The Ecology of Human Diets during the Holocene at North Creek Shelter, Utah

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Abstract

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Chair of the Supervisory Committee:
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Department of Anthropology

This research examines the ecology of human diet using archeological evidence from a specific site in western North America – North Creek Shelter (NCS) near Escalante, Utah. I use ecological measures and theory to quantify human dietary change during the early to middle Holocene and in the context of local ecosystems that supplied plant and animal food resources. Vegetation sampling techniques are used to quantify the landscape and dietary palettes that may have been available to the occupants of NCS during the Holocene. According to my sampling, the pinyon-juniper woodland and cool desert scrub vegetation types would have supplied the majority of dietary plant resources, while the other types were either devoid of, or had low cover by, dietary species.

I also combine evidence from dietary plant macro- and microfossil remains with dietary faunal remains to examine this comprehensive dataset in the context of ground stone abundance and environmental change. Two periods of increased dietary species richness occurred at 9400 and 8000 ^{14}C BP, when people were focusing their subsistence on deer and *Chenopodium* seeds,

respectively. The shift in emphasis between deer and *Chenopodium* was accompanied by a shift in stone tool technology. The assemblage of chipped stone tools in substratum 3e (9400 ^{14}C BP) was dominated by hunting and bone-processing implements. Ground stone tools became dominant in substratum 5t (8000 ^{14}C BP), simultaneous with a peak in *Chenopodium* abundance. Increasing aridity began by 9000 ^{14}C BP and had progressed significantly by 8000 ^{14}C BP, indicated by a shift in vegetation from a mixed conifer forest of cool-adapted species to a semi-arid woodland and shrub mosaic. This coincided with a broadening of the diet dependent upon an intensified use of small seeds and ground stone technology.

Intensive processing of small seeds on ground stone tools was not the only such practice at NCS. Underground storage organs were also processed and possibly roasted in pits uniquely found on the living surface of substratum 5t (8000 ^{14}C BP). Although taxonomic assignments for the starch grains are difficult at this point, there are minimally two “taxa” (“centric” and “eccentric”) that can be added to the tally of dietary species richness developed from macrobotanical remains (above). Adding these starch-producing plants to dietary species richness would accentuate a shift toward broader diet concurrent with a period of rapid environmental change during the middle Holocene.

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This is to certify that I have examined this copy of a doctoral dissertation by

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and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

Chair of the Supervisory Committee:

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Chapter 1

INTRODUCTION

The ecology of human diets has long been an issue in the prehistory of arid western North America (Broughton and Grayson 1993; Elston 1982; Elston and Zeanah 2002; Geib and Jolie 2008; Grayson 1993; Huckell 1996; Jennings 1980; Jennings et al. 1980; Madsen 2007; Madsen and Schmitt 1998; O'Connell et al. 1982; Rhode et al. 2006; Rhode and Louderback 2007; Simms 1987). In an archaeological context, the human diet is an ecological phenomenon because it is about the supply, harvest, processing and energetic returns of plant and animal resources from natural ecosystems.

Understanding past human diets requires knowledge of the subsistence landscape. Therefore, I am using ecological measures and theory to examine human dietary change through time from a single site in western North America, North Creek Shelter (NCS). I accomplish this by combining plant macro- and microfossil evidence and an understanding of the modern vegetation of the region to position diet in its environmental context. I couple this with archaeological data developed from ground stone assemblages, faunal remains and living surface features of NCS. When combined, the environmental context and archaeological data link human behavior to the limitations imposed on all organisms that derive subsistence from a changing landscape.

I attempt to answer three over-arching questions pertaining to plant and animal remains associated with food processing features (living surfaces, hearths, pits, ground stone tools) at NCS in southern Utah:

1) What dietary plant resources were available to NCS occupants from local ecosystems (Chapter 2)?
2) Do changes in diet breadth, driven by environmental change during the Holocene, conform to predictions of foraging theory (Chapter 3)?
3) What do microbotanical remains collected from grinding stones tell us about food processing, the ecology of human diet, and environmental change (Chapter 4)?

North Creek Shelter

Regional Environmental Setting

North Creek Shelter is a well-stratified rock shelter that lies at the base (1900 m) of a south-facing sandstone cliff, overlooking Escalante Valley in southern Utah (Figure 1.1). Escalante Valley is surrounded by the Aquarius Plateau (3444 m) to the north, Table Cliff Plateau (3082 m) to the west, and Kaiparowits Plateau (2438 m) to the southwest (Figure 1.2). East of the valley are lower elevation plateaus: Big Flat (1859 m) and Antone Flat (1981m). The valley is well-watered by runoff from Upper Valley Creek, Birch Creek, and North Creek that by confluence form the Escalante River. Of the three, North Creek is the largest and flows year-round (Janetski et al. 2012).

The contemporary vegetation of Escalante Valley has been described as Upper Sonoran zone (*sensu* Merriam 1893), but NCS is embedded in pinyon-juniper woodland (*Pinus edulis* and *Juniperus osteosperma*) which extends for miles in all compass directions from the site (see Chapter 2). However, the local influence of North Creek and the south-facing cliff face introduce other azonal vegetation types (e.g., riparian forest and saltbush scrub). At higher elevations, ponderosa pine and spruce-fir forests cover large portions of the Dixie National Forest.

Archaeological Site Description

Excavations of NCS took place from 2004 to 2008 under the direction of Dr. Joel Janetski of Brigham Young University. NCS has produced numerous archaeological features as well as abundant stone tools, faunal assemblages and botanical remains. These materials are distributed across a series of seven cultural strata deposited between 10,000 and 700 ^{14}C BP (Table 1.1). These occupations are culturally defined as Paleoarchaic (Strata 1, 2, 3 and 4) (10,000 – 9000 ^{14}C BP), Early Archaic (Stratum 5) (9000 – 8000 ^{14}C BP), Mixed Archaic (Stratum 6) (8000 – 6000 ^{14}C BP) and Fremont (Stratum 7) (1100 – 700 ^{14}C BP) (Figure 1.3). These were further subdivided into 68 levels or substrata (e.g., 2a, 2b, 2c, etc.) which were delineated and excavated (Janetski et al. 2012). Some of these substrata (e.g., 3e and 5t) are interpreted as short-term living/use surfaces (Janetski et al. 2012).

There is a significant break in site occupation from approximately 6000 to 1000 ^{14}C BP. Although the break is consistent with middle Holocene hiatuses in other Great Basin and Colorado Plateau sites (e.g., Geib 1996; Geib and Davidson 1994; Grayson 2011; Jennings 1980; Lindsey et al. 1968; Louderback et al. 2011; Talbot et al. 1999), it is most likely due to the fact that the middle Archaic deposits were found to be highly bioturbated and thus were avoided for dating. The lack of sediments that date between 6000 and 1000 ^{14}C BP might also be due to site surface leveling during Fremont times (Janetski et al. 2012). This potentially false hiatus does not affect my research because I focused on the sequence of undisturbed, well-stratified deposits from the early to middle Holocene (Strata 1 – 6).

Stratigraphic analysis of NCS sediments defined a dramatic contrast between the lower (pre-8000 ^{14}C BP) and upper (post-8000 ^{14}C BP) deposits (Figure 1.3). The lower sediments resulted from colluvial, alluvial and aeolian processes spanning 2,000 years of the early

Holocene. Beginning roughly at 10,000 ^{14}C BP, large amounts of finely-laminated sands and silts were rapidly deposited in multiple layers with an overall thickness of 3.5m. Interbedded are darkened cultural strata that include the hearth features, plant and animal remains and ground stone tools that form the basis of this study. Overlying these strata are sediments consisting of sands and rubble that were deposited slowly, by the same geologic processes operating earlier. Although these sediments are darkened from human activity and bioturbation over the past 8000 years, some important features remain intact. These features include slab-lined hearths and use surfaces that date to Fremont age (~1000 ^{14}C BP).

The lower (Paleoarchaic 10,000 – 9000 ^{14}C BP) and upper (early Archaic 9000 – 8000 ^{14}C BP) deposits differ in many ways, including the frequency and structure of activity areas, prevalent technologies, and the composition of faunal assemblages. Hearths and pits are more common in the early Archaic deposits and the few that are present in Paleoarchaic occupations are smaller and shallower. The distribution of projectile points differs as well. In the Paleoarchaic, stemmed points are most common while in the early Archaic, notched points become the preferred technology. Another significant difference in technology is the apparent increased use of ground stone tools through time in early Archaic deposits (Yoder et al. 2010) (see Chapter 4).

Dissertation Structure

This dissertation examines the ecology of human diet using archaeological evidence from a single site in western North America – North Creek Shelter (NCS) near Escalante, Utah. The reason for using NCS is its extraordinary record and how long and varied it is in terms of human occupation, artifacts, features, living surfaces and the remains of organisms. Its setting on the

Colorado Plateau is also unique with topographic relief, different vegetation zones, and a flora derived from multiple geofloristic sources. From all of this comes an ability to reconstruct the dietary choices of people that witnessed extraordinary change in the landscape and its resource base. That change also led to technological innovation that has been observed in other parts of the world. Therefore, we can search for a unifying explanation that ties NCS and Southern Paiute of Utah to other people on very distant parts of the planet that experience the same ecological conditions.

The following chapters examine the ecology of human diets at NCS during the transition from early to middle Holocene. Chapter 2 uses modern vegetation and ethnobotanical data to understand what plant resources would be available and ultimately contribute to the plant fraction of the diet. I employed vegetation sampling techniques to quantify the landscape and dietary palettes that may have been available to the occupants of NCS during the Holocene. This is made possible by the proposition that changes in plant communities in response to climatic gradients caused by elevation are a reasonable surrogate for changes in plant communities driven by climatic variation through time. Chapter 3 brings together subsistence and technological data to quantify diet breadth through time based on patterns of species richness and evenness from plant and animal remains. To see if the changes in diet breadth coincided with environmental change, I am also testing the notion of climate-driven subsistence shifts from a foraging theory perspective. Chapter 4 investigates microbotanical evidence for the processing of small seeds and tubers from ground stone tool surfaces. Starch grains preserved in adhering sediments or as residues pressed into cracks and crevices into stones themselves are extracted, examined and interpreted with respect to diet breadth. Although ground stone tools and plant processing are “hallmarks” for a shift in subsistence strategy and broadening of the diet, they have never been examined this closely and within a foraging theory framework in this ecogeographic region.

Figures and Tables

Figure 1.1. View of North Creek Shelter looking east. Site is located at base of sandstone cliff (1900 m). Escalante Valley is in background.

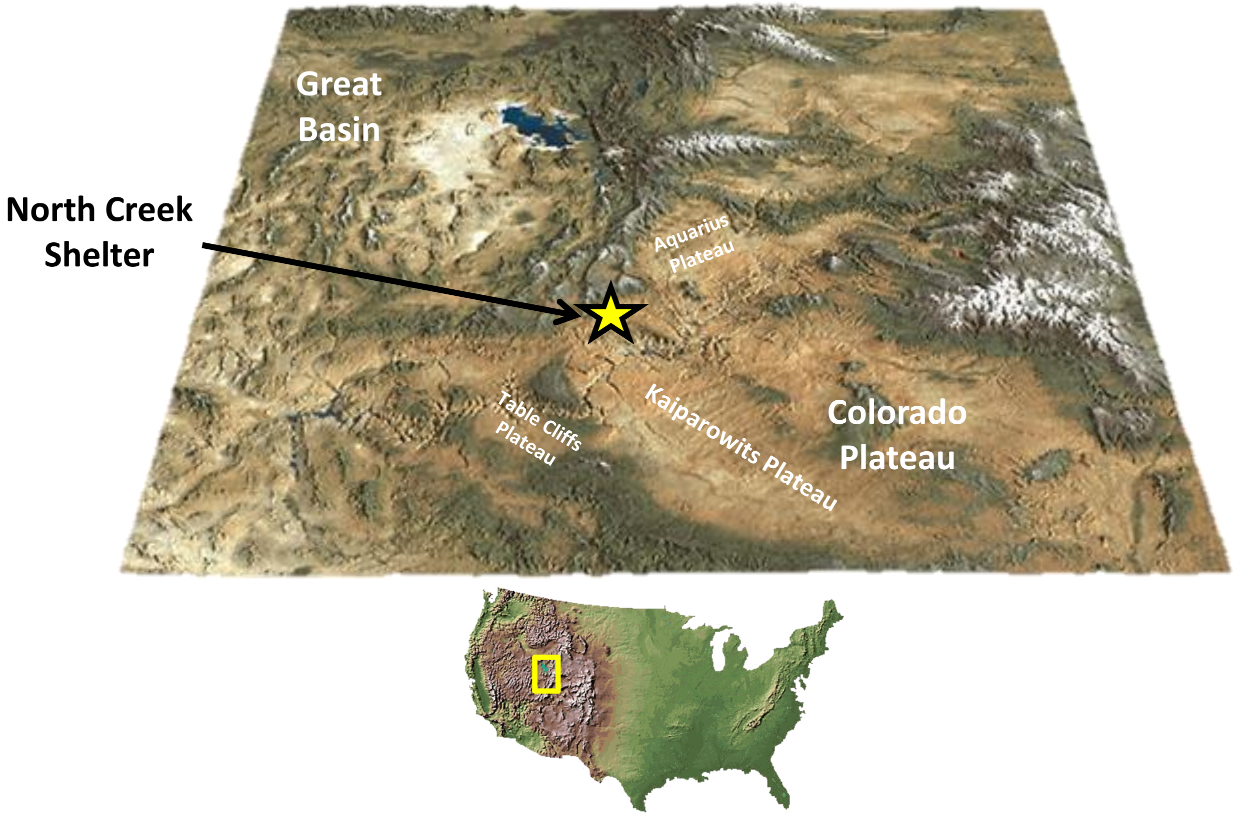

Figure 1.2. Location of NCS on the northern Colorado Plateau. Image from www.shaderelief.com.

Table 1.1. Radiocarbon dates for North Creek Shelter (J. Janetski pers. comm.)

Sample No	**Stratum**	**Material**	**Conventional ^{14}C age**
Beta-197358	7a	*Zea mays*	940±40
AA78631	7c	dentin	902±40
Beta 195226	4i	*Atriplex*	890±40
AA89634	7c	collagen	196±38
Beta-221411	7b	*Zea mays*	1050±40
Beta 261678	6c	*Zea mays*	1030±40
Beta-26176	7a	*Zea mays*	1130±40
Beta-261677	6d	*Zea mays*	1130±40
Beta-261678	6c	*Zea mays*	1030±40
Beta-221414	6d	*Juniperus*	6020±60
AA89632	6d	dentin	7526±70
Beta-221412	5u	*Acer, Pseudotsuga, Pinus*	7670±80
Beta-239024	5u	*Juniperus*	7700±50
PRI-07-102-4364	5u	*Juniperus*	7990±30
Beta 207167	5t	*Juniperus*	7970±80
Beta 210253	5t	*Juniperus/Pinus*	8320±120
Beta 197359	5q	*Pinus*	8310±70
Beta 239023	5h	*Juniperus*	8310±40
AA89637	5a	bone collagen	8816±78
PRI-07-102-4029	5h	*Juniperus*	8860±25
Beta 194030	5c	*Pinus*	9020±70
AA89640	4a	bone collagen	9490±92
AA89642	3f	*O. hemionus*	9642±84
AA89641	3e	bone collagen	9237±83
AA89637	3e	dentin	9406±96
AA89638	3e	coll/dent	9384±91
AA89635	1i	coll/dent	9410±82
AA89633	3b	collagen	9556±84
Beta 207168	4a	*Pinus*	9510±80
Beta 221415	3a	*Juniperus/Pinus*	9690±60
AA89643	2g	*O. hemionus* bone collagen	9733±84
AA89639	1i	dentin	9736±95
AA89645	2e	*O. hemionus* bone collagen	9739±81
Beta 239022	2a	Salicaceae	9800±50
PRI-07-102-3716	2a	Salicaceae	9960±30

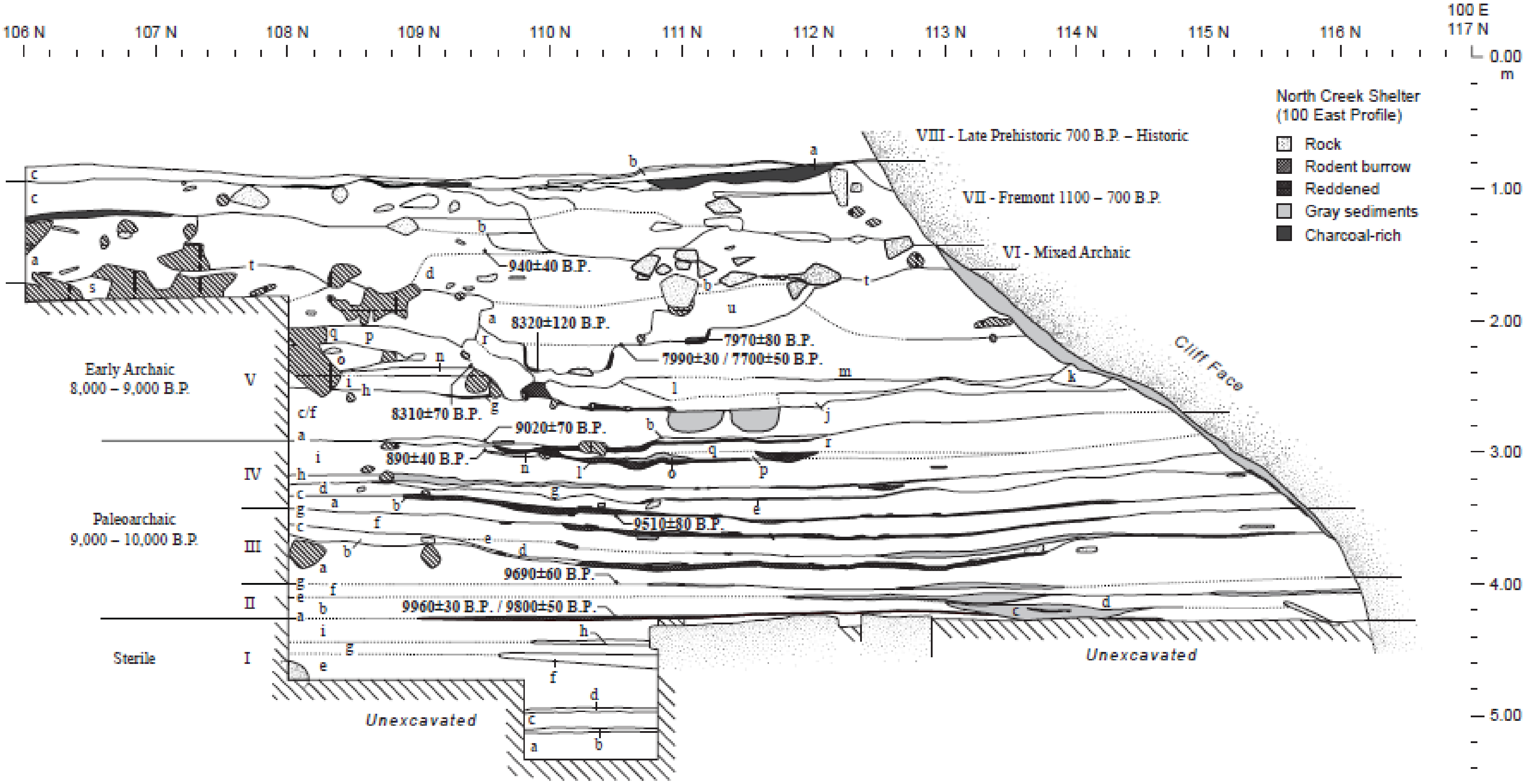

Figure 1.3. Stratigraphic profile of North Creek Shelter. Image from Janetski et al. 2012.

Chapter 2

USING MODERN VEGETATION AND ETHNOGRAPHIC DATA TO UNDERSTAND THE ARCHAEOLOGY OF DIET AT NORTH CREEK SHELTER

Introduction

Plant food resources are provided to native people through the richness, abundance and productivity of natural vegetation. On the Colorado Plateau, major vegetation units include several types of conifer forests, needle-leaf and broad-leaf woodlands, desert scrub, and grassland, distributed along elevation and moisture gradients. This spatial distribution of plant resources is a complex response of component species to variations in precipitation and temperature across these gradients, thus mimicking the temporal variation in species distributions during the Holocene. Correspondence between species distributions and vegetation units is approximate but useful in describing landscape patterns over a wide area. The vegetation and its responses to climate across space and through time ultimately "sets the table" for human subsistence adaptations in terms of available plant resources.

To integrate the modern vegetation of the North Creek Shelter (NCS) area with the potential ethnographic use of plant food resources, dietary "inventories" are generated from the published literature (i.e. Fowler 1986). The inventory is limited to food plants used by Utah and Nevada Southern Paiute and are developed based upon plant species and the edible roots, stems, leaves, seeds and fruits produced in a given vegetation type at a given elevation in a given year. Dietary inventories are conducted within a "landscape palette" of vegetation types, ultimately producing a "dietary palette" of component species that have edible parts. These inventories are compared to the composition of modern vegetation types in the vicinity of NCS to determine a potential dietary palette.

Physiographically, complex environments could presumably offer greater landscape diversity (e.g., number of vegetation types) and species-rich vegetation types should offer more varied human dietary palette. For example, there are 368 species of important food plants in the Great Basin, but only 38 listed for the entire North American Plains, an area three times the size (Fowler 1986, Wedel and Frison 1986, respectively). Although there may be differences in ways these lists were compiled, there is about an order of magnitude difference owing to landscape and floristic diversity (Barbour and Billings 2000). With respect to a single archaeological site, the valid inventory of plant resources is drawn from the evaluation of vegetation types in the foraging radius of archeological deposits. Therefore, we can borrow the approach and methods of vegetation ecology in order to develop quantitative linkages relevant to behavioral predictions originating from foraging theory.

The purpose of this chapter is to use vegetation sampling techniques to quantify the landscape and dietary palettes that may have been available to the occupants of NCS during the Holocene. I accomplish this by: a) identifying the local dietary palette within the landscape palette along an elevation gradient and b) measuring the absolute abundance of edible and non-edible species in their respective vegetation types by sampling presence, cover, density, and basal area. This approach makes the assumption that species comprising contemporary plant assemblages respond to environmental gradients as in the past. That is, they tend to occupy similar ecological conditions and are likely to be members of the same assemblage of species (vegetation type) even in the face of environmental change. This individualistic view of vegetation acknowledges variation in composition across space and through time, but allows prediction of where species could occur along a gradient and therefore, the structure and productivity of a landscape (Gleason 1926; Whittaker and Niering 1964). Herein I use vegetation types to predict the occurrence of dietary plants in the modern Escalante landscape and infer their past occurances under changing environmental conditions during the Holocene.

Southern Paiute

The Southern Paiute refers to several groups living in southern Utah, Arizona, southern Nevada, and southeastern California (Chemehuevi). As Kelly (1934) put it: "The area as a whole is arid, and aside from the Colorado, there are no perennial streams save the Virgin system, the south fork of the Sevier, and possibly the Escalante river. This briefly is the Southern Paiute landscape" (pp. 549-550). Within this area, the Southern Paiute are composed of fifteen bands (or tribes), but for the purposes of this study, I rely on ethnographic data from the Kaiparowits (Kelly 1934, 1964).

The Kaiparowits lived primarily in Potato-Escalante Valley, contiguous with the Kaibab to the southwest, the Panguitch to the northwest, and the San Juan to the southeast (Kelly 1964). As with most Southern Paiute, the Kaiparowits were hunter-gatherers and regarded small seeds as "the chief vegetable staple" (Kelly 1964:152). While agriculture is well-documented in bands such as the Kaibab, the Kaiparowits are described by Kelly (1964) as "a non-agricultural population" (p.151). Ethnographic information on the Kaiparowits is sparse compared to other Southern Paiute groups, so little is known about their past subsistence practices. In addition, many of the Kaiparowits informants were born well after the arrival of white settlers and their way of life. Settlers brought intensive agriculture and range practices to the Escalante Valley, which had severe impacts on natural vegetation and the dietary palette. Therefore, specific knowledge of the Kaiparowits country and its resources can be quite limited (Kelly 1964).

Methods

Determining the Dietary Palette from Modern Vegetation

Ethnographic Record

The most comprehensive list of plants that might have been used by Southern Paiute groups is provided by Fowler (1986). She conducted extensive interviews with live informants and analyzed the available records from explorers, such as John C. Frémont and John W. Powell, biologists such as Frederick Coville, C. Hart Merriam, Ralph Chamberlin, Edward Palmer, Robert Bye, and ethnographers including Isabel Kelly, Julian Steward, and Maurice Zigmond. She was careful to only add species to the list and if "…specific documentation [was] lacking, attribution was avoided" (Fowler 1986: 64). I generate my list by choosing plant food materials (i.e., seeds and fruits) associated with Utah and Nevada Southern Paiute that would persist in the archaeological record (Appendix A). Therefore, underground storage organs (i.e., bulbs, roots, tubers) are not considered in this analysis, but are discussed in Chapter 4. I also exclude the non-native weeds and cultivated plants that would not have been present before contact. This "dietary inventory" of plants is compared to the composition of modern vegetation types in the vicinity of NCS to determine a local dietary palette.

Analysis of Modern Vegetation Communities

Using the vegetation types recognized by Welsh et al. (2008) and West and Young (2000), I selected major vegetation types along an elevation gradient from 1400 to 2830 m that centered at NCS (1900 m). These include a range of physiognomies from sparse desert scrub to dense coniferous forest, thus requiring multiple sampling methods suited to the structural changes (number and height of canopy layers, life forms of dominant species) encountered. All types have herbaceous and shrub canopy layers that were sampled using quadrat and line-intercept methods, respectively (Mueller-Dombois and Ellenberg 1974). Another method, point-centered quarter, was added in woodland and forest types that have an overstory canopy of trees (Mueller-Dombois and Ellenberg 1974). The taxonomic identity, relative abundance (e.g. density, cover) and presence of food resources on plant species included in these samples are used to inventory the potential dietary palette.

Representative stands of each vegetation type are recognized by their dominant species after surveying along minor roads that run from the bottom of Kaiparowits Plateau in the southeast (1400 m) up to Griffin Top Mountains in the northwest (2830 m) (Figure 1.2). This involves examining topographic maps, satellite photos and driving until accessible, representative stands can be identified and described. I avoid atypical landscape features, such as narrow canyons and small-scale drainages, which might introduce azonal plant communities into the sample. Once located in a homogenous, representative stand, the plot center is established. The plot center marks the intersection of two 50 m transects (fiberglass tapes) oriented along north, south, west and east compass points. I repeat this process twice in each vegetation type and assign a site number and a GPS location (NAD 83) to each plot center. All vegetation types in the study are comprised of shrub-dominated and herbaceous-dominated canopy layers, therefore the line-intercept cover measurements are uniformly applied to all sites. The higher elevation sites with tree-dominated overstories are subject to the point-centered quarter sampling technique, in addition to the line-intercept method.

The herbaceous canopy layer of all vegetation types was sampled using a 0.5 X 0.5 m PVC quadrat. At each 5 m interval along the 50 m transect, the quadrat was laid on the undisturbed side of the tape. All forb and grass species rooted inside were recorded and assigned a total absolute cover estimate (% of ground area).

The shrub canopy layer of each vegetation type was sampled along the 50 m transects of the line-intercept method. Because the tape was laid on top of whatever shrubs happened to occur in its path, estimates of absolute cover (% of 50 m) could be made for each species. Only live branches onto which the tape could be projected were included. The linear distance each shrub intercepted the tape was recorded along with its taxonomic identity.

When an overstory canopy of trees was present, the point-centered quarter method was added to the transect (Mueller-Dombois and Ellenberg 1974). This method provides a way of estimating tree density (number per unit ground area) and a surrogate measure for canopy cover, stem basal area (cm^2 of wood at breast height). I established point centers every 10 m along each transect, already laid out for quadrat and line-intercept sampling. Passing through each point center was an imaginary line perpendicular to the transect that defined four quarters. In each quarter, the distance between the point center and the nearest live tree trunk with a diameter at breast height (dbh) greater than 5 cm was measured. Each tree was identified, the distance recorded, and its dbh measured. No individual tree was counted twice in adjacent quarters and if the distance to a tree in a quarter exceeded 8 m, the quarter was considered empty. If the nearest tree had multiple trunks, the largest was measured.

Dietary Composition of Modern Vegetation Types

I compare the species composition of sampled vegetation types in the vicinity of NCS with the dietary inventory of food plants of Utah and Nevada Southern Paiute. This is done to determine how well the modern vegetation types supply the dietary resources identified ethnographically. This includes the species richness (NTAXA) of dietary taxa as a fraction of the species richness that was sampled and the abundance of those resources as indicated by the absolute cover (%). Dominance for the tree overstory is measured by the absolute density and basal area measurements using the point center method. I chose the highest two densities among all species in the samples within a vegetation type. Dominance for the shrub understory is measured by the absolute mean cover using the line intercept method. I chose the highest two cover estimates for all species in the samples within a vegetation type. Dominance for the herbaceous groundcover is also measured by the absolute mean cover, but by using the quadrat method.

Absolute density and basal area of trees and canopy cover of shrubs and groundcover species are used as structural measures of abundance for vegetation dominants and dietary dominants. Vegetation dominants are the taxa in each canopy layer with the highest values for structural measures. Dietary dominants are the taxa in all canopy layers that occur in both the ethnographic record and in the vegetation sampling regardless of which canopy layer. Again, absolute cover is used as a structural measure of abundance. I also sum the absolute cover of all dietary taxa in the samples from each vegetation type. I chose the highest two cover estimates for all species in the samples within a vegetation type. Dietary plants are considered dominant if they are dominant in our vegetation sampling as well as in the ethnographic literature.

Results

Determining the Dietary Palette from Modern Vegetation

Ethnographic Record

The dietary inventory of native seeds and fruits consumed by Utah Southern Paiute groups consist of 30 families, 50 genera and 85 species (Appendix A). The families Amaranthaceae, Asteraceae, Brassicaceae, Chenopodiaceae and Poaceae contribute the most species and all these plants produce small seeds and fruits.

Analysis of Modern Vegetation Communities

A total of seven vegetation types are recognized at, above and below NCS, spanning a total of 1400 to 2830 m over a total distance of 100 km (Figure 2.1 and Table 2.1). These include three forest types, two woodland types and two scrub types. Five of these vegetation types occur within a radius of 16 km of NCS, and NCS itself is surrounded by a mosaic of pinyon-juniper woodland, riparian forest and cool desert scrub depending upon topographic position. North-facing slopes tend to be wooded, south-facing slopes tend to be scrub and the canyon bottom can be dense thickets of woody, hydrophilic species. There are also considerable amounts of local human disturbance that is due to a long history of grazing, agriculture and drainage alteration. Consequently, introduced weeds such as *Bromus tectorum* (cheat grass), *Tamarix* sp. (salt cedar) and *Elaeagnus* sp. (Russian olive) have scattered populations in certain vegetation types.

Forest types in the Escalante region include mature stands of spruce-fir (*Picea-Abies*), ponderosa pine (*Pinus ponderosa)* and cottonwood-willow riparian (*Populus-Salix*). These forests range in elevation from 2830 to 1900 m, respectively. The riparian forest occurs in the immediate vicinity of NCS while spruce-fir and ponderosa pine forests lie 28 to 22 km respectively to the northwest of the rockshelter. Total average tree density ranges from 673 to 926 trees/HA (dbh >5 cm, Table 2.1). Total average tree basal area (a surrogate measure of cover) ranges from 91 to 136 m^2/HA. Total average shrub cover in the understory ranges from

19% to 93% and total average ground cover from 11% to 55%. Species richness ranges from 20 species to 29 (Table 2.1).

Woodland vegetation includes mature stands of pinyon-juniper and juniper savanna. The differences between these types are that the latter does not include *P. edulis*, the shrub understory is sparse, and the groundcover understory is dominated by desert grasses (especially *Bouteloua* and *Pleuraphis* [= *Hilaria*]). Juniper savanna also lies approximately 610 m lower in elevation than pinyon-juinper woodland. NCS is located near stands of pinyon-juniper but is several miles from the juniper savanna. Total average tree density for the woodland types ranges from 398 to 637 trees/HA (Table 2.1). Total average tree basal area ranges from 7 to 467 m^2/HA. Total average shrub cover ranges from 14% to 18% and total average ground cover from 0% to .1%. Species richness ranges from 18 species to 25 (Table 2.1).

Scrub vegetation includes cool and warm desert scrub, separated by 500m of elevation and more than 64km of gradual decline in the landscape towards the southwest. The cool desert scrub is dominated by sagebrush (*Artemisia tridentata*) and four-wing saltbush (*Atriplex canescens*) and in this way is similar to Great Basin scrub vegetation. Along with pinyon-juniper woodland and riparian forest, it forms a mosaic in the immediate vicinity of NCS. The warm desert scrub consists primarily of blackbrush (*Coleogyne ramosissima*), joint fir (*Ephedra* sp.) and galleta grass (*Pleuraphis jamesii*), vegetation characteristic of the Colorado Plateau and often transitional to Mojave scrub at lower elevations (Pavlik 2008; Randall 1972; Vasek and Barbour 1977). Total average shrub cover for the scrub types ranges from 32% to 43% and total average ground cover from 0.1% to 4%. Species richness ranges from 12 species to 16 (Table 2.1).

Dietary Palette of Modern Vegetation Types

I estimate the dietary contributions of modern vegetation (dietary palette) by combining the ethnographic record of Utah Southern Paiute food plants (the dietary inventory) (Appendix A) with the composition and structural data from the seven vegetation types. The palette richness is the number of taxa found in both the ethnographic record and the sampling data. Palette richness varies from high to low, with a maximum of 10 dietary taxa (Tables 2.2a, 2.2b, 2.2c).

Three vegetation types are dominated by plants that have very little or no record of dietary use by the Utah Southern Paiute. These include spruce-fir, cottonwood-willow riparian and warm desert scrub. Ponderosa pine and juniper savanna vegetation types contain few dietary plant species. By far, the most dietary plants occur in pinyon-pine woodland and cool desert scrub types.

Discussion

Ethnographic summaries of common food plants are often drawn from a wide geographic range and over uncertain periods of time. They are compiled from multiple informants whose personal histories may not be well known and many of whom were born well after the arrival of white settlers and their way of life (Kelly 1964). Specific knowledge of the landscape and its resources can therefore be quite limited:

> "Lack of first-hand knowledge of the [Kaiparowits] country is a manifest handicap, and much of the confusion reported in the preceding section results from my unfamiliarity with the region…informants' efforts at drawing maps on

> the ground and on paper were conspicuously unsuccessful" (Kelly 1964: 145-146).

This does not invalidate ethnographic inventories (some have been recently verified, e.g. Louderback et al. 2013), but their application to studies of dietary ecology at an archeological site must be circumscribed. A given site is imbedded in specific landscape features and local ecosystems that will not reflect the broad array represented in those comprehensive inventories. Instead, the inventories represent a "universe" of possibilities with respect to diet choice that was narrowed by decision-making within a localized palette. Thus, an archeological food assemblage reflects the ecological and social circumstances at hand.

Foraging behavior is the product of those circumstances (O'Connell and Hawkes 1984). Most foraging is local, meaning that the amount of energy obtained from harvesting is constrained by costs in finding and transporting the plant resources (e.g., O'Connell and Hawkes 1984). Vegetation sampling was originally conducted at, above and below NCS in order to begin to capture the entire dietary palette that might have been available to the occupants of NCS throughout the Holocene and its variable climate. As it turned out, this includes seven distinct vegetation types than contain at least 91 total species in the samples, of which 37 constitute the dietary palette as informed by the ethnographic record. That palette, however, is not evenly distributed among those vegetation types.

According to my sampling, the pinyon-juniper woodland and cool desert scrub vegetation types supply the majority of dietary plant resources, while the other types are either devoid of, or have low cover by, dietary species. Kelly (1964) alludes to this in her notes:

> "Because of winter snows, the high country was not considered suitable for semipermanent camps. Population was concentrated in the middle and lower

> levels, which are predominantly aird, with few perennial streams. Springs, which occur chiefly at the base of plateaus and cliffs, determined the location of the semipermanent settlements. The latter were conviently adjacent to the valleylike flats, which supplied seeds and small game, and from them the high country, essentially a hinterland, could be visited periodly for pine nuts, large game and other products" (p. 2).

Woodland and scrub vegetation types now surround NCS, but archaeological evidence suggests this was not always the case (see Chapter 3). Other than seeds of Pinaceae, dietary resources from spruce-fir and ponderosa pine communities are not represented in NCS deposits. This is also true for riparian, juniper savanna and warm desert scrub vegetation types; dietary plant remains from these types are not found in archaeological deposits. Although the pinyon-juniper and cool desert mosaic communities shifted over time, the remains of dietary plants from these types are found throughout NCS deposits (see Chapter 3). This might be reflecting what ethnographers have observed: "modern hunter-gatherers…forage selectively in areas chosen for some reason other than mere proximity" (O'Connell and Hawkes 1984: 504).

Vegetation sampling also reveals that food species in the contemporary palette may not appear in the archaeological record, despite high cover and high seasonal productivity. *Berberis fremontii* (= *Mahonia fremontii*) and *Shepherdia rotundifolia* (silverscale), for example, are large floriferous shrubs (each individual can easily exceed 1 m^3 in canopy volume, Welsh et al. 2008) contributing two to five percent cover in pinyon-juniper and cool desert scrub types (Tables 2.2b and 2.2c) and, based on my own observations, capable of producing $>10^2$ fruits per individual per year. Ethnographically, *Berberis* was "eaten raw; not dried" (Kelly 1964: 153). *Shepherdia* was "eaten fresh, dried and ground on metate" (Kelly 1964: 153). Yet neither is present in the long archaeological record. A search for the abundant starch grains of *Shepherdia* on groundstone extracts was not successful (see Chapter 4). Perhaps the fruits of both taxa were eaten as they were gathered rather than back at the rockshelter or the species may not have been present within the foraging radius of NCS during much of the Holocene.

Conversely, there are some plant taxa in the archeological record that are not detected in the vegetation samples. This could be due to the small number of transects (they are not designed to be complete vegetation descriptions for the region), but extensive floristic observations have been made during the course of three field seasons. These include sampled and unsampled areas within all seven types, as well as an inventory of specimens in the herbarium of the BLM office in Escalante. Certain dietary taxa are difficult to find on the landscape and within available collection records. For example, at least two species of *Chenopodium* (i.e. *C. berlandieri* and *Chenopodium* sp.) are known as macrofossils from NCS hearth features with high ubiquity among strata and at times a very high abundance (see Table 3.4 and Figure 3.6). Yet, only one individual of *Chenopodium* (i.e. *C. fremontii* [accession #83]) is found in the vicinity of the juniper savanna samples. Non-native, disturbance-dependent species of *Chenopodium* (accession #84) are found on roadsides along Highway 12, but these species would not have been present until recent times. Although known from Garfield County (Welsh et al. 2008), we did not come across *C. berlandieri* during our vegetation surveys.

Similarly, it is possible (though evidence is lacking) that many of the eccentric starch grains found on ground stone surfaces in substrata 5t and 5u may have come from wild potato (*Solanum jamesii*), the only native potato in southern Utah (see Chapter 4). But extensive searches for *S. jamesii* from known collection localities (i.e. Bamberg et al. 2003 and Welsh et al. 2008) and informant interviews (DeLane Griffin and Elray Nixon, pers. comm. Sept. 2013) produced only three populations in the vicinity of Escalante, consisting of 78 total individuals, some of which may have been clones. This species was once so important and iconic that Escalante was called “Potato Valley” by the first settlers (Roundy 2005; Woolsey 1964), but now it is very uncommon on the landscape, perhaps even rare with populations in the Escalante area reduced to less than 100 plants.

Clearly, the vegetation that can be observed today and its dietary palette differ from those observed by the inhabitants of NCS. This limits interpretation of the archaeobotanical record using the ethnobotanical inventory. As Fowler (2000: 100) has pointed out, “Since the 1840’s, habitat changes due to grazing, settlement, stream diversion, and the establishment of reserves and preserves have likewise affected changes in indigenous knowledge systems”. This was also experienced by Isabel Kelly, who wrote about her Southern Paiute informant, L:

> “L accompanied me on a hasty trip as far as Escalante, where we spent 1 night. She saw her homeland for the first time in 40 years, and her comment is a terse summary of the effects of white occupation: ‘This country is no good any more; everything is dry; the creeks are cut deep; the food plants are all gone’” (Kelly 1964: 146).

Heavy dependence on weedy or cultivated species in historic diets is also evidence of sweeping and rapid changes in the dietary palette caused by human disturbance. Fowler’s inventory incorporates 12 such taxa, including sunflower (*Helianthus annuus*), *Chenopodium album*, tansy mustard (*Descurainia pinnata* and *Descurainia sophia* syn. *Sisymbrium sophia*) in addition to wheat (*Triticum aestivum*) and maize (*Zea mays*).

The history of settlement and land use provides insight into the nature and scale of recent human impacts on natural vegetation. The Mormon cavalry first entered Escalante in 1866 during the Blackhawk wars (Nelson 1952). Settlement began in 1875 when the name “Potato Valley” was bestowed and agriculture began. Eventually, “Most of the capital, management, and labor of the village was devoted to producing range cattle and sheep” (Nelson 1952: 89). In 1923 (which predates Isabel Kelly’s ethnography), Potato Valley was overwhelmed by range livestock, which included 33,000 head of sheep and over 10,000 head of cattle (Nelson 1952, Table 9). Severe overgrazing, especially during World War II, led to a decline to 7,000 and 5,000 head, respectively: “The cumulative effect of years of misuse manifested itself by 1950 in the disastrous decline in the major economic base on which Escalante rests” (Nelson 1952: 113).

Combining ethnographic and modern vegetation analyses provides insight into the dietary ecology of NCS during the Holocene, despite limitations imposed by their inherent methodologies and uncertainties. Comprehensive inventories derived from contemporary informants can provide a universe of food plants to be used in conjunction with analyses of the archaeological record, but the record itself will always be local and ultimately reflect the particular ecosystems available for foraging. Furthermore, selectivity which can operate on individual preferences as well as group tradition may still not exploit all taxa in the local palette. Vegetation samples will likely contain many but not all of the dietary species available through time even when recent human impacts, especially livestock grazing, have altered the composition, structure and function of contemporary plant communities. It appears that herbaceous species are more likely to have been reduced or eliminated due to those impacts. As a result, these species appear in the archaeological record even though they are rare or absent on the modern landscape. But in general perennial species from high elevation vegetation types (spruce-fir and ponderosa pine) dominate the plant fraction of the early Holocene diet, while herbaceous taxa from mid-elevation types (pinyon-juniper woodland and cool desert scrub) characterize the middle Holocene as diet breadth increased and low-return resources were intensively processed (see Chapter 3). The latter include charred seeds as well as above and below ground plant materials processed with ground stone tools.

Figures and Tables

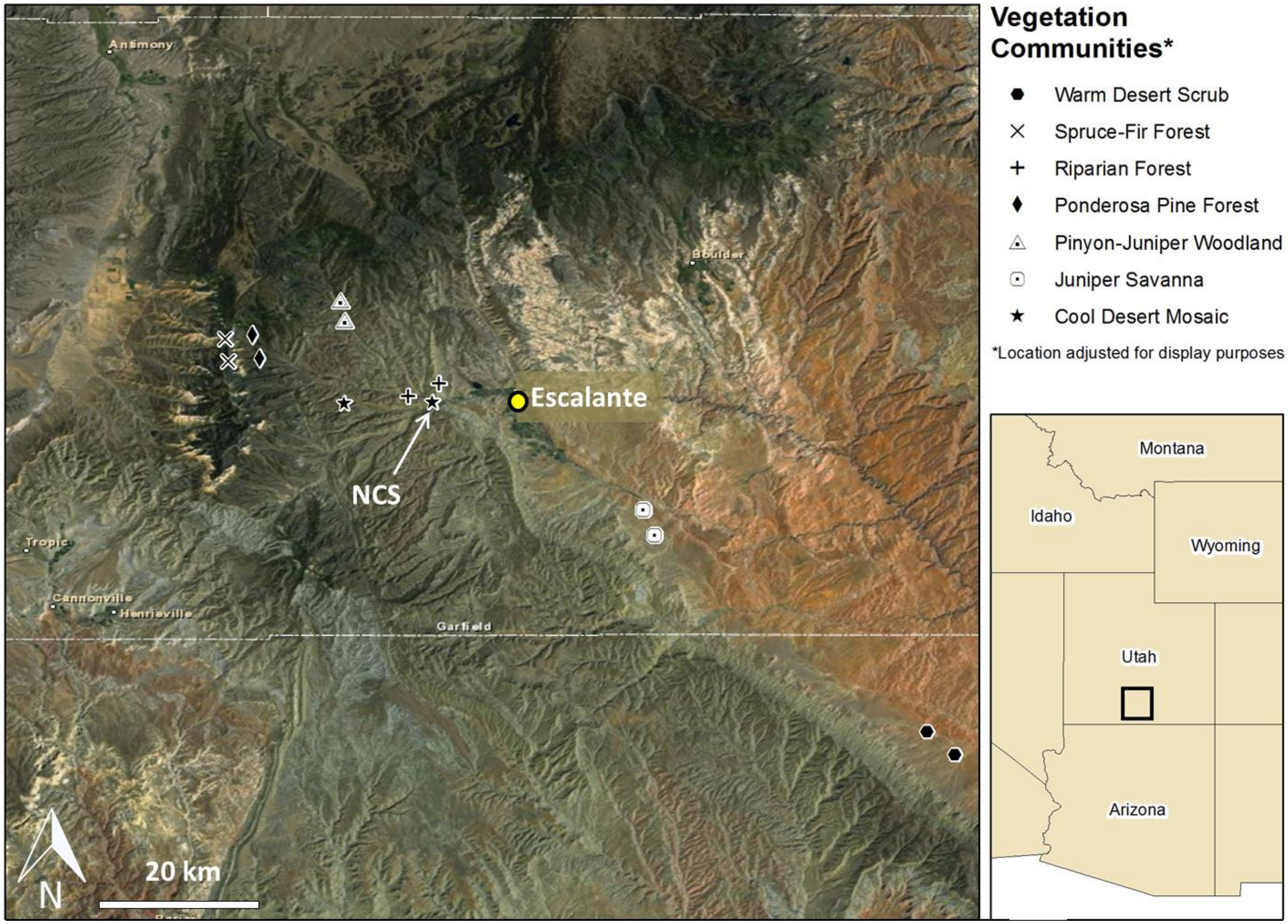

Figure 2.1. Map of vegetation sampling locations in the vicinity of NCS.

Table 2.1. Modern vegetation communities sampled at, above and below NCS.

	Spruce-Fir Forest		**Ponderosa Pine Forest**		**Pinyon-Juniper Woodland**		**Riparian Forest**		**Cool Desert Mosaic**		**Juniper Savanna**		**Warm Desert Scrub**	
Elevation (m)	2813	2833	2438	2509	2195	2214	1917	1923	1881	1899	1640	1664	1402	1423
GPS location (NAD 83)	37°49.236 111°53.111	37°49.452 111°52.987		37°49.867 111°51.385	37°51.714 111°46.044	37°51.02 111°46.00	37°46.538 111°41.641	37°46.915 111°40.689	37°46.127 111°46.044	37°46.200 111°40.812	37°38.921 111°27.592	37°39.313 111°27.798	37°25.280 111°09.780	37°26.655 111°11.449
Slope	west-facing	west-facing		west-facing					south-facing	east-facing				
Aspect														
distance to NCS	28 miles		22 miles						0					
Total average tree density (trees/HA)	926		673		637		742		X		398		X	
Total average tree basal area (m^2/HA)	136		132		467		23		X		7		X	
Total average shrub cover (%)	46		19		14		23		43		18		32	
Total ground cover (%)	14		4		0.1		11		4		0		0.9	
Total bare ground (%)	90		95											
Species richness	29		20		18		24		16		25		12	
Species composition	*Pseudotsuga menziesii*		*Pinus ponderosa*		*Pinus edulis*		*Populus angustifolia*		*Atriplex canescens*		*Juniperus osteosperma*		*Coleogyne ramosissima*	
	Abies lasiocarpa		*Populus tremuloides*		*Juniperus osteosperma*		*Populus fremontii*		*Berberis fremontii*		*Aster* sp. 1		*Achnatherum hymenoides*	
	Abies concolor		*Pseudotsuga menzesii*		*Berberis fremontii*		*Betula* sp.		*Ephedra viridis*		*Achnatherum hymenoides*		*Opuntia macrorhiza*	
	Pinus flexilis		*Quercus gambelii*		*Shepherdia rotundifolia*		*Juniperus osteosperma*		*Artemisia tridentata*		*Aster* sp. 2		*Ephedra torreyana*	
	Picea sp.		*Juniperus scopulorum*		*Amelanchier utahensis*		*Equisetum* sp. 1		*Artemisia cana*		*Pleuraphis jamesii*		*Psorothamnus* sp.	
	Pinus ponderosa		*Juniperus communis*		*Quercus gambelii*		*Equisetum* sp. 2		*Juniperus osteosperma*		*Bouteloua* sp.		*Juniperus osteosperma*	
	Juniperus communis		*Symphoricarpos oreophilus*		*Pinus ponderosa*		*Poa* sp.		*Opuntia macrorhiza*		Caryophyllaceae		*Pleuraphis jamesii*	
	Ribes aureum		*Rosa woodsii*		*Stanleya elata*		*Clemetis* sp.		*Sphaeralcea parvifolia*		*Gutierrezia diversifolia*		*Eriogonum* sp.	
	Amelanchier alnifolia		*Lupinus* sp.		*Chrysothamnus* sp. 1		*Chrysothamnus* sp. 1		*Hesperostipa* sp.		*Yucca glauca*		*Euphorbia* sp.	
	Symphoricarpos oreophilus		*Aster* sp. 1		*Opuntia macrorhiza*		*Chrysothamnus* sp. 2		*Chrysothamnus* sp. 1		*Stipa coronata* var. *depauperata*		*Gutierrezia diversifolia*	
	Rosa woodsii		*Cirsium* sp.		*Arabis* sp.		*Salix* sp.		*Achnatherum hymenoides*		*Andropogon* sp.		*Poa* sp.	
	Populus tremuloides		*Berberis repens*		*Sitanion* sp.		*Koeleria* sp.		*Pinus edulis*		*Linanthus* sp.		*Cryptantha* sp.	
	Linanthus sp. (Syn. *Leptodactylon*)		*Arctostaphylos patula*		*Aster* sp. 1		*Cirsium* sp.		*Oenothera* sp.		*Sphaeralcea parvifolia*		*Opuntia polyacantha var. erinacea*	
	Balsamorhiza sp.		*Ribes aureum*		*Achnatherum hymenoides*		*Rhus aromatica* var. *trilobata*		*Cleome* sp.		*Chrysothamnus nauseosus*			
	Castilleja sp.		*Leymus cinereus*		*Ipomopsis aggregata*		*Rosa woodsii*		*Solanum jamesii*		*Astragalus* sp.			
	Chrysothamnus sp. 1		*Stipa coronata* var. *depauperata*		Boraginaceae		*Artemisia tridentata*		Scrophulariaceae		*Ephedra viridis*			
	Sambucus sp.		*Sambucus* sp.		*Astragalus* sp.		*Oenothera* sp.		*Opuntia polyacantha var. erinacea*		*Opuntia macrorhiza*			
	Calochortus nuttallii		*Achnatherum hymenoides*		*Symphoricarpos* sp.		*Leymus cinereus*				*Aster* sp. 3			
	Achillea millefolium		*Amsinckia sp.*				*Calamagrostis* sp.				*Muhlenbergia* sp.			
	Aster sp.		*Astragalus* sp.				*Agropyron* sp.				Sclerocactus			
	Crepis sp.						*Asclepius* sp.				*Sitanion* sp.			
	Penstemon sp.						*Tamarix* sp.				*Eriogonum* sp.			
	Astragalus sp.						*Castilleja* sp.				*Castilleja* sp.			
	Erigeron sp.						*Ipomopsis* sp.				*Ambrosia* sp.			
	Allium sp.										*Aster* sp. 4			
	Poa sp.										*Opuntia polyacantha var. erinacea*			
	Stipa coronata var. *depauperata*													
	Berberis repens													
	Thalictrum sp.													

Table 2.2a. Composition and structure of forest vegetation types in the vicinity of NCS. Dietary dominants may be drawn from any canopy layer, but are verified from ethnographic literature.

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Canopy layer	Spruce-Fir				Ponderosa Pine				Riparian			
	Taxon	**Density (tress/HA)**	**Basal area (m^2/HA) or Cover (%)**	**Species Richness**	**Taxon**	**Density (tress/HA)**	**Basal area (m^2/HA) or Cover (%)**	**Sp. Rich**	**Taxon**	**Density (tress/HA)**	**Basal area (m^2/HA) or Cover (%)**	**Sp. Rich**
Overstory dominants	*Abies concolor*	265			*Pinus ponderosa*	618.6	131		*Populus angustifolia*	693.1	21.3	
	Pinus flexilis	253			*Juniperus scopulorum*	40.2	1		*Betula* sp.	28.3		
	Picea sp.		81.5		**All taxa**	**673**	**132**	3	*Populus fremontii*		1.3	
	Populus tremuloides		19.9						**All taxa**	**742**	**22.8**	
	All taxa	**900**		6								
Understory dominants												
	Juniperus communis		26		*Arctostaphylus patula*		8.8		*Leymus cinereus*		4.7	
	Abies concolor		8		*Symphoricarpos oreophilus*		5		*Clematis* sp.		4.4	
	All taxa		**46**	17	**All taxa**		**19**	14	**All taxa**		**23.1**	16
Groundcover dominants												
	Vicia sp.		8		*Poa* sp.		2.4		*Oenothera* sp.		1.8	
	Thalictrum sp.		2		*Symphoricarpos oreophilus*		0.6		*Penstemon* sp.		0.75	
	All taxa		**14**	17	**All taxa**		**4.4**	7	**All taxa**		**2.7**	4
Dietary dominants												
	Berberis repens		3.5		*Arctostaphylus patula*		8.8		*Leymus cinereus*		4.7	
	Rosa woodsii		0.4		*Berberis repens*		0.8		*Atremisia tridentata*		2.5	
	Balsamorhiza sp.		0.1		*Quercus gambelii*		0.9		*Rosa woodsii*		0.8	
	All dietary taxa		**4.1**	4	**All dietary taxa**		**10.5**	3	**All dietary taxa**		**8.4**	4

Table 2.2b. Composition and structure of woodland vegetation types in the vicinity of NCS. Dietary dominants may be drawn from any canopy layer, but are verified from ethnographic literature.

Canopy layer	P-J Woodland				Juniper Savanna			
	Taxon	**Density (tress/HA)**	**Basal area (m^2/HA) or Cover (%)**	**Sp. Rich**	**Taxon**	**Density (tress/HA)**	**Basal area (m^2/HA) or Cover (%)**	**Sp. Rich**
Overstory dominants	*Pinus edulis*	403.5	417.1		*Juniperus osteosperma*	397.8	7.3	
	Juniperus osteosperma	188.1	259.4		**All taxa**	**397.8**	**7.3**	1
	All taxa	**673**	**934.6**	3				
Understory dominants								
	Shepherdia rotundifolia		4.8					
	Pinus edulis		4.3					
	All taxa		**13.9**	15				
Groundcover dominants	*Cymopterus* sp.		0.03		*Andropogon* sp.		5.9	
					Pleuraphis jamesii		5.2	
	All taxa		**0.03**	1	**All taxa**		**18.0**	19
Dietary dominants								
	Shepherdia rotundifolia		4.8		*Muhlenbergia sp.*		0.2	
	Pinus edulis		4.3		*Yucca glauca*		0.16	
	Amelanchier utahensis		1.58		*Achnatherum hymenoides*		0.1	
	All dietary taxa		**13.2**	8	**All dietary taxa**		**0.5**	4

Table 2.2c. Composition and structure of scrub vegetation types in the vicinity of NCS. Dietary dominants may be drawn from any canopy layer, but are verified from ethnographic literature.

Canopy layer	**Cool Desert Mosaic (NCS)**				**Warm Desert Scrub**			
	Taxon	**Density (tress/HA)**	**Basal area (m^2/HA) or Cover (%)**	**Sp. Rich**	**Taxon**	**Density (tress/HA)**	**Basal area (m^2/HA) or Cover (%)**	**Sp. Rich**
Overstory dominants								
Understory dominants								
	Atremisia tridentata		12.3		*Ephedra viridis*		10.9	
	Atriplex canescens		8.2		*Pleuraphis jamesii*		9.3	
	All taxa		**43.3**	22	**All taxa**		**31.8**	11
Groundcover dominants								
	Artemisia cana		0.5		*Cryptantha* sp.		0.03	
	Cleome sp.		0.4		**All taxa**		**0.03**	1
	All taxa		**1**	3				
Dietary dominants								
	Atremisia tridentata		12.3		*Juniperus osteosperma*		0.4	
	Atriplex canescens		8.2		*Opuntia polyacantha var. erinacea*		0.4	
	Opuntia polyacantha var. erinacea		4.8		*Achnatherum hymenoides*		0.3	
	All dietary taxa		**34.0**	10	**All dietary taxa**		**1.1**	4

Chapter 3

DIET BREADTH AND RESOURCE INTENSIFICATION IN RELATION TO ENVIRONMENTAL CHANGE

Introduction

The dietary choices of hunter-gatherers in arid North America are investigated using ecological approaches to the interpretation of archaeological evidence (Boone and Smith 1998; Broughton 1999; Broughton and Grayson 1993; Elston 1982; Elston and Zeanah 2002; Grayson 1993, 2011; Huckell 1996; O'Connell et al. 1982; Madsen and Schmitt 1998; Rhode and Louderback 2007; Rhode et al. 2006; Simms 1987; Steward 1938). Based on the principles of foraging theory (MacArthur and Pianka 1966), human diets are variously described as broad or narrow depending on the number of different kinds of resources in the diet. For example, "…human foragers broaden the range of prey taken by progressively adding lower-ranked (i.e., less efficiently harvested) prey types to a previously narrower diet of higher-ranked prey types" (Boone and Smith 1998:145-146).

According to foraging theory, low-return resources are incorporated into the diet as the availability of higher-return resources declines. This indicates an overall reduction in foraging efficiency, which often results in resource intensification. Resource intensification occurs when individuals expend greater effort (i.e., more time and energy) on subsistence-related activities in order to consume a resource or set of resources (thus increasing energetic returns) (Basgall 1987; Boserup 1965; Broughton 1994, 1999). Archaeologically, this can be evidenced by one or more of the following: a) an increase in diet breadth (i.e., number of resources used); b) an increase in the abundance of low-return resources in the diet; or c) the development of energetically expensive technologies.

This is apparently what happened between 8500 and 8000 ^{14}C BP in the Great Basin and northern Colorado Plateau when the intensive incorporation of small seed processing and the increased use of grinding stone technologies appear in the archaeological record (Fowler and Rhode 2011; Geib and Jolie 2008; Huckell 1996; Jennings 1980; Lindsay et al. 1968; Rhode and Louderback 2007; Rhode et al. 2006; Simms 2008; Yoder et al. 2010).

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). As Bird and O'Connell (2006:148) put it, "Climate- or predation-related declines in the availability of the high-ranked items (those with relatively low processing costs) were consistently identified as critical to the shift to lower-ranked prey". With respect to the Great Basin and Colorado Plateau, the dietary shift to intensive small seed processing and ground stone technology is attributed to intense aridification that began at about 8000 BP (e.g., Grayson 2000, 2011; Louderback et al. 2011; O'Connell et al. 1982; Rhode et al. 2006; Rhode and Louderback 2007; Schmitt and Lupo 2012).

In this study, I test predictions derived from foraging theory by combining plant macro- and microfossil evidence with faunal data from North Creek Shelter (NCS) and examining this comprehensive dataset in the context of ground stone abundance and environmental change. Specifically, this project attempts to establish whether a) an increase in diet breadth occurred at NCS, b) there was a shift to low-return resources, and c) the increase and/or shift coincided with changes in local vegetation consistent with increased aridification.

Foraging Theory

Diet-breadth model

The diet-breadth model ranks resources based on their expected post-encounter energetic return (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 (Bird and O'Connell 2006; Kelly 1995; Simms 1987, Table 3.1). The diet-breadth model predicts that a forager, having encountered a resource item, will take that item only if doing so does not decrease the overall expected return rate (Kelly 1995; Winterhalder and Smith 1992). This means that resources are included or excluded from the diet as a function of their rank relative to other available resources, as well as the absolute abundance of higher ranked resources in a given landscape. The diet-breadth model also 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. 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 1995; MacArthur and Pianka 1966; Winterhalder and Smith 1992).

The diet-breadth model has been applied to small seed use in arid lands in both ethnographic and archaeological contexts (e.g. O'Connell and Hawkes 1981, 1984; O'Connell et al. 1982). O'Connell and Hawkes (1981, 1984) studied hunting and plant collecting practices among the contemporary Alyawara of central Australia. They found that the Alyawara abandoned the harvest and consumption of native grasses and tree seeds that were abundant on the landscape. Government rations, specifically flour, had displaced traditional low-return plant foods. As access to exogenous, higher-return items increased, small seeds were eliminated, consistent with predictions from the diet-breadth model. In an archaeological example, O'Connell et al. (1982) applied the diet-breadth model to explain the presence of grinding stones and small seed chaff at Danger Cave as a strategy of early subsistence diversification in response to local environmental deterioration. Drawing from foraging theory, they suggested that people resorted to seeds only after calorically higher-ranked resources and high-quality resource patches diminished in abundance in response to climate change.

Resource Intensification

Resource intensification is the expenditure of greater effort in order to maintain or increase energetic returns. This can be accomplished by employing new technologies or improving existing ones. Models of resource intensification predict declines in foraging efficiency and a broadening of the diet (Boserup 1965; Broughton 1994, 1999). In other parts of the world, resource intensification may have been caused by high density of the human population and consequent resource depression (Bettinger 1991; Boserup 1965; Broughton 1994, 1999; Cannon 2000; Nagaoka 2002). In the Great Basin and Colorado Plateau, the basic argument is that increasing aridity and resultant changes in vegetation may have led people to include small seeds in their diet and incorporate more expensive technologies (e.g. ground stone tools) to process them (Grayson 2011; O'Connell et al. 1982; Simms 2008). "The appearance of ground stone by about 8,500 yrs ^{14}C BP and the processing of hard, small seeds that…have relatively low return rates … suggest[s] that the diet breadth of Archaic foragers was even broader than that of the Paleoarchaic " (Madsen 2007:15).

Hypotheses

I apply foraging theory to understand human dietary patterns through time using the NCS animal and plant assemblages. I focus my approach on the use of the diet-breadth model, which examines dietary choice from the standpoint of energetic yields from all available food resources. Diet breadth, defined as the number of resources pursued, will expand as new items are added to the diet until a point of diminishing returns is reached. If the number of both animal and plant resources (taxonomic richness) from each substratum increases from early to middle Holocene, then I conclude an increase in diet breadth occurs. The diet-breadth model predicts low foraging efficiency if high-ranked resources (i.e. large-bodied animals) decline in abundance and are replaced by lower-ranked resources (i.e. small-bodied animals and seeds). I test this prediction by determining if a shift to low-return resources occurred during the early to middle Holocene at NCS, coincident with major environmental change. If the prediction is met, I then determine if resource intensification has taken place, evidenced by increasing abundance of ground stone tools when small seeds are also increasing. Maximizing overall caloric yields is achieved by the development of grinding stone technology coupled with increased exploitation of lower-return resources.

A standard explanation is that human dietary changes are driven by the environment, especially as increasing aridity causes major changes in the composition, structure and distribution of local ecosystems from which the diet is drawn. Progressive aridification also leads to greater uncertainty (stochasticity) with respect to precipitation regime, plant productivity and animal population sizes (Ehleringer 1994; Pavlik 2008), further affecting the type and quantities of available foods. I determine if diet breadth changes and/or a shift to low-return resources are coincident with environmental change by examining paleovegetation responses to temperature and available moisture as revealed by the plant microfossil (pollen) and non-dietary plant macrofossil records. Specifically, if the abundances of high-return resources decline when pollen and/or non-dietary macrobotanicals of xerophilic taxa (Amaranthaceae/Chenopodiaceae) increase relative to mesophilic taxa (conifers), then I will conclude that major shifts in vegetation composition sufficiently account for human dietary change regarding diet at NCS. If the patterns do not conform, then alternative explanations are implicated.

Methods

Faunal Dietary Patterns

Descriptive summaries of the NCS mammalian fauna can be found in Janetski et al. (2012) and Newbold (2009). Faunal remains from NCS were studied by Bradley Newbold (strata 1, 2, 3, 4, and 5) and Lindsey Johannson (stratum 6, Johannson 2013) from Brigham Young University (BYU) (Appendices B and C). I relied on these identifications to calculate relative abundances (i.e., Artiodactyl Index), richness (NTAXA), and evenness (1/Simpson's Index). Previous evaluations of all faunal remains did not properly account for taphonomy, thereby potentially including non-cultural taxa in analyses of diet breadth. I avoided this by using the annotated data record and segregated specimens into dietary and non-dietary based on burning and cut marks as cultural markers (Appendices B and D). Additionally, relative abundance indices had been previously calculated for cultural periods (e.g., Paleoarchaic and Early Archaic) rather than for individual substrata (e.g., 5a, 5b, 5c, etc.), thereby blurring any quantitative changes that may have occurred. Thus, I re-calculated the relative abundances for individual substrata rather than cultural periods (Appendix C). I also revised the faunal inventory to better reflect accepted designations that ultimately determine the number of taxa, thus eliminating overlapping taxa (Grayson 1991; Appendix B). Specimens identified as "cf." are included. For example *Spermophilus* spp., *S. variegatus,* and cf. *S. variegatus* were counted as a single taxon (Newbold's work was conducted prior to the thorough revision of *Spermophilus* by Helgen et al. 2009 and was carried over into Janetski et al. 2012; I retain his terminology here). I included the lowest taxonomic category that could be assigned with confidence. The same means of counting taxa was applied consistently across all assemblages.

Artiodactyl Index

Changes in the relative abundance of higher- and lower-return resources are often used in archaeological studies to detect a broadening of the diet (e.g. Broughton 2002; Codding et al. 2010). Relative abundance indices express variability in foraging efficiency by calculating the ratio of higher-return prey relative to lower-return prey, where 1 indicates the sample is composed entirely of higher-return prey and 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). For this analysis, I use the two most abundant dietary taxa in the NCS faunal assemblage, artiodactyls and leporids, to calculate the Artiodactyl Index. The artiodactyl category was calculated by aggregating large- and small-bodied artiodactyls (unassigned Artiodactyla) with the medium-bodied artiodactyls (species of *Odocoileus, Ovis, Antilocapra Cervus*). Similarly, I aggregated unassigned Leporidae with *Lepus* sp. and *Sylvilagus* sp. to calculate the leporid category. The Artiodactyl Index is simply the ratio of artiodactyl bones to the sum of the artiodactyl and leporid bones: $(\text{NISP}_{\text{Artiodactyls}})/(\text{NISP}_{\text{Artiodactyls}} + \text{NISP}_{\text{Leporids}})$.

Taxonomic Richness and Evenness

Taxonomic richness (NTAXA) and evenness (distribution of abundances of individuals across taxa) were calculated for the dietary faunal assemblages. In determining these values, only non-overlapping taxa were counted (see above). Although richness is simply the tally of taxa, there are multiple ways of defining evenness mathematically, each of which has its own advantages and disadvantages. I decided to use the Simpson Index ($D = \Sigma\ [n_i/N]^2$, where n_i = the number of specimens in the *i*th species and N = the total number of specimens) (Grayson and Delpech 2002, 2006; Magurran 1988). The Simpson Index gives more weight to abundant taxa (those likely to be 'dominant' in the ecological sense) and discounts the contributions of rare taxa (Magurran 1988). I report the values for the inverse of Simpson's index (1/D) (Grayson and Delpech 2002, 2006) because it heightens the potential for detecting sample size effects by minimizing the contribution of more common species (Magurran 1988). Only samples with more than one taxon (NTAXA>1) are used to calculate evenness because relative abundances cannot be calculated with only one taxon.

Because richness and evenness are often positively correlated with sample size in archaeological faunas, the impacts of sample size are taken into account in assessing changes in diet breadth at NCS through time (Grayson 1984). This I did by using correlation and regression techniques following protocols outlined in Grayson (1991, 1998) and Grayson and Delpech (1998), using a P = .05 level of significance. When regressing the NISP and NTAXA of dietary faunal remains from NCS, I excluded taxa represented by a single specimen in any given substratum in order to minimize the effects of an accidental movement of specimens across strata (Grayson 1991).

If a significant correlation is detected between sample size and either richness or evenness, I then use analytical techniques implied by Grayson (1998, 1991) and Grayson and

Delpech (1998). I rank substrata by NISP and search for the largest discontinuity (gap) between adjacent sample sizes. The discontinuity allows strata to be divided into two separate datasets (low and high NISP), which in all cases (dietary faunal, macrobotanical, and combined faunal and macrobotanical), fall at NISP = 50 (i.e., NISP<50 and NISP>50). I am then able to test for sample size and NTAXA correlations using the separate low and high NISP datasets. These correlations are analyzed by comparing the slopes, the particular substrata contributing to those slopes (including their age), and the species compositions of substrata in different NISP datasets.

Macrobotanical Dietary Patterns

To examine changes in dietary plant use at NCS, I depend on the recovery of macrobotanical remains (e.g. seeds, seed coats, fruits) floated from sediment samples. The samples are taken from all cultural strata (1-6) including pit, hearth, and hearth-like features (Appendix E). These were subdivided into the 68 substrata, or “levels”, according to which the site was excavated (see Chapter 1) (Janetski et al. 2012). Hearth features were present and excavated from 44 of these substrata. A majority of the sediment samples (n=140) were previously floated, processed, and analyzed (see Hill 2004; Yoder et al. 2010), but are reexamined here for a more detailed assessment of changes in dietary plant use. Additional sediment samples (n=63) were excavated in 2008. Eleven of those samples are missing, so I floated, processed, and analyzed 52 at the University of Washington according to standard procedures outlined in Pearsall (1989). Therefore, a total of 192 sediment samples spanning cultural strata 1 through 6 are analyzed for plant macrofossils (Appendix E).

Dietary plant remains are those considered as potentially edible (e.g., seeds, seed coats and fruits) and showing evidence of charring. Non-dietary plant remains mostly consist of conifer leaf and needle fragments or uncharred hackberry (*Celtis* sp.) endocarps. Macrobotanical remains are identified to the lowest possible taxonomic level using contemporary reference material from herbaria (e.g. Royal Botanic Gardens Kew; University of Nevada Reno), seed reference collections at Desert Research Institute, as well as plant specimens gathered at the study site itself. Local and regional floras are also used (e.g., Welsh et al. 2008). Nomenclature conforms to USDA GRIN (http://www.ars-grin.gov/).

Relative Abundance and Ubiquity Index

I quantitatively measure differences in dietary plant use between substrata by developing indices based on the abundance of taxonomically assigned plant materials. Absolute and relative abundances of goosefoot seeds (*Chenopodium*) and all other dietary plant remains are determined for each substratum. The ubiquity index (expressed as a percentage) describes the occurrence of a plant taxon based on number of features or stratigraphic units in which that resource is recovered: % of taxon_i = (N of substrata with taxon_i / Σ N substrata) x 100 (Popper 1988). Higher percentages indicate more pervasive use over time, thus having implications for the stability of resource availability as well as cultural importance.

Taxonomic Richness and Evenness

Following the protocols I use for the faunal assemblages, taxonomic richness and evenness are calculated and sample size effects are analyzed for the dietary macrobotanical assemblages. Similar to the faunal assemblages, only non-overlapping taxa are counted. For example *Chenopodium* spp. and *C. berlandieri*, are counted as a single taxon and herein referred to as *Chenopodium*.

Measures of Diet Breadth: Combined Faunal and Macrobotanical Data

Diet breadth is measured by combining numbers of plant and animal taxa within each substratum of the archaeological assemblage at NCS. To measure general changes in diet breadth over time, I rank all species (plant and animal) of a substratum based on presumed post-encounter return rates (e.g., Kelly 1995; Simms 1987) (Table 3.1). The categories (e.g., large mammals, small mammals, pine nuts, tuber plants, and small seeds) are assigned a range of post-encounter return rates using values in the published literature. Attempts were made to match species and geographic regions, but this was not always possible. The large mammal group is comprised of species solely from NCS cultural deposits (deer, pronghorn, bighorn sheep) using the widest spread of values in Kelly (1995: Table 3-3). This is repeated for the small mammal group (jackrabbits and rabbits). The values for tubers (underground storage organs – USOs) do not have a clear correspondence between species in the deposits and those in the literature, so a range is derived from the widest spread of available values of multiple species with USOs, though these do not take processing costs into account (Couture et al. 1986) (Table 3.1).

Species richness and evenness are calculated based on the combined plant and animal data and are used to describe dietary diversity of each substratum (Appendix F). These indices are then compared across strata, producing dietary patterns through time. Similar to the faunal and macrobotanical assemblages, I employ linear regression to search for the presence of sample size effects.

Testing the Diet Breadth Model and Resource Intensification Predictions

According to the diet-breadth model, lower-ranked resources are incorporated into the diet as higher-ranked resources diminish in abundance. To test this, the taxonomic composition and abundance of the faunal (higher-ranked) and plant (lower-ranked) assemblages are examined to see if they conform to the predictions of the diet-breadth model. Evidence for resource intensification includes an increase in diet breadth (i.e., richness across all plant and animal taxa) and/or an increase in low-return resources relative to higher return resources. Further evidence for resource intensification comes from an increase in ground stone abundance. To test for these outcomes, I calculate richness values from each substratum to determine if the number of resource types changes through time. The same data I use to test the diet breadth model also allow a search for increases in low-return resources. Finally, I calculate the abundance of ground stone tools through time to determine if this new technology was developed simultaneously as lower-return resources were incorporated into the diet to maximize overall caloric returns.

Ground Stone Abundance

Ground stone tools from NCS were previously catalogued and described by Mark Bodily (see Yoder et al. 2010). Those descriptions, upon which I rely, include raw material, weight, thickness, length and width (Appendix G). Only stones identified as manos or metates are used in this analysis. Other stones that resemble ground stone tools (i.e., incised stones) are present in earlier deposits but are not considered here because they cannot be identified as manos or metates with certainty. I use this refined inventory to calculate ground stone tool abundance in each substratum, roughly between 9000 and 6000 ^{14}C BP.

Environmental Change

Environmental change is broadly reflected in paleovegetation responses to temperature and available moisture as revealed by the plant microfossil (pollen) and non-dietary plant macrofossil records.

Pollen

Pollen analysis of sediment samples from NCS was conducted in the University of Nevada, Reno Palynology Laboratory. Extraction from the sediment was accomplished using standard procedures, including successive HCl, HF, KOH, and acetolysis treatments (Faegri and Iversen 1989; also see Louderback and Rhode 2009), as well as heavy liquid separation (Lentfer and Boyd 2000; Munsterman and Kerstholt 1996). Known quantities of *Lycopodium* spores were added to each sample to calculate pollen concentration and accumulation rates, providing evidence of the depositional environment at a specific time. I processed half of the 133 sediment samples (n = 67) that were collected in 5 cm intervals from the entire profile of the east and west walls at NCS. I successfully extracted and analyzed pollen from 23 of the 67 samples. The remaining 44 samples did not contain pollen grains or produced too few to interpret paleovegetation change.

Glass slides of pollen extracts were prepared and then examined through a light microscope at 400x magnification. Pollen was identified to the lowest possible taxonomic level using modern reference material and published pollen keys (Kapp et al. 2000; Moore and Webb 1978). Most pollen grains were identified to genus, but for some types identification was only possible to family. Pine pollen grains are typically identified as one of three different categories: diploxylon (e.g., *Pinus ponderosa*), haploxylon (e.g., *Pinus flexilis,* pinyon-type), and undifferentiated pine. The poor preservation of archaeological pollen from NCS prevents such precise identifications. The pollen diagrams I present, therefore, combine the pine categories into one category (*Pinus*). Grains that could have been provided by either pine or true fir (*Abies*) are assigned to another category, *Pinus/Abies*. Unidentifiable pollen grains fall into two categories, unknown and indeterminate; unknown grains are intact but could not be assigned to a taxon whereas indeterminate grains are either damaged beyond recognition or obscured behind other material within the slide matrix.

Pollen data are expressed as absolute abundances and illustrated using the C2 program (Juggins 2003). Ratios that compared specific taxa (e.g., Amaranthaceae and all conifers) are used to differentiate between warm and cool environmental conditions (Madsen and Currey 1979; Mehringer 1985). The ratios are calculated as RCA = (C-A)/(C+A), where RCA = the ratio between Conifers to Amaranthaceae, C = absolute abundance of conifer pollen, and A = absolute abundance of Amaranthaceae pollen. The ratio is measured in standard units from +1 to -1. A value of zero denotes an equal percentage of grains from each pollen type. Values of +1 or -1 reflect the complete absence of one type or the other, respectively.

Pollen can be deposited by both natural and cultural processes, an ambiguity that is frequently cited in the literature (Hevly 1981; Madsen 1990). Data on vegetation change, however, can still be obtained from dry cave fill that also contains archaeological deposits, as documented at a number of sites in the arid west (e.g. Byrne et al. 1979; Thompson and Kautz 1983; Wigand and Mehringer 1985).

Dissimilarities between modern and fossil pollen assemblages at NCS are also examined. Surface (modern) sediment samples were collected in vegetation sampling localities at, above, and below NCS (see Chapter 2, Figure 2.1). These samples were processed and analyzed for pollen using heavy liquid separation. The abundances of the modern pollen samples are compared to the fossil pollen abundances from NCS sediments by using the squared chord distance measure: $d_{ij} = \Sigma_k (P_{ik}^{.5} - P_{jk}^{.5})^2$ where d_{ij} is the dissimilarity between fossil and modern pollen (Jackson and Williams 2004).

Non-dietary Plant Macrofossils

The non-dietary plant macrofossil remains mostly include burnt leaf or needle fragments or unburnt endocarps in the case of *Celtis*. The morphology and vascular structure of conifer needles are different across species, allowing differentiation of taxa to species level (e.g., Cole et al. 2008). I quantitatively measure changes in the local environment between strata by calculating relative abundances of these taxonomically assigned, non-cultural plant materials.

Non-dietary plant macrofossil data are expressed as absolute abundances and illustrated using the C2 program (Juggins 2003). A ratio that compares specific taxa (e.g., cool-adapted conifer to pinyon-juniper) is used to differentiate between warm and cool environmental conditions. The ratio is calculated as RCP = (C-P)/(C+P), where RCP = the ratio between cool-adapted conifers species to pinyon-juniper species, C = absolute abundance of conifer species (*Abies concolor, Pseudotsuga menziesii, Pinus ponderosa* and *Juniperus scopulorum*), and P = absolute abundance of pinyon-juniper species (*Pinus edulis* and *Juniperus osteosperma*). The ratio is measured in standard units from +1 to -1. A value of zero denotes an equal percentage of grains from each pollen type. Values of +1 or -1 reflect the complete absence of one type or the other, respectively.

Results

Faunal Dietary Patterns

Raw abundances (NISP) and NTAXA for all (dietary and non-dietary) faunal remains are presented in Appendix C. Deer (*Odocoileus hemionus*) bones and fragments are the most abundant among all animal taxa, constituting 72% ($[\Sigma\ \mathrm{NISP}_{\mathrm{deer}}/\Sigma\ \mathrm{NISP}_{\mathrm{all\ faunal}}] \times 100$) of the dietary faunal remains at NCS (Figure 3.1). This is followed by bones of *Sylvilagus* (18%), *Lepus* (4%), *Ovis canadensis* (4%), with pronghorn and elk totaling less than 0.7%.

Artiodactyl Index

Artiodactyl Index values vary among strata, ranging from 0.5 (equal abundance of artiodactyls and leporids) to 1.0 (all artiodactyls) (Appendix H, Figure 3.2). Values are lowest in substrata 4b and 4e, corresponding to the early Holocene (9000 – 9400 ^{14}C BP) (Table 3.2). Values are highest in substrata 1j, 3d, and 3e which date from 10,000 to 9400 ^{14}C BP. But overall the NCS assemblage is dominated by artiodactyls. The variation in artiodactyl abundance is dependent on sample size ($r = +0.28$, $P = .04$) (Figure 3.3), indicating that larger sample sizes have higher abundances of artiodactyls.

Taxonomic Richness and Evenness

Taxonomic richness for dietary faunal material varies among strata, ranging from 1 to 6 taxa (Appendix C). Values are lowest in substrata 1j, 1i, 1g, 3g, 3d, 4c, 4n, 5b and 5k, which are not limited to particular time periods (Table 3.2). Values are highest in substrata 5r, 6d, 6b and 6a (8000 – 6000 ^{14}C BP), but overall the NCS assemblage is dominated by deer.

Tests for the validity of relationships between sample size and taxonomic richness and between sample size and evenness (1/Simpson's Index) were conducted on dietary faunal remains. Sample size (NISP) and richness (NTAXA) are positively correlated and significant with log transformation (Table 3.3). This indicates that NTAXA is a function of sample size. The faunal dataset was then separated into substrata with low and high NISP (NISP<50 and NISP>50) and again tested for correlations. The low NISP group (r = +0.62, P<.001) is dominated by samples from early substrata (66% of these points are from strata 1-4) and includes all six dietary faunal taxa (Figure 3.4). The high NISP group (r = 0.00, P = 0.99) is dominated by samples from later substrata (64% of these points are from strata 5-6) and includes five of the six dietary faunal taxa found in the low NISP group (Figure 3.4). The relationship of NISP to 1/Simpson's Index is always negative, falling just short of statistical significance at P = .057 (Table 3.3, Figure 3.5).

Macrobotanical Dietary Patterns

A total of 28 types of dietary plant taxa were recovered from 192 hearth features at NCS (Table 3.4, Appendix I). This includes 16 families, 13 genera and 2 identified to species level. 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; for example, the lenticular, beaked and rimmed seeds of *Chenopodium*. *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 (my specimens are distinctively striated, perhaps due to burning). In only two cases are materials identified to species, *Atriplex confertifolia* (shadscale) by its two-winged fruits and *Achnatherum hymenoides* (Indian ricegrass) by its distinctive flask-shaped achene. Indeterminate seeds and fruit are either too fragmented or too degraded to identify at any taxonomic level. Categories assigned as Species A, B, C, D, E and F are distinct enough to separate into different groups, but could not be identified to a genus or species either because there is not a large enough sample size or because the comparative collections to which I had access to are inadequate. 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 see Chapter 4 for recovery of microbotanical remains).

Relative Abundance and Ubiquity Index

Abundances of dietary macrobotanical remains fluctuate through time, ranging from 1 to over 270 seeds, seed coats, fruits and fragments thereof in a single substratum (Figure 3.6). The lowest abundances occur throughout strata 1, 2 and 4. These plant materials tend to be Pinaceae seeds. Higher abundances of dietary plant remains occur in substrata 3c and 3e as well as throughout strata 5 and 6. Remains of *Chenopodium* seeds and fruits are dominant in these deposits, although they are matched in abundance by *Rhus* sp. seeds in substrata 5h and 5i. Overall, there is a progressive increase in dietary plant remains after substratum 5a (9000 ^{14}C BP).

Chenopodium seeds make up 71% of the assemblage ($[\Sigma \text{ NISP}_{Chenopodium}/\Sigma \text{ NISP}_{\text{all plant}}] \times 100$) regardless of when they were deposited (Figure 3.7), making this dietary resource both abundant and ubiquitous (68%) (Table 3.4). In contrast, Pinaceae seed coats are ubiquitous (64%), but not very abundant (7%). This suggests constant but low level use. A third fraction is that of *Rhus* sp. seeds, which are the second most abundant plant remain (10%), but occur in only 11% 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 (Cheno-Ams) have a total ubiquity index of 86%, thus dominating the diet through a considerable period of time.

Taxonomic Richness and Evenness

Taxonomic richness for dietary macrobotanical material varies among strata, ranging from 1 to 11 taxa (Appendix I). Values are low in several substrata; such values are not limited to particular time periods. Values are highest in substrata 5t (~8000 ^{14}C BP), 5h (~8500 ^{14}C BP), 3e (9400 ^{14}C BP), 3c (n.d.), and 2g (~9700 ^{14}C BP) but overall the NCS dietary plant assemblage is dominated by *Chenopodium* seeds. The earliest deposits (Str. 1-3; ~10,000 – 9300 ^{14}C BP) with low richness values almost always contain Pinaceae seeds. Later deposits (Str. 4-6; ~9300 – 6000 ^{14}C BP) are more varied and are dominated by *Chenopodium* seeds.

Tests for the validity of relationships between sample size and taxonomic richness and between sample size and evenness (1/Simpson's Index) were conducted on dietary macrobotanical remains. NISP and NTAXA are positively correlated and significant with or without log transformations (Table 3.5). Similar to the dietary faunal data, there is thus a sensitivity of NTAXA to sample size that required further analysis. The dietary macrobotanical dataset was then separated into substrata with low and high NISP (NISP<50 and NISP>50) and again tested for correlations. The low NISP group ($r = +0.62$, $P = 0.002$) is dominated by samples from early substrata (86% of these points are from strata 1-4) and have a lower range of richness values (Figure 3.8). The high NISP group ($r = +0.67$, $P = 0.006$) is dominated by samples from later substrata (87% of these points are from strata 5-6) and a higher range of richness values (Figure 3.8). In the case of plants, however, only two or three of the taxa found in early substrata (Pinaceae, *Chenopodium*, possibly Amaranthaceae) are the same as in later substrata. Later substrata not only include more plant taxa, but also have taxa normally associated with lower elevation, more arid vegetation types (e.g., *Atriplex*, Cactaceae, *Achnatherum*). The relationship of NISP to 1/Simpson's Index is always negative and for two of the three relationships, insignificant (Table 3.5, Figure 3.9).

Measures of Diet Breadth: Combined Faunal and Macrobotanical Data

To measure general changes in diet breadth over time, I include all dietary taxa (plant and animal) from NCS in a categorical ranking according to post-encounter return rates (e.g., Kelly 1995; Simms 1987) (Table 3.1). The highest ranked food resources at NCS are the artiodactyls contained in the large mammal category (deer, pronghorn, bighorn sheep). The lowest ranked food resources at NCS are contained in the small seeds group (dominated by *Chenopodium* seeds, but also include all other small-seeded plants). Throughout all strata, deer and *Chenopodium* seeds are the most abundant and dominant food resources at NCS, with a combined total of 72% of all animal and plant dietary remains ($[\Sigma \text{ NISP}_{\text{deer}} + \text{NISP}_{\textit{Chenopodium}}]/[\Sigma \text{ NISP}_{\text{all}}] \times 100$) (Figure 3.10).

Tests for the validity of relationships between sample size and taxonomic richness and between sample size and evenness (1/Simpson's Index) were conducted on combined dietary faunal and macrobotanical data. NISP and NTAXA are positively correlated and significant with or without log transformations (Table 3.6), thus indicating a sensitivity of NTAXA to sample size. As before, the combined dataset was then separated into substrata with low and high NISP (NISP<50 and NISP>50) and tested for correlations. The low NISP group ($r = +0.50$, $P = 0.008$) is dominated by samples from early substrata (89% of these points are from strata 1-4) and has a lower range of richness values than samples from later substrata (Figure 3.11). The high NISP group (r = +0.56, P = 0.015) is dominated by samples from later substrata (72% of these points are from strata 5-6) and have a higher range of richness values, which is essentially due to the addition of plant taxa (from arid vegetation types) to the diet (noted above) (Figure 3.11). Unlike the separate analyses of dietary faunal and macrobotanical remains, the relationship of NISP to 1/Simpson's Index for the combined dataset is always negative and never close to significant (Table 3.6, Figure 3.12).

Taxonomic richness and evenness are used to describe the dietary characteristics of each stratum (Figure 3.13a). The earliest deposits in Stratum 1(f through i) yielded meager samples of material to analyze, consisting of a few large and small animal bones and burned conifer and *Chenopodium* seeds. Beginning in Stratum 2a (~10,000 ^{14}C BP), deer become the most dominant dietary resource taken at NCS and there are nearly steady increases in species richness with the addition of *Sylvilagus*, *Lepus* and the seeds or fruits of oak (*Quercus* sp.), legumes, and wild rose (*Rosa* sp.). Simultaneously, evenness is fairly steady with slight fluctuations in value and declines before 9400 ^{14}C BP because of the large and increasing number of deer bones (r = +0.34, P = 0.24). At this time, species richness reaches a maximum (substratum 3e, NTAXA = 14), and evenness is low due to the preponderance of deer.

A second pattern emerges between 9400 and 9000 ^{14}C BP (3g and 5a) as evenness achieves maximal values while richness declines and stays very low (r = +0.45, P = 0.12). This is because deer bones decrease while the abundances of everything else remain fairly constant.

A third pattern emerges shortly after 9000 ^{14}C BP, as species richness and evenness become roughly correlated, though it is not a significant relationship (r = +0.38, P = 0.25). All species tend to be relatively abundant in the deposits, whether they are carried over (e.g. deer, bighorn and *Chenopodium* seeds) or newly added (e.g. sumac [*Rhus* sp.], buckwheat [Polygonaceae] and saltbush [*Atriplex confertifolia*] seeds and fruits). This correlation continues until approximately 8000 ^{14}C BP (substratum 5t), with a reversion to the pattern (high richness, low evenness) observed around 9400 ^{14}C BP (substratum 3e). The dominant food resource at this time, however, is *Chenopodium* seeds, with deer and *Sylvilagus* sp. equally abundant.

There are two significant depositional peaks that emerge from this analysis (Figure 3.13b). In the first peak (substratum 3e), richness reaches a maximum (14), and evenness remains low (2.0) due to the dominance of deer bones (NISP = 292), with an absence of ground stone tools (see below). In the second peak (substratum 5t), the same pattern is observed with high richness (14) and low evenness (1.9). The dominant food resource at this time, however, is *Chenopodium* seeds (NISP = 222) and the dominant tool is ground stone. This shift in dietary emphasis from animal to plant is significant when the composition of these peaks (3e and 5t) are compared (chi square = 254.81, P<.001).

Testing the Diet Breadth Model and Resource Intensification Predictions

The abundances of artiodactyl bones, leporid bones and *Chenopodium* seeds, expressed as NISP, vary widely between 10,000 and 6000 ^{14}C BP (Figure 3.14). The maxima for (high-ranked) artiodactyl bones appear to be clustered, with peaks in earlier substrata 2f and 3e (~10,000 – 9400 ^{14}C BP) and peaks in later substrata 5r, 6a, 6c and 6d (~8300 – 6000 ^{14}C BP). *Chenopodium* seeds (which are lowest-ranked), however, only have peaks of abundance in later substrata 5m, 5t and 5u (~8300 – 8000 ^{14}C BP). In absolute terms, artiodactyl bones and fragments from the early 3e substratum number in the hundreds (NISP = 659) whereas *Chenopodium* seeds and fragments are far fewer (NISP = 84). Later on there appears to be a reversal; *Chenopodium* peaks in substrata 5m and 5t are stronger (NISP = 124 and 222, respectively) and coincident with artiodactyl troughs (NISP = 25 and 99, respectively). Leporid bones have peaks that are barely discernible across the entire sequence of substrata but increase slightly in 5t (NISP = 41).

Peaks of dietary taxonomic richness (plants and animals combined) also appear to be clustered, with maxima occurring in early substrata 2g and 3e and then much later in substratum 5t. These correspond to peaks in artiodactyl (2g and 3e) and *Chenopodium* abundances (5t).

The earliest ground stone tools (manos and metates) occur in substratum 5a (9000 ^{14}C BP), a time when *Chenopodium* exhibits a minor but proportional surge in abundance (Figure 3.15). Increased abundance of ground stone tools across all strata (between 10,000 and 6000 ^{14}C BP) correlates with the increased abundance of all small seeds ($r = +0.69$, $P < .001$) and with *Chenopodium* seeds alone ($r = +0.71$, $P < .001$) (Figure 3.16).

Environmental Change

Pollen

Absolute abundances of pollen from NCS sediments are displayed in Figure 3.17 and Appendix J. Pollen from Stratum 1 (>10,000 ^{14}C BP) shows equally dominant abundances of douglas fir and sagebrush (*Artemisia* sp.). Lower abundances of *Pinus/Abies*, Asteraceae and Amaranthaceae (including Cheno-Ams) also appear during this time. After that, the NCS record is dominated by douglas fir and *Pinus/Abies* pollen, with lower abundances of oak (*Quercus* sp.) and sagebrush. This trend continues until about 9400 BP (substratum 3e). Pollen preservation is very poor between substrata 4a and 5i (approximately 9400 to 8800 ^{14}C BP), but an increase in sagebrush pollen and decrease in conifer pollen at about 9200 ^{14}C BP suggests that the mixed conifer assemblage has decreased in abundance. At approximately 8300 ^{14}C BP (substratum 5q), high abundances of *Pinus/Abies, Pinus, Juniperus* and Amaranthaceae dominate the NCS pollen record, with lesser abundances of sagebrush and grass (Poaceae) pollen. The pine pollen might possibly be pinyon pine (semiarid pine) and the juniper might be Utah juniper. This trend continues until substratum 6d (~6000 ^{14}C BP), where the pollen record is dominated by Amaranthaceae, pine and juniper.

Paleovegetation shifts are perhaps more apparent in the ratio between conifer and Amaranthaceae pollen (Figure 3.18). The steady decline in conifer pollen begins at 9000 ^{14}C BP and continues until the end of the early Holocene. After 8000 ^{14}C BP, Amaranthaceae pollen dominates the NCS pollen record.

The abundances of the modern pollen samples (Figure 3.19) are compared to the fossil pollen abundances from NCS sediments by using the squared chord distance measure. This shows that between 10,000 and 9400 ^{14}C BP, fossil pollen from NCS is most similar to modern pollen from the spruce-fir forests above NCS (Figure 3.20). After 9000 ^{14}C BP, fossil pollen from NCS is most similar to modern pollen from the cool desert mosaic including pinyon-juniper woodlands and amaranth shrubs.

Non-dietary plant macrofossils

Tallies for the non-dietary macrobotanical remains are shown in Appendix K and absolute abundances are displayed in Figure 3.21. Small amounts of non-dietary plant material were recovered from strata 1 and 2, including needle fragments from fir (*Abies concolor*), Douglas fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*) trees, scale leaves from Rocky Mountain juniper (*Juniperus scopulorum*), conifer seed cones, and hackberry (*Celtis* sp.) endocarps. Substratum 3e (9400 ^{14}C BP) yielded a mixed assemblage of needle leaves of fir (*Abies concolor*), Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*). After 9400 BP, the non-dietary plant macrofossil record is dominated by ponderosa pine needle fragments and lesser amounts of conifer seed cones and hackberry endocarps. Then, from about 8800 ^{14}C BP (substratum 5h) to 6000 ^{14}C BP (substratum 6d), the record is dominated by Utah juniper (*Juniperus osteosperma*) and two-leaf pinyon pine (*Pinus edulis*). Small amounts of conifer seed cones, ponderosa pine, rocky mountain juniper and Douglas fir needles are also found scattered in those strata.

Patterns of paleovegetation change are more clearly depicted when the abundances of cool-adapted conifer leaves (i.e., *Abies concolor, Pseudotsuga menziesii, Pinus ponderosa and Juniperus scopulorum*) are compared to the abundances of pinyon-juniper leaves (i.e., *Pinus edulis* and *Juniperus osteosperma*). This ratio reveals a shift to pinyon-juniper woodland occurring shortly after 9000 ^{14}C BP (Figure 3.22).

Discussion

The deposits at NCS show that species richness for dietary plants and animals fluctuate through time, with peaks and valleys presumably reflecting increased or decreased human activity at the site. Human activity at NCS increases later on in strata 5 and 6, as evidenced by higher abundances (NISP) and a greater number of dietary taxa taken. Deer and *Chenopodium* are consistently included in the diet spanning the 10,000 – 6000 ^{14}C BP period. 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. I have also shown that the species composition of faunal remains at NCS remains essentially the same despite environmental change between early and later substrata. Only *Cervus* is absent from the later, high NISP assemblages. But the species composition of the dietary plants changes markedly between early and later substrata. At least five different plant taxa are added to the middle Holocene substrata (those with high NISP), all of which are typical components of low elevation, arid vegetation types. The early substrata assemblages (low NISP) appear to be more typical of mesic plant communities, although there is overlap with Pinaceae and *Chenopodium*. But the genus *Chenopodium* is comprised of cool- and warm-adapted species (i.e., C3 and C4, respectively), implying that several different taxa may be included in the tally as climate change drove vegetation change in the region.

The rich archaeological record from NCS reflects the use of dietary animals and plants over extended periods of time, with large fluctuations in abundances (i.e., NISP values). A typical analysis, which might focus on either animals or plants separately, would have reached the conclusion that larger sample sizes are dominated by one or a few common taxa. That is, the correlation between NISP and 1/Simpson's Index would have been significant or nearly so (depending on the accepted value of a Type II error) in four of the six relationships (Tables 3.3 and 3.5). But by combining the animal and plant datasets (realistic in terms of human diet), there are no significant or even close to significant sample size effects regardless of what transformations are used (Table 3.6).

There are also two periods of increased diet breadth when a wide array of species is added to the diet. These peaks occurring at 9400 and 8000 ^{14}C BP include species from high and low elevations, such as *Ovis* and *Lepus*, and *Pinus* and *Atriplex*, respectively. Overall, a maximum of 14 taxa and a minimum of 2 taxa are found in the dietary deposits at NCS, a relatively small subset of the dietary palette supplied by local ecosystems (see Chapter 2).

In terms of abundance, deer bones account for 67% of all plant and animal remains ($[\Sigma\ \mathrm{NISP}_{\mathrm{deer}}/\Sigma\ \mathrm{NISP}_{\mathrm{all}}] \times 100$) in substratum 3e (9400 ^{14}C BP), which coincides with the early peak of species richness. The calculated dietary evenness approaches its lowest values owing to the dominance of deer as a food source. At the same time, *Chenopodium* constitutes 19% of all remains ($[\Sigma\ \mathrm{NISP}_{Chenopodium}/\Sigma\ \mathrm{NISP}_{\mathrm{all}}] \times 100$). In contrast, relative abundances of deer and *Chenopodium* at 8000 ^{14}C BP are the opposite, 10% and 70% respectively. The next six taxa (*Syvilagus*, *Rhus*, Pinaceae, Poaceae, *Ovis* and *Lepus*) contribute a combined total of 25% of the dietary remains across all substrata. *Chenopodium* dominance at this time thus results in low values of dietary evenness.

The shift in emphasis between deer and *Chenopodium* is accompanied by a shift in stone tool technology. The assemblage of chipped stone tools in substratum 3e is dominated by hunting and bone-processing implements, including a North Creek Stemmed projectile point, a knife, bifaces, steep-edge scrapers, unifacially flaked stone tools, and cobbles (Janetski et al. 2012). Ground stone tools do not arrive until 400 years later in substratum 5a (9000 ^{14}C BP), becoming dominant in substratum 5t (8000 ^{14}C BP), simultaneous with a peak in *Chenopodium* abundance. It is also possible at this time and thereafter that other plant foods are being processed on these stones, including starch-laden tubers and underground parts of plant taxa such as, *Solanum, Fritillaria, Lomatium* and *Leymus* (see Chapter 4).

The diet-breadth model predicts that decreases in the abundance of high-ranked resources from the landscape coincide with increases in the abundance of lower-ranked resources. This prediction appears to be met during several discrete events, when *Chenopodium* seeds outnumber the sum of artiodactyl and leporid bones (e.g., 3c, 5a, 5m, 5p and 5t). But only in substratum 5t (8000 ^{14}C BP) is resource intensification suggested, because taxonomic richness is maximal, low-return resources increase dramatically, and ground stone tools are very abundant. I might expect resource intensification to be associated with several adjacent substrata, rather than a single, short-term living surface because the practice may be sustained over a longer period of time if climate diminished the availability of higher-ranked resources. Nevertheless, this is the *only* substratum in the stratigraphic sequence where the prediction and the data coincide.

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). Climate change is detected in this study by major shifts in pollen produced by the dominant species of plant in the immediate vicinity of NCS. Increasing aridity begins by 9000 ^{14}C BP and progresses significantly by 8000 ^{14}C BP, indicated by a shift in vegetation from a mixed conifer forest of cool-adapted species (e.g., true fir, douglas fir, and ponderosa pine) to a semi-arid woodland and shrub mosaic (dominated by pinyon-pine, juniper and Amaranthaceae). This coincides with greater use of small seeds and ground stone technology, and therefore, resource intensification in the absence of changes in dietary species richness.

The archaeological deposits in NCS span a time of increasing aridity on the Colorado Plateau occurring between 8000 and 6000 ^{14}C BP. With increasing aridity comes increasing environmental stochasticity, uncertainty with respect to precipitation regime, plant productivity and animal population sizes (Pavlik 2008). As middle Holocene aridity increased, I expect greater use of low-ranked resources because of major changes to ecosystem composition and food availability. However, deer bones remain abundant in the deposits (with the exception of substratum 5t) and *Chenopodium* seeds seem to decline until Fremont times (unpublished data).

This begs the question: Why is the shift to low-ranked resources an uncommon and unsustained change in diet during most of the middle Holocene at NCS? First, there is some indication that living surfaces such as 5t are short-term occupations that may not reflect an environmentally-caused change in dietary behavior. These short-term occupancies may or may not include animal and/or plant remains, hearth/pit features, stone tools in varying abundances. There is no consistent pattern. Regardless, this does not discount the possibility of resource intensification even if practiced by a few people for relatively limited amounts of time. Secondly, it would be better if additional strata were available to allow a finer-grained analysis that extends further into the developing middle Holocene. Unfortunately, later deposits (after 6d, ~6000 ^{14}C BP) are poorly stratified, truncating the most critical period of analysis. Thirdly, local depletion of artiodactyl populations may be regularly mitigated by deer immigration from distant sources. Unlike the Great Basin, the landscape of the western Colorado Plateau consists of nearly continuous and large areas of upland that may provide corridors for constantly reestablishing herds in the vicinity of NCS, regardless of climate-driven vegetation change.

It is also possible that social factors are at work. The shift to *Chenopodium* use in substratum 5t may reflect the development of different foraging strategies between men and women, thus accounting for the observed changes in resource use (Janetski et al. 2012). Women foraged in more reliable resource patches, accumulating more low-return resources and heavily investing in plant-processing tools, whereas men pursued fluctuating, but highly mobile herds of large-bodied animals at some distance from the site.

With the onset of the middle Holocene, dietary shifts to small seed use, enabled by grinding stone technology, took place in both the Great Basin and northern Colorado Plateau. Increasing aridity between 8500 and 8000 ^{14}C BP brought major changes to these landscapes, with redistributions of animal and plant resources that constrained some harvests while facilitating others. From a foraging theory perspective, I demonstrate a broading of the diet at NCS concurrent with these environmental events, evidenced by fluctuations in species richness and abundances, increases in the frequency of ground stone tools, and a documented (but short-lived) shift from high- to low-ranked resources. This resource intensification is often mentioned in studies of Great Basin archaeology, but here it is fully supported by a remarkable stratigraphic sequence that bridges this critical period in human prehistory. The coincidence of a broadening diet, pronounced technological change and possible social reorganization represents a holistic adjustment of people to difficult and uncertain conditions of existence.

Figures and Tables

Table 3.1. Post-encounter return rates and relative rank of dietary resources at NCS. Return rates based on Simms (1987) and Kelly (1995). Underground storage organ (USO) plants include those with tubers, bulbs, rootstocks, corms and rhizomes.

Category	**Dietary Resource Type**	**Post-encounter return rate (kcal/hr)**	**Rank**
Large mammal	deer, pronghorn, bighorn sheep	15,725 - 31,450	A (High-rank)
Small mammal	jackrabbit, rabbit	8,983 - 15,400	B
USO plants	*Lomatium* spp., *Lewisia redivia*, *Perideridia gairdneri*	172 - 3,831	C
Pine nuts	conifer seeds	841 - 1,408	D
small seeds	*Chenopodium* spp. and various small seeds	92 - 652	E (Low-rank)

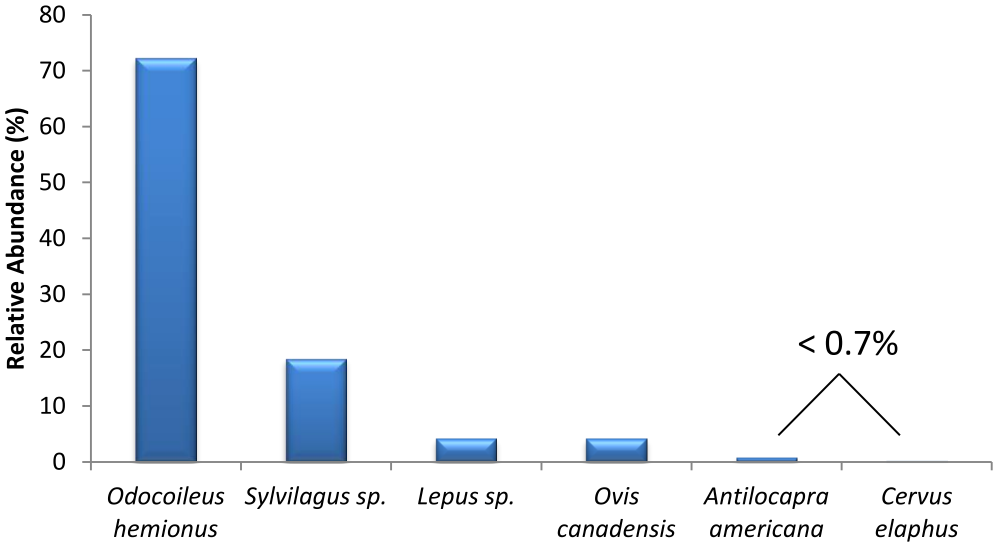

Figure 3.1. Relative abundances of dietary faunal remains (% of NISP$_{\text{all animals}}$) at NCS. Includes specimens identified as “cf” (see Appendix C).

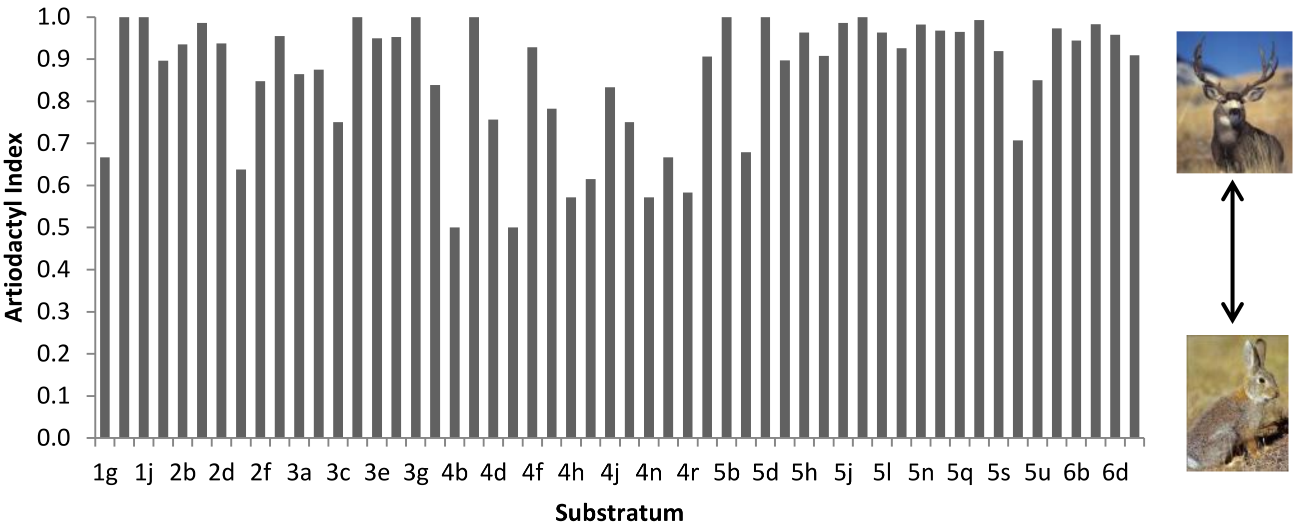

Figure 3.2. Artiodactyl Index (Artiodactyls/[Artiodactyls+Leporids]) for NCS dietary faunal assemblages (NISP > 1).

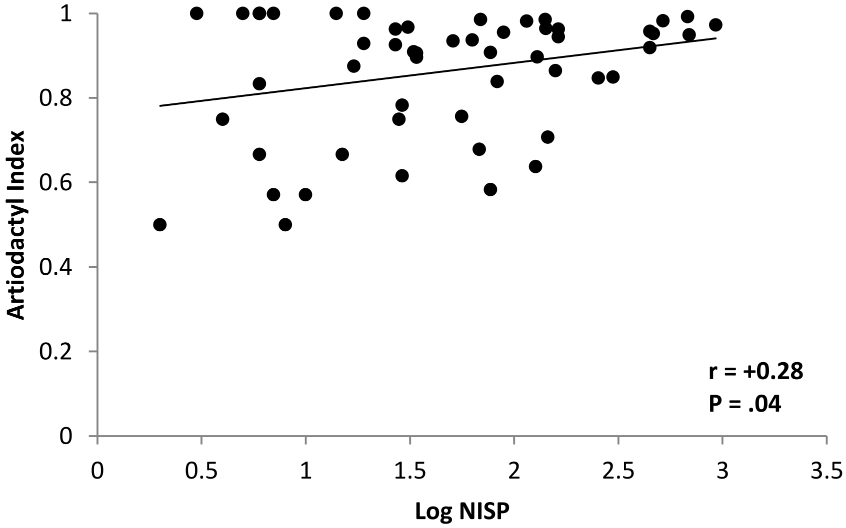

Figure 3.3. Relationship between Artiodactyl Index and Log NISP for all faunal remains at NCS (NISP>1).

Table 3.2. Summary table of approximate radiocarbon dates of substrata from NCS.

Substratum	**Approximate ^{14}C age (yrs BP)**
6d	6000
5u	7700
5t	8000
5h – 5q	8300
5a	8800
4a	9500
3e	9400
3b	9560
3a	9700
2g	9740
2a	10,000

Table 3.3. Relationships between sample size (NISP) and taxonomic richness (NTAXA) and evenness (1/Simpson's Index) for dietary faunal assemblages at NCS. Correlation coefficients (r) and probabilities (P) included, with log transformations.

Relationship	**r**	**P**
Taxonomic Richness		
(NISP ~ NTAXA)	+0.28	.054
(Log NISP ~ Log NTAXA)	+0.58	< .001
Low NISP		
(Log NISP ~ Log NTAXA)	+0.62	< .001
High NISP		
(Log NISP ~ Log NTAXA)	0.00	.99
1/Simpson's Index		
(NISP ~ 1/Simpson's Index)	-0.29	.057
(Log NISP ~ Log 1/Simpson's Index)	-0.30	.087
(Log NISP ~ 1/Simpson's Index)	-0.26	.084

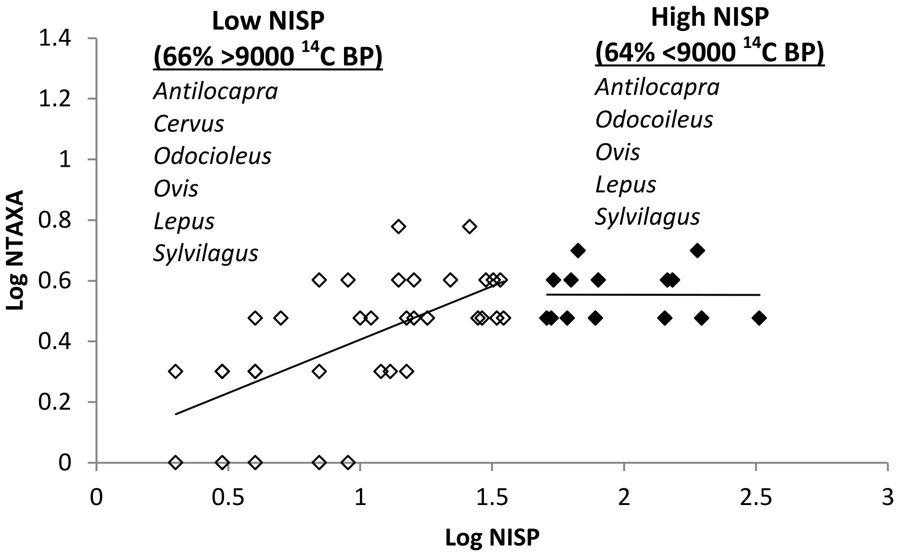

Figure 3.4. Relationship between Log NTAXA and Log NISP for dietary faunal remains at NCS (NISP>1). Low NISP = open diamonds, High NISP = closed diamonds. Low NISP relationship (r = +0.62, P<.001) is composed of roughly the same number of taxa as the high NISP relationship (r = 0.00, P = 0.99). The list of Low NISP taxa comes from substratum 6d and the list of High NISP taxa comes from 6a.

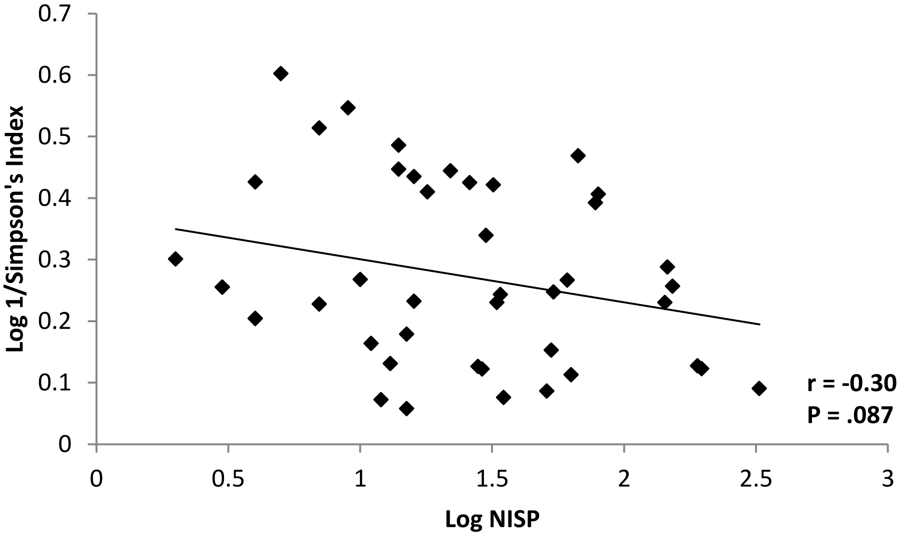

Figure 3.5. Relationship between Log 1/Simpson's Index and Log NISP for dietary faunal remains at NCS (NISP>1, NTAXA>1).

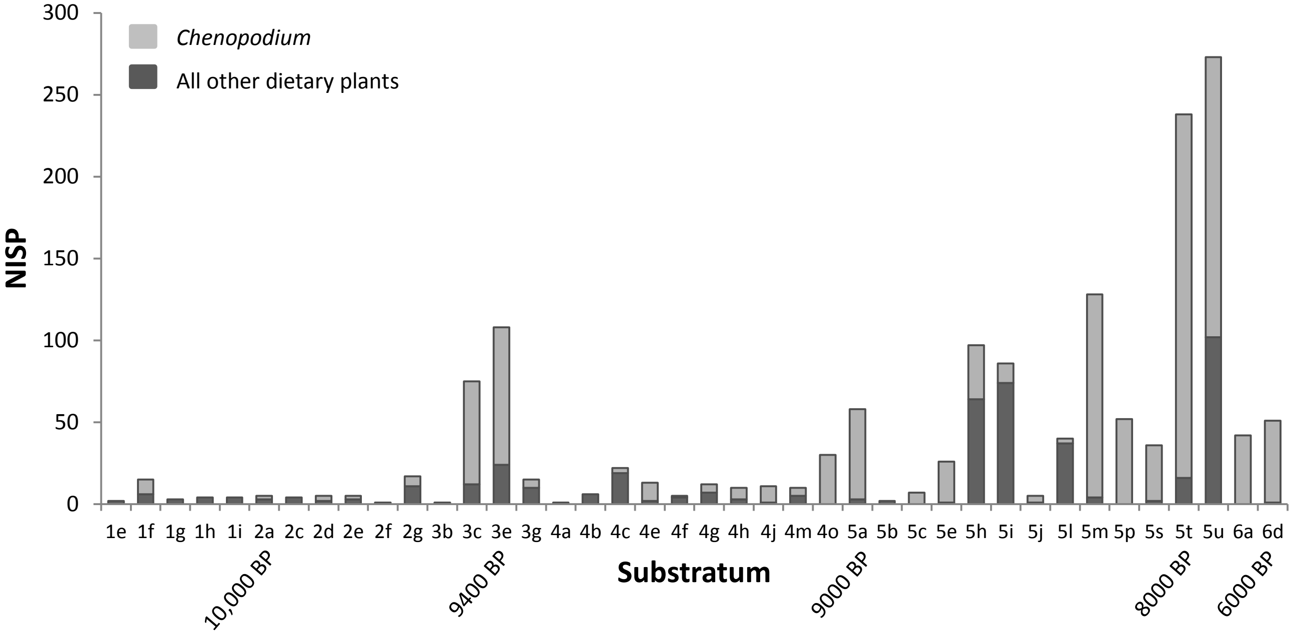

Figure 3.6. Abundance (NISP) of *Chenopodium* relative to all other dietary macrobotanical remains from NCS. Only substrata with NISP≥1 are included. Strata with no identified specimens have been excluded.

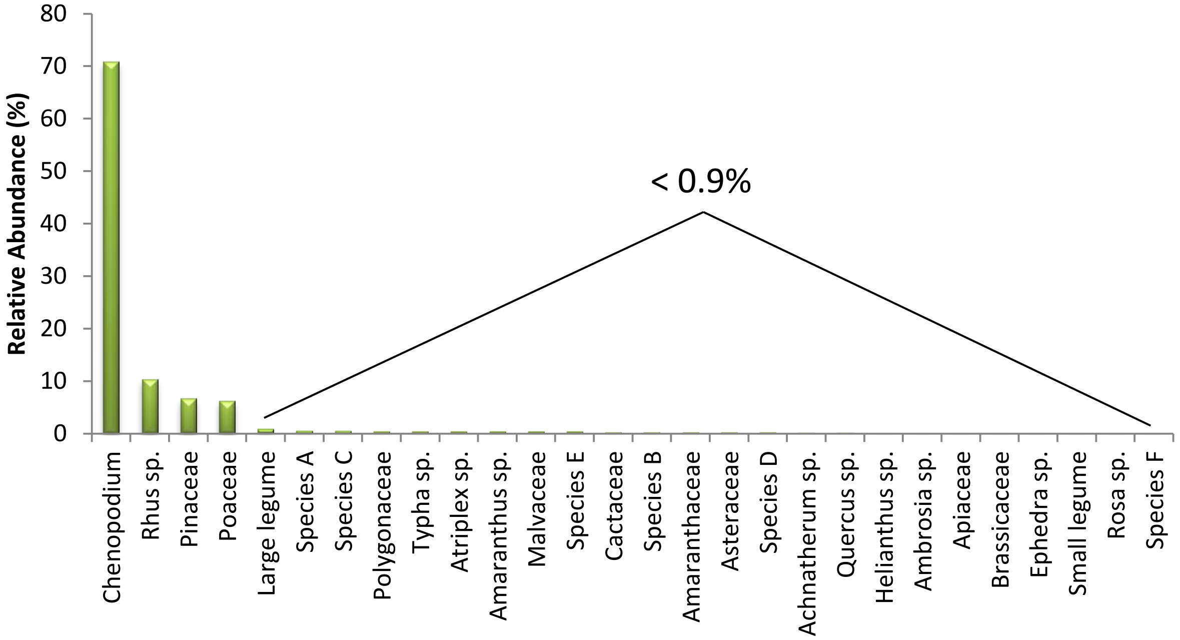

Figure 3.7. Relative abundances of dietary macrobotanical remains (% of $\text{NISP}_{\text{all plants}}$) at NCS.

Table 3.4. Ubiquity index of dietary macrobotanical remains from NCS.

Plant Taxon	**Plant Parts**	**Ubiquity (% Presence)**
Chenopodium	seeds, fruits	68
Pinaceae	seeds, seed coats	64
large legume	seeds	14
Rhus sp.	seeds	11
Atriplex confertifolia	fruits	9
Polygonaceae	achenes	9
Malvaceae	seeds	9
Amaranthaceae	seeds, fruits	7
Cactaceae	seeds	7
Species A	unid. seeds/frags	7
Asteraceae	achenes	5
Apiaceae	mericarps	5
Acnatherun hymenoides	caryopses	5
Poaceae	caryopses	5
Quercus sp.	nuts	5
Typha sp.	fruits	5
Species B	unid. seeds/frags	5
Species D	unid. seeds/frags	5
Amaranthus sp.	seeds, fruits	2
Helianthus sp.	achenes	2
Ambrosia sp.	achenes	2
Brassicaceae	seeds, siliques	2
Ephedra sp.	seeds	2
small legume	seeds	2
Rosa sp.	hypanthia	2
Species C	unid. seeds/frags	2
Species E	unid. seeds/frags	2
Species F	unid. seeds/frags	2

Table 3.5. Relationships between sample size (NISP) and taxonomic richness (NTAXA) and evenness (1/Simpson's Index) for dietary macrobotanical assemblages at NCS. Correlation coefficients (r) and probabilities (P) included, with log transformations.

Relationship	r	P
Taxonomic Richness		
(NISP ~ NTAXA)	+0.58	< .001
(Log NISP ~ Log NTAXA)	+0.55	< .001
Low NISP		
(Log NISP ~ Log NTAXA)	+0.62	.002
High NISP		
(Log NISP ~ Log NTAXA)	+0.67	.006
1/Simpson's Index		
(NISP ~ 1/Simpson's Index)	-0.20	.289
(Log NISP ~ Log 1/Simpson's Index)	-0.32	.083
(Log NISP ~ 1/Simpson's Index)	-0.24	.200

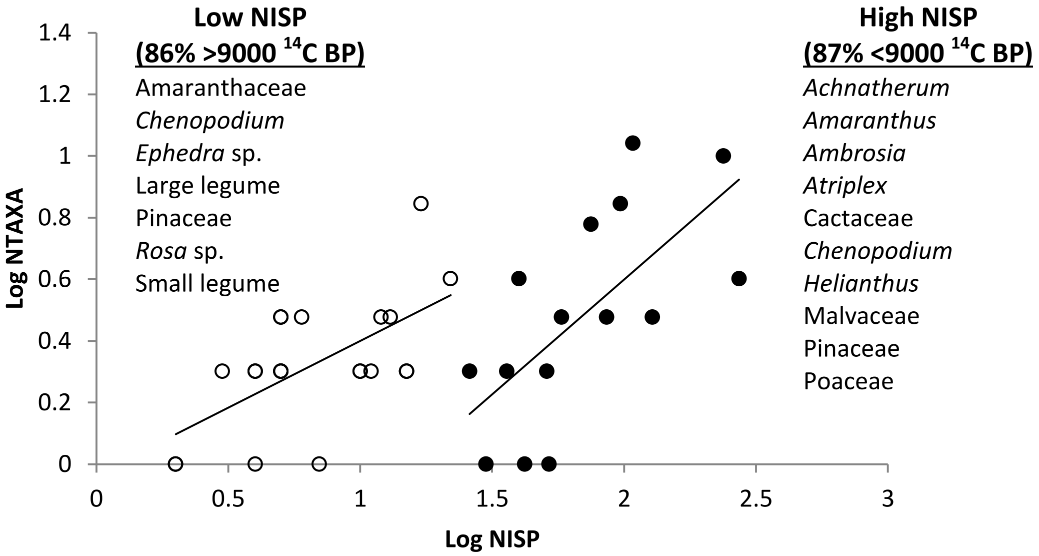

Figure 3.8. Relationship between Log NTAXA and Log NISP for dietary macrobotanical remains at NCS (NISP>1). Low NISP = open circles, High NISP = closed circles. Low NISP relationship (r = +0.62, P = .002) has a lower range of richness values, while the high NISP relationship (r = +0.67, P = .006) has higher range of richness values. List of Low NISP taxa comes from substratum 2g and list of High NISP taxa comes from 5t.

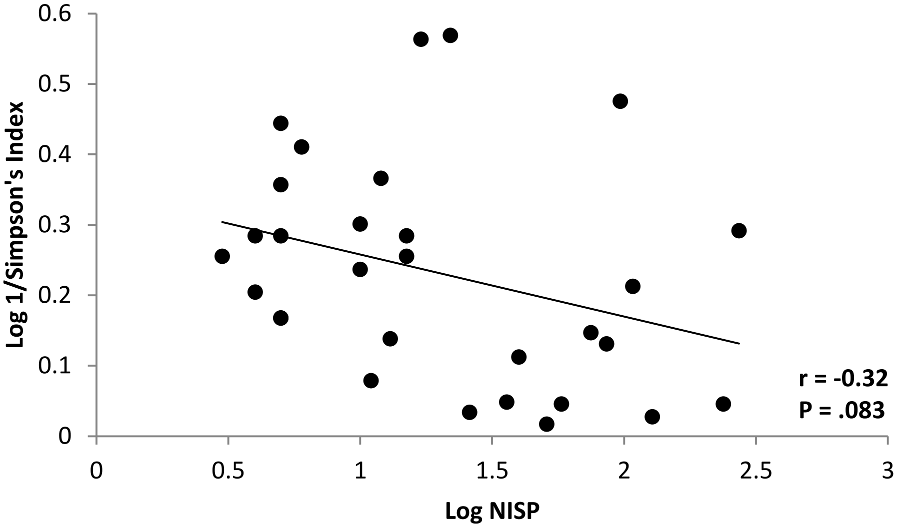

Figure 3.9. Relationship between Log 1/Simpson's Index and Log NISP for dietary macrobotanical remains at NCS (NISP>1, NTAXA>1).

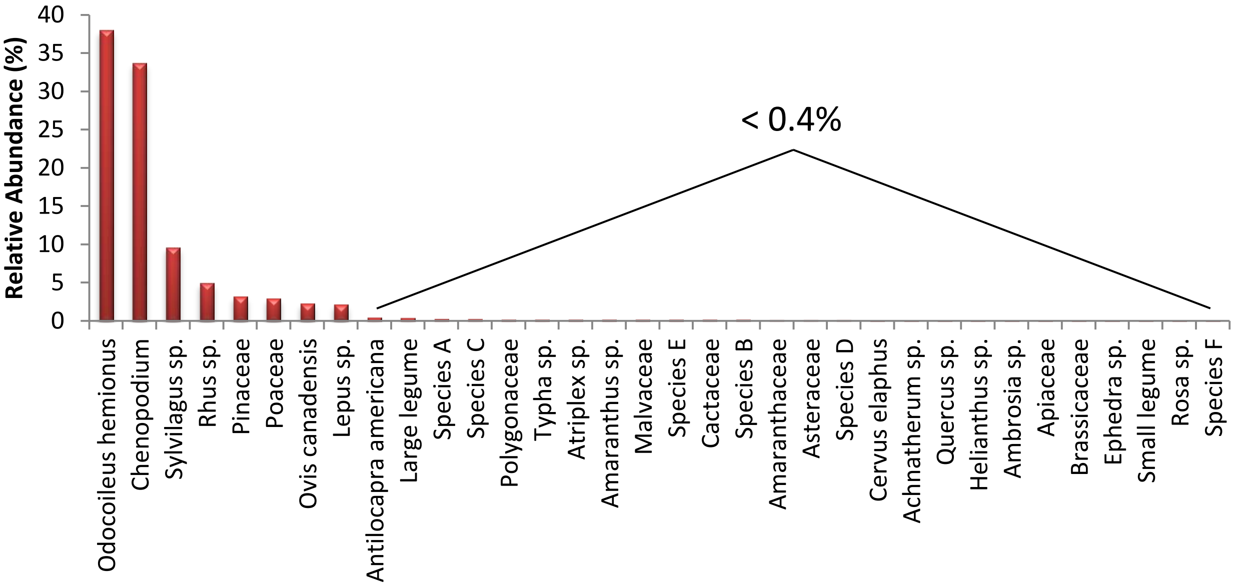

Figure 3.10. Relative abundances (% of $\text{NISP}_{\text{plants+animals}}$) for combined dietary plant and animal assemblages at NCS.

Table 3.6. Relationships between sample size (NISP) and taxonomic richness (NTAXA) and evenness (1/Simpson's Index) for combined dietary (plant and animal) assemblages at NCS. Correlation coefficients (r) and probabilities (P) included, with log transformations.

Relationship	r	P
NTAXA		
(NISP ~ NTAXA)	+0.72	< .001
(Log NISP ~ Log NTAXA)	+0.71	< .001
Low NISP		
(Log NISP ~ Log NTAXA)	+0.50	.008
High NISP		
(Log NISP ~ Log NTAXA)	+0.56	.015
1/Simpson's Index		
(NISP ~ 1/Simpson's Index)	-0.01	.929
(Log NISP ~ Log 1/Simpson's Index)	-0.10	.537
(Log NISP ~ 1/Simpson's Index)	-0.08	.589

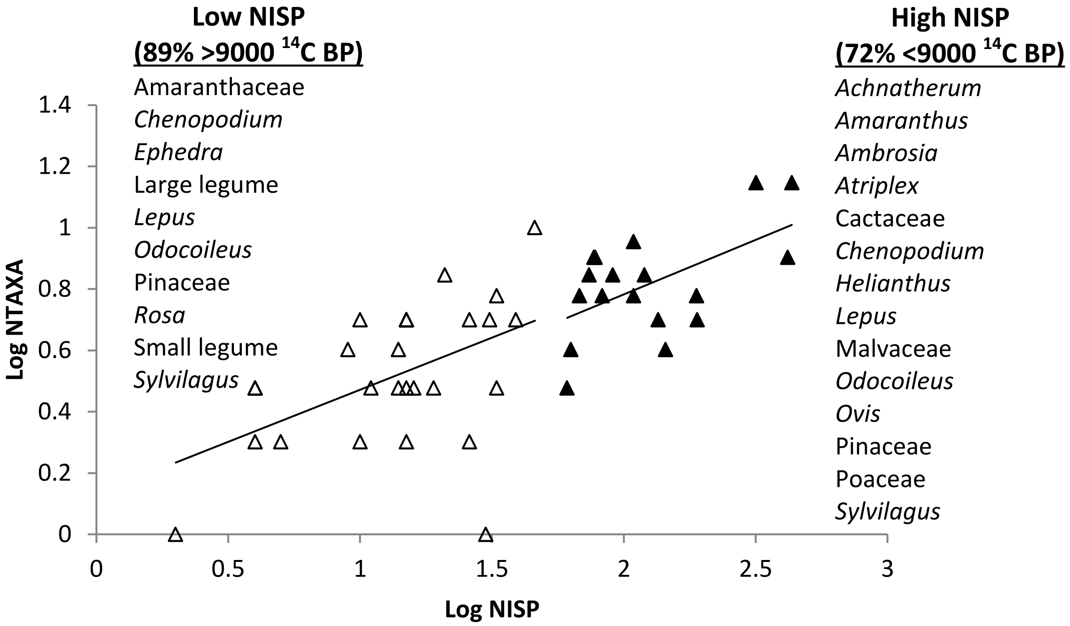

Figure 3.11. Relationship between Log NTAXA and Log NISP for combined dietary (plant and animal) remains at NCS (NISP>1). Low NISP = open triangles, High NISP = closed triangles. Low NISP relationship (r = +0.5, P = .008) has a lower range of richness values, while the high NISP relationship (r = +0.56, P = .015) has a higher range of higher richness values. The list of Low NISP taxa comes from substratum 2g and this list of High NISP taxa comes from 5t.

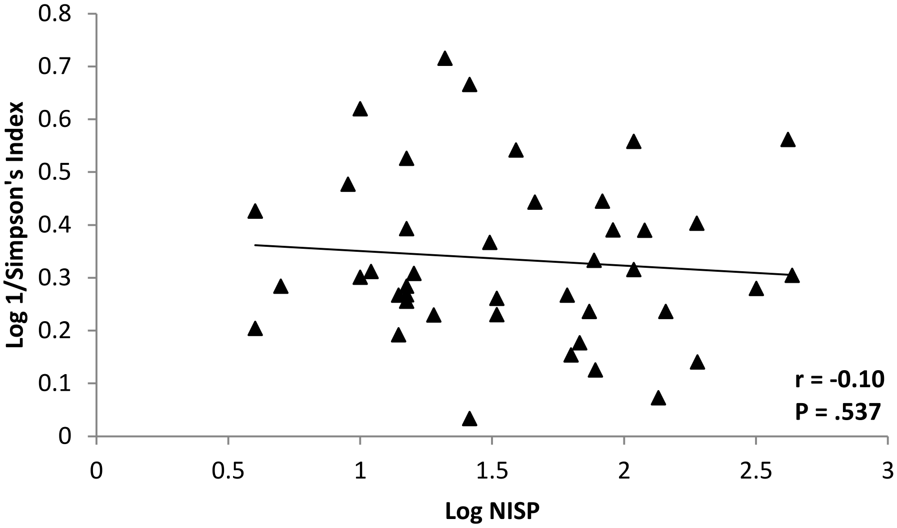

Figure 3.12. Relationship between Log 1/Simpsons's Index and Log NISP for combined dietary (plant and animal) remains at NCS (NISP>1, NTAXA>1).

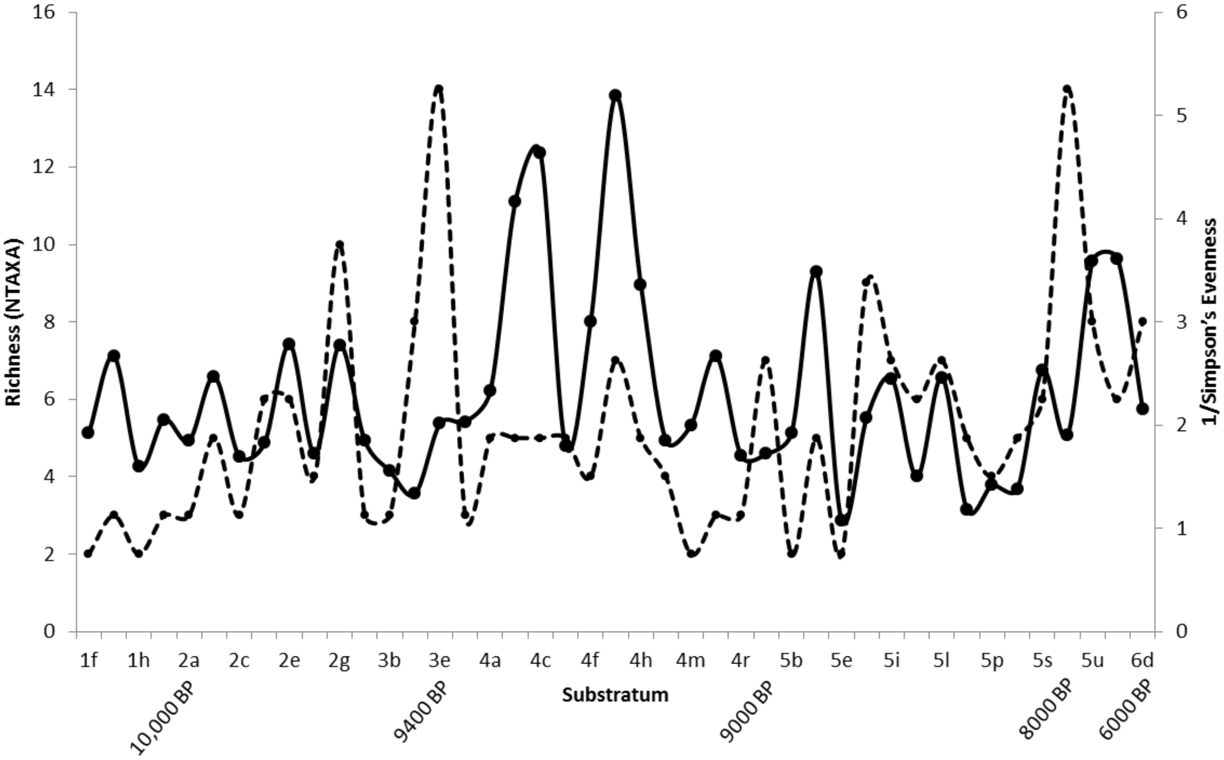

Figure 3.13a. Taxonomic richness (dotted line) and 1/Simpson's Index of Evenness (solid line) for combined faunal and macrobotanical dietary assemblages from substrata at NCS.

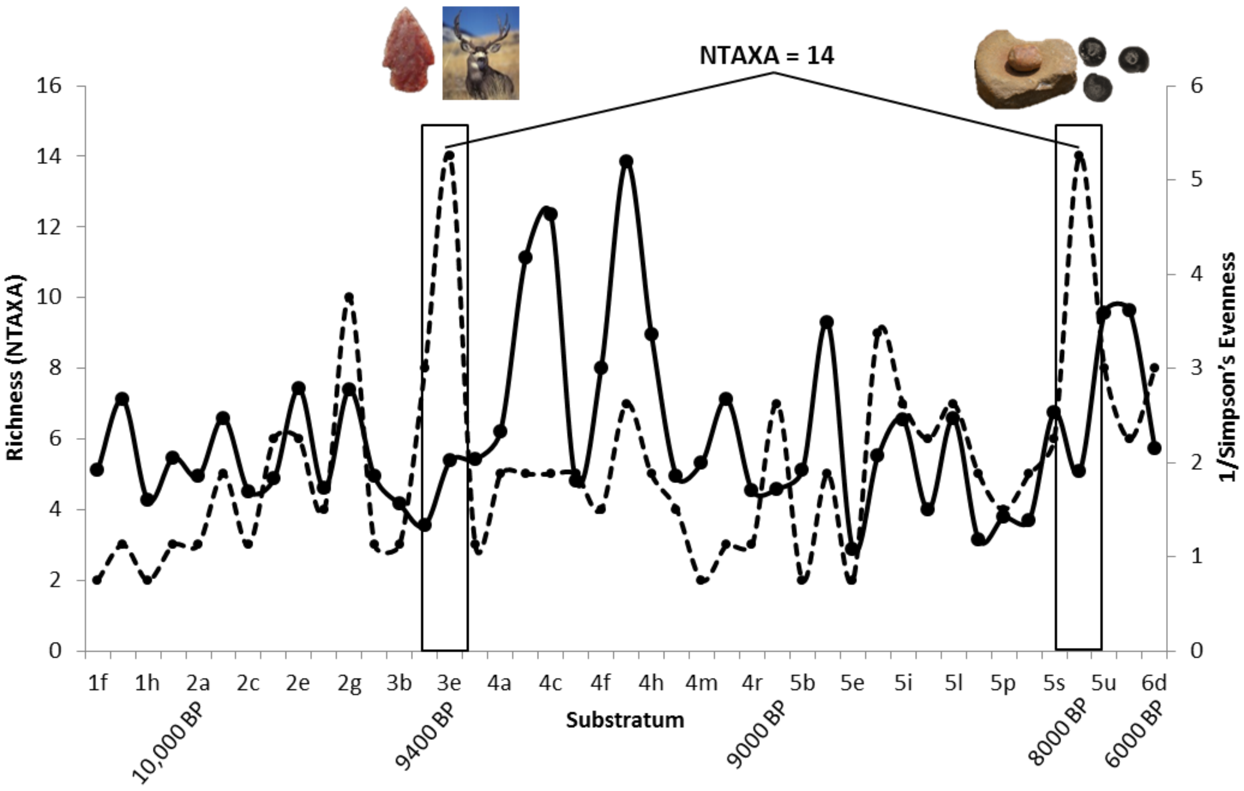

Figure 3.13b. Richness and evenness as in Figure 3.12a. Substratum 3e is dominated by deer and stemmed projectile points. Substratum 5t is dominated by *Chenopodium* seeds and ground stone tools.

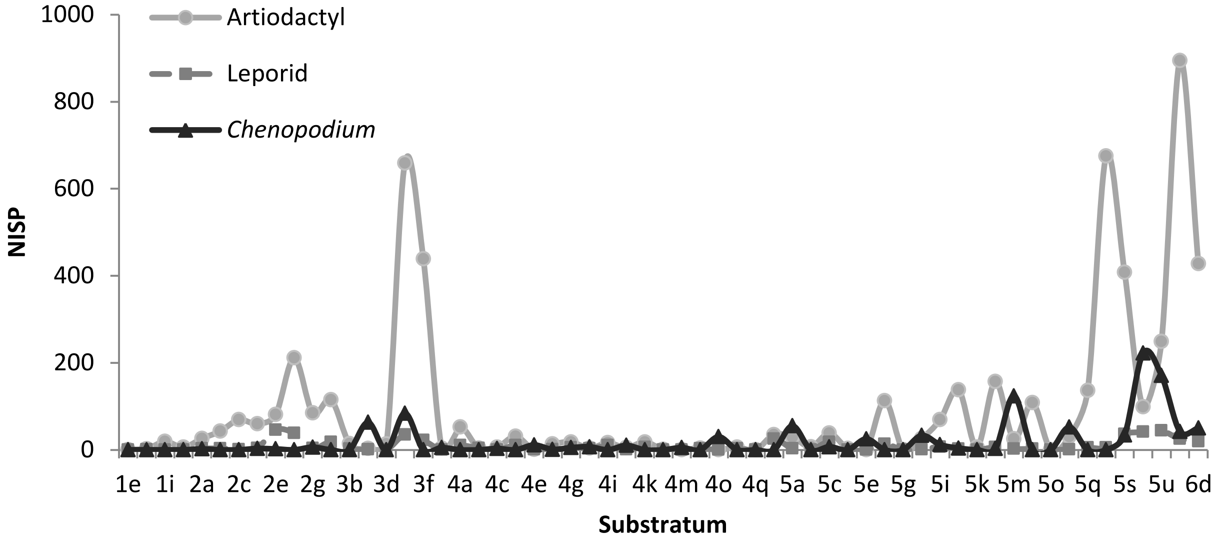

Figure 3.14. Abundances (NISP) of artiodactyl bones, leporid bones and *Chenopodium* seeds.

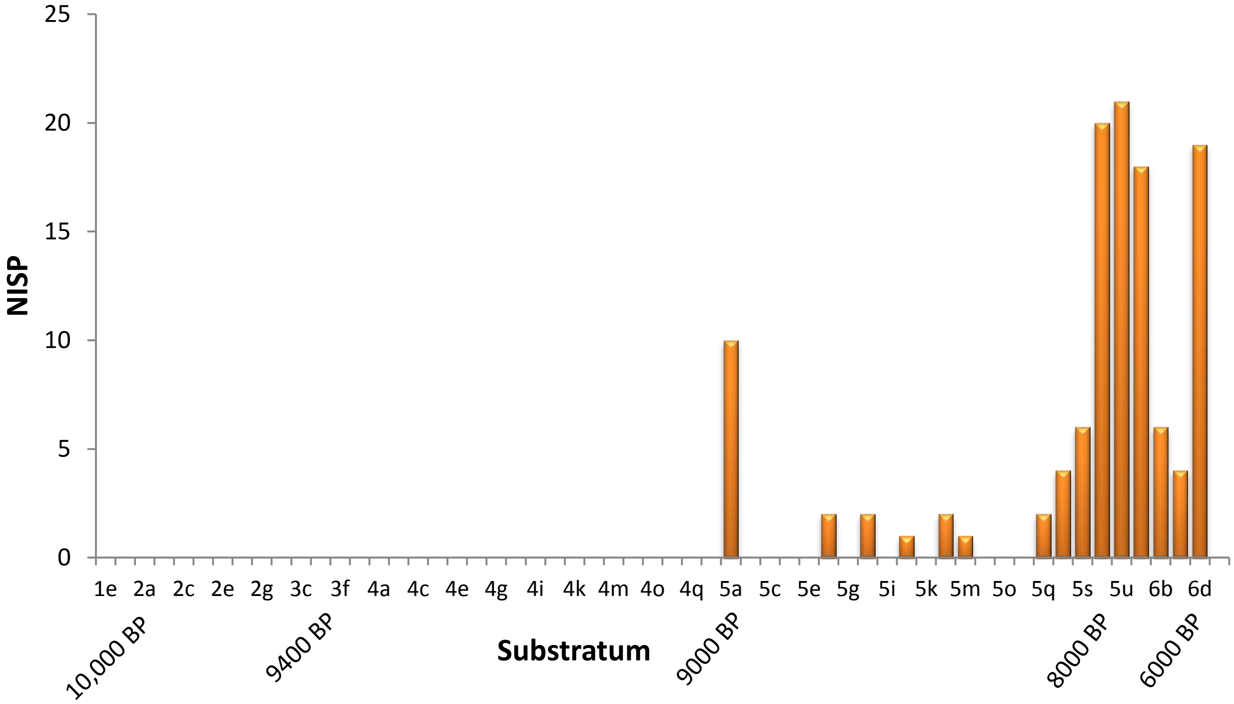

Figure 3.15. Abundance (NISP) of ground stone tools at NCS. (Raw data from M. Bodily).

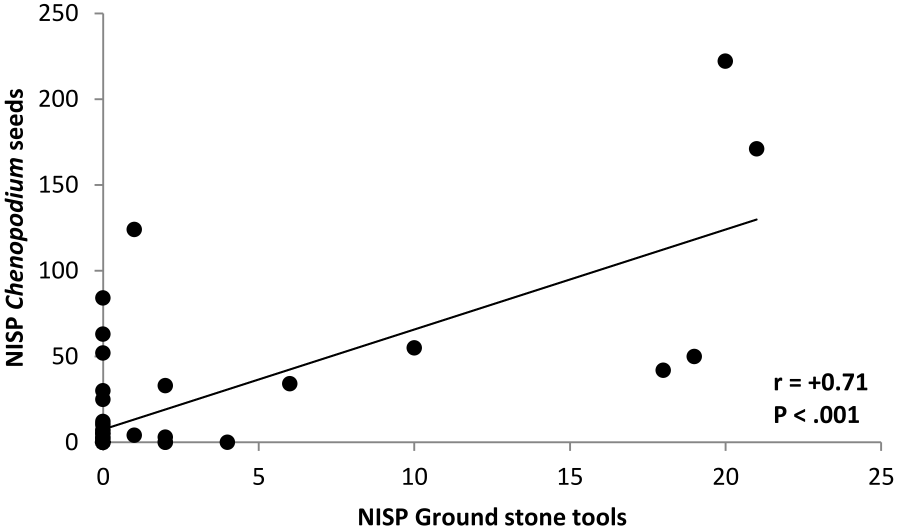

Figure 3.16. Relationship between NISP *Chenopodium* seeds and NISP Ground stone tools from all strata at NCS.

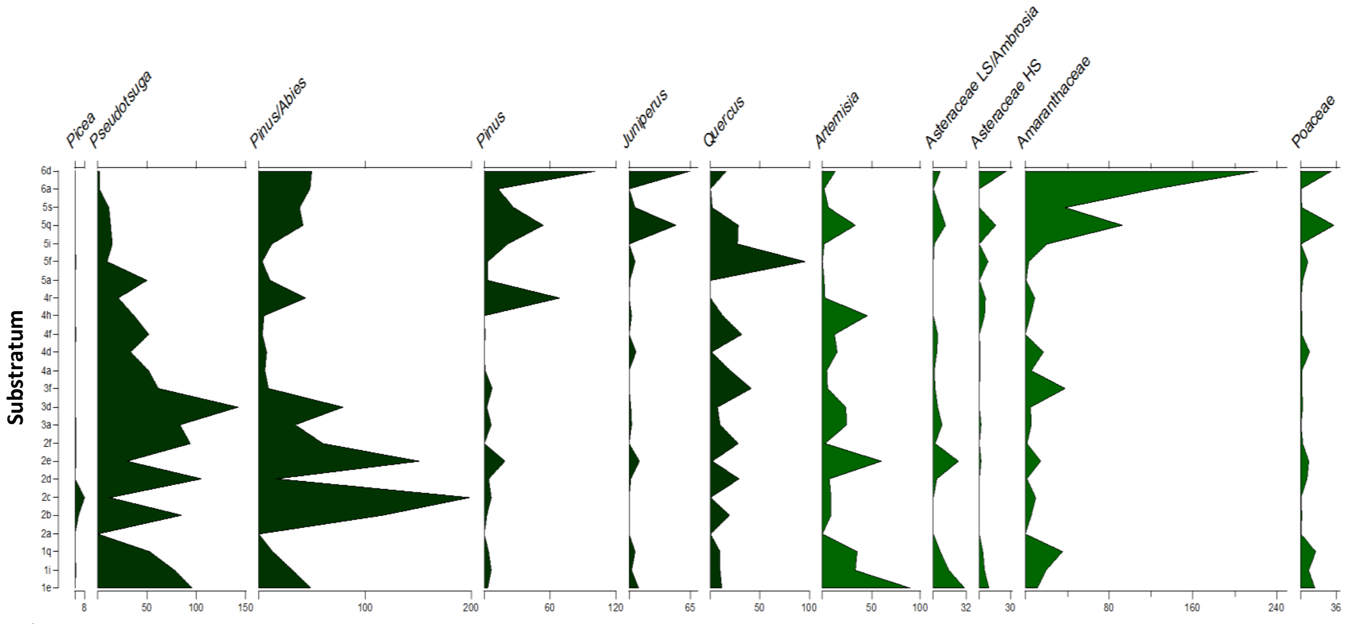

Figure 3.17. Abundances (raw counts) for pollen assemblages from NCS sediments.

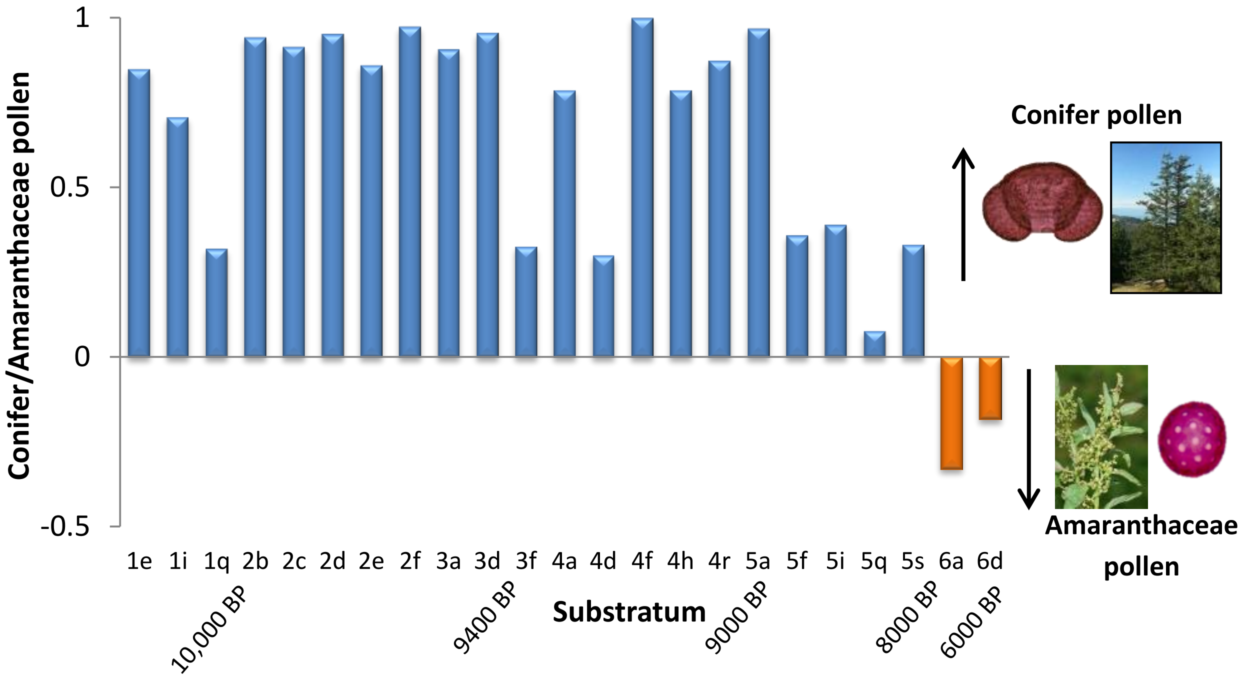

Figure 3.18. Ratio of conifer pollen to Amaranthaceae pollen from NCS sediments.

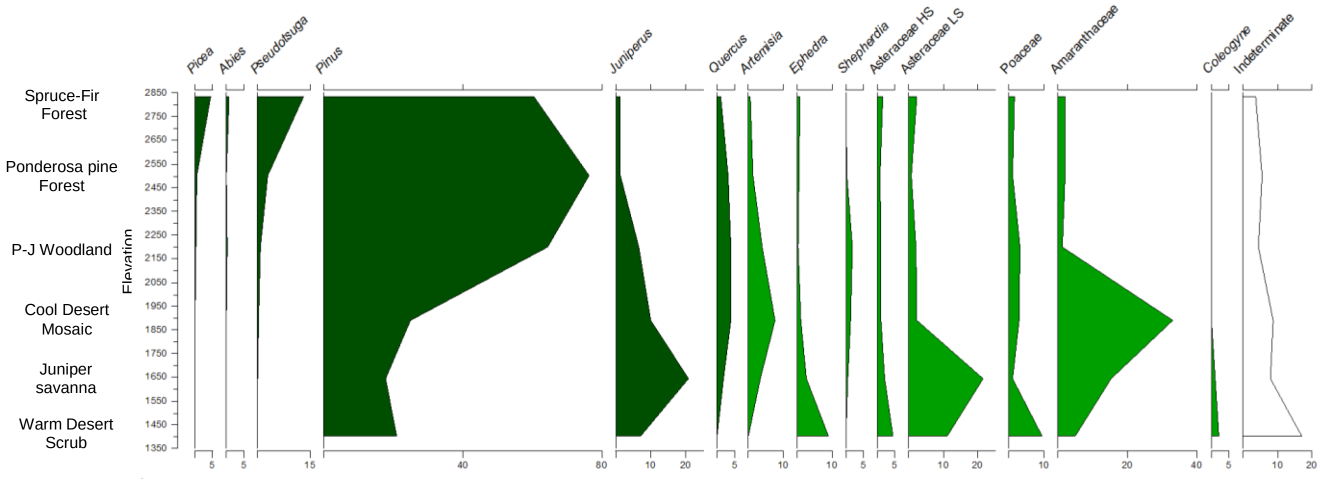

Figure 3.19. Relative abundances (% of all pollen) of key terrestrial plant pollen taxa from modern pollen rain. Samples were collected in different vegetation communities situated at, above and below NCS (1900m). Taxa that contributed minor amounts (<1%) are not shown.

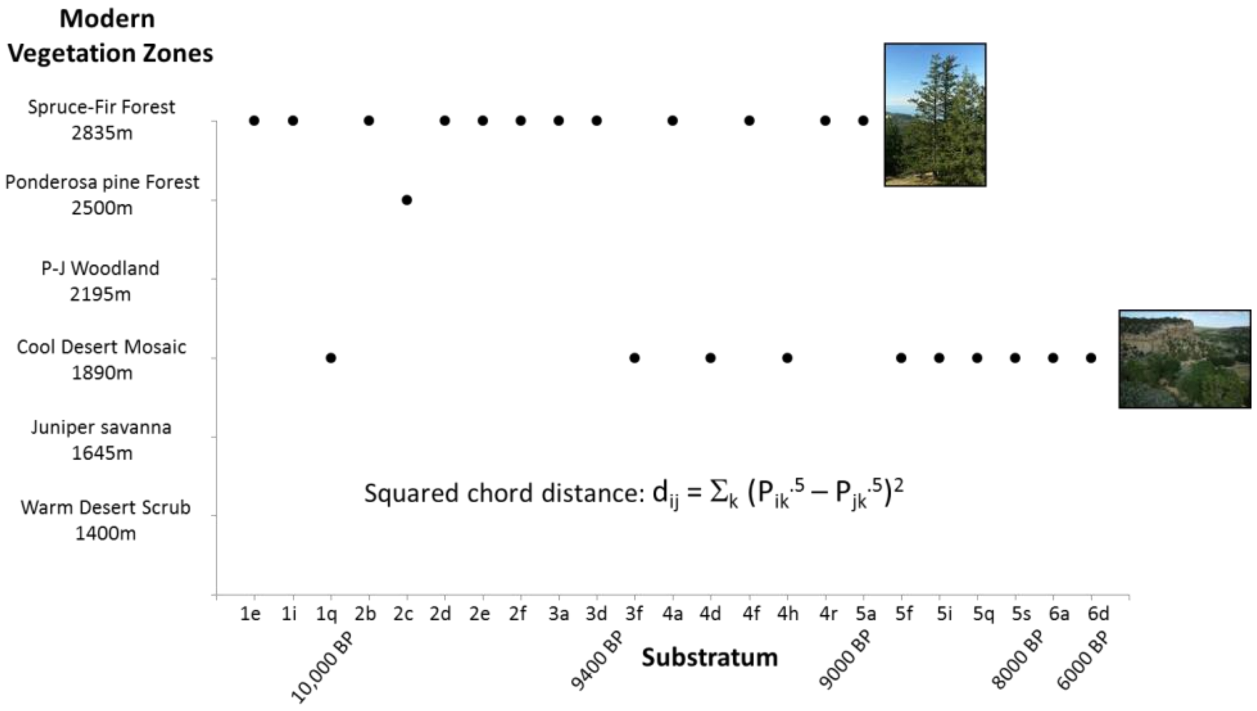

Figure 3.20. Maximum similarity values of each fossil pollen assemblage compared to modern pollen rain in the vicinity of NCS.

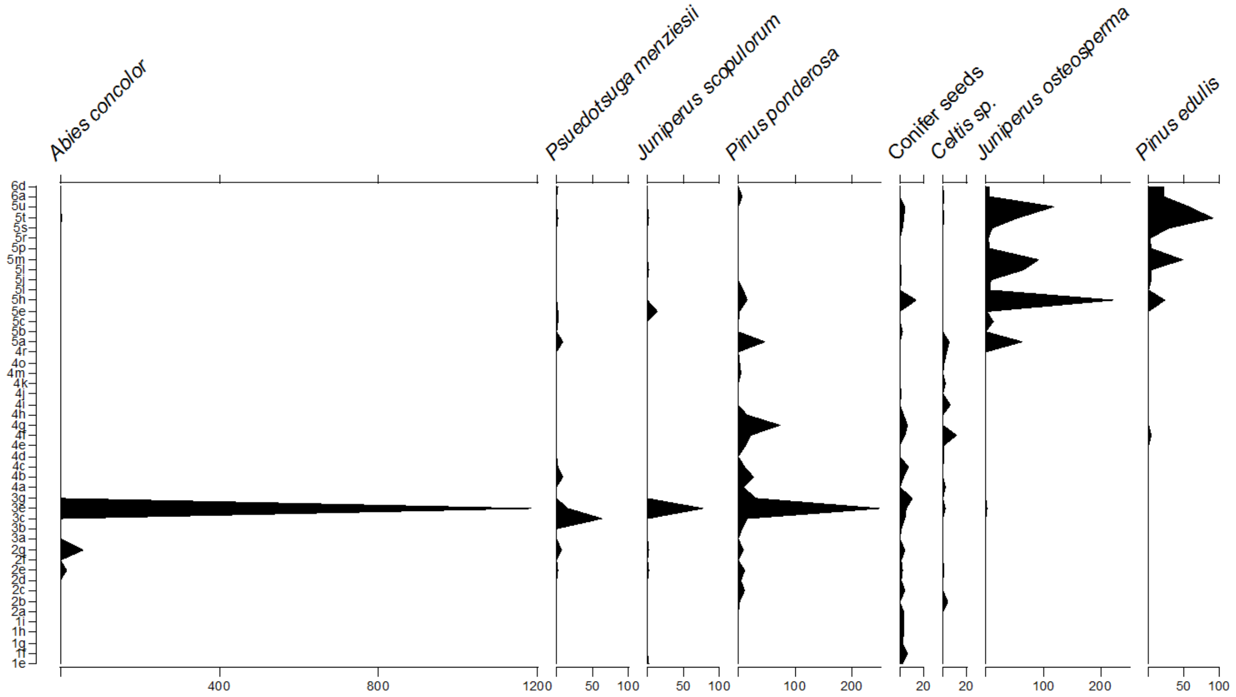

Figure 3.21. Absolute abundances (NISP) of non-dietary plant remains from NCS.

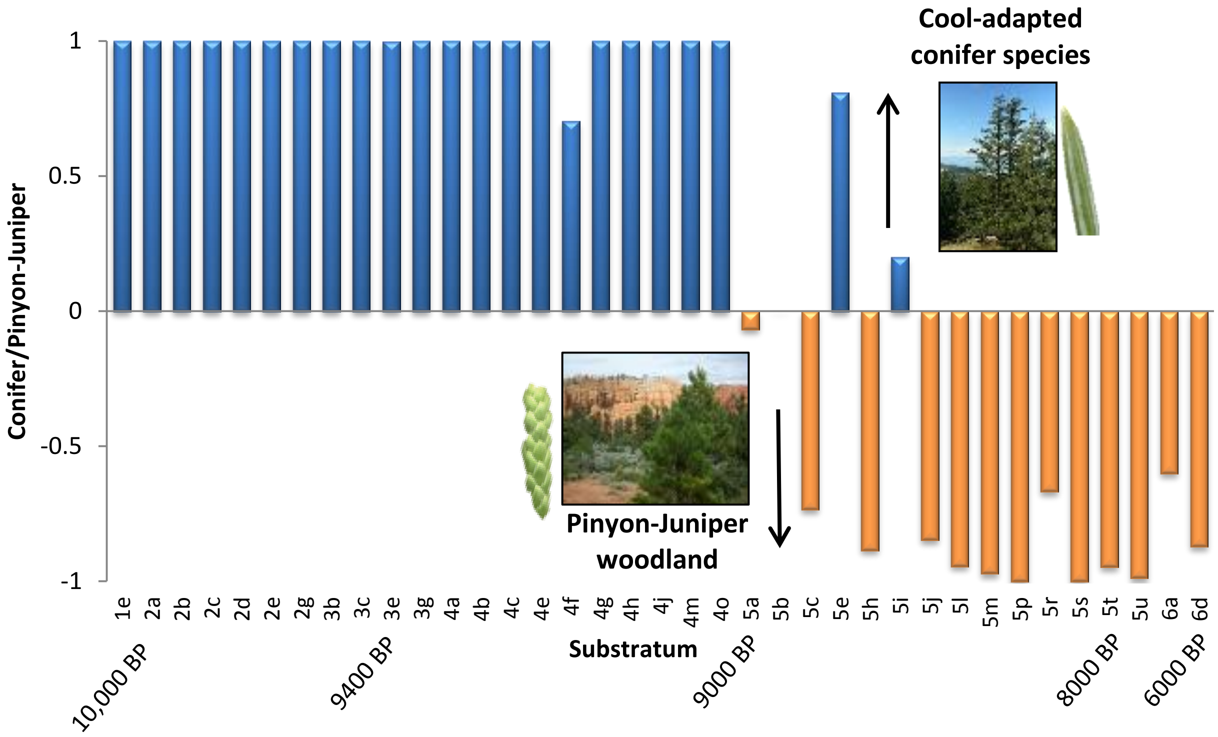

Figure 3.22. Ratio of cool-adapted conifer species (i.e. *Abies concolor*, *Pseudotsuga menziesii*, *Pinus ponderosa* and *Juniperus scopulorum*) to pinyon-juniper species (*Pinus edulis* and *Juniperus osteosperma*) from non-dietary macrobotanical remains at NCS.

Chapter 4

ANALYSIS OF STARCH GRAINS FROM THE GROUND STONE TOOLS OF NORTH CREEK SHELTER

Introduction

The processing of small seeds from wild plants has been described as a significant global development with respect to human dietary patterns during the middle Holocene (Flannery 1969, Weiss et al. 2004). On virtually every continent, people intensively exploited grasses and forbs as food sources when climate-driven environmental change reconfigured the geography of major ecosystems, with expansion of grasslands and deserts (Edwards and O'Connell 1995; O'Connell and Hawkes 1981, 1984). It has been argued that this novel exploitation (the shift to small seed grinding) was necessary because of the decline of higher-return resources and high-quality resource patches (O'Connell et al. 1982), requiring new technologies to maximize overall caloric returns. The wide-spread adoption of grinding stone technology enabled the preparation of seeds for cooking and/or storage. A side effect may have been an increased division between male and female labor, the former emphasizing hunting and the latter gathering, processing and preparation (Codding 2010; Elston and Zeanah 2002). Thus, the arrival of small seed processing and ground stone technology during the early to middle Holocene not only had ecological and dietary impacts, it may also have fostered a major restructuring of human societies.

The earliest evidence for intensive small seed processing and ground stone technology in the Great Basin comes from Danger Cave at 8700 ^{14}C BP (Rhode et al. 2006). In the northern Colorado Plateau, the use of grinding stone technology for the processing of small seeds began at North Creek Shelter (NCS) as early as 9000 ^{14}C BP (Janetski et al. 2012; Yoder et al. 2010). Ten manos and metates were found in these deposits, associated with small hearth features containing a total of 55 *Chenopodium* spp. (goosefoot) seeds, two Cactaceae (cactus) seeds, one

Polygonaceae (buckwheat) seed and a smattering of unidentifiable seeds (see Chapters 2 and 3). Ground stone tools and *Chenopodium* seeds (herein use of this genus signifies the possible inclusion of multiple species in a sample) became even more abundant after 8000 ^{14}C BP, substratum 5t (Figures 3.6, 3.15). The living surface of 5t was different from those of earlier strata because it was hard-packed, heavily reddened and contained at least one posthole and numerous ground stone artifacts. Ten pits originate on this surface, some overlapping and most with reddened rims suggesting roasting activity (Janetski et al. 2012) (Figure 4.1). To determine whether ground stone tools from strata 5 and 6 were used to process plant material and specifically to establish which plant taxa were processed, these artifacts were assayed for the presence and identities of starch grains.

Although the archaeological potential of ancient starch was documented over a century ago (Reichert 1913; Wittmack 1905), it has been developed into a viable avenue of archaeobotanical study only in the past few decades. Several studies have produced ground-breaking results on plant domestication, diet, tool function, mobility, land use and vegetation histories (e.g., Cosgrove et al. 2007; Denham et al. 2003; Field et al. 2009; Henry et al. 2011; Liu et al. 2010; Loy et al. 1992; Piperno and Holst 1998; Therin et al. 1999; Ugent et al. 1982). Most studies were based on archaeological collections from Europe, Southeast Asia, Australia, Africa and South America. Very few investigations have been completed in North America (e.g., Messner 2011; Messner and Schindler 2010; Zarillo and Kooyman 2006) and even fewer published from arid western North America (e.g., Scholze 2010). Other studies completed in this region are either unpublished Master’s theses or ‘grey’ literature. The study presented here is the first robust analysis of starch grains on ground stone tools from archaeological deposits in the northern Colorado Plateau.

This research aims to:

1) establish whether ancient starch grains are preserved on ground stone tools from NCS;
2) determine the range of starch grain morphologies by size, shape, and surface (optical) patterning;
3) investigate whether these attributes enable the identification of dietary plants;
4) account for other archaeological features associated with the living surfaces of NCS;
5) explore the implications of starch processing as it relates to the ecology of human diets during the Holocene.

Methods

NCS Ground Stone Tools

Starch grain analysis was undertaken on excavated manos and metates, which occurred in abundance throughout strata 5 and 6 (9000 – 6000 ^{14}C BP) (Chapter 3, Figure 3.15, Appendix G). Grinding stones from substrata 5a, 5f, 5q, 5s, 5t, 6a and 6d were paired with control sediment samples to investigate the preservation of starch grains throughout the site. Ground stone tools from substrata 5r and 5u did not have a control sample because sediments were not collected during excavation, but were analyzed to capture the early to middle Holocene transition. Other stones that resembled ground stone tools (i.e., incised stones) were present in earlier strata, but not processed for starch because they could not be identified as manos or metates with certainty.

Recovery of Starch Grains

All sediments were handled in the same way in order to maximize recovery of starch grains that were suspended in water or still adhering to ground stone tools. Each sediment sample was sieved using a 125 μm mesh Endecott sieve (to remove material >125 μm). Water plus sample <125 μm was transferred to 50 ml Falcon® tube (or into a beaker if the volume exceeded 150 ml). Samples were centrifuged for three minutes at 3000 RPM. The supernatant was discarded and the re-suspended sample transferred to a 15 ml centrifuge tube.

A heavy liquid separation technique was used to isolate any starch or phytoliths in the archaeological sample. Sodium polytungstate (Specific Gravity 2.35) was added to the sample pellet in each tube, resuspended with a vortex mixer, and centrifuged for 15 minutes at 1000RPM. The suspended fraction (with starch and phytoliths if present) was decanted into another set of labeled centrifuge tubes. Two more rinses (addition of DH_2O and centrifugation, three minutes at 3000 RPM) were undertaken to remove any residual heavy liquid. Acetone was added to each, spun and allowed to dry overnight.

The pellets were resuspended in a few drops of a 50/50 glycerol and DH_2O solution and the sample mounted on a glass slide. Total slide scans were completed using a Zeiss Axioskop II transmitting, brightfield microscope fitted with polarizing filters and Nomarski optics. A Zeiss HRc digital camera and Zeiss Axiovision software were used for image capture and archiving.

Post-excavation Practices and Treatments for Ground Stone Tools

Sediments adhering to ground stone tools from NCS were obtained in three ways, reflecting different post-excavation practices (see below). I want to determine if these different ways of handling the tools (including when and how cleaning took place) allow sufficient starch grain recovery for purposes of dietary reconstruction. Accession practices of the past often included cleaning tools within a short time after excavation and the sediments discarded. This practice leaves behind only residual sediments in the cracks and crevices found on stone surfaces and probably applies to tools in most archaeological collections. More recently, cleaning has become minimal and adhering sediments may remain on the tool or may even be collected as part of the accession. Both of these practices were applied to the ground stone tools from NCS, affecting the availability of sediments containing starch grains. I worked with these tools up to eight years after they had been stored at the Museum of Peoples and Cultures (BYU) so that the passage of time was also an inherent variable. By examining different post-excavation practices, I hope to determine if similarly accessed tools housed in other museums would still produce adequate amounts of use-related starch grain-containing sediment. If grains could be recovered from stones regardless of their accession and curation practices or years in storage, then a whole new source of dietary information would become available from these collections.

Joel Janetski and his crew employed two post-excavation practices at NCS during their work in 2004 to 2008. One set of ground stone tools were immediately cleaned with DH_2O, liberating all of the adhering sediments into the wash. This wash and its sediment were stored along with the associated stone for up to eight years when I initiated starch grain analysis in 2012. Another set of stones were taken back to the lab, lightly rinsed with DH_2O, but the sediment was not kept. These stones were subsequently dried, wrapped in foil and stored in cardboard boxes. In this case, I hope that residual sediments containing starch grains still adhered to the stones and could be extracted by my own treatments some years later.

For these distinct post-excavation practices, I develop three different treatments that could be tested for starch grain recovery (Table 4.1). The first treatment (Treatment 1 – "Sediments conserved") analyzes the stored wash and sediments that Janetski and his colleagues produced from the stones cleaned immediately after excavation. The second treatment (Treatment 2 – “Residual sediments recovered by brush”) utilizes a subset of the lightly rinsed stones (those that are large and difficult to handle). I attempted to remove any residual sediments with a sterile toothbrush and DH_2O for analysis. The third treatment (Treatment 3 – “Residual sediments recovered by sonicator”) utilizes another subset of the lightly rinsed stones that tend to be small or fragmented. The stones of Treatment 3 were placed in a sonicator for five minutes to agitate and release the residual sediments into the bath DH_2O for subsequent recovery.

Comparison of treatment effects was possible with stones of similar size. All ten ground stone tools from Treatment 1 were matched with the 10 largest tools from Treatment 2 (Treatment 3 stones were smaller or fragmented and thus could not be compared). Surface areas (cm^2) (i.e., worked surfaces) of all stones were calculated by multiplying length x width x number of worked sides (one-sided or double-sided manos or metates) while weights were measured in kilograms (kg). Starch grain yields were then obtained by dividing grain counts by surface area or weight of a given stone and compared using ANOVA ($P<0.05$).

Control Sediments

Control sediments were collected by Janetski and the BYU excavation team from deposits on the east and west profile walls at NCS in 2006 and 2007 (Janetski et al. 2012). These samples were processed for pollen grains to generate a local paleoenvironmental record (Chapter 3) and were also used to establish background levels of starch grains. Although control sediments in the vicinity of the ground stone tools may have been contaminated with starch from associated plant materials, this source would predictably be insignificant when compared to accumulations pressed into cracks, crevices, and interstitial spaces on stone surfaces. Unlike those surfaces, hearth and floor features are unlikely to have been coated by concentrations of starch residue from the incessant grinding and pounding of dietary plant materials. Therefore, sediment samples could serve as controls to separate background from processed starch grains.

Control sediment samples were collected from *in situ* substrata 5a, 5f, 5q, 5s, 5t, 6a and 6d. The samples were weighed and placed in a labeled 50ml Falcon® tube. Calgon© detergent was added to deflocculate clays by mixing for several hours.

In order to directly compare starch grain counts, sediment amounts from control and Treatment 3 samples were normalized by weight **(**it was impractical to weigh wash sediments obtained by Treatments 1 and 2)**.** One gram from each of seven control samples was processed according to standard protocols for starch (see above). Sediment weights were also available for Treatment 3 samples (n=34) by weighing the stones before and after sonication. Because there was ten times more control sediment than Treatment 3 sediment in any one sample, the probability of detecting background levels of starch grains was enhanced.

Identification of Starch Grains

Modern Reference Collections

A species list was compiled from the ethnographic literature (e.g., Castetter and Opler 1936; Fowler 1986; Kelly 1964) of native perennial plants in the vicinity of NCS that store starch in underground organs (roots, rhizomes, bulbs and tubers) and reproductive parts (seeds and fruits; see Table 4.2). This list was used to collect fresh source materials from wild populations during the summers of 2011, 2012 and 2013. These included tubers of *Solanum jamesii* and *Typha* sp. and seeds and fruits from *Shepherdia rotundifolia, Mahonia fremontii, Pinus edulis* and *Juniperus osteosperma*. Due to the apparent rarity of *Solanum jamesii* in the vicinity of

Escalante (see Chapter 2), additional tuber material from two individuals was collected from a local private garden of Mr. DeLane Griffin (Escalante, UT) during 2012 and 2013.

If a taxon could not be found near NCS, dried materials were collected from voucher specimens in the herbaria at the University of Washington, Royal Botanic Gardens Kew and University of Nevada Reno or from existing reference collections at Desert Research Institute (DRI), Reno. These included seeds of *Chenopodium* (including *C. berlandieri* and *C. fremontii*), *Leymus cinereus*, rootstocks of *Lomatium roseanum* and bulbs of *Lewisia* sp., *Calochortus* (including *Calochortus leichtlinii*), *Fritillaria pudica* and *Sagittaria latifolia.*

Starch grains were extracted by grinding seeds and fruits with small amounts of distilled water using a glass mortar and pestle. In the case of bulbs, roots, and tubers, fresh material was cut and smeared on to a sterile microscope slide, while dried material was ground and mounted on a microscope slide with 50/50 glycerol and DH_2O solution.

Starch Grains from Ground Stone Tools

Starch can be often be distinguished between species by examination of a range of attributes including shape, size, hilum position to name a few (Lenfter 2009). Tissues in underground storage organs such as rhizomes, tubers, corms and roots contain storage cells (usually cortical parenchyma) containing starch-accumulating plastids (amyloplasts) that assemble grains (Figure 4.2). Simple grains have only one starch body in the amyloplast (e.g., *Solanum*) while compound grains are shaped from several separate bodies formed within a single amyloplast (e.g. *Chenopodium*) (Reichert 1913, Torrence and Barton 2006). The synthesis of the grains results in at least two distinct birefringent forms - those with centric hila (e.g., *Leymus*) and those with eccentric hila (e.g. tuber-like grains such as those of *Solanum*).

Each sample, recovered from either archaeological material or modern reference material, was classified (centric vs. eccentric), counted and measured for maximum length. The maximum length (μm) of a starch grain was measured through its hilum. Mean lengths of starch grains from ground stone tools were plotted alongside the same measurements from reference materials (see Field 2007; Fullagar et al. 2008; Liu et al. 2010). When the taxonomic identity of grains was known with certainty (e.g., reference material) a minimum of 100 starch grains were used for measurement and to establish a taxon-specific standard. The standard could then be compared to a minimum of 20 grains originating from a single tool and of a single type using a Tukey-Kramer non-parametric comparison test ($P < 0.05$). In some cases more than one taxon could be assigned to a sample of grains from a single stone and identification might only rely on birefringent characteristics.

Results

NCS Ground Stone Tools

Ninety-four ground stone tools spanning strata 5 and 6 were analyzed for starch (Table 4.1). The majority of tools were made from sandstone (88%), with quartzite (6%), volcanics (5%) and granite (1%) comprising the remainder (Appendix F). The weight of the tools varied from 4 grams to approximately 13.5 kilograms (Table 4.3). The majority (78%) of these were recovered from substrata 5t, 5u, 6a and 6d, dating to post-8000 ^{14}C BP. Manos and metates first appear in substratum 5a deposits (9000 ^{14}C BP), and then more than double in frequency after substratum 5t (8000 ^{14}C BP) (Chapter 3, Figure 3.15).

Recovery of Starch Grains

Starch grains were recovered from 83 (88%) of the 94 ground stone tools (Figure 4.3) regardless of post-excavation treatment. Sediments from a single stone yielded between 1 and 270 grains. Starch grains with centric hila were found on all 83 ground stone tools from substrata 5a – 6d. Starch grains with eccentric hila, however, were only found on 23 tools, which primarily came from substratum 5t and above (Table 4.4). Tools from substrata 5t and 5u produced the highest numbers of eccentric grains, accounting for 20% and 40%, respectively, of all grains from those deposits (Figure 4.4). All except two samples yielded small numbers of starch grains (less than 10 grains) per tool. Samples from stones FS 3607.2 (substratum 5t; Figure 4.3) and FS 2672 (substratum 5u) recovered the highest counts of eccentric starch grains, 23 and 21, respectively.

Post-excavation Practices and Treatments for Ground Stone Tools

The number of ground stone tools from each substratum and their treatment are listed in Table 4.1. Treatment 1 samples (sediments conserved) were collected from a total of ten manos and metates, Treatment 2 samples 2 (residual sediments - brushed) from 50 and Treatment 3 samples (residual sediments - sonicated) from 34. The stones that received Treatment 1 weighed on average more than five times the stones that received Treatments 2 and 3. They were also on average twice as thick, two to three times longer and twice as wide than the other tools from Treatments 2 and 3 (Table 4.3).

Comparison of post-excavation practices demonstrates that analysis of conserved sediments (Treatment 1) could produce higher starch grain counts from individual stones (e.g. maximum range of 118 – 270 grains per stone) than analysis of residual sediments (Treatment 2, maximum range of 8 – 12 grains per stone). However, in terms of starch grain yields (normalized per unit used surface area or weight), the difference was not statistically significant (Table 4.5). This was because of the high variability in counts from Treatment 1 (coefficient of variation = 2.45) compared to Treatment 2 (CoV = .98). Not only were Treatment 1 counts much higher, but only 7 of the 10 sediment samples produced any grains at all, whereas all ten of the Treatment 2 sediment samples produced grains. But overall, 88% of the ground stone tools analyzed produced starch grains regardless of treatment.

Control Sediments

The normalized yields of starch grains (# per gram of sediment) from all control sediments combined (i.e., the seven substrata, Table 4.6) were 100 times less than those recovered from the surfaces of Treatment 3 ground stone tools (Figure 4.5). Control samples contained an average of 1.3 starch grains per gram while Treatment 3 samples averaged 129 starch grains per gram (Figure 4.5).

Identification of Starch Grains

Modern Reference Collections

All reference materials, including the plant tissues and their sources, are listed in Table 4.2 and images of their starch grains appear in Appendix L. Counts and measurements of starch grains from these reference materials are listed in Tables 4.7 and 4.8.

Bulbs from *Lewisia redivia*, and rootstocks and rhizomes from *Cyperus esculentus*, *Lomatium roseanum, Perideridia* sp. and *Typha* sp. produce starch grains with centric hila. The average maximum length through the hilum ranges from 5 μm to 14 μm, depending on taxon (Table 4.7). Seeds of two species of *Chenopodium* (*C. fremontii* and *C. berlandieri*) produced the smallest grains of all, ranging from 0.6 to 2.0 µm. These were very difficult to image and measure, even at the highest magnification (at the limits of resolution of light microscopy). But all *Chenopodium* starch grains appeared to have centric hila, may be compound and remained aggregated even when the cell was ruptured (see Appendix L). Starch grains from the seeds and fruits of *Juniperus osteosperma, Opuntia* sp., *Leymus cinereus, Pinus edulis, Shepherdia rotundifolia*, and *Sphaeralcea* sp. ranged in length from 5 µm to 15 µm (Table 4.7).

The tubers of *Solanum jamesii* produced grains with eccentric hila, having an average length of 22.39 µm (Table 4.8). Eccentric hila were also observed in starch grains of bulbs from *Calochortus* sp. (length = 21.79 µm), *Fritillaria pudica* (length = 33.79 µm) and *Sagittaria latifolia* (length = 8.13 µm).

Starch Grains from Ground Stone Tools

Ten of the 83 starch-bearing ground stone tools had more $\geq$20 starch grains with centric hila and two had $\geq$20 starch grains with eccentric hila (Tables 4.9 and 4.10, respectively). These tools were from substrata (5a to 6d) spanning the entire early to middle Holocene sequence (9000 – 6000 ^{14}C BP).

The maximum lengths of both types of starch grains from these stones were compared with those from reference taxa (Figures 4.6 and 4.7). Centric starch grains have maximum lengths that range from 14 to 18 µm, with the exception of those from tool FS 2468, which had an average maximum length of 1.88 µm (Figure 4.6). Based on size and results of the Tukey-Kramer comparison, the larger grains could have originated from *Cyperus esculentus, Lewisia* sp., *Lomatium* sp., *Leymus* sp. and/or *Shepherdia* sp. Sample FS 2468 appears to include starch grains of *Chenopodium*, *Pinus edulis* and/or *Typha* sp. based on their overlapping size (Tukey-Kramer comparison).

Samples FS 3607.2 and FS 2672 were the only ground stone tools that produced >20 starch grains with eccentric hila (Figure 4.7). The average length of those grains ranged from 40 μm to 46 μm. These are significantly different (Tukey-Kramer, $P<0.05$) than the average lengths of all the reference specimens, which ranged from approximately 22 μm to 34 μm (Figure 4.7). Additional reference material is needed, however, and more rigorous identification techniques should be employed before definitive taxa are assigned.

Discussion

Ground stone processing of starch-laden plant parts, specifically seeds and fruits, took place at NCS as early as 9000 BP. The practice intensified by 8000 ^{14}C BP (substratum 5t and 5u) when over 40 ground stone tools were utilized for this purpose (see Chapter 3). The processing of tubers and other underground parts also began at this time as evidenced by their unique starch grain structure.

Starch grains extracted from NCS ground stone tools came in two distinct forms - those with centric hila and those with eccentric hila. Grains with centric hila occurred in abundance across all samples and strata, but grains with eccentric hila did not appear in abundance until after 8000 ^{14}C BP. It is not possible at present to taxonomically identify all sources of starch found on these stones, except to conservatively conclude that bulbs and tubers definitely supplemented the middle Holocene diet. Thus, small seeds were not the only plant resources intensively processed on ground stone tools at NCS.

The methods for recovering starch from ground stone tools can affect the yield of starch grains for analysis. Treatment 1, which analyzed the sediments conserved post-excavation, produced the highest counts of starch grains overall and from certain individual stones. Having the sediment, however, did not guarantee that starch grains would be present, as 30% did not contain any. It is also interesting to note that none of the grains that were recovered from these sediments were eccentric. This may be due to the small sample size (n=10 ground stones) that had been treated in this way. Stones that had been lightly rinsed after excavation still produced grains when either brushed or sonicated, indicating that despite cleaning and the passage of time in storage, they could still yield dietary information. Removing loose sediments that cling to external surfaces has been the standard protocol for accessing artifacts for decades. Because of this, many archaeologists have erroneously concluded that evidence of starch has thus been lost. The present study has demonstrated, however, that microfossil remains can be successfully extracted, counted and analyzed from ground stone tools even after having been rinsed and stored in museum collections.

The microbotanical data from NCS give us a very different picture of middle Holocene dietary choice when compared to other sites in the Great Basin and Colorado Plateau. Intensive processing of small seeds on ground stone tools was not the only such practice at NCS. Underground storage organs were also processed and possibly roasted in several large pits on the living surface of substratum 5t, features not found on other activity floors. Most floors contained only one or two hearths and no pits. There is even evidence of a hut with posts supporting some form of canopy (Janetski et al. 2012). This may have served as a plant processing camp, where bulbs and tubers were seasonally processed.

Taken together, the abundance of ground stone tools, the processing of seeds and fruits (possibly including *Chenopodium*), the grinding of tubers and bulbs, and the association with roasting pits and a hut-like feature may reflect the different occupancy and subsistence activities of women and men during the middle Holocene at NCS. Women may have utilized NCS preferentially, gathering and processing plant foods from nearby vegetation types. This would require a heavy investment in plant-processing tools, including manos and metates. At the same time, men may have been pursuing highly mobile and fluctuating herds of large-bodied animals at some distance from the shelter. Indeed, animal bones were relatively uncommon in substratum 5t (Chapter 3).

There are also implications of starch processing with respect to the ecology of human diets during the Holocene. Calculations of dietary species richness and evenness, used to define the energetics of food choices, have traditionally been based upon faunal evidence. The present study has added macrobotanical evidence to the calculations to achieve a fuller picture of the dietary palette as it changed through time (see Chapters 2 and 3). It would seem that adjustments to these calculations might eventually be made as microbotanical evidence reveals the identities of additional plant taxa in the diet. Although taxonomic assignments for the starch grains are difficult at this point, there are minimally two "taxa" ("centric" and "eccentric") that can be added to the tally of species richness. Adding these starch-producing plants to dietary species richness would accentuate a shift toward broader diet concurrent with a period of rapid environmental change during the middle Holocene, thus reinforcing conclusions noted in Chapter 3. Tubers rank just below small and large-bodied animals (see Table 3.1, Chapter 3), so the energetic gains would be greater than if small seeds had been added to the diet instead. Similar to pine nuts (and perhaps acorns), tubers would disproportionately mitigate for the loss for higher ranked resources. But unlike acorns and pine nuts, these perennial, vegetative storage organs would not be susceptible to reproductive failure during the increasing aridity and changing ecosystem composition of the middle Holocene.

Figures and Tables

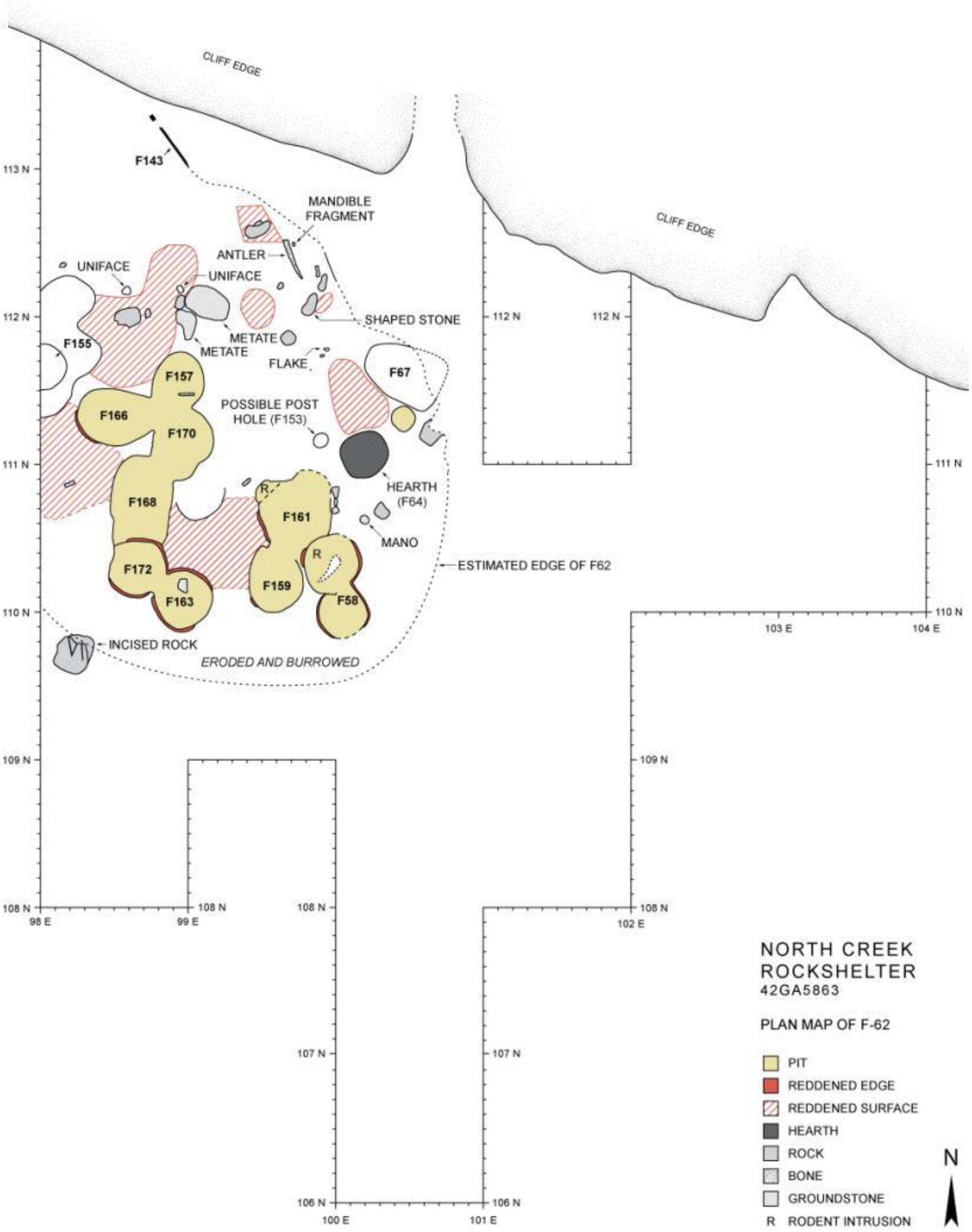

Figure 4.1. Plan view of substratum 5t, an 8000 ^{14}C BP surface with numerous manos and metates and large pits, possibly for roasting tubers. Image from Janetski et al. 2012.

Table 4.1. Inventory of manos and metates from each substratum, arranged by treatment. These were the sources of archaeological starch grains in this analysis.

Substratum	**Treatment 1 Sediments conserved**		**Treatment 2 Residual sediments (brushed)**		**Treatment 3 Residual sediments (sonicated)**		**Total**
	mano	**metate**	**mano**	**metate**	**mano**	**metate**	
6d		1	3	9	4	1	**18**
6a		1	5	5	2	2	**15**
5u	1		3	11	1	5	**21**
5t		1	3	3	2	10	**19**
5s		1	3	1	1		**6**
5r		1			1		**2**
5q			1	1			**2**
5f	1					1	**2**
5a	1	2	1	1	1	3	**9**
Total	**3**	**7**	**19**	**31**	**12**	**22**	**n=94**

Table 4.2. Inventory of modern reference plant material collected from nearby NCS, herbaria sheets and existing reference collections (DRI). These are the sources of reference starch grains in this analysis. Also indicated is the presence of starch grains (yes or no) and the hilum position of observed starch grains (E = eccentric, C = centric).

Taxon	**plant tissue**	**Collected**	**Starch?**	**Hilum position**
Allium sp.	bulb	Escalante, UT	no	
Calochortus leichtlinii	bulb	DRI	yes	E
Camassia quamash	bulb	DRI	yes	C
Chenopodium berlandieri	seed	Herbarium (UNR)	yes	C
Chenopodium fremontii	seed	Herbarium (UNR)	yes	C
Fritillaria sp.	bulb	DRI	yes	E
Juniperus osteosperma	seed cone	Escalante, UT	yes	C
Lewisia sp.	bulb	DRI	yes	C
Lomatium roseanum	root	DRI	yes	C
Mahonia repens	fruit	Escalante, UT	no	
Opuntia sp.	stem	Escalante, UT	yes	C
Perideridia sp.	root	DRI	yes	C
Pinus edulis	seed cone	Escalante, UT	yes	C
Rhus aromatica var. trilobata	seed, fruit	Herbarium (Kew)	no	
Sagittaria latifolia	Bulb	Herbarium (UW)	yes	E
Shepherdia rotundiflora	seed, fruit	Escalante, UT	yes	C
Solanum jamesii	tuber	Escalante, UT	yes	E
Sphaeralcea sp.	seed	Escalante, UT	yes	C
Typha sp.	rhizome	Escalante, UT	yes	C
Zea mays	seed	USDA	yes	C

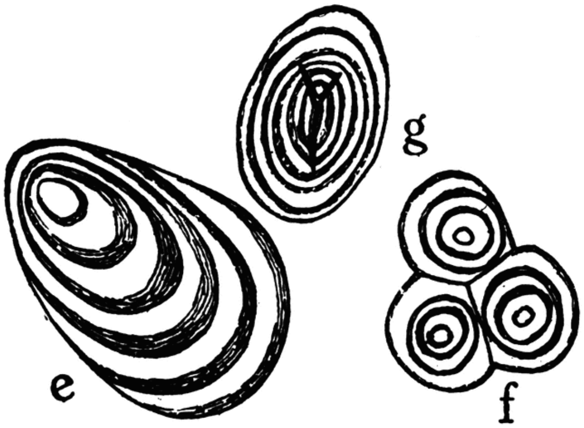

Figure 4.2. Forms of starch grains: e, eccentric hilum; g, centric hilum; and f, compound. Image from William Chase Stevens *Plant Anatomy* (1916).

Table 4.3. Ground stone tool characteristics (average weight, thickness, length, width) and starch grains recovered (average per stone and total for all stones) by treatment.

	Treatment 1 Sediments conserved	**Treatment 2 Residual sediments (brushed)**	**Treatment 3 Residual sediments (sonicated)**
Weight (g)	4,631.0	788.3	122.2
Thickness (cm)	6.2	3.9	2.4
Length (cm)	23.9	13.7	7.4
Width (cm)	19.4	10.2	5.5
Starch grain counts (#/stone)	66.5	7.4	12.2
Total starch grains (#/all stones)	665	369	415

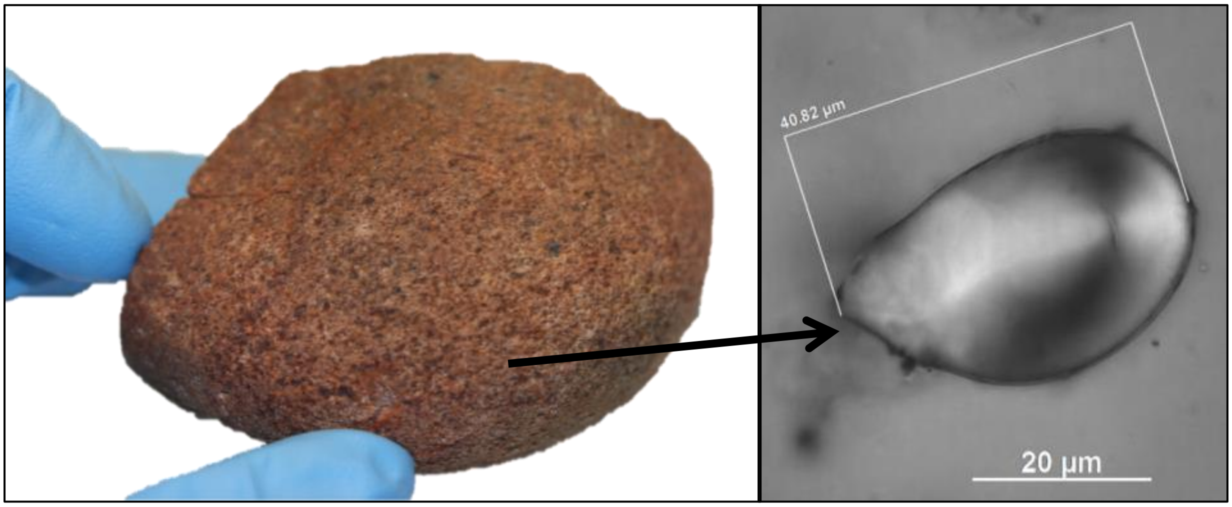

Figure 4.3. Quartzite mano fragment FS 3607.2 from substratum 5t and an eccentric starch grain recovered from that mano.

Table 4.4. Total counts (# per all stones in a substratum) of centric and eccentric starch grains, arranged by treatment.

Substratum	**Treatment 1**		**Treatment 2**		**Treatment 3**		**Total**
	Centric	**Eccentric**	**Centric**	**Eccentric**	**Centric**	**Eccentric**	
6d	53	0	82	5	25	0	**165**
6a	33	0	40	6	42	0	**121**
5u	0	0	80	58	39	1	**178**
5t	0	0	17	13	112	24	**166**
5s	7	0	6	0	18	0	**31**
5r	118	0	0	0	63	0	**181**
5q	0	0	7	0	0	0	**7**
5f	0	0	0	0	13	0	**13**
5a	402	0	11	0	59	0	**472**

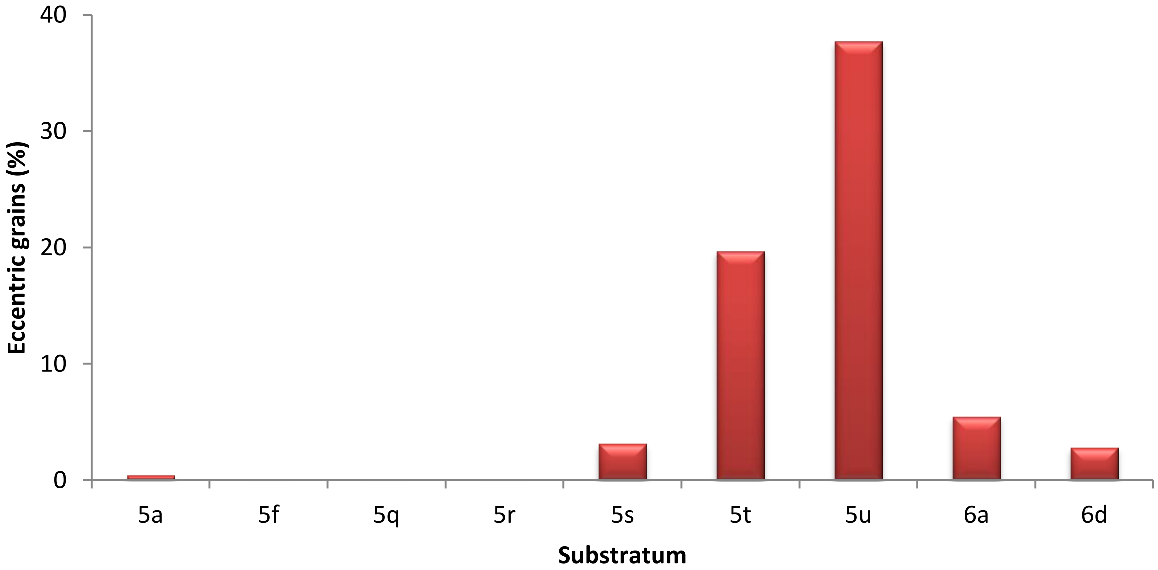

Figure 4.4. Occurrence of eccentric starch grains (% of all grains in a substratum).

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Table 4.5. Comparison of starch grain yields (grains/cm^2 or kg) from ground stone tools with different surface areas (cm^2) and weights (kg). Yields are not significantly different (ANOVA, n=10, P<0.05).

	Treatment 1 Sediments conserved	**Treatment 2 Residual sediments (brushed)**	**T1 x T2**
Surface Area (cm^2)			
mean	678.7	564.0	
95% CI	366.4	277.1	
Starch grain yield (grains/cm2)			
mean	0.19	0.02	P = 0.26
95% CI	0.34	0.01	
Weight (kg)			
mean	4.63	2.03	
95% CI	3.20	0.74	
Starch grain yield (grains/kg)			
mean	42.7	3.5	P = 0.26
95% CI	75.20	1.70	

Table 4.6. Control sediment samples with their stratigraphic designation, weight and count of starch grains recovered from each sample. Ground stone samples are indicated by “FS”.

Ground stone sample	Substratum	Weight (g)	Starch grains counts
762	6d	1.0	5
2526	6a	1.0	0
	5u	No sediment sample	
2817	5t	1.0	1
3050	5s	1.0	1
	5r	No sediment sample	
3026	5q	1.0	2
3032	5f	1.0	0
3027	5a	1.0	0

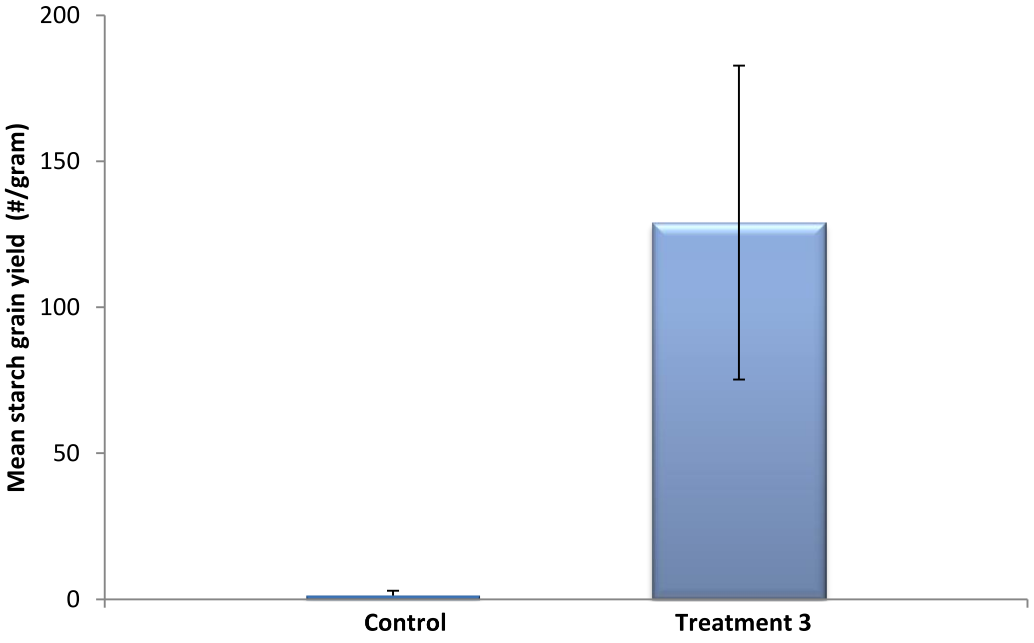

Figure 4.5. Mean (± 95% CI) starch grain yield per gram of sediment for Control and Treatment 3 samples from NCS.

Table 4.7. Starch grains with centric hila counts and measurements for the modern reference samples collected near NCS.

Reference species	**Starch grain counts**	**Length (μm)**				
		Min.	**Median**	**Max.**	**Mean**	**Std. Dev.**
Pinus edulis	198	2.07	4.58	10.66	4.73	1.42
Juniperus osteosperma	141	3.29	6.3	11.58	6.46	1.78
Sphaeralcea sp.	90	2.24	6.965	23.65	7.20	2.81
Shepherdia rotundifolia	208	3.61	9.715	30.21	10.21	3.39
Opuntia sp.	105	4.57	7.74	15.38	8.22	2.34
Chenopodium fremontii	110	0.63	1.27	2.14	1.30	0.33
Chenopodium berlandieri	105	0.56	0.97	1.54	0.97	0.18
Cyperus esulentus	107	6.404	11.684	19.917	11.64	2.79
Lomatium roseanum	101	6.45	14.701	21.446	14.78	3.19
Pterididia sp.	105	7.814	12.524	19.595	12.62	2.57
Lewisia redivia	103	7.376	13.234	26.052	13.59	4.01
Typha sp.	100	3.156	5.0665	8.737	5.19	1.25
Leymus cinereus	103	5.794	14.678	33.925	15.20	4.79

Table 4.8. Starch grains with eecentric hila counts and measurements for the modern reference samples collected near NCS.

Reference species	**Starch grain counts**	**Length (μm)**				
		Min.	**Median**	**Max.**	**Mean**	**Std. Dev.**
Solanum jamesii 1	176	3.96	16.36	43.38	18.02	7.81
Solanum jamesii 2	133	9.05	24.66	87.59	28.18	15.34
***Solanum jamesii* (all)**	**309**	**3.96**	**18.76**	**87.59**	**22.39**	**12.68**
Fritillaria pudica	**101**	**11.57**	**32.95**	**70.34**	**33.79**	**12.67**
Calochortus sp.	82	8.52	19.68	39.55	21.29	7.64
Calochortus leichtlinii	106	12.89	21.15	44.07	22.18	5.07
***Calochortus* (all)**	**188**	**8.52**	**20.83**	**44.07**	**21.79**	**6.32**
Sagittaria latifolia	**102**	**1.68**	**7.64**	**19.86**	**8.13**	**3.01**

Table 4.9. Centric starch grains counts and lengths for the samples from NCS ground stone tools. Ground stone samples are indicated by “FS”. Raw material abbreviations: S=sandstone, V=volcanic, Q=quartzite, G=granite. Shaded rows are samples that have 20 or more starch grains. These lengths are plotted in Fig. 4.6.

Sub-stratum	Ground stone sample	Ground stone type	Raw material	Treatment	Starch grain counts	Length (μm)				
						Min.	Median	Max.	Mean	Std. Dev.
6d	53	metate	S	2	12	12.27	19.26	24.26	19.17	3.59
	242.1	mano	V	3	2	19.03	22.62	26.21	22.62	5.08
	242.2	metate	S	3	5	14	16.37	22.17	17.06	3.36
	483.1	metate	S	2	0					
	483.2	metate	S	2	5	16.08	18.76	24.77	19.23	3.36
	517.1	mano	S	3	8	12.7	17.98	24.44	18.54	3.65
	517.2	mano	S	3	0					
	1316	metate	S	2	7	11.54	16.46	23.6	17.6	5.09
	1613	metate	S	1	53	4.05	15.22	50.86	14.11	7.83
	1719.1	metate	S	2	12	10.3	14.91	21.8	15.81	4.04
	1719.2	metate	S	2	16	14.13	20.33	23.21	19.24	3.25
	1757	mano	Q	2	17	11.21	17.4	24.23	17.71	3.49
	1758.1	metate	S	2	4	13.11	16.88	23.39	17.56	4.49
	1758.2	metate	S	2	0					
	1758.3	metate	S	2	0					
	1759	mano	S	2	6	25.24	26.48	31.7	27.43	2.41
	2239.1	mano	S	3	10	13.46	17.96	26.45	19.03	4.53
	2669	metate	S	2	3	15.2	16.73	21.29	17.74	3.17
6a	501	mano	S	2	3	15.2	17.5	19.13	17.28	1.98
	505	mano	S	2	9	8.72	18.41	21.12	16.7	4.27
	548	mano	S	2	1				21.11	
	561	mano	Q	2	2	20.13	21.58	23.02	21.58	2.04
	592	metate	S	2	4	17.65	20.42	21.12	19.9	1.56
	603	metate	S	2	7	10.83	16.08	24.19	17.33	4.54
	1676	metate	S	2	2	22.99	23.41	23.84	23.41	0.61
	2468	metate	S	1	33	0.89	1.61	10.94	1.88	1.68
	2548	metate	S	3	7	12.4	22.66	25.32	20.41	4.55
	2714	metate	S	2	4	17.79	20.85	23.31	20.7	2.27
	2744	mano	V	3	12	12.61	19.71	26.42	19.86	3.69
	2782	metate	S	3	13	9.88	16.33	28.38	17.43	4.83
	2858	metate	S	2	1				30.24	
	3003	mano	S	3	10	11.18	18.51	26.04	18.22	4.3
	3489	mano	S	2	7	12.14	16.38	21.01	16.84	2.95

Table 4.9. continued

Sub-stratum	Ground stone sample	Ground stone type	Raw material	Treatment	Starch grain counts	Length (μm)				
						Min.	Median	Max.	Mean	Std. Dev.
5u	2346	metate	S	2	3	14.64	21.15	21.35	19.05	3.82
	2347	mano	S	2	1				26	
	2407	mano	S	2	3	19.3	21.86	28.18	23.12	4.57
	2667.1	metate	S	2	2	14.12	17.3	20.47	17.3	4.49
	2667.2	metate	S	2	29	4.1	19.85	28.84	18.07	6.67
	2672	metate	S	2	2	20.8	21.03	21.26	21.03	0.33
	2673	metate	S	2	0					
	2674	metate	S	2	4	15.08	21.13	26.03	20.84	4.78
	2676	metate	S	2	3	20.88	23.93	27.1	23.97	3.11
	2731	mano	S	3	3	18	24.05	27.77	23.27	4.93
	2745	metate	S	2	2	17.98	19.72	21.46	19.72	2.45
	3070	mano	S	2	6	18.14	21.16	25.88	21.37	2.8
	3315	metate	S	3	7	13.25	21.14	31.18	20.75	5.68
	3316	metate	S	3	18	10.87	19.11	29.72	19.77	4.98
	3317	metate	S	2	14	14.72	17.81	30.51	19.41	4.26
	3390	metate	S	3	0					
	3393	metate	S	3	3	19.99	21.88	22.66	21.51	1.37
	3399	metate	S	2	6	14.77	20.18	23.68	19.65	3.53
	3414	metate	S	3	8	15.52	17.58	32.49	20.25	6.03
	3438	mano	G	1	0					
	3446	metate	S	2	5	16.54	22.65	24.94	22.09	3.26
5t	484	mano	Q	2	0					
	615	metate	S	3	0					
	1767	mano	Q	3	4	14.51	19.82	21.34	18.87	3.03
	2953	metate	S	3	20	10.58	17.4	27.04	17.48	4.62
	2994	metate	V	1	0					
	3474.1	mano	S	2	7	12.47	17.5	28.36	18.66	5.47
	3474.2	mano	S	2	3	17.33	18.9	20.44	18.89	1.55
	3491.1	metate	S	3	0					
	3495	metate	S	2	1				14.82	
	3513	metate	S	2	1				17.3	
	3516.1	metate	S	3	6	14.12	18.09	24.06	18.65	3.68
	3516.2	mano	S	3	4	15.2	17.49	21.38	17.89	2.56
	3528.1	mano	S	3	17	14.86	17.36	24.18	18.21	2.5
	3528.2	mano	S	3	4	16.39	17.99	20.68	18.26	2.16
	3528.3	mano	S	3	3	17.89	20.41	21.31	19.87	1.77
	3564	metate	S	2	5	12.03	19.04	24.05	17.89	4.61
	3573	metate	S	3	18	8.06	15.22	22.45	15.36	4.39
	3607.1	metate	S	3	3	15.88	16.07	19.1	17.02	1.81
	3607.2	mano	Q	3	33	8.84	18.97	28.41	17.81	4.84

Table 4.9. continued

Sub-stratum	Ground stone sample	Ground stone type	Raw material	Treatment	Starch grain counts	Length (μm)				
						Min.	Median	Max.	Mean	Std. Dev.
5s	1612	metate	S	1	7	18.59	21.04	28.31	21.57	3.37
	1628	metate	S	2	2	14.81	15.64	16.47	15.64	1.17
	1779	mano	Q	2	2	10.12	13.94	17.77	13.94	5.41
	1869	mano	S	3	18	10.41	16.99	24.82	17.66	4.12
	1940	mano	S	2	2	13.7	16.69	19.68	16.69	4.23
5r	608	mano	S	3	63	4.04	19.95	30.35	18.42	6.1
	3512	metate	S	1	118	10.08	17.71	31.1	18.1	4.29
5q	3071	mano	V	2	6	13.93	19.45	22.93	19.51	3.31
	3637	metate	S	2	1				12.46	
5f	2289	metate	S	3	13	9.63	20.6	26.26	19.34	4.95
	4316	mano	S	1	0					
5a	649	mano	S	2	11	14.52	18.71	35.68	19.95	5.7
	2151	mano	S	3	8	16.07	18.97	22.42	19.22	2.32
	2167	metate	S	3	17	11.8	20.21	29.66	21.04	5.29
	2254	metate	S	2	0					
	3072	metate	S	1	127	4.65	16.29	35.82	16.3	4.44
	4368	metate	S	3	27	6.64	14.82	25.31	14.97	5.49
	4369	metate	S	1	5	17.19	21.22	39.44	25.95	11.85
	4370	mano	S	1	270	12.28	20.62	30.22	20.63	5.07
	4591	metate	S	3	7	11.74	17.79	24.71	18.17	4.74

Table 4.10. Eccentric starch grains counts and lengths for the samples from NCS ground stone tools. Ground stone samples are indicated by "FS". Raw material abbreviations: S=sandstone, V=volcanic, Q=quartzite, G=granite. Shaded rows are samples that have 20 or more starch grains. These lengths are plotted in Fig. 4.7.

Sub-stratum	**Ground stone sample**	**Ground stone type**	**Raw material**	**Treatment**	**Starch grain counts**	**Length (μm)**				
						Min.	**Median**	**Max.**	**Mean**	**Std. Dev.**
6d	1316	metate	S	2	1				35.36	
	1719.1	metate	S	2	1				24.66	
	1719.2	metate	S	2	1				41.78	
	1759	mano	S	2	2	35.7	40.96	46.21	40.96	7.43
6a	505	mano	S	2	2	33.83	34.75	35.66	34.75	1.29
	548	mano	S	2	1				39.7	
	603	metate	S	2	1				32.31	
	3489	mano	S	2	2	32.85	46.46	60.07	46.46	19.24
5u	2346	metate	S	2	8	17.46	48.37	74.67	46.56	17.04
	2347	mano	S	2	7	22.66	44.64	64.3	43.32	13.69
	2667.1	metate	S	2	10	20.15	43.15	77.16	42.83	17.45
	2672	metate	S	2	21	24.88	44.26	74	46.09	15.1
	2673	metate	S	2	3	28.18	60.68	88.57	59.14	30.23
	2674	metate	S	2	4	43.29	53.48	63.58	53.46	8.85
	2676	metate	S	2	1				75.06	
	3070	mano	S	2	1				23.86	
	3316	metate	S	3	1				19.62	
	3446	metate	S	2	3	22.06	43.03	63.88	42.99	20.91
5t	3474.1	mano	S	2	8	19.26	51.26	78.93	52.93	7.41
	3474.2	mano	S	2	4	18.15	30.84	57.3	34.28	8.93
	3564	metate	S	2	1				15.54	
	3573	metate	S	3	1				20.52	
	3607.2	mano	Q	3	23	20.74	37.6	72.78	40.22	2.99

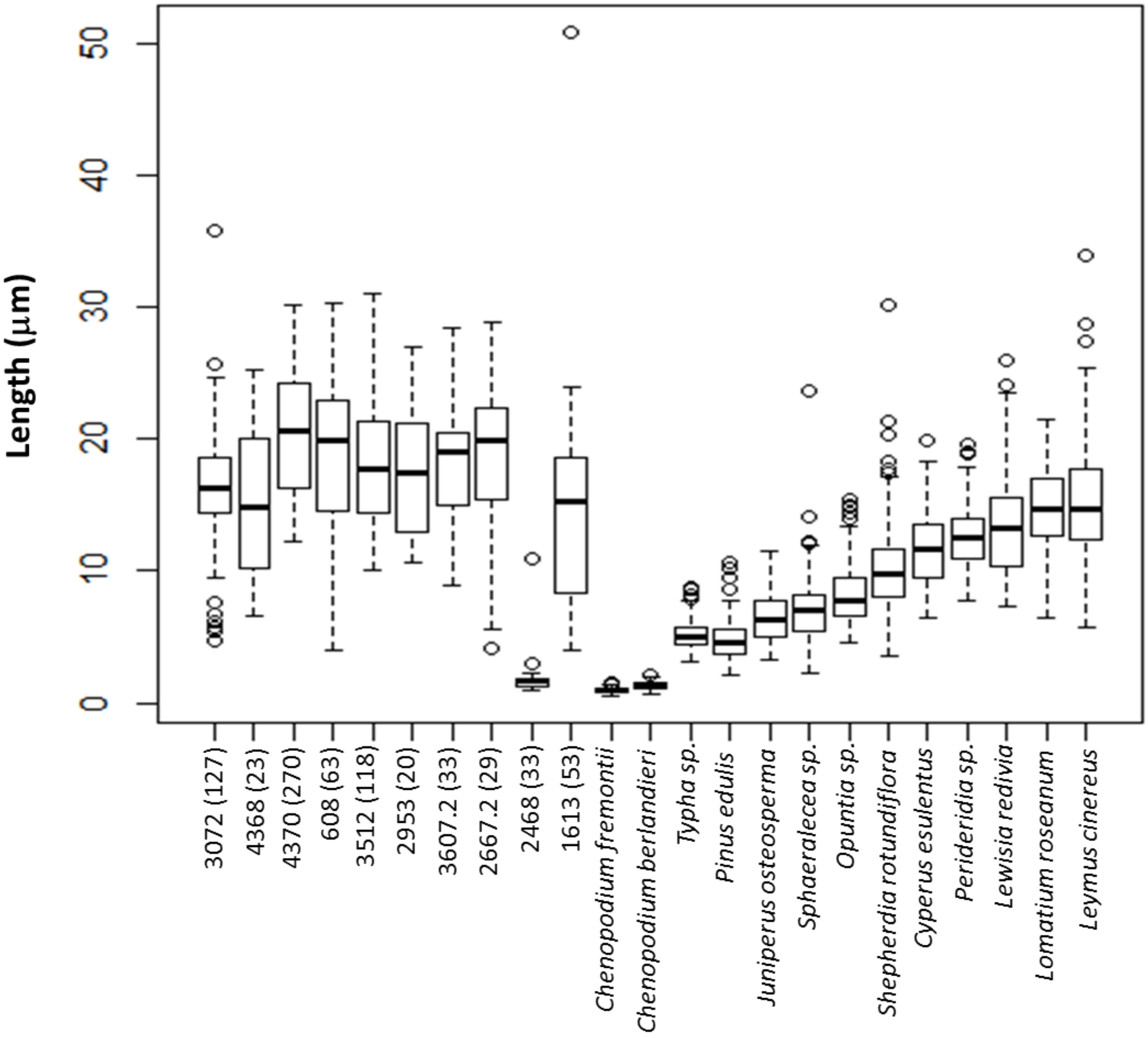

Figure 4.6. Comparison of centric starch grain length (µm) recovered from NCS ground stone tools (left) and reference materials (right). Data used to create the box and whisker plots include: median (dark line through box), the lower (25%) and upper (75%) quartiles (displayed as box), the minimum and maximum values of these quartiles (dashed lines), and outliers (open circles).

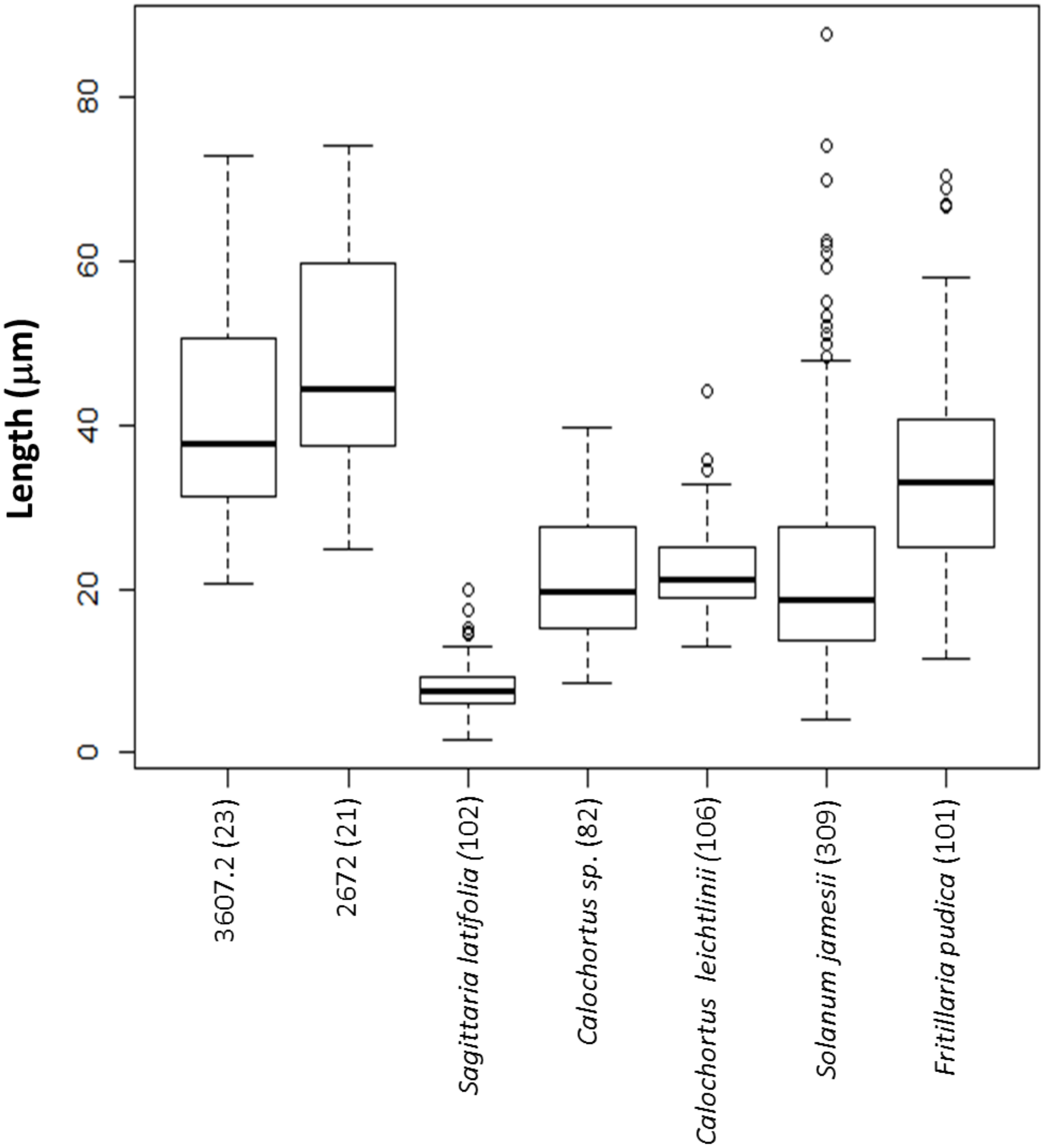

Figure 4.7. Comparison of eccentric starch grain length (μm) recovered from NCS ground stone tools (left) and reference materials (right). Data used to create the box and whisker plots include: median (dark line through box), the lower (25%) and upper (75%) quartiles (displayed as box), the minimum and maximum values of these quartiles (dashed lines), and outliers (open circles).

Chapter 5

CONCLUSIONS

In this dissertation I examine the ecology of human diet using archeological evidence from a very specific site in western North America – North Creek Shelter (NCS) near Escalante, Utah. I use ecological measures and theory to quantify human dietary change during the early to middle Holocene and in the context of local ecosystems that supplied plant and animal food resources.

In Chapter 1, I pose three over-arching questions pertaining to plant and animal remains associated with food processing features (living surfaces, hearths, pits, ground stone tools, etc.) at NCS. I summarize the answers to these questions below:

What dietary plant resources were available to NCS occupants from local ecosystems?

I use vegetation sampling techniques to quantify the landscape and dietary palettes that may have been available to the occupants of NCS during the Holocene. The way I accomplish this is to: a) identify the local dietary palette within the landscape palette along an elevation gradient and b) measure the absolute abundance of edible and non-edible species in their respective vegetation types by sampling presence, cover, density, and basal area.

Vegetation sampling was originally conducted at, above and below the elevation of NCS in order to capture the entire dietary palette that might have been available to occupants throughout the Holocene and its variable climate. As it turns out, this includes seven distinct vegetation types than contained at least 91 total species in the samples, of which 37 constituted the dietary palette as informed by the ethnographic record. That palette, however, is not evenly distributed among those vegetation types. According to my sampling, pinyon-juniper woodland

and cool desert scrub vegetation types supply the majority of dietary plant resources, while the other types are either devoid of, or have low cover by, dietary species.

Vegetation sampling also reveals that food species in the contemporary palette may not appear in the archaeological record, despite high cover and high seasonal productivity. *Berberis fremontii* and *Shepherdia rotundiflora*, for example, are large shrubs contributing two to five percent cover in pinyon-juniper and cool desert scrub types and known to be important food sources in the ethnographic record of the Southern Paiute. Yet neither species are present in the long archaeological record. Perhaps the fruits of both taxa were eaten as they were gathered or the species may not have been present within the foraging radius of NCS during much of the Holocene.

Conversely, there are some plant taxa in the archaeological record that are not detected in the vegetation samples. Certain dietary taxa are difficult to find on the landscape during three years of fieldwork, as well as within available collection records (e.g. herbarium specimens). For example, *Chenopodium* seeds and fruits are known as macrofossils from NCS hearth features with high ubiquity among strata and at times a very high abundance (see Chapter 3). Yet, *Chenopodium* appears to be uncommon on the landscape.

Clearly, the vegetation that can be observed today and its dietary palette are somewhat different from those observed by the inhabitants of NCS. This limits interpretation of the archaeobotanical record using the ethnobotanical inventory. But combining ethnographic and modern vegetation analyses provides insight into the dietary ecology of NCS during the Holocene, despite limitations imposed by their inherent methodologies and uncertainties. Comprehensive inventories derived from contemporary informants can provide a universe of food plants to be used in conjunction with analyses of the archaeological record, but the record itself will always be local and ultimately reflect the particular ecosystems available for foraging. Furthermore, selectivity which can operate on individual preferences as well as group tradition may still not exploit all taxa in the local palette. Vegetation samples will likely contain many but not all of the dietary species available through time even when recent human impacts, especially livestock grazing, have altered the composition, structure and function of contemporary plant communities.

Do changes in diet breadth, driven by environmental change during the Holocene, conform to predictions of foraging theory?

The deposits at NCS show that dietary species richness for plants and animals fluctuated through time, with peaks and valleys corresponding to increased or decreased human activity at the site. Deer and *Chenopodium* were consistently included in the diet spanning the 10,000 – 6000 ^{14}C BP period. Two periods of increased dietary species richness occurred at 9400 and 8000 ^{14}C BP, when people were focusing their subsistence on deer and *Chenopodium* seeds, respectively. Overall, a maximum of 14 taxa and a minimum of 2 taxa were found in the dietary deposits at NCS, a relatively small subset of the dietary palette supplied by local ecosystems (see Chapter 2).

The shift in emphasis between deer and *Chenopodium* was accompanied by a shift in stone tool technology. The assemblage of chipped stone tools in substratum 3e was dominated by hunting as well as bone- and hide-processing implements. Ground stone tools do not arrive until 400 years later in substratum 5a (9000 ^{14}C BP), becoming dominant in substratum 5t (8000 ^{14}C BP), simultaneous with a peak in *Chenopodium* abundance. It is also possible at this time and thereafter that other plant foods were being processed on these stones, including starch-laden tubers (see Chapter 4).

The diet-breadth model predicts that decreases in the abundance of high-ranked resources from the landscape would coincide with increases in the abundance of lower-ranked resources. This prediction appears to be met during several discrete events, when *Chenopodium* seeds outnumber the sum of artiodactyl and leporid bones (e.g., substrata 3c, 5a, 5m, 5p and 5t). But only in substratum 5t (8000 ^{14}C BP) is resource intensification indicated, because taxonomic richness is maximal, low-return resources have increased dramatically, and ground stone tools are very abundant.

In arid regions on a global basis, increasing aridity and resultant changes in vegetation composition have been 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). Climate change is detected in this study by major shifts in pollen produced by the dominant species of plant in the immediate vicinity of NCS. Increasing aridity begins by 9000 ^{14}C BP and had progresses significantly by 8000 ^{14}C BP, indicated by a shift in vegetation from a mixed conifer forest of cool-adapted species to a semi-arid woodland and shrub mosaic. This coincides with a broadening of the diet dependent upon an intensified use of small seeds and ground stone technology.

The shift to low-ranked resources from a diet dominated by artiodactyls, however, appears to be an uncommon and unsustained change in diet during most of the middle Holocene at NCS. Perhaps local depletion of artiodactyl populations was regularly mitigated by deer immigration from distant sources. The shift to *Chenopodium* use in substratum 5t may also have reflected the development of different foraging strategies between men and women, thus accounting for the observed changes in resource use (Janetski et al. 2012).

What do microbotanical remains collected from grinding stones tell us about food processing, the ecology of human diet, and environmental change?

Ground stone processing of starch-laden plant parts, specifically seeds and fruits, took place at NCS as early as 9000 ^{14}C BP. The practice intensifies by 8000 ^{14}C BP (substratum 5t and 5u) when over 40 ground stone tools are utilized for this purpose (see Chapter 3). The processing of tubers and other underground parts also begins at this time as evidenced by their unique starch grain structure. It is not possible at present to taxonomically identify all sources of starch found on these stones, except to conservatively conclude that bulbs and tubers supplemented the middle Holocene diet. Thus, small seeds are not the only plant resources intensively processed on ground stone tools at NCS.

The methods for recovering starch from ground stone tools can affect the yield of starch grains for analysis. Treatment 1, which analyzed the sediments conserved post-excavation, produce the highest counts of starch grains overall and from certain individual stones. Stones that had been lightly rinsed after excavation still produce grains when either brushed or sonicated, indicating that despite cleaning and the passage of time in storage, they can still yield dietary information. The present study demonstrates that microfossil remains can be successfully extracted, counted and analyzed from ground stone tools even after having been rinsed and stored in museum collections.

Taken together, the abundance of ground stone tools, the processing of seeds and fruits (possibly including *Chenopodium*), the grinding of tubers and bulbs, and the association with roasting pits and a hut-like feature may reflect the different occupancy and subsistence activities of women and men during the middle Holocene at NCS. Women especially may have utilized NCS preferentially, gathering and processing plant foods from nearby vegetation types. This would require a heavy investment in plant-processing tools, including manos and metates. At the same time, men may have been pursuing highly mobile and fluctuating herds of large-bodied animals at some distance from the shelter. Indeed, animal bones were relatively uncommon in substratum 5t (Chapter 3).

There are also implications of starch processing with respect to the ecology of human diets during the Holocene. Calculations of dietary species richness and evenness, used to define the energetics of food choices, have traditionally been based upon faunal evidence. The present study adds macrobotanical evidence to the calculations to achieve a fuller picture of the dietary palette as it changed through time (see Chapters 2 and 3). It would seem that adjustments to these calculations might eventually be made as microbotanical evidence reveals the identities of additional plant taxa in the diet. Although taxonomic assignments for the starch grains are difficult at this point, there are minimally two "taxa" ("centric" and "eccentric") that can be added to the tally of species richness. Adding these starch-producing plants to dietary species richness would accentuate a shift toward broader diet concurrent with a period of environmental change during the middle Holocene, thus reinforcing conclusions noted in Chapter 3.

The Future of Studying the Ecology of Human Diets

Studies of human diets, whether ethnographic or derived from archaeological remains, should be put into an ecological context that is defined by the composition and productivity of local ecosystems. As I have argued in my dissertation, human diet is an ecological phenomenon because it is about the supply, harvest, processing and energetic returns of plant and animal resources. Therefore, the modern distributions of plant and animals species, especially when combined with paleoecological data, provide insight into dietary palettes of the past.

To effectively study the ecology of human diets from archaeological remains, one should combine plant and animal datasets. Separating them for purposes of diet breadth analysis is artificial, as humans are omnivores. Along these same lines, microbotanical remains could and should also be included, as they represent plant species that were potentially important foodstuffs, but did not otherwise leave behind a visible ecofact. As I have shown, these data still exist on stone tools that have been stored in museum collections. There is also a need for a systematic survey of all plant taxa in the region that have perennial underground storage organs that could serve as sources of dietary starch. This would include a starch grain reference collection with images that might allow identification below the family level.

Until this present study, there have been no detailed analyses of combined dietary plant macro- and microfossils in the Great Basin and Colorado Plateau regions. Owing to major differences in landscape physiognomy, biogeography and cultural diversity, a comparative approach would be fruitful. There is no shortage of archeobotanical material as several other, well-excavated sites are distributed across these regions (e.g. Bonneville Estates Rockshelter, Danger Cave, Floating Island Cave, Camelsback Cave, Hogup Cave, Cowboy Cave, Sudden Shelter, Dust Devil Cave, Sand Dune Cave) and could be re-analyzed. This would begin the process of understanding changing diets among a wider variety of ecosystems and different groups of people during the Holocene.

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Appendix A

ETHNOGRAPHIC INVENTORY OF DIETARY PLANTS

The following table lists all the plant taxa and associated food materials (e.g., seeds, fruits, roots/bulbs) used by the Utah and Nevada Southern Paiute, based upon a master list published by Fowler (1986). Excluded are non-native and cultivated plants that would not have been present before European contact. Underground storage organs (i.e., bulbs, roots, tubers) are also excluded because unlike seeds and fruits, these plant parts would not have persisted as archaeological remains. Nomenclature follows USDA GRIN (http://www.ars-grin.gov/) with revisions in parentheses, if available. If taxon is not found in USDA GRIN, as indicated by an *, then nomenclature follows Welsh et al. 2008.

		Plant parts		**Native Groups**	
Family	**Taxon**	**seeds**	**fruits**	**Utah Southern Paiute**	**Utah+Nev Southern Paiute**
Adoxaceae	*Sambucus racemosa* (L.) *ssp. pubens* (Michx.) House *var. melanocarpa* (A.Gray) McMinn		x	x	
Agavaceae	*Yucca baccata* (Torr.)		x	x	
	Y. baileyi (Wooton & Standl.)		x	x	
Amaranthaceae	*Amaranthus albus* (L.)	x		x	
	A. hypochondriacus (L.)	x		x	
	A. palmeri (S. Watson)	x			x
	A. powellii (S. Watson)	x		x	
	A. retroflexus (L.)	x		x	
Anacardiaceae	*Rhus glabra* (L.)		x		x
	R. aromatic (Aiton) var. *trilobata* (Nutt.) A. Gray		x		x
Asteraceae	*Artemisia carruthii* (Alph. Wood ex Carruth.)	x		x	
	Balsamorhiza sagittata (Pursh) Nutt.	x		x	
	Helianthella uniflora (Nutt.) Torr. & A. Gray	x		x	
	Helianthis petiolaris (Nutt.)	x		x	
	Vigueria (Heliomaris) multiflora (Nutt.)	x		x	

Berberidaceae	*Berberis* (*Mahonia*) *fremontii* (Torr.)		x	x	
Brassicaceae	*Arabis holboellii* (Hornem.) A. Löve & D. Löve	x		x	
	Lepidium fremontii (S. Watson)	x		x	
	L. lasiocarpum (Nutt.)	x		x	
	Rorippa curvisiliqua (Hook.) Bessey ex Britton	x		x	
	Stanleya pinnata (Pursh) Britton	x			x
Cactaceae	*Echinocactus lecontei (Ferocactus cylindraceus* Engelm. Orcutt subsp. *Lecontei* Engelm. N.P. Taylor)	x		x	
	E. polycephalus (Englem. & J.M. Bigelow)	x		x	
	Echinocereus mohavensis (Engelm. & J.M. Bigelow) Rümpler		x	x	
	Echinocereus (Opuntia) engelmannii Salm-Dyck ex Engelm.		x	x	
	Opuntia sp.		x		x
	Opuntia (Cylindropuntia) whipplei (Engelm. & J.M. Bigelow) (F.M. Knuth)		x	x	
Chenopodiaceae	*Allenrolfea occidentalis* (S. Watson) Kuntz	x		x	
	Atriplex canescens (Pursh) Nutt.	x		x	
	A. confertifolia (Torr. & Frém.) S. Watson	x			x
	A. lentiformis (Torr.) S. Watson	x		x	
	A. powellii (S. Watson)*	x		x	
	Chenopodium fremontii (S. Watson)	x		x	
	C. incanum (S. Watson) A. Heller	x		x	
	C. leptophyllum (Moq.) Nutt. ex S. Watson	x		x	
Cucurbitaceae	*Cucurbita foetidissima* (Kunth)	x		x	
Cupressaceae	*Juniperus osteosperma* (Torr.) Little	x		x	
Cyperaceae	*Scirpus (Schoenoplectus) acutus* (Muhl. ex Bigelow) A. Löve & D. Löve	x		x	

	Scirpus (Bolboschoenus) maritamus (L.) Palla	x			x
Elaeagnaceae	*Shepherdia argentea* (Pursh) Nutt.		x	x	
Ericaceae	*Arctostaphylos pringlei* (Parry)* *var. drupacea*		x	x	
	A. pungens (Kunth)		x	x	
Fabaceae	*Prosopis glandulosa* (Torr.)	x			x
	P. glandulosa var. torreyana (L.D. Benson) M.C. Johnst.	x	x	x	
	P. pubescens (Benth.)	x			x
Fagaceae	*Quercus gambelii* (Nutt.)		x	x	
Grossulaceae	*Ribes aureum* (Pursh)		x	x	
Loaseae	*Mentzelia albicaulis* (Douglas) Douglas ex Torr. & A. Gray	x			x
	M. dispersa (S. Watson)	x		x	
	M. multiflora (Nutt.) A. Gray	x		x	
Lythraceae	*Ammannia coccinea* (Rottb.)	x		x	
Malvaceae	*Sphaeralcea parvifolia* (A. Nelson)	x		x	
Montiaceae	*Portulaca retusa (oleracea)* (L.)	x		x	
Pinaceae	*Pinus edulis* (Engelm.)	x			x
	P. monophylla (Torr. & Frém.)	x			x
Poaceae	*Echinochloa muricata* (P. Beauv.) Fernald var. *microstachya* Weigand	x		x	
	Elymus (Leymus) cinereus (Scrib. & Merr.) A. Löve	x		x	
	Muhlenbergia asperifolia (Nees & Meyen ex Trin.) Parodi	x			x
	M. rigens (Benth.) Hitchc.	x			x
	Oryzopsis (Achnatherum) hymenoides (Roem. & Schult.) Barkworth	x			x
	Sporobolus sp.	x		x	

	S. airiodes (Torr.) Torr.	x			x
	S. cryptadrus (Torr.) A. Gray	x		x	
Polygonaceae	*Eriogonum inflatum* (Torr. & Frém.)	x		x	
Rosaceae	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem. var. *alnifolia*		x	x	
	A. utahensis (Koehne)		x	x	
	Prunus virginiana var. demissa (Nutt.) Torr.		x	x	
	Rosa woodsii var. ultramontanum (S. Watson) Jeps.		x	x	
	Rubus sp.		x	x	
Santalaceae	*Comandra pallida (umbellate)* (L.) Nutt. subsp. *pallida* (A. DC.) Piehl		x	x	
Sarcobataceae	*Sarcobatus vermiculatus* (Hook.) Torr.	x		x	
	Suaeda diffusa (calceoliformis) (Hook.) Moq.	x		x	
	S. torreyana var. ramossima (S. nigra) (Raf.) J.F. Macbr.	x			x
Solanaceae	*Lycium andersonii* (A. Gray)		x	x	
	L. berlandieri (Dunal)		x	x	
	L. cooperi (A. Gray)		x	x	
	L. pallidum (Miers)		x	x	
	L. torreyi (A. Gray)		x	x	
Typhaceae	*Typha domingensis* (Pers.)	x		x	
Verbenaceae	*Verbena bracteata* (Lag. & Rodr.)	x		x	
Vitaceae	*Vitis arizonica* (Engelm.)		x		x

Appendix B

FAUNAL INVENTORY AND SYNONOMY FOR DETERMINING SPECIES RICHNESS (NTAXA)*

Previous Inventory (Newbold and Johannson)	**Revised Inventory (Louderback)**	**NTAXA**	
cf. Large Artiodactyl	Artiodactyla, unassigned	0	**Dietary NTAXA = 6**
Small Artiodactyl			
cf. Small Artiodactyl			
Unidentified Cervid	Cervid, unassigned	0	
cf. *Antilocapra americana*	*Antilocapra americana*	1	
cf. *Cervus elaphus*	*Cervus elaphus*	1	
Odocoileus hemionus	*Odocoileus hemionus*	1	
cf. *Odocoileus hemionus*			
Ovis canadensis	*Ovis canadensis*	1	
cf. *Ovis canadensis*			
Unidentified Leporid	Leporid, unassigned	0	
cf. Unidentified Leporid			
Lepus spp.	*Lepus* sp.	1	
cf. *Lepus* spp.			
Sylvilagus spp.	*Sylvilagus* sp.	1	
cf. *Sylvilagus* spp.			
Canis spp.	*Canis* sp.	1	**Non-dietary NTAXA = 16**
cf. *Canis* spp.			
cf. Medium Felid	Felid, unassigned	0	
Medium Mustelid	Mustelid, unassigned	0	
cf. Medium Mustelid			
Castor canadensis	*Castor canadensis*	1	
cf. *Castor canadensis*			
Erethizon dorsatum	*Erethizon dorsatum*	1	
cf. *Erethizon dorsatum*			
Marmota flaviventris	*Marmota flaviventris*	1	
cf. *Marmota flaviventris*			
Medium Sciurid	Sciurid, unassigned	0	
Small Sciurid			
cf. Small Sciurid			
Spermophilus spp.	*Spermophilus* sp.	1	
Spermophilus variegatus	*Spermophilus variegatus*		
cf. *Spermophilus variegatus*			
cf. *Tamias* spp.	*Tamias* sp.	1	
Thomomys spp.	*Thomomys* sp.	1	
Large Cricetid	Cricetid, unassigned	0	
Small Cricetid			
cf. Small Cricetid			
Microtus spp.	*Microtus* sp.	1	
cf. *Microtus* spp.			
Neotoma spp.	*Neotoma* sp.	1	
cf. *Neotoma* spp.			
Unidentified Vespertilionid	Vespertilionid, unassigned	0	
cf. Unidentified Vespertilionid			
Small Falconid	Falconid, unassigned	0	
Meleagris spp.	*Meleagris* sp.	1	
cf. *Meleagris* spp.			
Dendragapus obscurus	*Dendragapus obscurus*	1	
cf. *Dendragapus obscurus*			
Medium Anatid	Anatid, unassigned	0	
Aythya spp.	*Aythya* sp.	1	
Medium Colubrid	Colubrid, unassigned	1	
cf. *Crotaphytus collaris*	*Crotaphytus collaris*	1	
Bufo spp.	*Bufo* sp.	1	

Gila spp.	*Gila* sp.	1	

* As pointed out in Chapter 3, Newbold and Johannson’s analysis was conducted prior to the revision of *Spermophilus* by Helgen et al. 2009, and was repeated in Janetski 2012. In the absence of reidentification of the NCS sciurids, I have retained their terminology here.

Appendix C

FAUNAL COUNTS FROM SUBSTRATA AT NCS

Stratum 6

Taxon	**Substratum**				
	6e	**6d**	**6c**	**6b**	**6a**
Antilocapra americana	1	2		1	9
Cervus elaphus		1		1	
Odocoileus hemionus		4	6	6	34
Ovis canadensis	3	2	3	1	4
Artiodactyla, unassigned	26	419	500	144	847
Canis sp.					
Lepus sp.	1	2			4
Sylvilagus sp.	2	15	9	5	16
Leporidae, unassigned		2		4	5
Castor canadensis					
Erethizon dorsatum		1			
Marmota flaviventris					
Spermophilus variegatus					6
Tamias sp.					
Thomomys sp.					1
Microtus sp.		1			1
Neotoma sp.					
Meleagris sp.				1	
Dendragapus obscurus					
Aythya sp.					
Crotaphytus collaris					
Bufo sp.					
Gila sp.					
Total NISP per stratum	**7**	**28**	**18**	**15**	**75**
NTAXA	**4**	**8**	**3**	**6**	**8**

Stratum 5

Taxon	Substratum																				
	5u	**5t**	**5s**	**5r**	**5q**	**5p**	**5o**	**5n**	**5m**	**5l**	**5k**	**5j**	**5i**	**5h**	**5g**	**5f**	**5e**	**5d**	**5c**	**5b**	**5a**
Antilocapra americana				3																	
Cervus elaphus													1								
Odocoileus hemionus	97	33	110	160	44	9		32	5	46	1	55	25	11		39			7		12
Ovis canadensis	5	6	10	22	4	1		2				6	3			2			7	3	1
Artiodactyla, unassigned	144	60	288	489	88	20		74	20	111	5	77	36	15		72		3	24	4	16
Canis sp.	2																				
Lepus sp.	5	4	6	1		1				1		1		1		2			1		1
Sylvilagus sp.	39	37	27	4	5			1	2	4		1	5			11			17		2
Leporidae, unassigned			3					1		1			2								
Castor canadensis																					
Erethizon dorsatum		1																			
Marmota flaviventris																					2
Spermophilus variegatus	6		1																		
Tamias sp.			1																		
Thomomys sp.		1	1					4					5								
Microtus sp.																			1		
Neotoma sp.		3	1	1				1				1				3			11		
Meleagris sp.																					
Dendragapus obscurus					1																
Aythya sp.																					
Crotaphytus collaris																					
Bufo sp.																					
Gila sp.																					
Total NISP per stratum	**154**	**85**	**157**	**191**	**54**	**11**	**0**	**40**	**7**	**51**	**1**	**64**	**39**	**12**	**0**	**57**	**0**	**0**	**44**	**3**	**18**
NTAXA	**6**	**7**	**8**	**6**	**4**	**3**	**0**	**5**	**2**	**3**	**1**	**5**	**5**	**2**	**0**	**5**	**0**	**0**	**6**	**1**	**5**

Stratum 4

Taxon	**Substratum**																	
	4r	**4q**	**4p**	**4o**	**4n**	**4m**	**4l**	**4k**	**4j**	**4i**	**4h**	**4g**	**4f**	**4e**	**4d**	**4c**	**4b**	**4a**
Antilocapra americana																		
Cervus elaphus																		
Odocoileus hemionus	8							7	2	6	2	3	3	1	11	4		19
Ovis canadensis			1					1				1			1			1
Artiodactyla, unassigned	27		5		4		1	10	3	10	2	14	10		14	2	3	32
Canis sp.										1								
Lepus sp.	1		1					4		7	1	2	1		6		1	5
Sylvilagus sp.	24		2		2			2	1	3	2	3		1	4		3	5
Leporidae, unassigned					1													
Castor canadensis																		3
Erethizon dorsatum	3			5														
Marmota flaviventris															2			
Spermophilus variegatus	2									1		1	2		4			3
Tamias sp.																		
Thomomys sp.																		
Microtus sp.	1							1				1			1			
Neotoma sp.	11		6		3			2		1		4	2		8		1	12
Meleagris sp.															4			
Dendragapus obscurus								1					1		1			3
Aythya sp.																		
Crotaphytus collaris																		
Bufo sp.																		
Gila sp.																		
Total NISP per stratum	**50**	**0**	**10**	**5**	**5**	**0**	**0**	**18**	**3**	**19**	**5**	**15**	**9**	**2**	**42**	**4**	**5**	**51**
NTAXA	**7**	**0**	**4**	**1**	**2**	**0**	**0**	**7**	**2**	**6**	**3**	**7**	**5**	**2**	**10**	**1**	**3**	**8**

Stratum 3

Taxon	**Substratum**						
	3g	**3f**	**3e**	**3d**	**3c**	**3b**	**3a**
Antilocapra americana							
Cervus elaphus							
Odocoileus hemionus	1	175	292	9	2	11	43
Ovis canadensis							
Artiodactyla, unassigned	3	263	364	4	1	3	70
Canis sp.							
Lepus sp.		1	2				8
Sylvilagus sp.		21	32		1	2	10
Leporidae, unassigned			1				
Castor canadensis							
Erethizon dorsatum						1	2
Marmota flaviventris							
Spermophilus variegatus							1
Tamias sp.							
Thomomys sp.		1					
Microtus sp.							2
Neotoma sp.		1		1			9
Meleagris sp.							
Dendragapus obscurus	1						
Aythya sp.		4					
Crotaphytus collaris							1
Bufo sp.							12
Gila sp.			1				
Total NISP per stratum	2	203	327	10	3	14	88
NTAXA	2	6	4	2	2	3	9

Stratum 2

Taxon	Substratum						
	2g	**2f**	**2e**	**2d**	**2c**	**2b**	**2a**
Antilocapra americana							
Cervus elaphus							
Odocoileus hemionus	25	105	33	24	14	12	7
Ovis canadensis							
Artiodactyla, unassigned	57	105	47	33	54	30	18
Canis sp.	1						
Lepus sp.	1	7	9	1		1	1
Sylvilagus sp.	3	31	36	3	1	2	2
Leporidae, unassigned			1				
Castor canadensis							3
Erethizon dorsatum							
Marmota flaviventris							1
Spermophilus variegatus	1	3					2
Tamias sp.							
Thomomys sp.							
Microtus sp.							
Neotoma sp.	1	1					
Meleagris sp.							
Dendragapus obscurus		2	1	2		6	
Aythya sp.							
Crotaphytus collaris							
Bufo sp.							
Gila sp.							
Total NISP per stratum	**32**	**149**	**79**	**30**	**15**	**21**	**16**
NTAXA	**6**	**6**	**4**	**4**	**2**	**4**	**6**

Stratum 1

Taxon	**Substratum**			
	1j	1i	1g	1e
Antilocapra americana				
Cervus elaphus				
Odocoileus hemionus	1	7		
Ovis canadensis				
Artiodactyla, unassigned	4	12	2	
Canis sp.				
Lepus sp.				
Sylvilagus sp.			1	
Leporidae, unassigned				
Castor canadensis				
Erethizon dorsatum				
Marmota flaviventris				
Spermophilus variegatus				
Tamias sp.				
Thomomys sp.				
Microtus sp.	1			
Neotoma sp.			3	
Meleagris sp.				
Dendragapus obscurus				
Aythya sp.				
Crotaphytus collaris				
Bufo sp.				
Gila sp.				
Total NISP per stratum	2	7	4	0
NTAXA	2	1	2	0

Appendix D

CULTURAL MARKERS ON MAMMALIAN TAXA FROM NCS

Taxon	NISP	Burned	Butchery Marks
Antilocapra americana	16	1	0
Cervus elaphus	3	1	0
Odocoileus hemionus	1563	278	129
Ovis canadensis	90	16	2
Canis sp.	4	0	0
Lepus sp.	91	21	5
Sylvilagus sp.	399	53	0
Castor canadensis	6	1	0
Erethizon dorsatum	13	0	0
Marmota flaviventris	5	0	0
Spermophilus variegatus	33	1	0
Tamias sp.	1	0	0
Thomomys sp.	13	0	1
Microtus sp.	10	0	0
Neotoma sp.	87	3	0
Meleagris sp.	5	0	0
Dendragapus obscurus	19	1	0
Aythya sp.	4	0	0
Crotaphytus collaris	1	0	0
Bufo sp.	12	0	0
Gila sp.	1	0	0

Appendix E

Inventory of floated sediment samples processed and analyzed from each substratum at NCS.

Substratum	**No. of floated samples** N=192
6d	1
6a	2
	n=3
5u	8
5t	16
5s	2
5r	1
5p	2
5m	6
5l	4
5j	3
5i	3
5h	17
5e	3
5c	1
5b	1
5a	9
	n=76
4o	3
4m	2
4j	3
4h	1
4g	3
4f	4
4e	2
4c	4
4b	3
4a	2
	n=27
3g	5
3e	15
3c	7
3b	2
3a	1
	n=30
2g	5
2f	2
2e	3
2d	1
2c	1
2b	4
2a	4
	n=20
1i	12
1h	1
1g	6
1f	2
1e	14
1b	1
	n=36

Appendix F

INVENTORY OF DIETARY ANIMAL AND PLANT REMAINS FROM NCS

Stratum 6

Dietary Faunal	**6d**	**6a**
Antilocapra americana	2	9
Cervus elaphus	1	
Odocoileus hemionus	4	34
Ovis canadensis	2	4
Lepus sp.	2	4
Sylvilagus sp.	15	16
Dietary Macrobotanical		
Chenopodium spp.	36	37
C. berlandieri	14	5
Atriplex confertifolia		
Amaranthus sp.		
Amaranthaceae		
Asteraceae		
Helianthus sp.		
Ambrosia sp.		
Apiaceae		
Brassicaceae		
Cactaceae		
Ephedra sp.		
Large legume	1	
Small legume		
Achnatherum hymenoides		
Poaceae		
Polygonaceae		
Rosa sp.		
Quercus sp.		
Malvaceae		
Rhus sp.		
Typha sp.		
Pinaceae		
Species A		
Species B		
Species C		
Species D		
Species E		
Species F		
NISP	**77**	**109**
NTAXA	**8**	**6**
1/Simpson's Index	**2.152087**	**3.612344**

Stratum 5

Dietary Faunal	**5u**	**5t**	**5s**	**5r**	**5p**	**5m**	**5l**	**5j**	**5i**	**5h**	**5e**	**5c**	**5b**	**5a**
Antilocapra americana				3										
Cervus elaphus									1					
Odocoileus hemionus	97	33	110	160	9	5	46	55	25	11		7		12
Ovis canadensis	5	6	10	22	1			6	3			7	3	1
Lepus sp.	5	4	6	1	1		1	1		1		1		1
Sylvilagus sp.	39	37	27	4		2	4	1	5			17		2
Dietary Macrobotanical														
Chenopodium spp.	153	204	34		42	124	3	4	12	33	25	7		50
C. berlandieri	18	18			10									5
Atriplex confertifolia		1				2			1					
Amaranthus sp.		5												
Amaranthaceae														
Asteraceae														
Helianthus sp.		1												
Ambrosia sp.		1												
Apiaceae														
Brassicaceae														
Cactaceae		1								1				2
Ephedra sp.														
Large legume														
Small legume														
Achnatherum hymenoides		1												
Poaceae	94	1												
Polygonaceae										3				1
Rosa sp.														
Quercus sp.														
Malvaceae		2					1							
Rhus sp.						2	35		73	43				
Typha sp.	4									2				
Pinaceae	4	3	2				1	1		14			2	
Species A											1			
Species B														
Species C														
Species D														
Species E														
Species F										1				
NISP	**419**	**318**	**189**	**190**	**63**	**135**	**91**	**68**	**120**	**109**	**26**	**39**	**5**	**74**
NTAXA	**8**	**14**	**6**	**5**	**4**	**5**	**7**	**6**	**7**	**9**	**2**	**5**	**2**	**7**
1/Simpson's Index	**3.59**	**1.9**	**2.53**	**1.38**	**1.42**	**1.18**	**2.46**	**1.5**	**2.45**	**2.07**	**1.08**	**3.48**	**1.92**	**1.72**

Stratum 4

Dietary Faunal	**4r**	**4p**	**4o**	**4m**	**4j**	**4h**	**4g**	**4f**	**4e**	**4c**	**4b**	**4a**
Antilocapra americana												
Cervus elaphus												
Odocoileus hemionus	8				2	2	3	3	1	4		19
Ovis canadensis		1					1					1
Lepus sp.	1	1				1	2	1			1	5
Sylvilagus sp.	24	2			1	2	3		1		3	5
Dietary Macrobotanical												
Chenopodium spp.			30	5	10	7	5	1	11	3		
C. berlandieri												
Atriplex confertifolia												
Amaranthus sp.												
Amaranthaceae											2	
Asteraceae											1	
Helianthus sp.												
Ambrosia sp.												
Apiaceae												
Brassicaceae									1			
Cactaceae												
Ephedra sp.												
Large legume							1			6		
Small legume												
Achnatherum hymenoides												
Poaceae												
Polygonaceae												
Rosa sp.												
Quercus sp.												
Malvaceae									1			
Rhus sp.				5								
Typha sp.												
Pinaceae					1	3	6	4		7	3	
Species A										6		
Species B												
Species C												
Species D												1
Species E												
Species F												
NISP	**33**	**4**	**30**	**10**	**14**	**15**	**21**	**9**	**15**	**26**	**10**	**31**
NTAXA	**3**	**3**	**1**	**2**	**4**	**5**	**7**	**4**	**5**	**5**	**5**	**5**
1/Simpson's Index	**1.699**	**2.667**	**N/A**	**2**	**1.849**	**3.358**	**5.188**	**3**	**1.8**	**4.63**	**4.167**	**2.327**

Stratum 3

Dietary Faunal	**3g**	**3e**	**3c**	**3b**	**3a**
Antilocapra americana					
Cervus elaphus					
Odocoileus hemionus	1	292	2	11	43
Ovis canadensis					
Lepus sp.		2			8
Sylvilagus sp.		32	1	2	10
Dietary Macrobotanical					
Chenopodium spp.	5	84	63		
C. berlandieri					
Atriplex confertifolia		1			
Amaranthus sp.					
Amaranthaceae					
Asteraceae		2			
Helianthus sp.					
Ambrosia sp.					
Apiaceae					
Brassicaceae					
Cactaceae					
Ephedra sp.					
Large legume			1		
Small legume					
Achnatherum hymenoides		1			
Poaceae					
Polygonaceae		1	1		
Rosa sp.					
Quercus sp.		1			
Malvaceae		1			
Rhus sp.					
Typha sp.					
Pinaceae	10	5	4	1	
Species A			1		
Species B		3			
Species C		7			
Species D		2			
Species E			5		
Species F					
NISP	**16**	**434**	**78**	**14**	**61**
NTAXA	**3**	**14**	**8**	**3**	**3**
1/Simpson's Index	**2.031746**	**2.01571**	**1.334586**	**1.555556**	**1.848485**

Stratum 2

Dietary Faunal	**2g**	**2f**	**2e**	**2d**	**2c**	**2b**	**2a**
Antilocapra americana							
Cervus elaphus							
Odocoileus hemionus	25	105	33	24	14	12	7
Ovis canadensis							
Lepus sp.	1	7	9	1		1	1
Sylvilagus sp.	3	31	36	3	1	2	2
Dietary Macrobotanical							
Chenopodium spp.	6		2	3			2
C. berlandieri							
Atriplex confertifolia							
Amaranthus sp.							
Amaranthaceae	1						
Asteraceae							
Helianthus sp.							
Ambrosia sp.							
Apiaceae							
Brassicaceae							
Cactaceae							
Ephedra sp.	1						
Large legume	3			1			
Small legume	1						
Achnatherum hymenoides							
Poaceae							
Polygonaceae							
Rosa sp.	1						
Quercus sp.			1				
Malvaceae							
Rhus sp.							
Typha sp.							
Pinaceae	4	1	2	1	4		3
Species A							
Species B							
Species C							
Species D							
Species E							
Species F							
NISP	**46**	**144**	**83**	**33**	**19**	**15**	**15**
NTAXA	**10**	**4**	**6**	**6**	**3**	**5**	**3**
1/Simpson's Index	**2.773639**	**1.722832**	**2.783434**	**1.824121**	**1.694836**	**2.469136**	**1.851852**

Stratum 1

Dietary Faunal	**1i**	**1h**	**1g**	**1f**	**1e**
Antilocapra americana					
Cervus elaphus					
Odocoileus hemionus	7				
Ovis canadensis					
Lepus sp.					
Sylvilagus sp.			1		
Dietary Macrobotanical					
Chenopodium spp.				9	
C. berlandieri					
Atriplex confertifolia					
Amaranthus sp.					
Amaranthaceae					
Asteraceae					
Helianthus sp.					
Ambrosia sp.					
Apiaceae		1			
Brassicaceae					
Cactaceae					
Ephedra sp.					
Large legume					
Small legume					
Achnatherum hymenoides					
Poaceae					
Polygonaceae					
Rosa sp.					
Quercus sp.					
Malvaceae					
Rhus sp.					
Typha sp.					
Pinaceae	3	3	2	6	2
Species A					
Species B	1				
Species C					
Species D					
Species E					
Species F					
NISP	**11**	**4**	**3**	**15**	**2**
NTAXA	**3**	**2**	**2**	**2**	**1**
1/Simpson's Index	**2.050847**	**1.6**	**2.666667**	**1.923077**	**N/A**

Appendix G

GROUND STONE TOOL DESCRIPTIONS FROM NCS*

Sub-stratum	Sample (FS)	GS Type	Raw Material**	Wgt gms	Thick cm	Lgth cm	Wdth cm
6d	53	metate	S	278.1	2.88	10.8	7.52
	242.1	mano	V	45.9	3	4.81	3.14
	242.2	metate	S	204.4	1.88	9.34	8.19
	362	mano	S	196.8	4.63	5.18	7.52
	483.1	metate	S	298.2	3.1	11.26	9.37
	483.2	metate	S	426.3	5.14	11.2	6.48
	517.1	mano	S				
	517.2	mano	S	36.9	3.93	4.02	3.7
	1316	metate	S	1389.2	5.65	17	13.26
	1613	metate	S	13636.4	6.52	41.5	37
	1719.1	metate	S	258.5	1.75	13.57	10.45
	1719.2	metate	S	254.2	2.68	12.72	8.18
	1757	mano	Q	793.8	6.94	9.93	8.19
	1758.1	metate	S	310.3	1.5	13.94	11.55
	1758.2	metate	S	147.4	0.78	13.63	8.96
	1758.3	metate	S	280	0.67	17.5	12.6
	1759	mano	S	765.5	6.16	10.15	8.85
	2239.1	mano	S	58	4.11	4.19	3.71
	2669	metate	S	537.1	6.2	11.06	10.57
6c	2242	mano	G	1190.7	6.17	12.8	10.03
	2302	metate	S	216.7	1.51	11.15	9.77
	2684	metate	S	737.1	3.58	12.96	10.24
	2710	metate	S	850.5	1.68	2.5	24.5
6b	1469	metate	S	1275.8	9.01	12.2	11.63
	1584	mano	S	514.8	4.27	9.26	9.99
	1614	metate	S	2636.6	4.41	22.2	18.9
	1615	metate	S	3855.6	3.47	3.6	19
	2335	metate	S	1275.8	4.11	18.3	13.12
	2337	metate	S	220	2.71	9.17	6.94
6a	501	mano	S	492.9	4.25	10.33	7.48
	505	mano	S	221.7	4.03	7.39	6.12
	548	mano	S	878.9	6.12	10.21	9.81
	561	mano	Q	907.2	5.61	11.79	8.38
	592	metate	S	1077.3	2.03	24	15.9
	603	metate	S	1275.8	4.42	17.4	13.53
	1676	metate	S	297.4	2.38	13.47	7.8
	2468	metate	S	7767.9	8.71	32.5	22
	2548	metate	S	275.5	1.98	13.8	9.2
	2663	mano	S	34.2	3.65	3.45	2.26
	2714	metate	S	1049	6	16	9.15
	2717	metate	S	102.4	3.04	6.99	4.81
	2744	mano	V	198	6.13	6.77	3.84
	2782	metate	S	253.1	2.9	10.24	7.15
	2858	metate	S	765.5	3.92	17.5	12.63
	2985	mano	S	453.8	3.94	9.6	8.27
	3003	mano	S	156	4.6	5.95	5.54
	3489	mano	S	371.9	4.46	10.81	6.41

Sub-stratum	Sample (FS)	GS Type	Raw Material**	Wgt gms	Thick cm	Lgth cm	Wdth cm
5u	2346	metate	S	4536	4.02	33	20.2
	2347	mano	S	793.8	5.12	10.34	9.42
	2407	mano	S	765.5	5.51	10.81	8.88
	2667.1	metate	S	1938	1.87	34	33.2
	2667.2	metate	S	271	1.06	15.75	12.37
	2672	metate	S	1105.7	4.45	19.5	11.72
	2673	metate	S	1786.1	4.01	22.5	14.5
	2674	metate	S	1332.5	5.28	15.56	10.22
	2676	metate	S				
	2731	mano	S	142.2	4.21	6.72	4.31
	2745	metate	S	1190.7	3.58	18.8	11.46
	3070	mano	S	737.1	5.84	9.54	8.57
	3315	metate	S	125.2	1.92	7.18	7.73
	3316	metate	S	141.2	3.17	7.69	4.4
	3317	metate	S	299	4.07	8.18	6.31
	3390	metate	S	60.5	0.87	8.58	6.73
	3393	metate	S	112.2	2.76	6.17	5.05
	3399	metate	S	162.7	1.35	10.1	7.37
	3414	metate	S	181.1	2.71	8.36	6.56
	3438	mano	G	1389	8.02	11.34	12.68
	3446	metate	S	2013	10.07	21	10.69
5t	484	mano	Q	342.3	4.93	8	7.26
	615	metate	S	39	1.32	5.28	2.82
	1767	mano	Q	133.7	2.05	9	4.48
	2953	metate	S	371.6	3.2	11.71	7.46
	2994	metate	V	7597.8	8.18	31	20.5
	2995	metate	S	2466.5	6.5	21	18.5
	3474.1	mano	S	40	2.25	3.94	4.64
	3474.2	mano	S	708	4.21	11.08	9.26
	3491.1	metate	S	3.9	0.32	3.01	1.88
	3495	metate	S	319.8	3.62	11.57	7.89
	3513	metate	S	1786	5.28	17	13.15
	3516.1	metate	S	22	0.43	6.24	3.68
	3516.2	mano	S	108.3	2.67	7.53	4.76
	3528.1	mano	S	124.2	0.8	11.15	7.52
	3528.2	mano	S	13.1	0.56	4.56	4.14
	3528.3	mano	S	4.8	0.41	2.34	2.83
	3564	metate	S	878	3.72	10.42	9.81
	3573	metate	S	114.8	0.75	10.59	10.12
	3607.1	metate	S	56.1	1.37	8.89	3.65
	3607.2	mano	Q	174.8	4.59	7.28	5.72
5s	1612	metate	S	258.4	0.58	20	17.5
	1628	metate	S	3033.45	3.69	29.5	19.6
	1779	mano	Q	396.4	4.08	8.92	7.43
	1869	mano	S	104.5	6.08	3.89	4.42
	1940	mano	S	529	3.08	14.58	8.75
5r	601	mano	S	222.3	4.32	7.55	6.24
	608	mano	S	45.2	4.25	3.32	2.99
	3473	metate	S	5.4	0.72	2.88	1.65
	3512	metate	S	8278	12	31	18

Sub-stratum	**Sample (FS)**	**GS Type**	**Raw Material****	**Wgt gms**	**Thick cm**	**Lgth cm**	**Wdth cm**
5q	3071	mano	V	765.5	4.7	11.59	9.25
	3637	metate	S	365.5	2.44	11.12	9.75
5m	3796	mano	S	964	5.22	13.77	8.79
5l	3886	metate	S	406.4	3.34	10.08	8.58
	3961	mano	G	110.1	2.54	7	5.43
5j	3915	metate	S	305.1	1.81	13.96	9.41
5h	4050	mano	Q	583	4.96	9.92	8.42
	4182	mano	S	325	7.66	5.29	9.73
5f	2289	metate	S	202.1	2.17	12.94	6.89
	4316	mano	S	493.9	3.46	10.58	10.55
5a	649	mano	S	216.7	3.83	5.68	6.86
	2151	mano	S	33.7	1.69	5.7	4.49
	2167	metate	S	13.6	0.79	5.1	2.56
	2220	metate	S	793.8	3.53	18	12.28
	2254	metate	S	501.3	2.4	14.9	13.4
	3072	metate	S	3628.8	4.55	27.5	22.2
	4368	metate	S	306.6	1.14	13	14.5
	4369	metate	S	2466	3.8	23.5	24
	4370	mano	S	794	6.44	9.59	9.3
	4591	metate	S	156.7	1.53	8.28	8.05

*Raw data provided by M. Bodily

**Ground stone raw material: S = sandstone, V = volcanic, Q = quartzite, G = granite

Appendix H

ARTIODACTYL INDEX VALUES FROM SUBSTRATA AT NCS (NISP>1)

$(\mathrm{NISP}_{\mathrm{Artiodactyls}})/(\mathrm{NISP}_{\mathrm{Artiodactyls}} + \mathrm{NISP}_{\mathrm{Leporids}})$

Substratum	Artiodactyl Index
1g	0.67
1i	1
1j	1
2a	0.9
2b	0.93
2c	0.99
2d	0.94
2e	0.64
2f	0.85
2g	0.96
3a	0.86
3b	0.88
3c	0.75
3d	1
3e	0.95
3f	0.95
3g	1
4a	0.84
4b	0.5
4c	1
4d	0.76
4e	0.5
4f	0.93
4g	0.78
4h	0.57
4i	0.62
4j	0.83
4k	0.75
4n	0.57
4p	0.67
4r	0.58

Substratum	Artiodactyl Index
5a	0.91
5b	1
5c	0.68
5d	1
5f	0.9
5h	0.96
5i	0.91
5j	0.99
5k	1
5l	0.96
5m	0.93
5n	0.98
5p	0.97
5q	0.96
5r	0.99
5s	0.92
5t	0.71
5u	0.85
6a	0.97
6b	0.94
6c	0.98
6d	0.96
6e	0.91

Appendix I

INVENTORY OF DIETARY PLANT REMAINS FROM NCS

Taxonomic assignments are non-overlapping, except in the case of *Chenopodium* (species combined into a single taxon for all calculations).

Stratum 6

Dietary Macrobotanical	**6d**	**6a**
Chenopodium spp.	36	37
C. berlandieri	14	5
Atriplex confertifolia		
Amaranthus sp.		
Amaranthaceae		
Asteraceae		
Helianthus sp.		
Ambrosia sp.		
Apiaceae		
Brassicaceae		
Cactaceae		
Ephedra sp.		
Large legume	1	
Small legume		
Achnatherum hymenoides		
Poaceae		
Polygonaceae		
Rosa sp.		
Quercus sp.		
Malvaceae		
Rhus sp.		
Typha sp.		
Pinaceae		
Species A		
Species B		
Species C		
Species D		
Species E		
Species F		
NISP	**51**	**42**
NTAXA	**2**	**1**

Stratum 5

Dietary Macrobotanical	**5u**	**5t**	**5s**	**5r**	**5p**	**5m**	**5l**	**5j**	**5i**	**5h**	**5e**	**5c**	**5b**	**5a**
Chenopodium spp.	153	204	34		42	124	3	4	12	33	25	7		50
C. berlandieri	18	18			10									5
Atriplex confertifolia		1				2			1					
Amaranthus sp.		5												
Amaranthaceae														
Asteraceae														
Helianthus sp.		1												
Ambrosia sp.		1												
Apiaceae														
Brassicaceae														
Cactaceae		1								1				2
Ephedra sp.														
Large legume														
Small legume														
Achnatherum hymenoides		1												
Poaceae	94	1												
Polygonaceae										3				1
Rosa sp.														
Quercus sp.														
Malvaceae		2					1							
Rhus sp.						2	35		73	43				
Typha sp.	4									2				
Pinaceae	4	3	2				1	1		14			2	
Species A											1			
Species B														
Species C														
Species D														
Species E														
Species F										1				
NISP	**273**	**238**	**36**	**0**	**52**	**128**	**40**	**5**	**86**	**97**	**26**	**7**	**2**	**58**
NTAXA	**4**	**10**	**2**	**0**	**1**	**3**	**4**	**2**	**3**	**7**	**2**	**1**	**1**	**3**

Stratum 4

Dietary Macrobotanical	**4o**	**4m**	**4j**	**4h**	**4g**	**4f**	**4e**	**4c**	**4b**	**4a**
Chenopodium spp.	30	5	10	7	5	1	11	3		
C. berlandieri										
Atriplex confertifolia										
Amaranthus sp.										
Amaranthaceae									2	
Asteraceae									1	
Helianthus sp.										
Ambrosia sp.										
Apiaceae										
Brassicaceae							1			
Cactaceae										
Ephedra sp.										
Large legume					1			6		
Small legume										
Achnatherum hymenoides										
Poaceae										
Polygonaceae										
Rosa sp.										
Quercus sp.										
Malvaceae							1			
Rhus sp.		5								
Typha sp.										
Pinaceae			1	3	6	4		7	3	
Species A								6		
Species B										
Species C										
Species D										1
Species E										
Species F										
NISP	**30**	**10**	**11**	**10**	**12**	**5**	**13**	**22**	**6**	**1**
NTAXA	**1**	**2**	**2**	**2**	**3**	**2**	**3**	**4**	**3**	**1**

Stratum 3

Dietary Macrobotanical	**3g**	**3e**	**3c**	**3b**	**3a**
Chenopodium spp.	5	84	63		
C. berlandieri					
Atriplex confertifolia		1			
Amaranthus sp.					
Amaranthaceae					
Asteraceae		2			
Helianthus sp.					
Ambrosia sp.					
Apiaceae					
Brassicaceae					
Cactaceae					
Ephedra sp.					
Large legume			1		
Small legume					
Achnatherum hymenoides		1			
Poaceae					
Polygonaceae		1	1		
Rosa sp.					
Quercus sp.		1			
Malvaceae		1			
Rhus sp.					
Typha sp.					
Pinaceae	10	5	4	1	
Species A			1		
Species B		3			
Species C		7			
Species D		2			
Species E			5		
Species F					
NISP	**15**	**108**	**75**	**1**	**0**
NTAXA	**2**	**11**	**6**	**1**	**0**

Stratum 2

Dietary Macrobotanical	**2g**	**2f**	**2e**	**2d**	**2c**	**2b**	**2a**
Chenopodium spp.	6		2	3			2
C. berlandieri							
Atriplex confertifolia							
Amaranthus sp.							
Amaranthaceae	1						
Asteraceae							
Helianthus sp.							
Ambrosia sp.							
Apiaceae							
Brassicaceae							
Cactaceae							
Ephedra sp.	1						
Large legume	3			1			
Small legume	1						
Achnatherum hymenoides							
Poaceae							
Polygonaceae							
Rosa sp.	1						
Quercus sp.			1				
Malvaceae							
Rhus sp.							
Typha sp.							
Pinaceae	4	1	2	1	4		3
Species A							
Species B							
Species C							
Species D							
Species E							
Species F							
NISP	**17**	**1**	**5**	**5**	**4**	**0**	**5**
NTAXA	**7**	**1**	**3**	**3**	**1**	**0**	**2**

Stratum 1

Dietary Macrobotanical	**1i**	**1h**	**1g**	**1f**	**1e**
Chenopodium spp.				9	
C. berlandieri					
Atriplex confertifolia					
Amaranthus sp.					
Amaranthaceae					
Asteraceae					
Helianthus sp.					
Ambrosia sp.					
Apiaceae		1			
Brassicaceae					
Cactaceae					
Ephedra sp.					
Large legume					
Small legume					
Achnatherum hymenoides					
Poaceae					
Polygonaceae					
Rosa sp.					
Quercus sp.					
Malvaceae					
Rhus sp.					
Typha sp.					
Pinaceae	3	3	2	6	2
Species A					
Species B	1				
Species C					
Species D					
Species E					
Species F					
NISP	**4**	**4**	**2**	**15**	**2**
NTAXA	**2**	**2**	**1**	**2**	**1**

Appendix J

RAW COUNTS OF POLLEN FROM NCS SEDIMENTS

Arboreal Pollen

Depth	*Picea*	*Pseudotsuga*	*Pinus/Abies*	*Pinus*	*Juniperus*	*Quercus*	*Betula/Alnus*	*Salix*
1e	0	96	49	3	10	11	0	2
1i	1	78	32	6	3	10	1	0
1q	0	53	13	4	6	10	1	0
2a	0	0	0	0	0	0	0	0
2b	3	85	117	2	0	19	0	1
2c	8	12	198	6	0	0	0	0
2d	0	105	16	4	2	29	0	0
2e	1	30	151	19	11	2	0	0
2f	1	94	60	0	0	28	0	0
3a	1	83	34	6	3	10	0	1
3d	0	142	79	2	2	7	1	0
3f	0	61	9	7	0	41	0	0
4a	0	52	6	1	0	20	1	0
4d	0	33	7	1	7	1	0	2
4f	1	52	3	1	0	32	1	0
4h	0	37	5	0	3	12	3	0
4r	0	21	84	29	0	0	0	0
5a	0	50	11	3	1	0	0	0
5f	1	10	3	3	6	96	0	0
5i	0	15	12	21	0	27	14	0
5q	0	13	92	4	49	28	0	2
5s	0	11	38	27	6	2	1	0
6a	0	2	48	13	0	0	1	0
6d	0	2	50	101	64	16	1	3

Shrub/Herb Pollen

Depth	***Shepherdia***	***Artemisia***	**Roseaceae**	**Asteraceae (low spine/Ambrosia)**	**Asteraceae (high spine)**	***Ephedra***	**Poaceae**	**Amaranthaceae**	**Total (Trees+ Shrubs)**	**Control**
1e	0	89	0	30	9	7	14	12	332	1467
1i	0	34	0	15	5	4	8	20	217	1841
1q	0	35	0	7	3	8	15	36	191	1191
2a	0	0	0	0	0	0	0	0	0	0
2b	0	9	0	0	0	2	1	6	245	1311
2c	0	9	0	0	0	0	0	10	243	427
2d	0	7	0	3	0	1	6	2	175	1779
2e	0	60	0	24	2	4	8	15	327	1142
2f	0	3	0	2	0	2	2	2	194	1134
3a	0	25	0	8	2	5	0	6	184	2220
3d	0	24	0	4	0	1	2	5	269	1435
3f	0	5	0	2	0	1	1	38	165	4096
4a	0	4	0	1	1	0	1	6	93	4077
4d	0	15	0	3	1	0	9	22	101	2352
4f	0	12	0	4	0	0	1	0	107	5056
4h	0	46	3	0	5	1	1	5	121	2701
4r	0	3	0	0	6	1	0	9	153	1048
5a	0	2	0	0	0	1	2	1	71	2580
5f	0	0	0	0	8	0	7	3	137	2329
5i	0	2	0	1	0	1	0	21	114	2403
5q	0	34	0	12	16	0	34	93	377	1192
5s	0	6	0	6	0	4	1	38	140	1702
6a	0	2	0	0	0	1	0	125	192	486
6d	2	13	0	7	26	23	31	222	561	908

Appendix K

INVENTORY OF NON-DIETARY PLANT REMAINS FROM NCS HEARTHS

Stratum 6

Taxon	**6d**	**6a**
Abies concolor		1
Picea sp.		
Pseudostuga menziesii	2	
Juniperus scopulorum		
Pinus ponderosa		6
Celtis sp.		1
Juniperus osteosperma	6	6
Pinus edulis	22	22
Conifer seeds		
NISP	**30**	**36**

Stratum 5

Taxon	**5u**	**5t**	**5s**	**5r**	**5p**	**5m**	**5l**	**5j**	**5i**	**5h**	**5e**	**5c**	**5b**	**5a**
Abies concolor		2				1								
Picea sp.														
Pseudostuga menziesii		1									2	1		9
Juniperus scopulorum		1					2				14			
Pinus ponderosa	1			1		1		1	9	15	3	1		47
Celtis sp.		1												5
Juniperus osteosperma	118	54	9	4	6	92	65	7	6	221	2	3		16
Pinus edulis	57	91	29	1	4	48	4	4		24				
Conifer seeds	4	3	2				1	1		14			2	
NISP	**180**	**153**	**40**	**6**	**10**	**142**	**72**	**13**	**15**	**274**	**21**	**5**	**2**	**77**

Stratum 4

Taxon	4r	4o	4m	4k	4j	4i	4h	4g	4f	4e	4d	4c	4b	4a
Abies concolor								1						
Picea sp.													1	
Pseudostuga menziesii												1	9	
Juniperus scopulorum														
Pinus ponderosa		3	4		1		16	73	23	13		11	26	9
Celtis sp.	3	1		2		6			12	1	1			2
Juniperus osteosperma														
Pinus edulis									4					
Conifer seeds					1		3	6	4			7	3	
NISP	**3**	**4**	**4**	**2**	**2**	**6**	**19**	**80**	**43**	**14**	**1**	**19**	**39**	**11**

Stratum 3

Taxon	3g	3e	3c	3b	3a
Abies concolor		1185			
Picea sp.					
Pseudostuga menziesii		15	63		
Juniperus scopulorum		78			
Pinus ponderosa	30	248	15	7	
Celtis sp.		2			
Juniperus osteosperma		2			
Pinus edulis					
Conifer seeds	10	5	4	1	
NISP	**40**	**1535**	**82**	**8**	**0**

Stratum 2

Taxon	2g	2f	2e	2d	2c	2b	2a
Abies concolor	57		16				1
Picea sp.							
Pseudostuga menziesii	7		1				
Juniperus scopulorum	2		2				
Pinus ponderosa	8		12	4	10	2	1
Celtis sp.			1			4	
Juniperus osteosperma							
Pinus edulis							
Conifer seeds	4	1	2	1	4		3
NISP	**78**	**1**	**34**	**5**	**14**	**6**	**5**

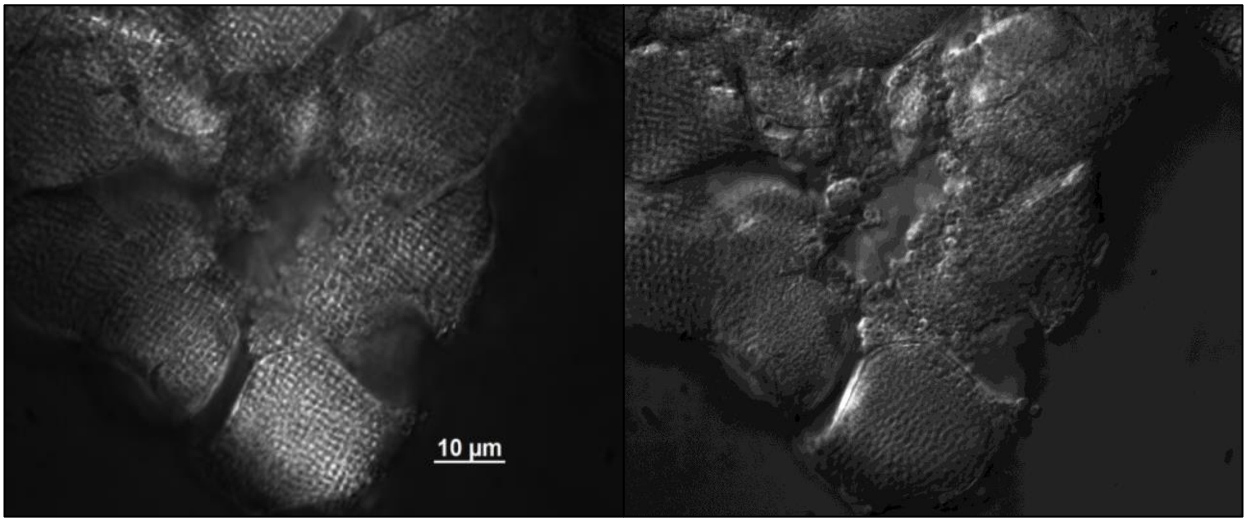
Stratum 1

Taxon	1i	1h	1g	1f	1e
Abies concolor					
Picea sp.					
Pseudostuga menziesii					
Juniperus scopulorum					
Pinus ponderosa					
Celtis sp.					
Juniperus osteosperma					
Pinus edulis					
Conifer seeds	3	3	2	6	2
NISP	**3**	**3**	**2**	**6**	**2**

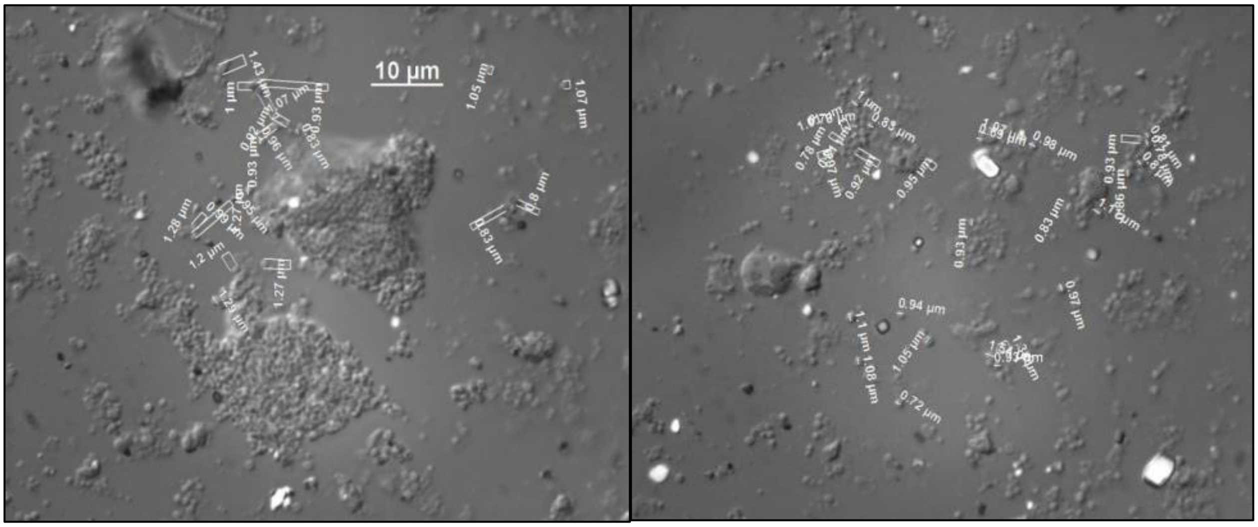
Appendix L

IMAGES OF REFERENCE STARCH GRAINS

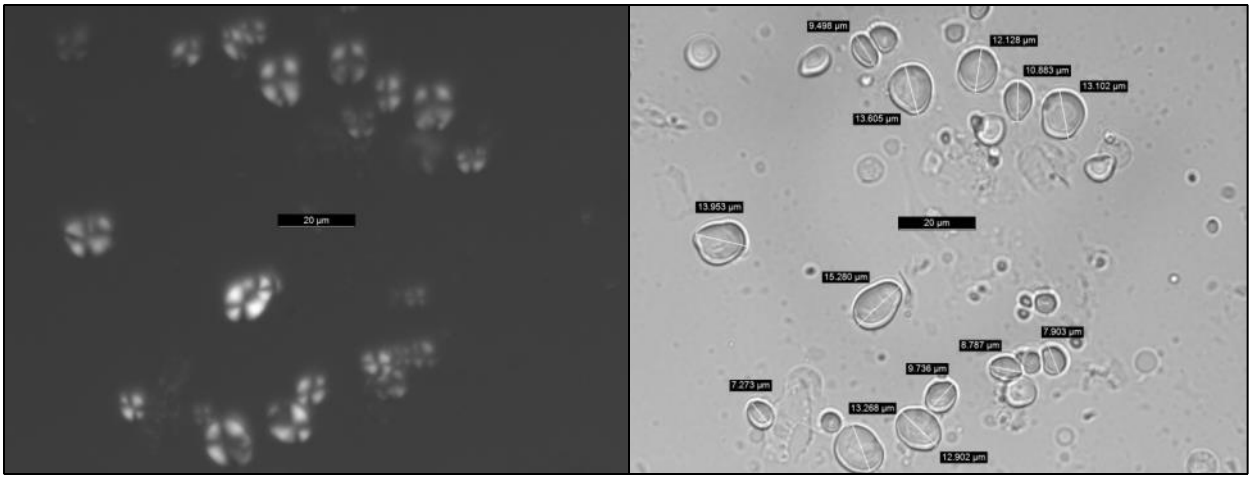
1. Taxa with centric hila



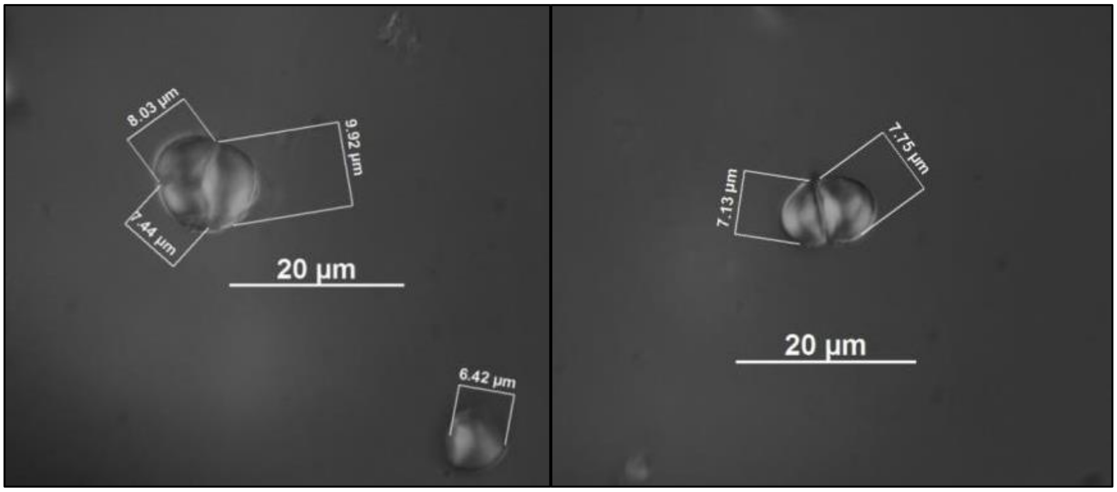
Chenopodium fremontii – Starch grains are formed in dense clusters of amyoplasts (sheets) bounded by cell walls. Cross-polarization image is on left. Nomarski image is on right.



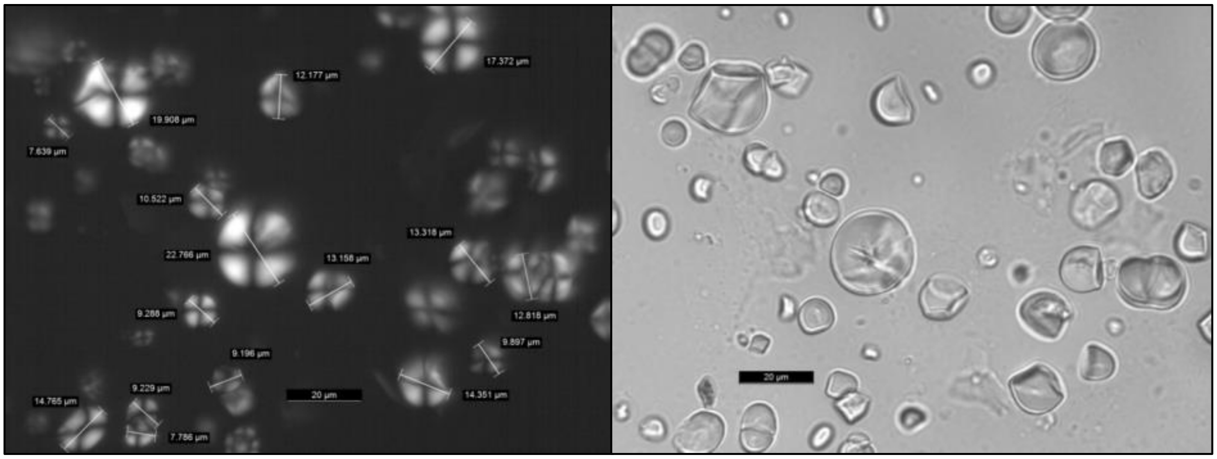
***Chenopodium berlandieri* -** Note ruptured cells exposing clusters of amyoplasts containing starch grains.



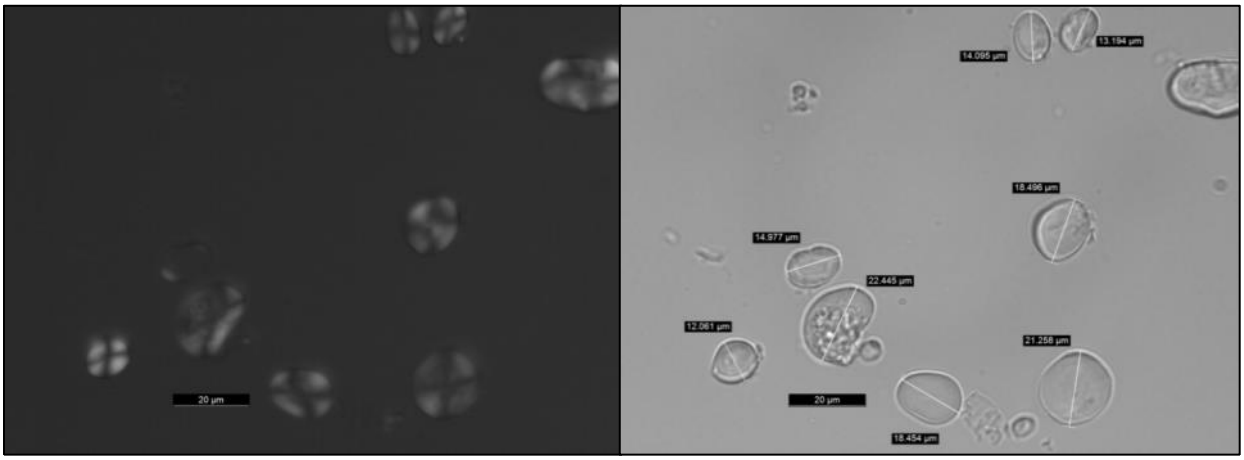
Cyperus esculentus Individual starch grains viewed with cross-polarization (l) and brightfield (r).



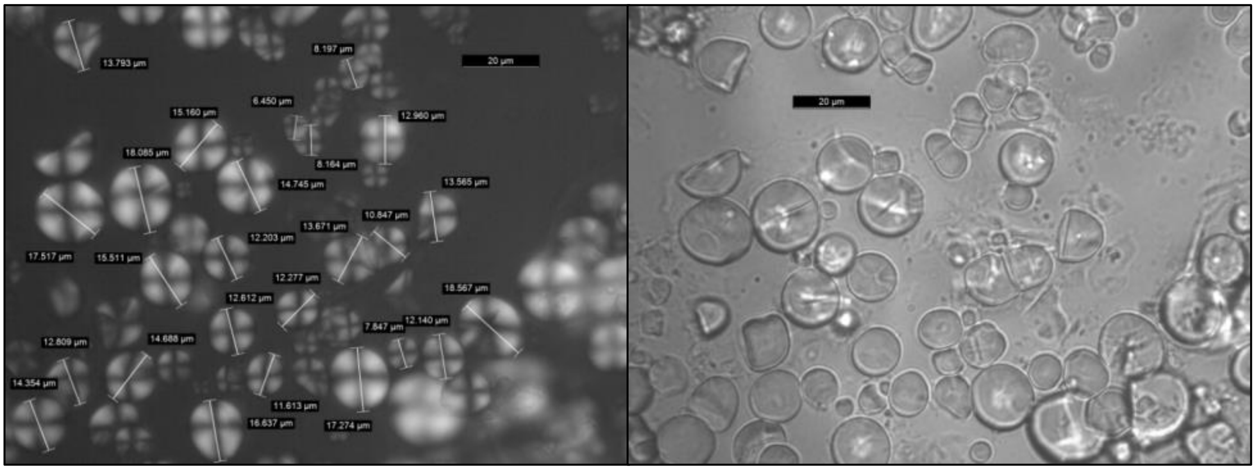
Juniperus osteosperma Compound starch grains viewed with Nomarski Optics.



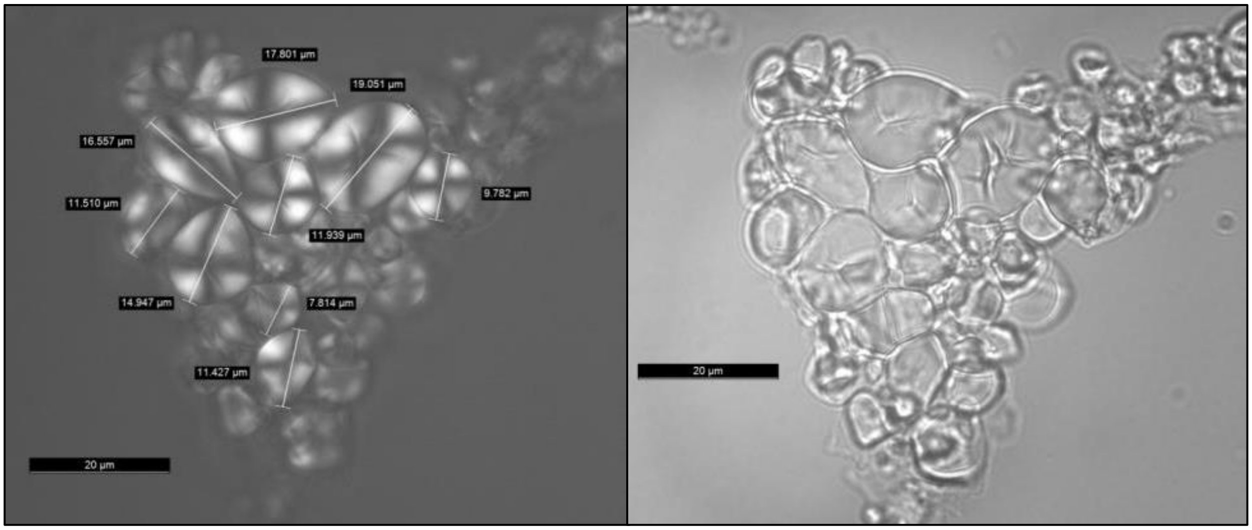
Lewisia redivia Individual starch grains viewed with cross-polarization (l) and brightfield (r).



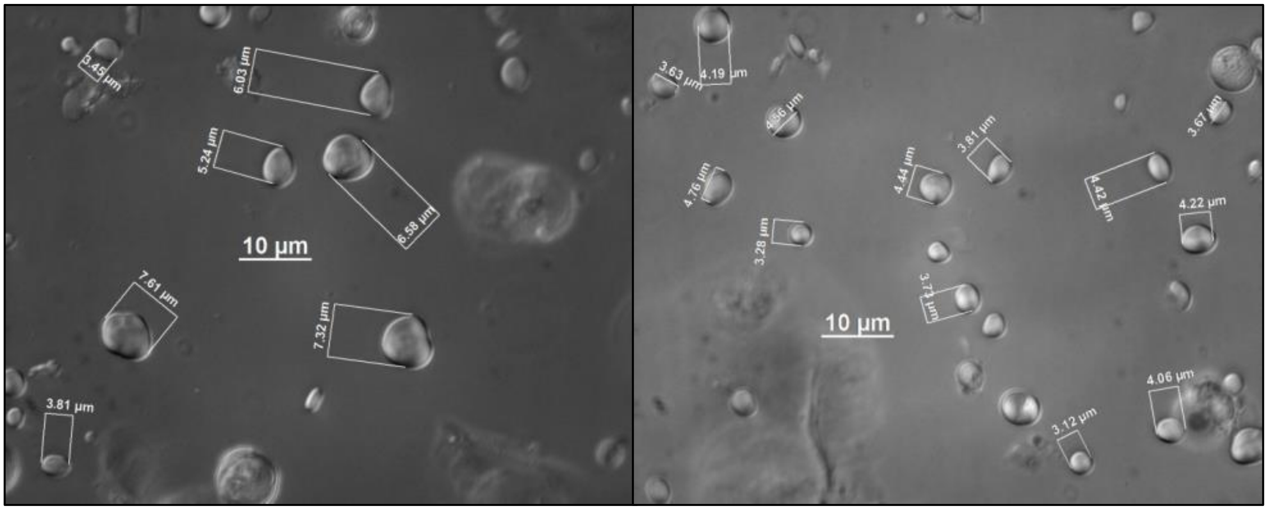
Leymus cinereus Individual starch grains viewed with cross-polarization (l) and brightfield (r).



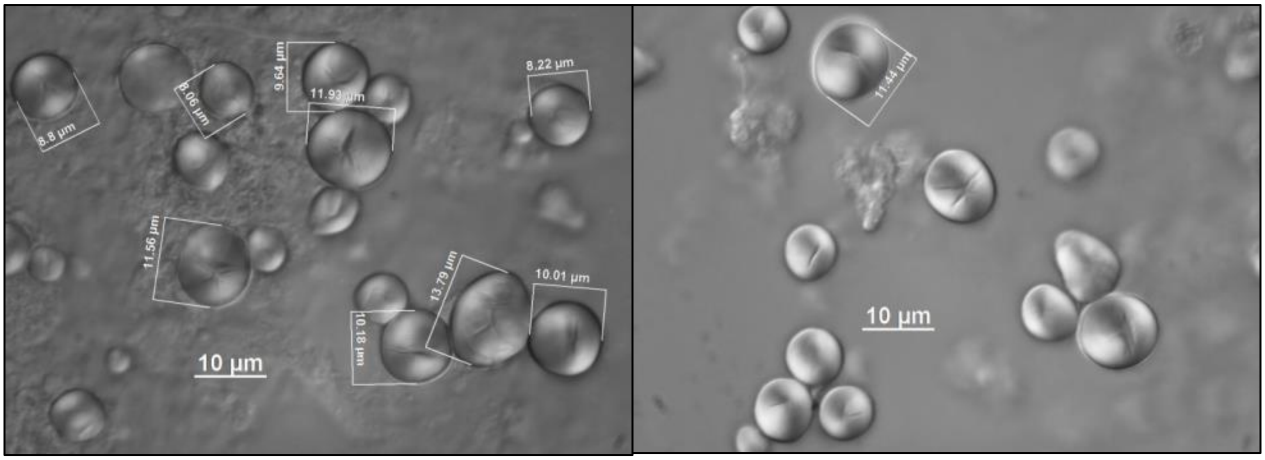
Lomatium roseanum Individual starch grains viewed with cross-polarization (l) and brightfield (r).



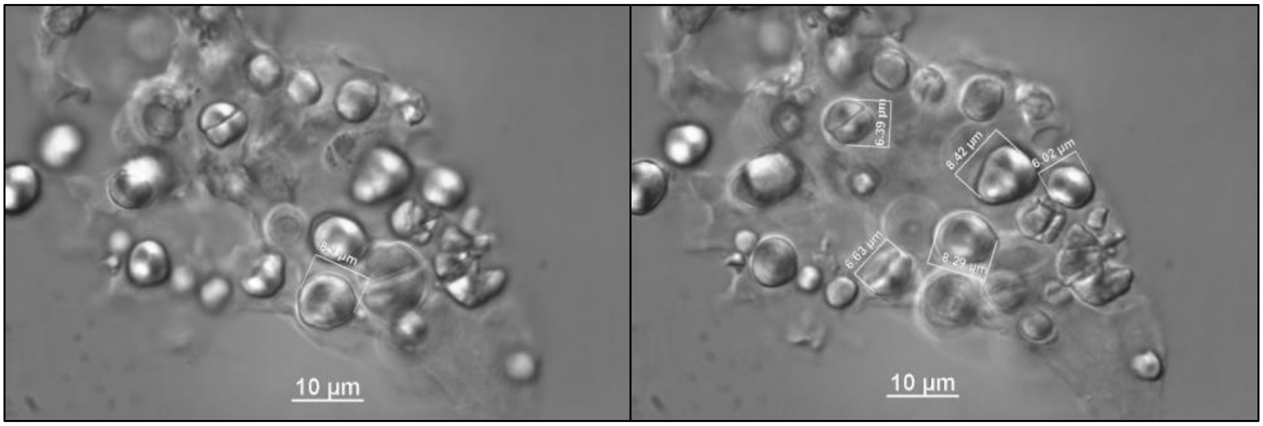
***Perideridia* sp.** Individual starch grains viewed with cross-polarization (l) and brightfield (r).



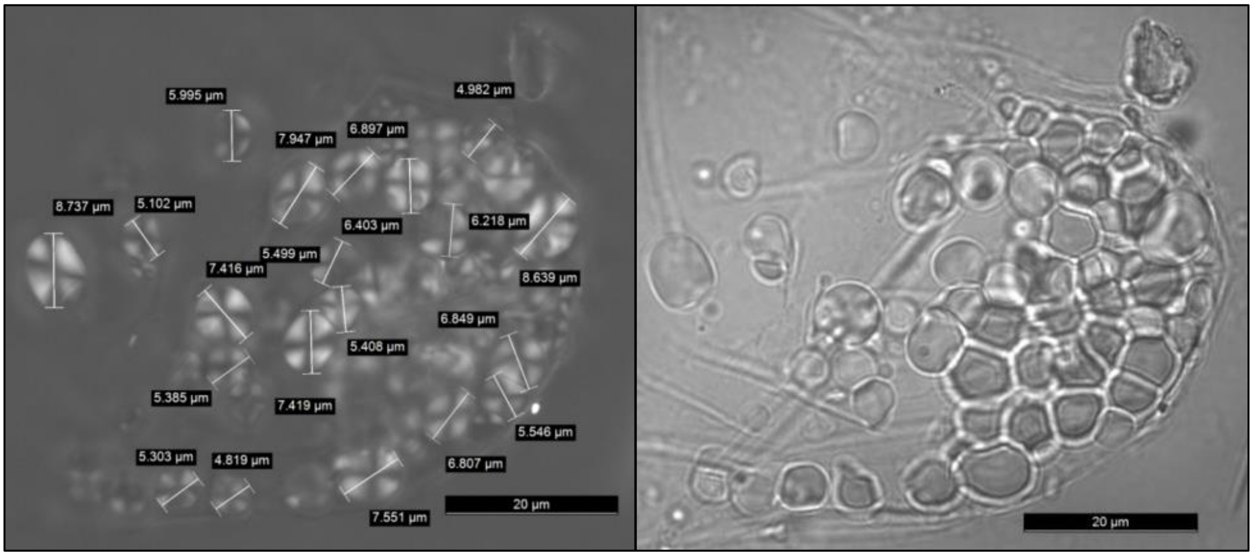
Pinus edulis Individual starch grains viewed with Nomarski optics.



Shepherdia rotundiflora Individual starch grains viewed with Nomarski optics.

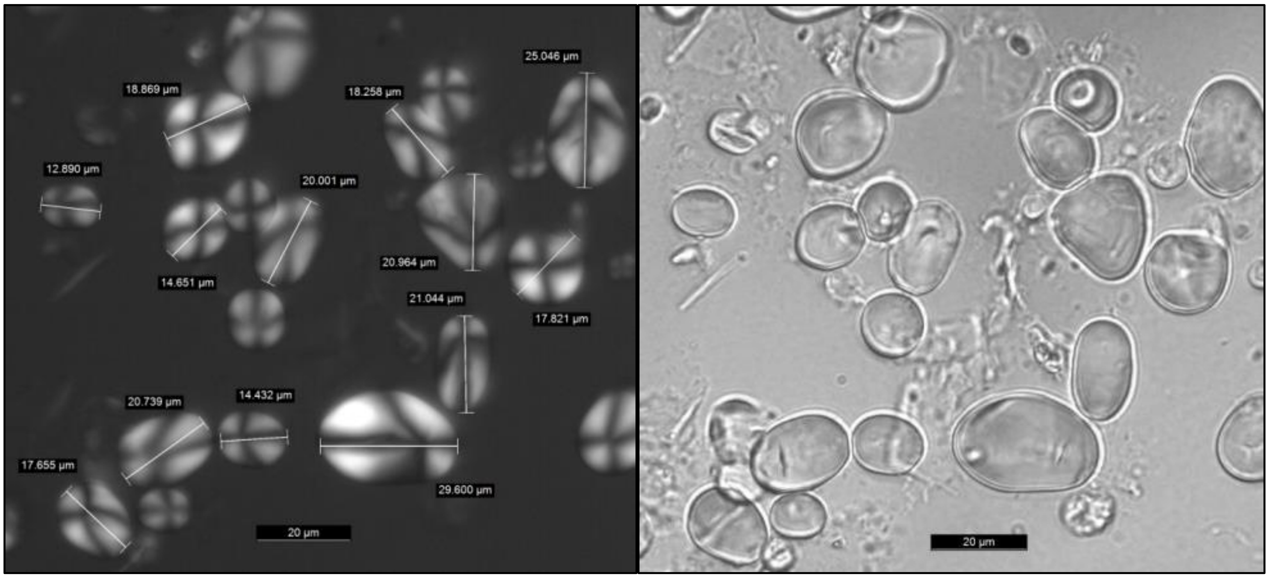


***Sphaeralcea* sp.** Individual starch grains viewed with Nomarski optics.

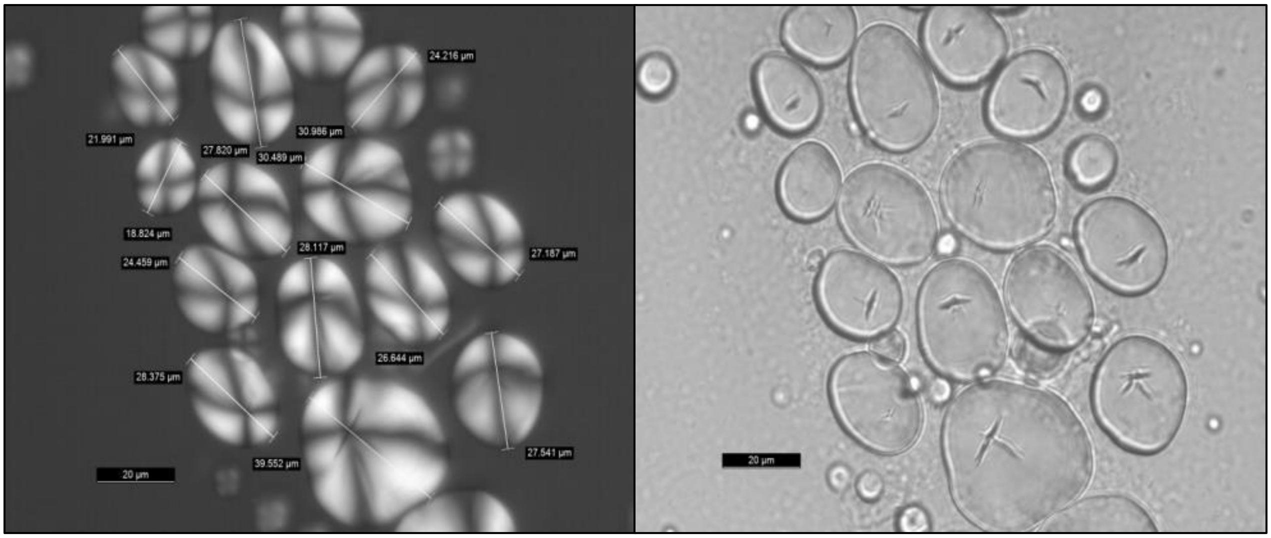


***Typha* sp.** Individual starch grains viewed with cross-polarization (l) and brightfield (r).

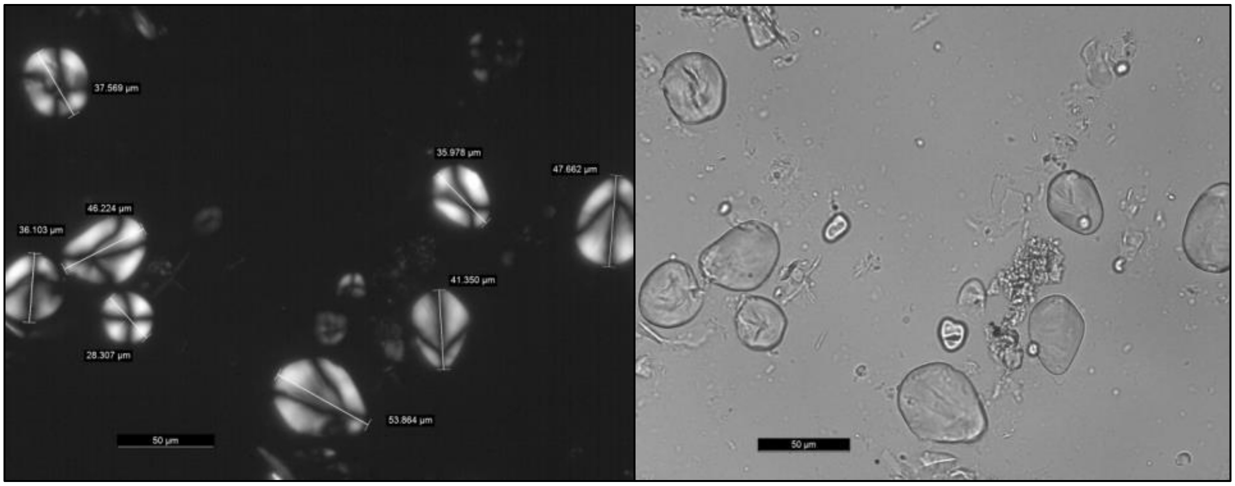
2. Taxa with eccentric hila



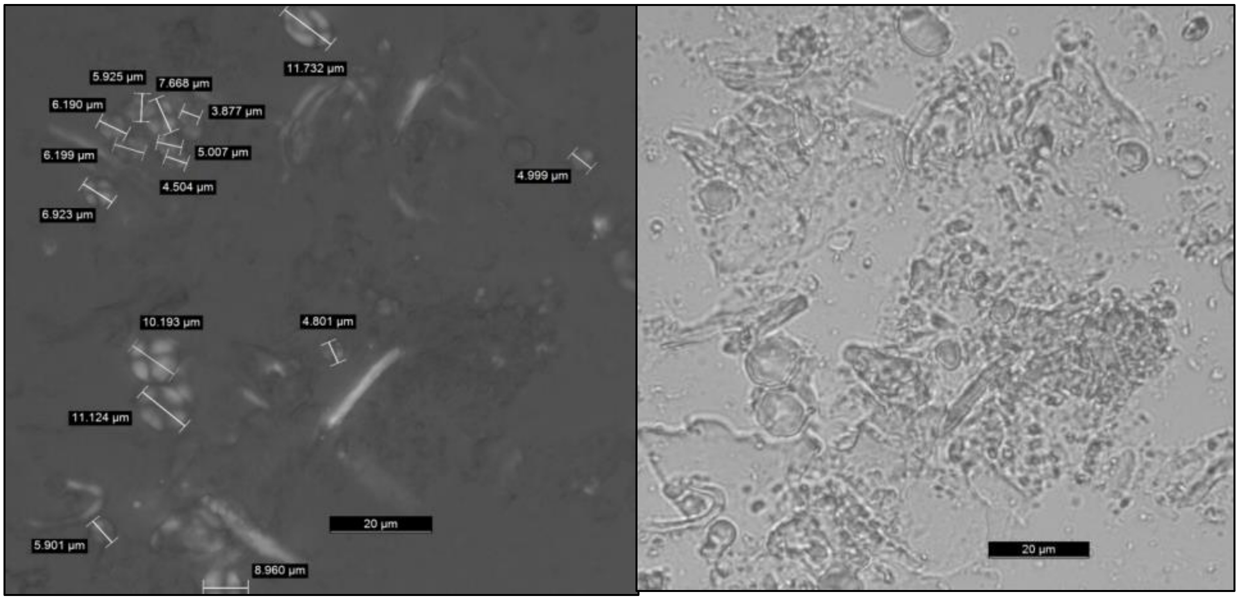
Calochortus leichtlinii Individual starch grains viewed with cross-polarization (l) and brightfield (r).



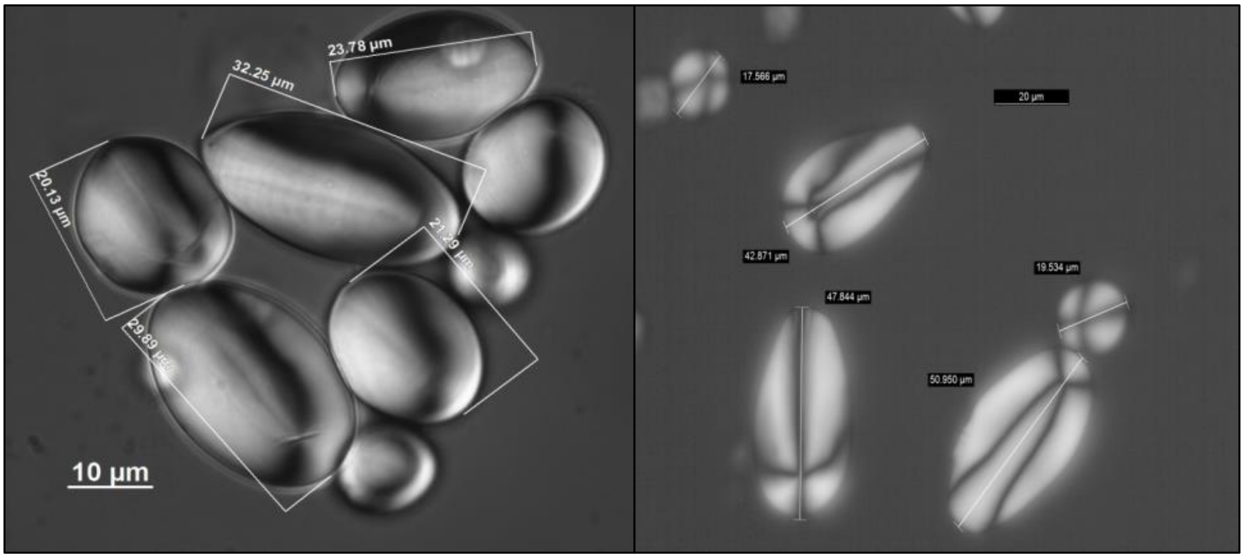
***Calochortus* sp.** Individual starch grains viewed with cross-polarization (l) and brightfield (r).



Fritillaria pudica Individual starch grains viewed with cross-polarization (l) and brightfield (r).



Sagittaria latifolia Individual starch grains viewed with cross-polarization (l) and brightfield (r).

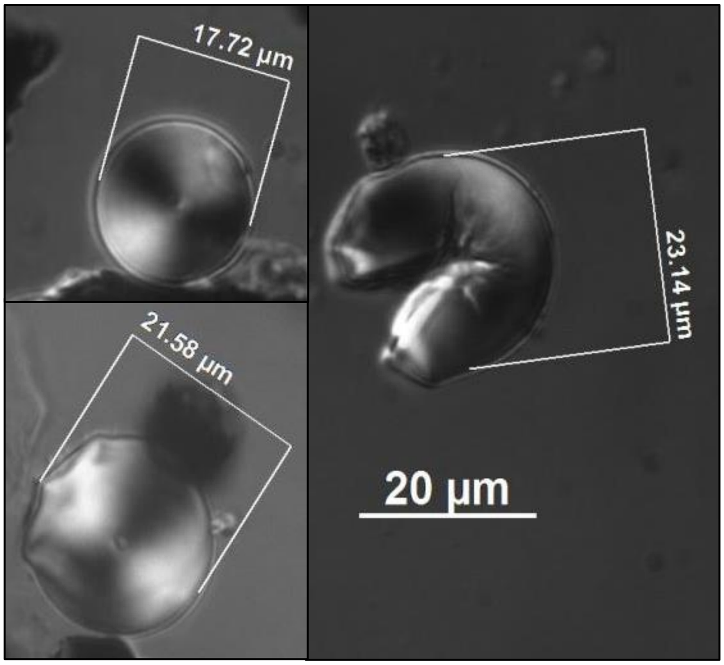


Solanum jamesii Individual starch grains viewed with Nomarski optics (l) and cross-polarization (r).

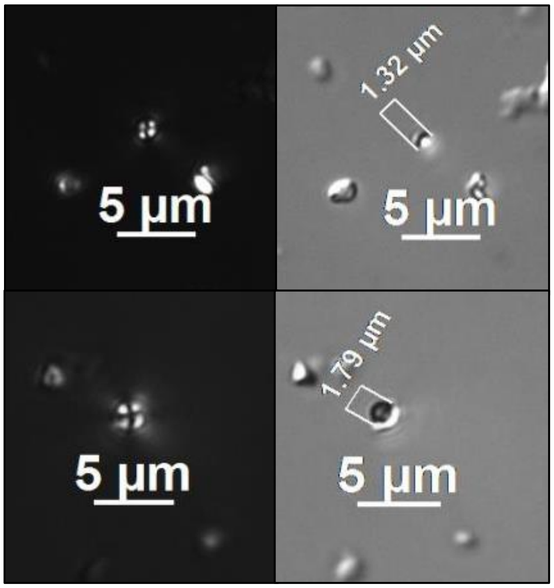
Appendix M

IMAGES OF ARCHAEOLOGICAL STARCH GRAINS

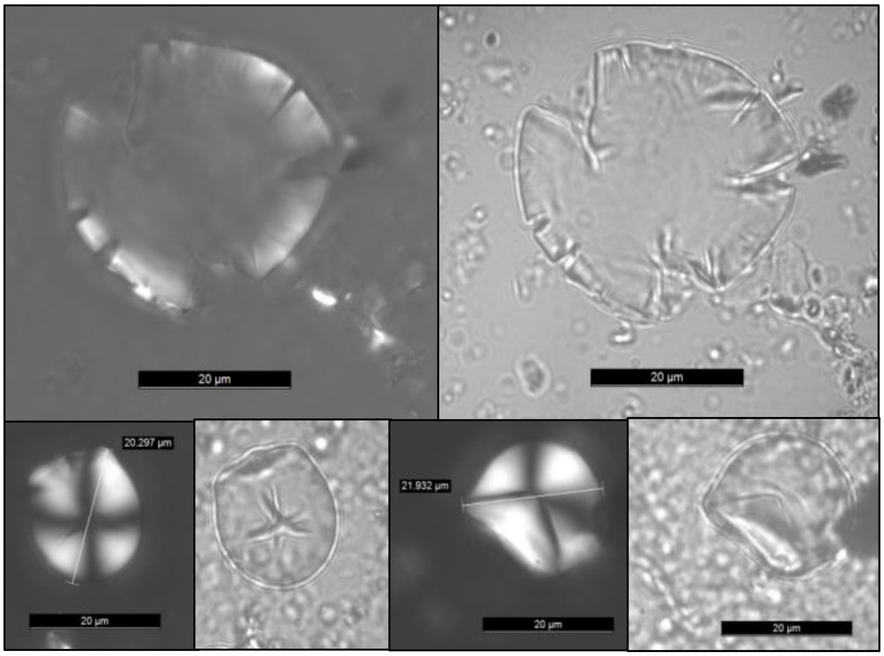
1. Taxa with centric hila



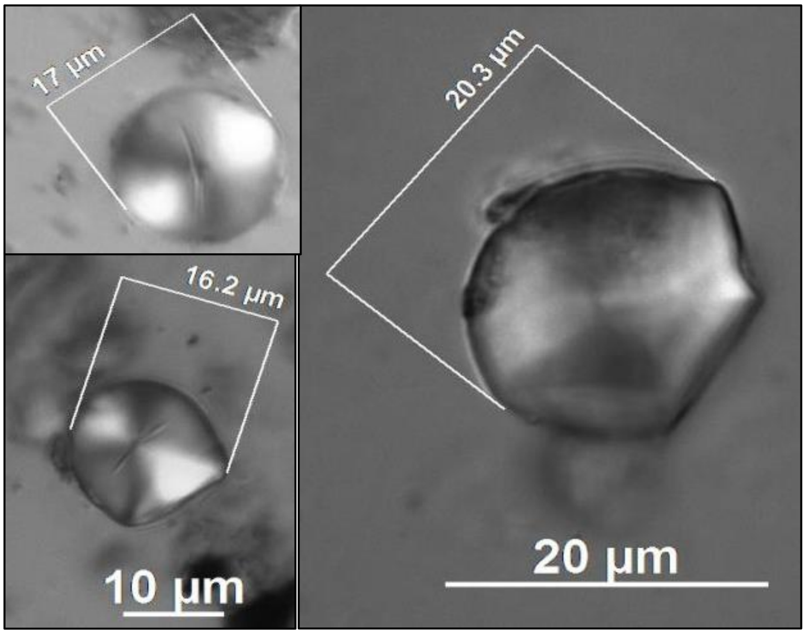
M.1. Starch grains from ground stone sample FS 1613 (substratum 6d) viewed with Nomarski optics.



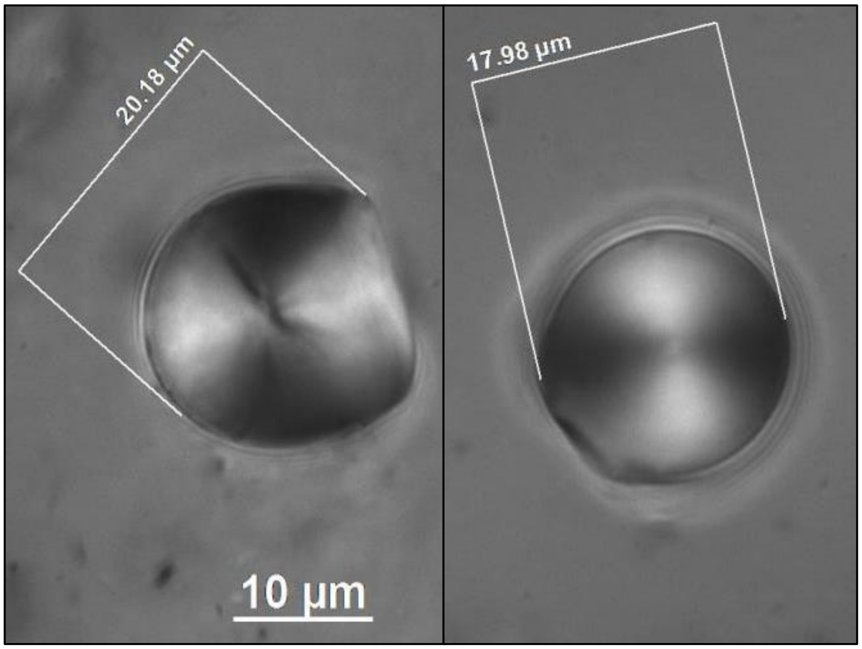
M.2. Starch grains from ground stone sample FS 2468 (6a) viewed with cross-polarization and brightfield.



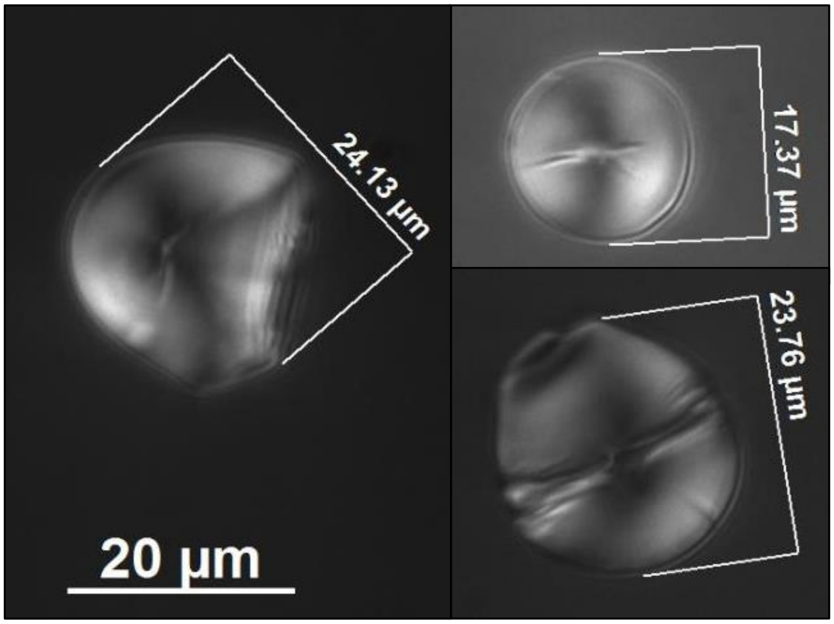
M.3. Starch grains from ground stone sample FS 2667.2 (5u) viewed with cross-polarization and brightfield.



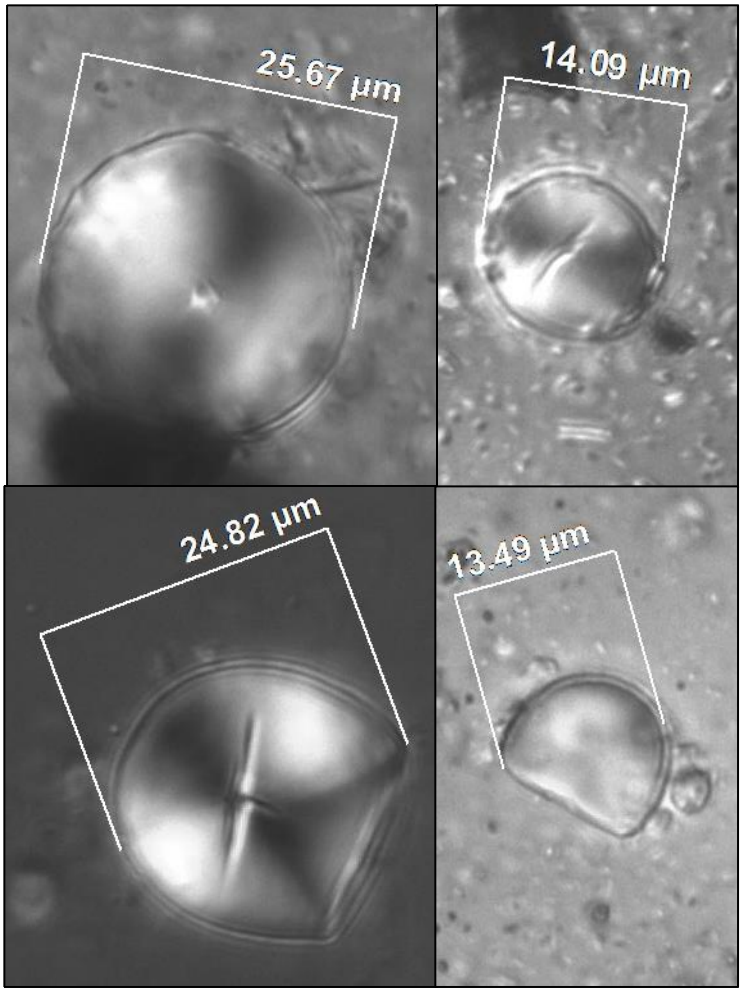
M.4. Starch grains from ground stone sample FS 2953 (5t) viewed with Nomarski optics.



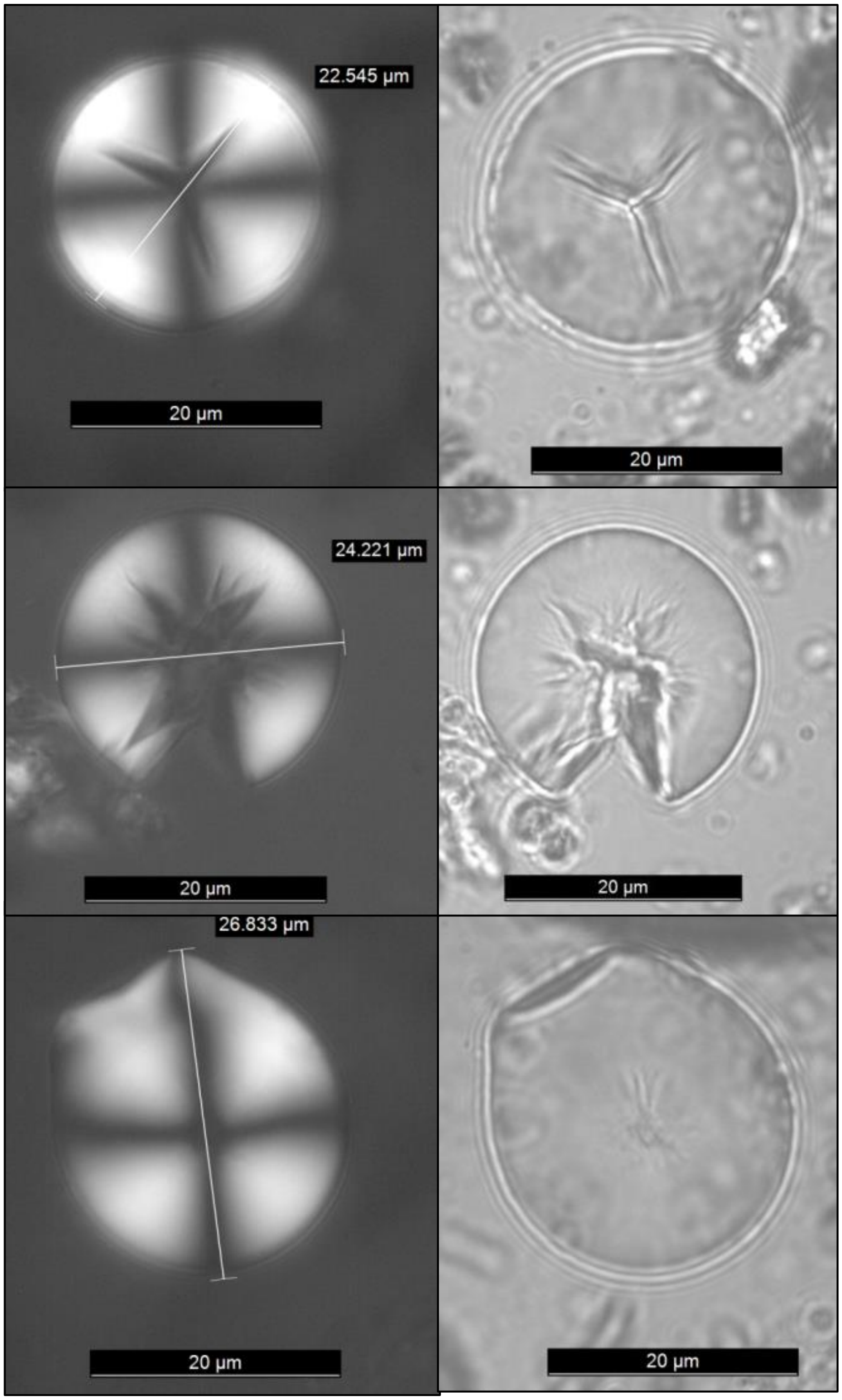
M.5. Starch grains from ground stone sample FS 3607.2 (5t) viewed with Nomarski optics.



M.6. Starch grains from ground stone sample FS 608 (5r) viewed with Nomarski optics.

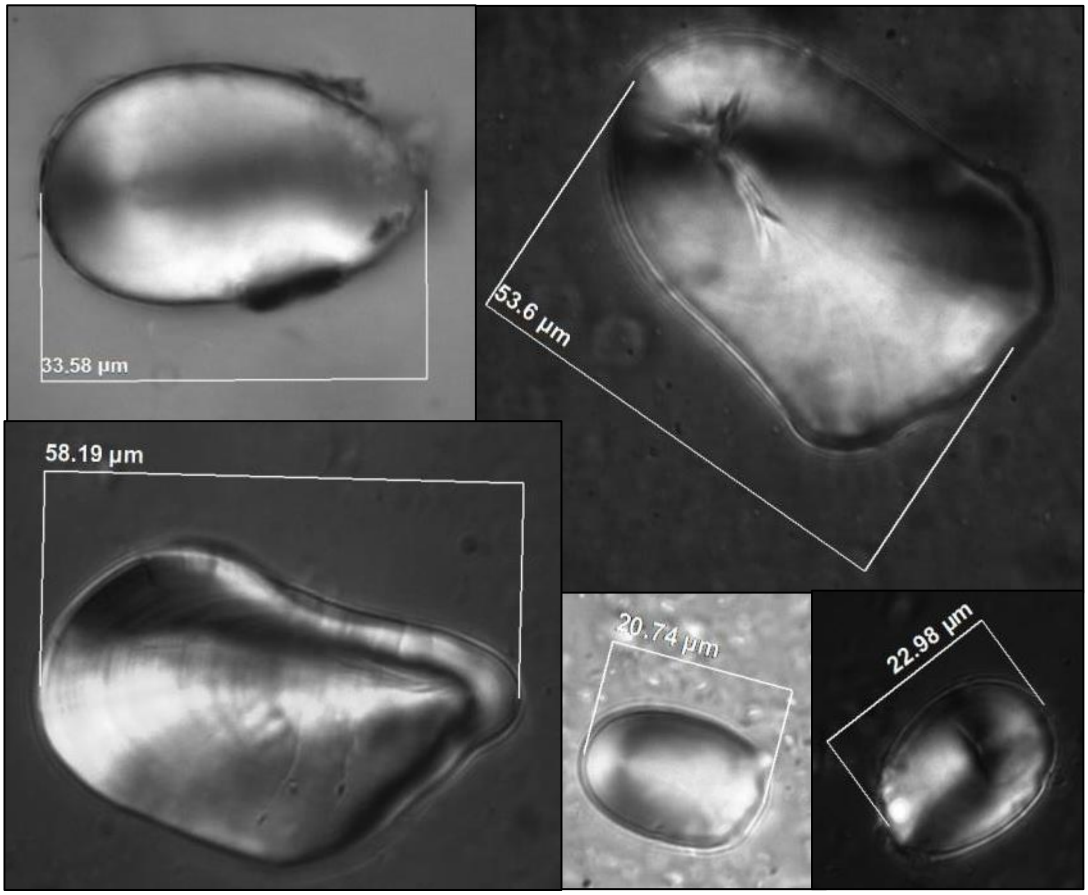


M.7. Starch grains from ground stone sample FS 3512 (5r) viewed with Nomarski optics.

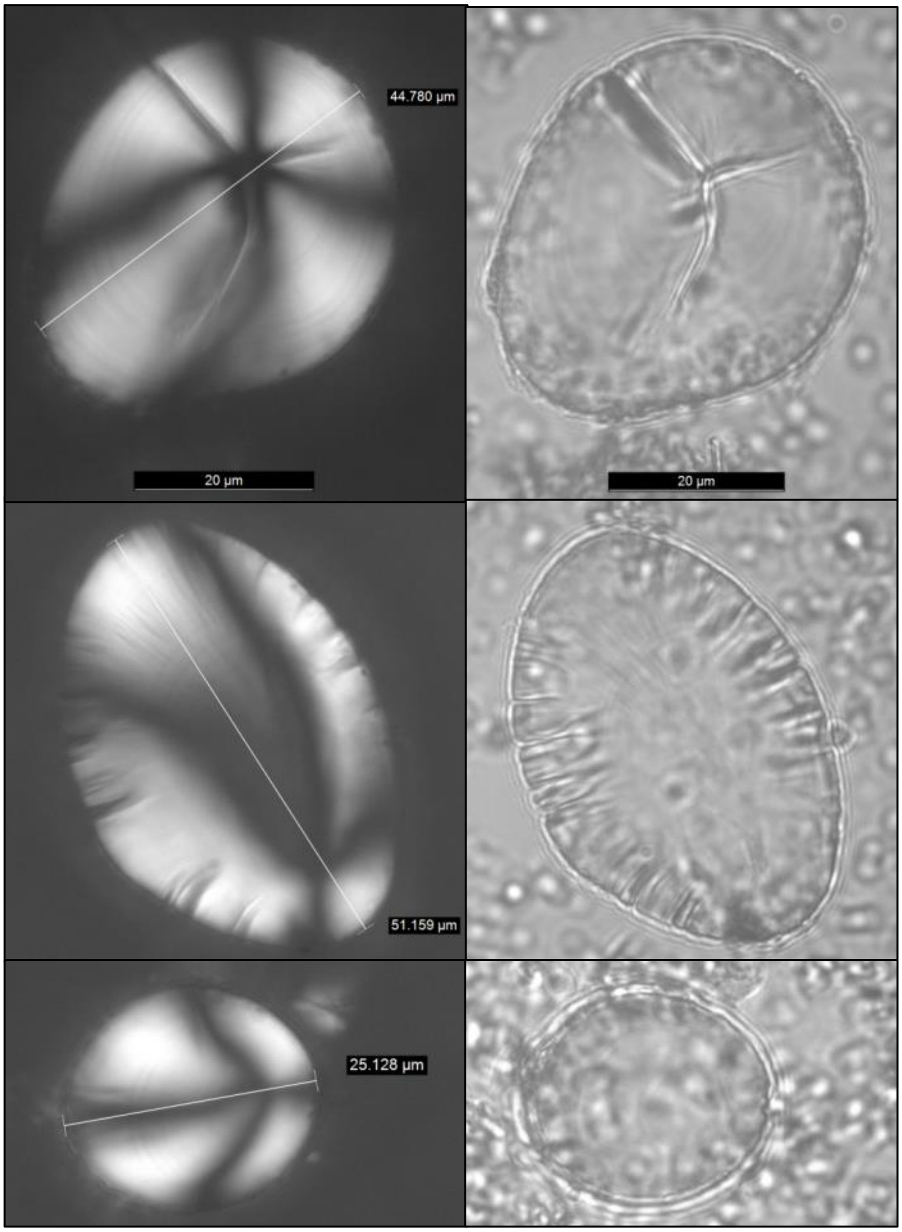


M.8. Starch grains from ground stone sample FS 4370 (5a) viewed with cross-polarization and brightfield.

2. Taxa with eccentric hila



M.9. Starch grains from ground stone sample FS 3607.2 (5t) viewed with Nomarski optics.



M.10. Starch grains from ground stone sample FS 2672 (5u) viewed with cross-polarization and brightfield.