelter (NCS) radiocarbon age probability distributions by substratum. Calibrated ages are plotted as filled curves connected by a dotted line. Hatched curves are outlying or old wood ages (not used in this study). Probability distributions were calibrated and imported from OxCal (Bronk-Ramsey and Lee 2013). (Figure published in Louderback et al. 2020.)

Supplemental Table 1. Radiocarbon Dates from North Creek Shelter.

Supplemental Table 2. Number of Individual Specimens (NISP) of Dietary Faunal and Botanical Remains, Chipped Stone and Ground Stone Tools, and Pollen from Substrata at North Creek Shelter.

Supplemental Table 3. Summary of Model Results Including the Estimate, Standard Error, *T*-Value and *P*-Value for the Parametric Terms.

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