

FIRE IN THE DESERT: HOLOCENE PALEOENVIRONMENTS
IN THE BONNEVILLE BASIN

By

CHRISTOPHER ALBERT KIAHTIPES

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF ARTS IN ANTHROPOLOGY

WASHINGTON STATE UNIVERSITY
Department of Anthropology

MAY 2009

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of CHRISTOPHER A. KIAHTIPES find it satisfactory and recommend that it be accepted.

Karen D Lupo, Ph.D., Chair

William Andrefsky Jr., Ph.D

John G. Jones, Ph.D

David B. Madsen, Ph. D

ACKNOWLEDGMENTS

Financial assistance for this thesis was provided by the Nicholas Michael Scoales Scholarship, the WSU department of Anthropology, and the WSU Graduate School. My thanks also goes out to my committee and my committee chair for their patience and guidance through this project.

FIRE IN THE DESERT: HOLOCENE PALEOENVIRONMENTS
IN THE BONNEVILLE BASIN

Abstract

By Christopher Albert Kiahtipes, M.A.
Washington State University
May 2009

Chair: Karen D. Lupo

Paleoenvironmental research has been a crucial part of archaeological research in the Great Basin, playing a key role in discussions about human subsistence practices and the ways in which people shaped the environments that they occupied. Palynological data from a sediment core collected from Mosquito Willies, a spring complex in northeastern Utah, contributes additional details to environmental records spanning the Holocene. Details from this core shed light on the chronology of the development of modern plant communities in the Great Basin, human subsistence and mobility adaptations, and the role of human foragers in shaping plant communities in the northeastern Great Basin.

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS.....	iii
ABSTRACT.....	iv
LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
CHAPTERS	
1. INTRODUCTION.....	1
2. GREAT BASIN ENVIRONMENTS AND PREHISTORY.....	4
3. PALEOENVIRONMENTAL ANALYSIS AND GENERAL RESULTS....	32
4. SYNTHETIC RECONSTRUCTION AND DISCUSSION.....	61
5. DISCUSSION AND CONCLUSIONS.....	76
BIBLIOGRAPHY.....	88
APPENDIX	
A. PANLYNOLOGICAL RESULTS.....	100

LIST OF TABLES

2.1 Bonneville Basin Climatic, Environmental, and Cultural Chronology.....	5-10
2.2 Economic Plants From Bonneville Basin Archaeological Sites and Ethnography.....	12
3.1 Mosquito Willies Samples and Radiocarbon Dates.....	34
3.2 Principal Components Analysis: Terrestrial Taxa.....	56
3.3 Principal Components: Regional Taxa.....	58
4.1 Results of Zonation Analysis and Summary Statistics.....	62

LIST OF FIGURES

2.1 Great Basin and Bonneville Basin maps.....	4
3.1 Map of the Bonneville Basin.....	34
3.2 Pollen Diagram for Mosquito Willies.....	35
3.3 Summary Percentages and Concentration Values for Mosquito Willies.....	36
3.4 Taxa Loadings on Principal Components: Terrestrial Taxa.....	57
3.5 Taxa Loadings on Principal Components: Regional Taxa.....	59
4.1 Pollen Diagram with Zonation Overlay.....	63
4.2 Sample Loadings on Principal Components.....	64
4.3 Sample Loadings: Zone I.....	66
4.4 Sample Loadings: Zone II.....	68
4.5 Sample Loadings: Zone III.....	71

CHAPTER 1: INTRODUCTION

Driving across the Interstate-15 south from the foothills of southern Idaho, the view of the Great Basin is commanded by the contrast of the vastness of the Great Salt Lake and the mountain ranges that rise up out of the valley. Along its eastern margin, the Great Salt Lake almost reaches the foothills of the Wasatch range, but to the west, the lake is bordered by vast salt flats, dune fields, and, in some places, some small springs and wetlands persist in the salt desert. However, scars along the mountain slope tell of a different past. The Pleistocene Great Basin was dominated by the massive Lake Bonneville, which reached heights above 1,500 m (Oviatt et al. 2003), well above the modern location of Salt Lake City (1,320 m). Glaciers were present in Snowbird Canyon (Currey and Madsen 1976) and now-extinct megafauna inhabited the landscape (Grayson 2006a). Although the Pleistocene ended some 14,000 years ago, modern conditions did not emerge until later in the Holocene. This thesis project contributes further details to environmental reconstructions from the last 9,000 years through palynological analysis of a sediment core from the Mosquito Willies spring in northeastern Utah. This chapter introduces the subject matter of all subsequent chapters and outlines the salient points of this research project.

Chapter two describes the northeastern Great Basin's general physical features, and the regional paleoenvironmental and archaeological record. This chapter also describes the techniques researchers use to reconstruct past environments and what these lines of evidence indicate about Holocene environments in the Great Basin. Because of the significant linkages between paleoenvironmental and archaeological research, I review data from both

paleoenvironmental and archaeological contexts. Although some basin-wide trends are highlighted, this chapter specifically focuses on the Bonneville Basin and general features of prehistoric populations and climate change in the region and is organized into broad time intervals identified by previous research.

Chapter three presents the methods of analysis and data derived from a sediment core taken from the Mosquito Willies spring. After describing the coring location and its local environment, this chapter discusses the methods I employed to sample, process, and quantify pollen from the core. The results are organized stratigraphically, with references to the sedimentary record and radiocarbon dates, which are utilized to build the chronology for the pollen samples. I also describe the results of statistical analyses of the samples, which illustrate important temporal dimensions of palynological variability.

Chapter four presents some broad patterns that I identify using analytical methods provided by PSIMPOLL and utilizes comparisons with other paleoenvironmental records to make basic paleoenvironmental interpretations. I use these patterns to identify long term changes in vegetation patterns in response to climate change associated with local changes in the hydrological budget. These changes may also have implications for species migrations, and human adaptations. This synthesis contextualizes the results of the Mosquito Willies within a regional picture of the emergence of modern plant communities in the northeastern Great Basin, the implications of which make up the discussion in chapter five.

Chapter five presents a discussion of what evidence from the Mosquito Willies core indicates about Great Basin archaeology and how paleoenvironmental data are crucial to understanding the evolution and nature of human behavior. I evaluate the relationship between

the results of this analysis and archaeological phenomenon in the northeastern Great Basin. I then evaluate the limitations of the conclusions that can be drawn from my research and describe how they support and inform previous conclusions regarding important dimensions of forager subsistence adaptations, the role of hunter-gatherers in ecosystems, and the adoption of agriculture in the Bonneville Basin.

CHAPTER 2: GREAT BASIN ENVIRONMENTS AND PREHISTORY

This chapter describes the geology, ecology, and archaeology of the Bonneville Basin starting from the Terminal Pleistocene (14,000 ¹⁴C BP) and proceeding until present. I introduce the larger Great Basin region and how it and the Bonneville Basin are defined. I then move on to discuss the datasets from which the interpretations reviewed here are drawn and the major time periods employed to group those interpretations. Following this I describe the Bonneville Basin during the Terminal Pleistocene and the major changes reflected in archaeological and paleoenvironmental record representing the Holocene. Although the entire Holocene archaeological and climatic sequence is presented here to provide contextual background,

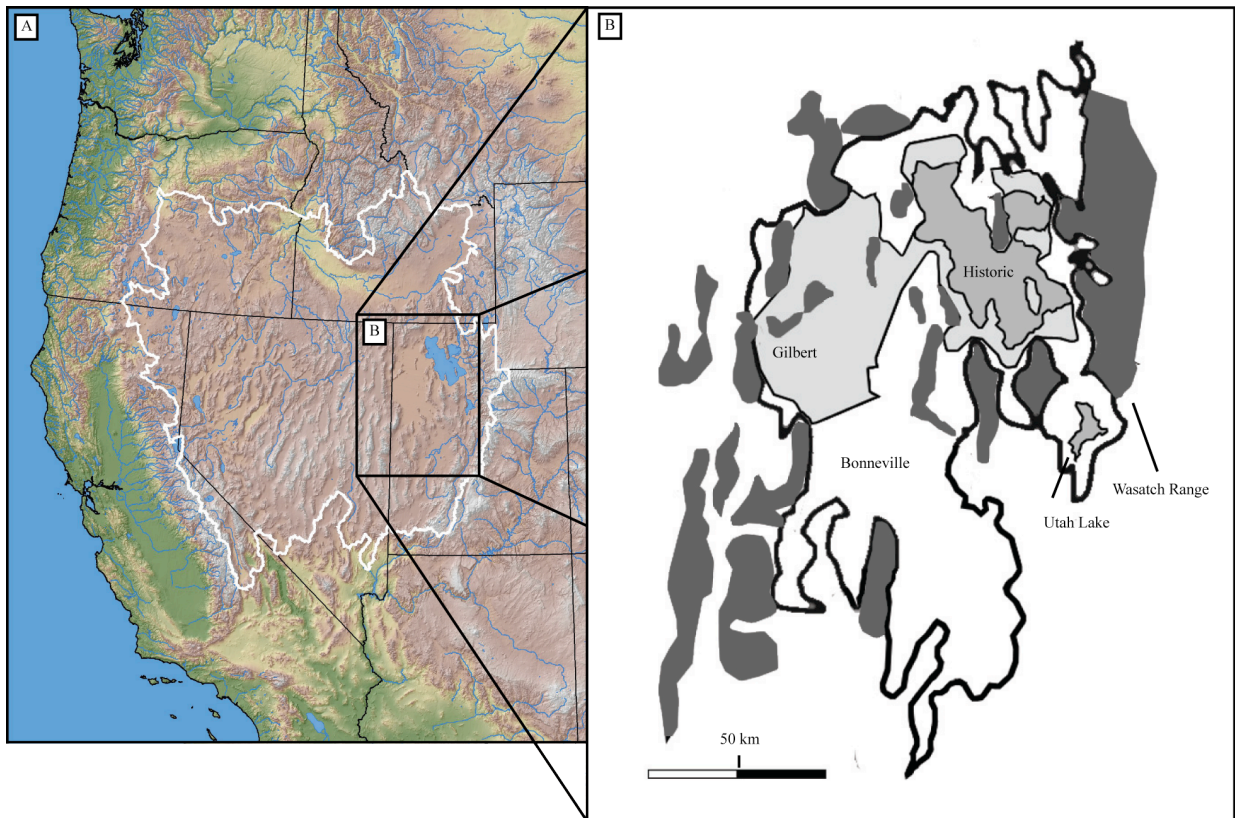


Figure 2.1 A. The western United States, with the hydrographic Great Basin outlined in white (USDA Forest Service). B. Detail of the Bonneville Basin showing mountain chains (dark gray) and the extent of Lake Bonneville during the Provo highstand (thick black outline), Gilbert highstand (black outline with gray fill), and the modern extent of the Great Salt Lake (black outline with medium gray fill).

Bonneville Basin Climatic, Environmental, and Cultural Chronology

Time Period	Cultural Period	14C kya	Cal. Kya BP	Geologic/Hydrologic Events
Pleistocene - Holocene Transition	Paleoarchaic	14-10	16-11.6	Lake Bonneville falls from Provo Shoreline to below historic levels, but rebounds to Gilbert level by end of Younger-Dryas. Seveir basin flows into Bonneville, creating the Old River Bed (ORB) gravel and sand channels. ^{<i>h, k, o</i>}
Pleistocene - Holocene Transition	Paleoarchaic - Early Achaic Transition	10-8.9	11.6-10	Gradual drying trend, deposition of terminal moraines in Wasatch range, flow from Seveir Basin flows into an expanding wetland system between two shrinking lakes. ^{<i>i, k, o</i>}
Early Holocene	Early Archaic	8.9-8	10-8.1	Great Salt Lake within historical limits, ORB wetlands dry up, development of substantial dune fields. ^{<i>i, o</i>}
Middle Holocene	Early Archaic	8-5.8	8.1-6.6	Bonneville Basin springs desiccate at around 7 (8) kya, but evidence for dune stabilization and increased summer moisture dates to ~6.9 (7.6) and ~5.5 (6) kya. Mt. Mazama erupts at ~6.9 kya. ^{<i>h, o, s</i>}

Table 2.1. Bonneville Basin chronology as defined climatically and culturally. Associated changes in geology/hydrology, flora, fauna, site location, and site contents are described within each time period. References are noted at the top of each column with italicized letters and are as follows: *a.* Aikens 1970, *b.* Benson et al. 1990, *c.* Fry and Dalley 1979, *d(1).* Grayson 2000, *d(2).* Grayson 2006a, *e.* Graf 2007, *f.* Jennings 1957, *g.* Jones et al. 2003, *h.* Louderback and Rhode, in press, *i.* Madsen et al. 2005, *j.* Madsen and Simms 1998, *k.* Oviatt et al. 1992, *l.* Rhode et al. 2006, *m.* Schmitt and Lupu 2005, *n.* Schmitt et al. 2002, *o.* Schmitt et al. 2007, *p.* Simms 2008, *q.* Simms and Madsen 1989, *r.* Thompson 1990, *s.* Thompson 1992, *t.* Wigand and Rhode 2001. Time period designations and dates are organized as in Madsen et al. 2005 with the exception of 2.7-.6 14C kya and .6-0 14C kya, which more closely resemble those in Simms 2008.

Bonneville Basin Climatic, Environmental, and Cultural Chronology

	Flora	Fauna
14C kya		
14-10	Limber pine woodland, subalpine conifers, sagebrush-steppe. ^{h, r, s, t}	Megafauna die out, Pikas, heather voles, and other mesic mammals present. Fish are present in the lake. ^{d, r}
10-8.9	Sagebrush-Shadscale scrub expands, subalpine conifers migrate upslope. Limber pine survives in some lowland refugia. Mesophilic shrubs remain common in woodrat middens from this period. ^{r, s, t}	Reduction in most mesic species including marmots, voles, and pigmy rabbits. Increased numbers of jackrabbits, kangaroo rats. Massive fish die-offs occur with reduction in lake size and depth. ^{d, t}
8.9-8	Expansion of shadscale-scrub and greasewood-scrub, conifers retreat upslope, limber-pine disappears from lowland refugia. Utah Juniper and Rocky Mountain Juniper co-dominate with Singleleaf Pinyon in some ranges. ^{h, r, s, t}	Expansion of jackrabbits and kangaroo rats. Pigmy rabbit, woodrat, and cottontail populations are extirpated. ^{d, m}
8-5.8	Expansion of conifer pollen in some records points to expansion of pinyon-juniper woodlands. Sagebrush-shadscale scrub and bunchgrasses expand at expense of greasewood-scrub vegetation. ^{h, r, s, t}	Continues to show dominance of xeric-adapted species. ^{d, m}

Table 2.1 Cont'd

Bonneville Basin Climatic, Environmental, and Cultural Chronology

14C kya	Site Location	Site Contents
14-10	Early occupations at Bonneville Estates, Danger Cave, and initial occupation at Hogup and the ORB. ^{a, e, f, o}	Stemmed points, Crescents, and long-distance transport of high quality toolstone. ^{g, i, o}
10-8.9	Occupations of cave sites are intermittent, occupation of wetlands increases along with number of sites. ^{i, o}	Coiled Basketry, expedient biface technology, and Stemmed/shouldered points persist. Reduced influx of non-local toolstone. ^{a, o, p}
8.9-8	Occupation of Camel's Back cave begins, Danger Cave occupations intensify, Bonneville Estates is abandoned early in this period but is re-occupied 7.3 (8) kya. ^{e, i, l}	Grinding stones are added to toolkits, increased emphasis on expedient biface technology and non-local toolstone. Stemmed points still present. Nets and snares appear in archaeological contexts. ^{f, i, l}
8-5.8	Number of archaeological sites in the region continues to increase, initial occupations of foothills and uplands of Bonneville Basin ranges date to this time period. ^{i, p}	Grinding stones are a common part of archaeological assemblages from this time period. Lithic tools are predominantly made from local toolstone. ^{f, i, p}

Table 2.1 Cont'd

Bonneville Basin Climatic, Environmental, and Cultural Chronology

Time Period	Cultural Period	14C kya	Cal. Kya BP	Geologic/Hydrologic Events
Middle Holocene	Middle Archaic	5.8-4.7	6.6-5.5	Sedimentary records show dramatically reduced sedimentation rates. However, few paleoenvironmental records date to this arid period. ^{d, h, r, s}
Late Holocene	Late Archaic	4.7-2.7	5.5-2.8	The Great Salt Lake expands, almost reaching the Nevada border as cool conditions emerge at 4 kya and moisture increases after 3 kya. Wetlands are subsumed, but expand towards the end of this period. ^{i, f}
"	Fremont	2.7-.6	2.8-.6	Cooler than present at first but approaching warmer than present temperatures by .5 kya. Moisture shifts to variable summer rainfall. Great Salt Lake at highstand early in this period, falling to historic levels by .5 kya. ^{i, f}
"	Numic	.6-0	.6-0	Great Salt Lake expands under cool regime with winter-dominant precipitation that persists until about .2 kya, when arid conditions resume. ^{i, o, t}

Table 2.1 Cont'd

Bonneville Basin Climatic, Environmental, and Cultural Chronology

14C kya	Flora	Fauna
5.8-4.7	Existing records show a dramatic increase in xeric scrub communities, declines in sagebrush scrub vegetation cover, and rebounding greasewood/shadscale populations. ^{h, s, t}	Increased representation of ground squirrels and maximum relative abundances of kangaroo rats at Camel's Back Cave. ^m
4.7-2.7	Increased influx of pine pollen, decreased representation of Rocky Mountain juniper, and lower tree-lines. Increase in sagebrush steppe vegetation cover. Ephedra migrates into the region. ^{r, t}	Kangaroo rats decline in representation in faunal remains, harvest mice are better represented, and ground squirrels increase. ^{d, m}
2.7-.6	Fluctuations in moisture regime favor growth of grasses in lowland contexts and dominance of Utah juniper in upland records, but are otherwise modern in distribution. ^{k, t}	Increase in voles and the return of bushy-tailed woodrats. Bison are relatively common in the Bonneville Basin at this time. ^{d(1-2), i, m, p}
.6-0	Conifers expand dramatically early on, but are greatly reduced by European Colonization and the introduction of alien species. ^l	Largely the same as present, with greater diversity of waterfowl and small mammals prior to European colonization and the impacts of grazing and large scale agriculture. Bison and artiodactyl populations are reduced. ^{d(1-2), f}

Table 2.1 Cont'd

Bonneville Basin Climatic, Environmental, and Cultural Chronology

14C kya	Site Location	Site Contents
5.8-4.7	Relatively few radiocarbon dates from archaeological contexts date to this time. Sites are located in diverse environments, exploiting new lowland sources and upland sources alike. ^{d,i,f}	Increasing diversity of projectile point types and regionally defined basketry traditions. Technological toolkits reflect priorities of upland and lowland subsistence (eg. pinyon hooks and fishing weights). ^f
4.7-2.7	Increasingly regional representation of toolkits as the landscape became "full of foragers". Some foragers experiment with horticulture and corn is introduced into the region. Emphasis on personal storage features and defensive structures appear. ^{i,f}	Pottery is introduced into the region. Split-twig figurines and trade items become more common. Agriculture arrives by 2.5 kya. Residential architecture is largely pithouses. ^{s,i,f}
2.7-.6	Fremont sites occur in many contexts, including shoreline occupations of the expanded Great Salt Lake. Farming spreads as population growth and territorial expansions encroach on forager territory. ^{s,i,f}	Fremont complex emerges in the region during this time period, variably expressed by black on gray pottery, fremont-style metates, rosegate projectile points, and clay figurines. Residential architecture shifts to above-ground adobe dwellings. Bow and arrow is introduced into the region. ^{s,i,f}
.6-0	Farming subsistence disappears, replaced by seasonal hunter-gatherer occupations observed ethnographically. Populations are decimated by introduced diseases and European colonists. ^f	General categories of subsistence technologies do not change, but the loss of distinctive Fremont features is compensated by diverse hunter-gatherer toolkits and, eventually, European products. ^f

Table 2.1 Cont'd

subsequent chapters of this thesis focus on Holocene environments in the Bonneville Basin. This review is not exhaustive, but serves to familiarize the reader with the region, the environment, and human prehistory in the Great Basin. A summary table of major changes in Bonneville Basin flora, fauna, geology, and archaeological remains are presented in Table 2.1.

The Great Basin and Bonneville Basin

The Great Basin is defined as a physiographic, geologic, biotic, and cultural unit. Each of these dimensions have similar, but not identical boundaries (Grayson 1993). Here, I use the geologic definition of the Great Basin, which defines it as an area of internally draining mountain ranges and basins that generally run north-south between the Colorado Plateau on the east and the Sierra Nevada Mountains to the west (Figure 2.1:A). To the north, the Great Basin is bordered by the Snake River Plain; to the South it is bordered by the termination of the Sierra Nevada Range and the Lower Sonoran Desert. The landscape of the northeastern Great Basin is dominated by the Bonneville Basin, which is bordered by the Wasatch Range, Snake River Plain, Sevier Basin, and smaller north-south trending ranges on the west, north, south, and east respectively (Figure 2.1:B). This region is particularly amenable to exploring changes in prehistoric plant and animal communities because of a relative abundance of paleoenvironmental records (Madsen et al. 2001), especially when compared to other parts of the Great Basin. Paleoenvironmental changes in this region are further clarified by complimentary archaeological and geological datasets. Changes in the hydrologic budget of this region are readily reflected in lacustrine geomorphology (Benson et al. 1990; Oviatt et al. 1992) and depositional sequences in dry cave sites (Aikens 1970; Hunt et al. 2005; Jennings 1957).

Modern Great Basin Environments

Modern Bonneville Basin vegetation cover is characterized by zonal distribution of Upper Sonoran vegetation along elevational gradients. Lowland playa and playa margins are dominated by shadscale (*Atriplex confertifolia*), greasewood (*Sarcobatus* sp.), and saltbush (*Atriplex bonnevillensis*). Plants identified from archaeological sites by Rhode (2008) and their ethnographic occurrence are listed in Table 2.1. Sagebrush (*Artemisia* sp.)-dominated communities with bunchgrass (e.g. *Leymus cinereus*) understories are common in lower foothill environments and form a distinctive belt of vegetation cover. Pinyon (*Pinus monophylla*)-juniper (*Juniperus monosperma*) woodlands are dominant from ~1,600-2,300 m, and form a

Plant Taxon	Scientific Name	Ethnographic Subsistence
Iodinebush	<i>Allenrolfea occidentalis</i>	-
Bulrush	<i>Schoenoplectus</i> cf. <i>americanus</i>	Chamberlin 1911
Wedgescale	<i>Atriplex</i> cf. <i>argentea</i> or <i>truncata</i>	Chamberlin 1911
Shadscale	<i>Atriplex confertifolia</i>	Chamberlin 1911
Goosefoot	<i>Chenopodium</i> spp.	Chamberlin 1911
Pepperweed	<i>Lepidium</i> cf. <i>densiflorum</i> or <i>montanum</i>	-
Wild rye	<i>Leymus cinereus</i>	Chamberlin 1911
Alkali sacaton	<i>Sporobolus</i> cf. <i>aeroides</i>	-
Ricegrass	<i>Achnatherum hymenoides</i>	-
Blazing Star	<i>Mentzelia laevicaulis</i>	-
Sunflower	<i>Helianthus</i> cf. <i>annuus</i>	Chamberlin 1911, Steward 1938
Prickly pear cactus	<i>Opuntia polyacantha</i>	Chamberlin 1911, Steward 1938
Hedgehog cactus	<i>Echinocereus</i> cf. <i>triglochidiatus</i>	-
Serviceberry	<i>Amelanchier</i> spp.	Chamberlin 1911, Steward 1938
Elderberry	<i>Sambucus</i> cf. <i>caerulea</i>	Steward 1938
Chokecherry	<i>Prunus virginianus</i>	Chamberlin 1911, Steward 1938
Pinyon pine	<i>Pinus monophylla</i>	Chamberlin 1911, Steward 1938
Utah juniper	<i>Juniperus osteosperma</i>	Chamberlin 1911

Table 2.2 Bonneville Basin plant taxa identified from archaeological remains by Rhode (2008). Ethnographic use of these plants among the Gosiute as recorded by Steward (1938) and Chamberlin (1911) is provided as a comparison.

woodland belt interrupted by occasional patches of sagebrush and grasses. Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and limber pine (*Pinus flexilis*) are common in ranges like the Deep Creek Range in the Eastern Bonneville Basin, while woodlands and subalpine areas in western ranges like the Wasatch Mountains contain species that prefer wetter habitats such as quaking aspen (*Populus tremuloides*) and subalpine fir (*Abies lasiocarpa*). Weather patterns also impact the distribution of vegetation. Modern lake-effect systems increase the amount of effective moisture in the Wasatch Range (see discussion in Madsen and Schmitt 2005:5-8), while the eastern Bonneville Basin relies predominantly on winter-spring precipitation originating from marine air masses moving in from the arctic, which support the growth of subalpine conifers in this otherwise arid region (Wells 1983). Summer-fall precipitation comes in the form of monsoonal storms as they move north from tropical air masses and is an especially important source of precipitation for lowland grass communities (Rhode 2000).

Paleoenvironmental Reconstructions

Paleoenvironmental reconstructions bring together many lines of proxy evidence such as fossil pollen, macrobotanical remains from packrat (*Neotoma sp.*) middens, faunal remains, and geological evidence to approximate the composition of prehistoric environments. These lines of evidence allow a basic reconstruction of the composition of prehistoric plant communities, which map onto prehistoric ecosystems because they are a fundamental substrate of ecological systems that is simultaneously responsive to climatic change. Local and regional records of

paleoenvironmental conditions are derived from microscopic pollen trapped in sediments and macrobotanical evidence from packrat/woodrat middens (Spaulding et al. 1990). This review concentrates on reconstructions of prehistoric plant communities, but because changes in faunal communities can also reflect information about plant communities, ground cover, and available food resources, I also refer to natural accumulations of bone from Homestead Cave (Grayson 2000a, 2000b) and archaeological accumulations such as Camel's Back Cave (Schmitt and Lupo 2005; Schmitt et al. 2002), Hogup Cave (Aikens 1970), and Danger Cave (Jennings 1957) that are the cumulative product of humans, raptors, scavengers, and packrats (*Neotoma* sp.).

Although paleoenvironmental records from the northeastern Great Basin extend well beyond 20,000 ¹⁴C BP (Currey and James 1982; Madsen et al. 2001; Wigand and Rhode 2001), I will focus here on the last 14,000 years of changes in prehistoric biotic communities for several reasons. First, the most abundant and least ambiguous records date to this period. Second, the last 14,000 years contextualize the development of the modern biotic communities of the northeastern Great Basin and these are the communities that are of the most immediate concern to ecologists, land managers, and archaeologists. Finally, paleoenvironmental data from this period records the first known occupation of this region by humans and, as such, is a valuable means for understanding the interactions of prehistoric foragers with their environment and identifies important regional variability in these periods (Rhode 1999).

The last fifty years of paleoenvironmental research has not only lead to a radical increase in the sources of data on biotic communities (Madsen et al. 2001), but has also lead to changing definitions of basic chronologies. The earliest paleoenvironmental definitions of broad climatic periods come from the research of Ernst Antevs (1931), who divided the last 9,000 years of

prehistory into three periods (Altithermal, Medithermal, and Anathermal) that were characterized by changes in summer temperatures and precipitation. General trends identified by Antevs have been supported by subsequent research, but the development of radiocarbon dating and discovery of more paleoenvironmental records has refined the time-spans of these periods (Rhode 1999). Currey and James (1982) used major glacial and pluvial cycles to define broad periods of change. Still others (Grayson 2000a; Madsen et al. 2001; Wigand and Rhode 2001) use slightly different terminology for broad geological epochs (e.g. early, middle, or late Holocene) and glacial events (e.g. early, middle, or late Wisconsin). Following Wigand and Rhode (2001), I use the following temporal designations: Terminal Pleistocene, Early, Middle, or Late Holocene, but I draw the dates for these time periods from Madsen et al. (2005: Table 2.1, Table 2.2). Table 2.3 compares these time intervals to conventional archaeological chronologies, radiocarbon dates, calibrated dates, and notable changes in both paleoenvironmental and archaeological records associated with each period.

Terminal Pleistocene (14,000 – 10,000 ¹⁴C BP)

Although lake levels are one of the most useful proxy datasets for prehistoric climate, lake chronology in the Bonneville Basin has traditionally been poorly understood. The earliest chronologies suggested that at the onset of the Terminal Pleistocene, climatic forcing caused Lake Bonneville to rapidly decline from the Provo shoreline (1,450 m) to levels comparable to historical lows between 12,000 and 13,000 ¹⁴C BP (Benson et al. 1990:255). However, Godsey et al. (2005) report radiocarbon dates that indicate a much more sudden and rapid transgression of Lake Bonneville at around 12,000 ¹⁴C BP. Fish die-offs represented in Homestead Cave fauna

dating between ~11,200 and ~10,400 ¹⁴C BP support this conclusion (Broughton 2000; Oviatt et al. 2005:276). By 10,500 -10,000 ¹⁴C BP the lake had risen to the Gilbert shoreline (~1,300 m), which is slightly below the Old River Bed (ORB) threshold (1,400 m) and effectively divided the Sevier and Bonneville Basins. This left a shallow lake in the Sevier Basin that overflowed into the southern Bonneville Basin until 10,000 ¹⁴C BP, forming the Old River Bed (ORB) and other geomorphic features (Benson et al. 1990:258; Oviatt et al. 2003:203; Schmitt et al. 2007:109). These streams flowed into the Great Salt Lake as it receded (Oviatt et al. 2003), leaving sandy deposits marking their terminus in the lake at 1,301 and 1,303 m. Radiocarbon dates indicate that the sand channels developed in the ORB delta slightly before and after the lake reached the Gilbert shoreline (Oviatt et al. 2003; Schmitt et al. 2007). The resurgence of the lake to the Gilbert shoreline may be related to a sudden return to glacial conditions at 11,200 - 10,000 ¹⁴C years BP known as the Younger-Dryas (Madsen 1999:77; Oviatt et al. 2005:280). During the Terminal Wisconsin, Lake Bonneville fluctuated between a cold-deep lake and a shallow-warm saline lake, becoming the Great Salt Lake at or just before ~10,000 ¹⁴C BP when the lake reached the Gilbert Shoreline (Oviatt et al. 2005).

Evidence suggests that the extinction of 36 genera of Pleistocene mammals (Grayson 2006a) was complete by around 12,000 ¹⁴C BP (Cummings and Puseman 2005). Fish remains from the Bonneville Basin indicate that the lake supported substantial fish populations during the Pleistocene (Smith et al. 1968), but regressions of the lake below the Gilbert shoreline at around 12,000 ¹⁴C BP led to massive fish die-offs and subsequent recolonization events by Utah chub (*Gila atraria*) as lake levels fluctuated (Broughton 2000). Pika (*Ochotona princeps*) fecal pellets dating to the Terminal Pleistocene have been recovered from woodrat middens located well

below the species' current range (Rhode 2000:144; Rhode and Madsen 1995). Bird remains from cave deposits suggests that a broad range of waterfowl occupied the region at this time, but abundances of shallow water species were on the rise (Livingston 2000:100).

Open conifer woodland and sagebrush-steppe were the dominant vegetation types of the Bonneville Basin during the Pleistocene. Subalpine conifers dominated woodlands, occurring up to 1000 m lower (Thompson 1990:215; Rhode 2000:144) than their present distributions (1800 m). Montane brush vegetation covered much of the lowlands up to elevations of 2,000 m (Rhode and Madsen 1995; Thompson 1990). Bristlecone pine (*Pinus longaeva*) is abundant during the Pleistocene, but starting at 14,000 ¹⁴C BP, its range becomes more restricted as sagebrush steppe and stands of limber pine expanded their territories (Thompson 1990). Bristlecone pine, limber pine, and local stands of Englemann spruce (*Picea engelmannii*) commonly occur with other montane and mesic plant species (Rhode 2000) like snowberry (*Symphoricarpos* sp.) and prostrate juniper (*Juniperus communis*). Limber pine becomes increasingly common in paleoenvironmental records starting at around 13,000 ¹⁴C BP and persists in some localities until 10,800 ¹⁴C BP (Rhode 2000; Rhode and Madsen 1995:250; Thompson 1990:219). Packrat middens from the eastern Bonneville Basin contain limber pine and white fir, but middens from the Wasatch Front dating to the same time span (12,500 ¹⁴C BP) yielded limber pine, Englemann spruce, and mountain juniper (Rhode 2000; Rhode and Madsen 1995; Wigand and Rhode 2001). Starting at 11,000 ¹⁴C BP, shadscale, sagebrush, and xerophytic shrubs like rabbitbrush (*Chrysothamnus viscidiflorus*) and snakeweed (*Gutierrezia* sp.) displaced many conifer species and Bonneville Basin lowlands were dominated by xeric desert shrubs by 9,600 ¹⁴C BP (Rhode and Madsen 1995).

The Terminal Pleistocene captures a dramatic shift in continental air masses that increased temperatures and reduced overall precipitation, reflected in lower lake-level fluctuations (Benson et al. 1990; Godsey et al. 2005) and the expansion of limber pine at the expense of bristlecone pine (Thompson 1990). Summer precipitation becomes more important by 10,000 ¹⁴C BP, encouraging the expansion of desert shrubs (Rhode and Madsen 1995). The development of massive wetlands in the ORB area (Madsen et al. 2005; Schmitt et al. 2007) indicate that local environments were also shaped by groundwater flow (Oviatt et al. 2003), isostatic rebound (Madsen 2000), and geomorphic processes like erosion and downcutting at Red Rock Pass (Godsey et al. 2005).

Definitive evidence of human occupation of the Bonneville Basin dates to around 11,500 ¹⁴C BP (Madsen et al. 2005:29). Projectile points at these early sites are largely Great Basin Stemmed types, with Clovis artifacts being rare by comparison (Beck and Jones 2007). The earliest sites in the ORB are located on top of 12,000 year-old inverted gravel channels (Oviatt et al. 2003; Schmitt et al. 2007). Faunal and botanical remains indicate a broad diet that included large and small game and readily available wetland resources, in addition to some seeds, roots, and other plant products (Hockett 2007; Jennings 1957; Simms 1987). Although Great Basin foragers undoubtedly pursued big game (Jenkins 2007; Kelly and Todd 1988), many sites within the Bonneville Basin show an increased reliance on wetland resources, waterfowl, and small game (Fry 1976; Hockett 2007).

Toolkits feature diagnostic GBS projectile points, crescents, and biface-oriented technologies that reflect long-distance transport of lithic material and relatively high mobility (Jones and Beck 1999). Late in this period, there appears to be a reduction in mobility in the

vicinity of the Old River Bed marshes, which expanded dramatically after 11,000 ¹⁴C BP and persisted until the Holocene. Artifacts from the region frequently show signs of re-use and increasingly local toolstone procurement (Schmitt et al. 2007). Human foragers had colonized North America well before the Terminal Pleistocene (Jenkins 2007; Jones and Beck 2007), this period represents a first step in the development of a highly integrated relationship between Great Basin foragers and the environment as the Bonneville Basin's first settlers skimmed the cream from the top of a dynamic landscape (Simms 2008).

Early Holocene (10,000 – 8,000 ¹⁴C BP)

The early Holocene began with the abrupt end of the Younger Dryas around 10,000 ¹⁴C BP and ends around 8,000 ¹⁴C BP with the onset of the middle Holocene and drier conditions (Grayson 2000a:184, 2000; Madsen 1999; Wigand and Rhode 2001:347). Major geologic/hydrologic changes take place early in this time period include Lake Bonneville falling from the Gilbert shoreline to historic levels or lower starting at ~10,000 ¹⁴C BP (Oviatt et al. 2005) and the cessation of flow from the Sevier Basin into the Bonneville Basin (Currey and James 1982; Madsen et al. 2001). Glaciers in Snowbird Canyon deposit terminal moraines (Madsen and Currey 1979) and some pollen cores show an increase in grass pollen at 8,000 ¹⁴C BP, signaling wetland reduction (Louderback and Rhode 2009:323). These shifts appear to have occurred rather rapidly between 9,000 and 8,000 ¹⁴C BP.

Sudden reductions in the number of pygmy rabbits (*Brachylagus idahoensis*) and yellow-bellied marmots (*Marmota flaviventris*) at Homestead cave signal local extinctions of these

species as their ranges were reduced to high-elevation montane habitats (Grayson 2000a, 2006a). The record from Camel's Back Cave shows a similar pattern of declining numbers of species adapted to cool-moist conditions throughout the early Holocene (Schmitt and Lupo 2005; Schmitt et al. 2002). Artiodactyl remains in archaeological sites becomes less abundant in comparison to the contribution of small mammals (Madsen et al. 2005) and pika pellets disappear from midden records (Thompson 1990). The broad impacts of Early Holocene climate altered the distribution of mammals in upland and lowland contexts alike.

The record of changes in plant communities reflect a continuation of changes that began between 12,000 and 10,000 ¹⁴C BP with the montane regions of northern Utah becoming increasingly dominated by *Pinus contorta* and *Pinus flexilis*, while desert scrub cover expands at around ~10,000 years B.P. (Mehring 1977:141). Woodrat middens dating to the Early Holocene are rare as increasing aridity shifted their habitat range to higher elevations, but plant remains from surviving middens and dry caves suggest that the onset of the early Holocene is characterized by mesophilic plants occupying lower elevations than their present distributions (Smith and Betancourt 2003; Thompson 1990; Wigand and Rhode 2001). Hackberry (*Celtis reticulata*) endocarps from Homestead cave (about 1,600 meters elevation) point to generally cool and moist conditions as does evidence from packrat middens, while pollen data, faunal remains, and pickleweed/iodinebush (*Allenrolfea occidentalis*) remains from Danger Cave indicate a dramatic shift to warm/dry environmental conditions by 8,500 years ago (Madsen et al. 2001; Wigand and Rhode 2001). Communities of mesophilic plants such as bristlecone pine, limber pine, and common juniper, shifted upslope to protected locations (Rhode and Madsen 1995; Wigand and Rhode 2001). Rhode (2000) explains the contrast between upland and

lowland records as a result of the differential impact of monsoonal precipitation on higher elevations. In addition to these shifts, pollen cores from the region show evidence of expanding xeric shrub communities (Louderback and Rhode 2009; Thompson 1992) and an expansion of Rocky Mountain juniper (*Juniperus scopulorum*) in montane habitats (Madsen et al. 2001). Singleleaf pinyon pine (*Pinus monophylla*) expands towards its modern distribution at this time as well (Rhode and Madsen 1995). The sum of this evidence indicates expanding xeric communities of big sagebrush (*Artemisia tridentata*) and Chenopods in the lowlands with a concomitant shift of mesophilic communities upslope.

The Early Holocene is characterized by summer-dominated rainfall which encouraged the spread of grasses and desert scrub vegetation (Louderback and Rhode 2009) into shrinking wetland environments as conditions became increasingly dry (Rhode 2000). The expansion of pinyon pine and Rocky Mountain juniper while Utah juniper remained constrained to southerly locations further indicates the importance of monsoon-derived summer precipitation (Rhode 2000). These changes are also reflected by the colonization of territories or ecozones made habitable by favorable temperatures. As lake levels decreased, mesophilic plants move upslope, allowing desert-scrub and pinyon pine to expand into lowland and upland environments. Although these environments and vegetation types are broadly similar in composition to modern plant communities (Grayson 2000a), the distribution of montane species points to more effective moisture during the Early Holocene compared to the Late Holocene (Rhode 2000).

The increasing number of cave and open sites suggests population growth, a trend that continues, albeit with some fluctuations, throughout the Holocene (Simms 2008). Sites are still concentrated in lowlands, suggesting an emphasis on the exploitation of wetland resources which

expanded as the lake regressed. Toolstone utilized by foragers in this period seems to be increasingly local and the tools themselves indicate an emphasis on efficient biface technologies. Shifts in projectile point morphology (Madsen et al. 2005) and the recovery of atlatl shafts (Jennings 1957; Dalley 1970) indicate the replacement of the thrusting spear with throwing spears at the end of this period. Grinding stones and coiled basketry appear in Danger Cave strata dating to 10,000 ¹⁴C BP (Jennings 1957:204; Rudy 1957:235), but subsequent dating of pickleweed/iodinebush chaff suggests that the actual grinding of seeds dates to around 8,600 ¹⁴C BP (Rhode et al 2006:336).

Although Archaic toolkits emerge during the latter portion of the Early Holocene, these artifacts set the stage for dramatic changes in the ways that foragers utilized landscapes and resources of the Bonneville Basin in later periods (Simms 2008). Although Early Archaic subsistence remains from Danger Cave, Bonneville Estates, and Hogup Cave are broadly similar in species composition, there are localized differences in the importance of pickleweed/iodinebush and upland resources like mountain sheep (*Ovis canadensis*) (Aikens 1970; Hockett 2007; Jennings 1957), particularly after coiled basketry and grinding appear in the record. Some areas, such as the ORB appear to have been abandoned, but seasonal occupation of Bonneville Basin cave sites become more frequent (Madsen et al. 2005). These changes in occupational patterns and artifacts appear to be tied to declining environmental productivity during the Early Holocene, making the exploitation of small grass seeds an economically viable option. (Goebel 2007; Rhode 2008; Rhode and Louderback 2007) This proximate explanation has proved useful for exploring the general differences between Paleoarchaic and Archaic foragers (Madsen 2007), but experimental measures of caloric returns from resources utilized by Great Basin foragers

indicates that the ultimate cause of the emergence of Archaic adaptations is better explained by a combination of changes in environmental productivity, aboriginal collection methods, the range of environments occupied by humans, and the intensity of seasonal shortfalls (Elston and Zeanah 2002; Madsen 2007; Madsen and Schmitt 1989; Madsen et al. 2005; Simms 1987, 2008).

Middle Holocene (8,000 – 4,700 ¹⁴C BP)

The middle Holocene represents the most radical historical shift in the hydrologic budget of the whole Great Basin. From about 7,300 until 4,700 ¹⁴C BP, the northeastern Great Basin grew increasingly dry and warm. Drying is signaled by nearly complete deglaciation of nearby mountain ranges and an influx in rockfall and aeolian deposition in both caves and sediment cores (Currey and James 1982; Wigand and Rhode 2001). Shoreline records of the Great Salt Lake from this period are difficult to interpret, but seem to indicate regressions in lake levels well below the current lake elevation, which appears to signal drying trends (Madsen et al. 2001). However, exceptions to the general drying trend include some evidence for dune stabilization (Schmitt et al. 2007) and standing water in nearby Ruby Valley, Nevada (Thompson 1992:9) at around ~6,000 and 6,900 ¹⁴C BP, respectively. This exception to the trend is corroborated by a similar interruption in increasing arid plant remains in archaeological sites at about 6,000 ¹⁴C BP (Mehring 1977). This dramatic warm/dry trend desiccated some western Bonneville Basin springs by around 7,100 ¹⁴C BP (Louderback and Rhode 2009).

Faunal records suggest a reduction in species diversity (Grayson 2000a, 2000b) and complete local extinction of mesophilic species. Increasing numbers of the black-tailed

jackrabbit (*Lepus californicus*) compared to cottontail rabbits (*Sylvagus* sp.) at both Camel's Back Cave and Homestead Cave suggest extreme aridity and reductions in ground cover (Grayson 2000b, 2006a; Schmitt et al. 2002; Schmitt and Lupo 2005). Furthermore, woodrat populations show changes in body mass and population size indicative of substantial warming (Smith and Betancourt 2003) and reductions in populations of Ord's Kangaroo rat (*Dipodomys ordii*) compared to chisel-toothed kangaroo rats (*Dipodomys microps*) at Homestead Cave suggest that the local flora was dominated by shadscale, which the chisel-toothed kangaroo rat is specifically adapted to consume (Grayson 2000a, 2006b). Similarly, the remains of shrub adapted horned larks (*Eremophila alpestris*) increase while the remains of ducks decrease (Livingston 2000).

Typical of drying trends, records of prehistoric vegetation grow increasingly scarce during the middle Holocene (Madsen et al. 2001, Wigand and Rhode 2001). These records show increases in xeric adapted plant pollen in comparison to their mesophilic counterparts with the exception of increases in pine pollen at about 6,000 ¹⁴C BP (Currey and James 1982; Madsen 1985; Madsen et al. 2001; Merhinger 1977; Wigand and Rhode 2001) and a slight increase in artiodactyl remains in Lakeside Cave (Broughton et al. 2008:13). Bristlecone pine migrated upslope in the northern Basin (Currey and James 1982) and Utah juniper and pinyon pine further expanded their ranges in the Bonneville Basin and began to approach their modern distribution (Madsen et al. 2001, Wigand and Rhode 2001). Rising temperatures and decreasing effective moisture triggers major reductions in conifer pollen and increases in *Artemisia* pollen in sediment cores from Swan Lake (Bright 1966). Patterns of summer-dominated precipitation during the middle Holocene also resemble modern conditions, but lowland plant communities

show increases in shadscale communities at the expense of sagebrush communities (Wigand and Rhode 2001). Distributions of limber pine and common juniper were reduced to minor refuges in protected drainages and north-facing slopes (Wigand and Rhode 2001).

The archaeological record has played an important role in paleoecological reconstructions of the Middle Holocene. For example, the relative scarcity of Middle Holocene radiocarbon dates from archaeological sites has often been cited as evidence for Middle Holocene drying (Grayson 2000a). Estimates of paleoecological parameters, especially where it concerns the abundance and availability of resources are a crucial part of evaluating hypotheses and assessing archaeological patterns (e.g. Byers and Broughton 2004, Hildebrant and McGuire 2002), but archaeological information is at best a proxy measure of local communities and their composition. Increasing human populations in the region at the close of the Middle Holocene indicate increasing impacts of human activities on paleoenvironmental and contemporary plant and animal communities (Grayson and Cannon 1999; Rhode 1999). However, this approach is limited because humans preferentially take game in semi-predictable patterns (for an especially clear example, see Broughton 1997), which may bias the archaeological faunas towards larger game (Byers and Broughton 2004; Hildebrant and McGuire 2002). However, Hockett (2005:729) shows evidence that the fluctuations in the abundance of small mammals in archaeological sites may be more sensitive to human population growth.

Human populations continue to expand in the early portion of the Middle Holocene (Simms 1977). Early Archaic occupation layers are well-represented in Danger Cave (Jennings 1957), Hogup Cave (Aikens 1970), and Camel's Back Cave (Hunt et al. 2005). Grinding stones and coiled basketry become increasingly widespread, while netting, snares, and traps are added

to forager toolkits by 7,000 ¹⁴C BP. At the same time, Early Archaic occupations appear in other Bonneville Basin caves like Black Rock Cave (Madsen 1983) and upland caves and rockshelters (Madsen et al. 2001) as foragers begin exploit a more diverse array of environments. This is a trend that becomes more pronounced during peak dry conditions at around 7,300 ¹⁴C BP (Madsen and Berry 1975; Madsen et al. 2005:33; Simms 2008:156). Shifts in human demography are reflected by westward movement of technologies circa 8,000 to 6,000 ¹⁴C BP, and may be a response to the diminished carrying capacities of northeastern Basin environments as the Middle Holocene drying trends altered the size and distribution of resources (Simms 1977; Weide and Weide 1977). As the Middle Holocene progresses, human occupation of upland sites becomes more intensive and frequent with intermittent occupation of lowland dune and wetland sites, which seems to emerge from a combination of deteriorating climatic conditions, increased population pressure, and subsistence traditions that emphasized broad-range foraging, small game procurement, and communal hunts (Hockett 2005; Madsen 1982; Simms 2008). Bettinger (1999) makes a good case for these archaeological patterns being fully realized only in the Late Holocene, but it is also clear that the roots of these behaviors are firmly established in the Early and Middle Holocene (Hockett 2005; Simms 2008).

Late Holocene (< 4,700 ¹⁴C BP)

The late Holocene period represents the last major period of climate and environmental change leading to the emergence of modern environments, beginning at 4,700 ¹⁴C BP. Geologic evidence indicates “Neoglacial” advances at about 3,300-2,400 ¹⁴C BP, correlating with higher lake levels and shoreline development dated to 3,600 and 2,800 ¹⁴C BP in addition to increases in

colluvial sedimentation, suggesting increases in summer moisture (Currey and James 1982:41; Mehringer 1977:121). These two wet periods are significantly wetter than the present.

Developments of marshes and shallow lakes in the eastern Bonneville Basin corroborate evidence for substantial cool and wet periods visible in many of the paleoenvironmental records from this period. Furthermore, this period sees the rise of maize (*Zea mays*) agriculture among indigenous populations who occupied eastern and southern portions of the Great Basin (Madsen and Simms 1998), suggesting suitable summer-dominant rainfall and cooler temperatures persisted until about 1,200 ¹⁴C BP.

Though the early Late Holocene faunal remains resemble the previous period, records from archaeological sites (Schmitt and Lupo 2005) and raptor deposits (Grayson 2000a, 2006b) suggest rebounds in artiodactyl populations and mesophilic small mammals alike starting at around 2,700 ¹⁴C BP (Broughton et al. 2008:12). Bison (*Bison bison*) remains are more common in archaeological sites around 1,500 ¹⁴C BP than during the rest of the Late Holocene (Grayson 2006a; Lupo and Schmitt 1995) and woodrats reappear in Great Basin caves (Grayson 2000a, 2000b). Taken together, these trends suggest that early Late Holocene climate changes favored the expansion of grasses. Increases in the Northeastern Basin's hydrologic budget between 4,700 and 1,900 ¹⁴C BP is indicated by increasing ratios of grass to sagebrush pollen and downward displacement of juniper as far as 150 meters lower in elevation than at present, but upper juniper woodlands remain restricted in elevational zonation by increasingly harsh winter conditions (Miller and Wigand 1994).

Increased juniper productivity appears to be responding to increased precipitation and lower summer temperatures (Miller and Wigand 1994). Periods of major grass expansion

between 4,000 and 2,000 ¹⁴C BP may be responding to more frequent fire regimes (Miller and Wigand 1994:470). Starting after the maximum expansion at about 2,000 ¹⁴C BP. and proceeding until European contact, pinyon-juniper woodlands have generally retreated upslope (Miller and Wigand 1994). The most recent 1,200 years of the Late Holocene are defined by increasing aridity, indicated by the failure of agriculture, reduced lake levels, declining bison populations, local extinctions of woodrat populations, and a 400-year-long trend in glacier reduction (Currey and James 1982; Grayson 2006a; Smith and Betancourt 2003), although tree-ring records from the western U.S. indicate that moisture deficits were more pronounced and frequent before 1,500 ¹⁴C BP and after 500 ¹⁴C BP in the Great Basin (Hughes and Funkhauser 1998; LaMarche 1974), indicated .

Historical changes in Bonneville Basin vegetation are driven by the introduction of invasive species and the loss of anthropogenic fire regime. Historic fire suppression is a primary factor in the latest expansion of Pinyon-Juniper woodlands at the expense of sagebrush-shadscale and greasewood scrub (Miller and Wigand 1994). Currently Pinyon-Juniper woodland is one of the most common vegetation types in the basin, covering some 17 million hectares. The cold deserts of lowlands in the Bonneville Basin are currently dominated by sagebrush on wetter sites or shadscale and greasewood on drier sites (Wells 1983). Mountain ranges are dominated by “extremely subalpine” (Wells 1983:367) species, which is surprising, given the moderate elevations of these ranges.

The Late Holocene captures dramatic changes in the archaeological record. The previous trend towards increasingly specific uses of resource areas continues through the Late Archaic, with simultaneous exploitation of lowland and upland resources expanding (Kelly 1997; Simms

2008). Communal hunting structures become more common in many areas and archaeological sites show a relative decrease in the abundance of small mammal remains (Hockett 2005). Substantial technological and subsistence changes like the bow-and-arrow, pottery, and agriculture are introduced into this matrix of increasingly tethered foragers with the emergence of the Fremont at around 2,700 ¹⁴C BP (Madsen et al. 2005:125; Simms 2008:198). Farmers come to dominate the landscape by around 1,500 ¹⁴C BP, but foraging subsistence practices continue alongside the emergence of the Fremont as a part of a dynamic cultural milieu (Kelly 1997:21; Madsen and Simms 1998). Madsen and Simms (1998) argue that classic Fremont attributes like agriculture, pottery, and the bow and arrow were differentially adopted by Late Archaic foragers who incorporated these attributes into existing patterns to different degrees. The appearance of corn in a 2,000 year old Late Archaic pre-ceramic burial in central Utah (Wilde and Godfrey 1986) and stable isotope evidence from skeletal material recovered from village sites along the Wasatch Front (Coaltrain and Leavitt 2002) support this conclusion. Bow and arrow technology appears some 500 years before Fremont ceramics at Buzz-cut dune and subsequent Fremont-era occupations represent a collection of visits to the area (Madsen and Schmitt 2005), much like the occupations of the Mosquito Willies site (Young et al. 2008).

The Late Prehistoric period is characterized by a return to the broad-range seasonal foraging patterns (Madsen et al. 2005) observed by Julian Steward (1938), after the dissipation of the Fremont in response to migrations of Numic-speaking populations, climatic conditions, and increasing social conflict (Simms 2008). Though the populations observed ethnographically, in some cases, likely emerged from these Late Prehistoric foragers, linguistic distributions suggest substantial population movement during this time period (Madsen and Rhode 1994). Some

evidence of technological shifts is evident in the archaeological record (Kelly 1997; Simms 2008), but the artifactual evidence is not conclusive. The subsistence base remains broad through this time period (Madsen et al. 2005), although the introduction of *Zea mays* (Coltrain and Leavitt 2002) and increasing representation of artiodactyls in strata dating prior to ~1000 BP (Broughton et al. 2008; Janetski 1997:1080) are notable exceptions.

Julian Steward (1938:Figure 12) mapped several villages and camps in the vicinity of Mosquito Willies based on observations of Gosiute foragers using lowland villages and spring locations for seasonally available roots, seeds, and shoots. Although ethnographically recorded population densities were relatively low in the region (Steward 1938; Fremont 1845), populations of foragers rarely went without food, making use of a broad array of seeds, roots, tubers, insects, reptiles, and small mammals (Chamberlin 1911). Family bands would merge into corporate villages during the spring/summer to procure jackrabbits and seeds, but would disperse into smaller winter villages in the fall and winter to harvest and store pinyon pine (Steward 1938). Ethnographic evidence of modification of the landscape via burning is common among Great Basin groups (Downs 1966; Steward 1938) and was employed to encourage the growth of economic plants like goosefoot, ryegrass, and bulrush in addition to recreational/medicinal plants like tobacco (Downs 1976; Winter 2005). Burning also appears to have been employed in collective hunts for jackrabbits and insects (Madsen and Schmitt 1989; Steward 1938). Aboriginal management of Great Basin environments appears to have been subtle, with little evidence for intensive irrigation, terracing, and landscape modification, but the sudden post-contact increase in pinyon-juniper woodland cover indicates that ethnographic groups had a significant impact of the distribution of plant species within Great Basin environments. Given

the proximity of ethnographic and archaeological occupations of the Bonneville Basin to the coring location, the plant taxa and charcoal remains represented by pollen in the Mosquito Willies core may yield clues as to the antiquity and impact of aboriginal burning in the Bonneville Basin.

Conclusions

The changes in Great Basin environments and peoples through the Holocene are substantial and are documented using a wide breadth of knowledge and data. Archaeologists, geologists, and paleoecologists have collaborated extensively through the last century, which has added considerable detail to understanding Great Basin prehistory. Elements of modern plant communities, cultures, and climatic conditions have been present in the Bonneville basin for at least the last 8,000 years, but the constellation of variables that influence these changes do not neatly co-vary from shadscale scrub to pinyon-juniper, warm/dry to cool/wet, or forager to farmer. Although general climatic features provide critical context and proximate explanations for the dynamics and adaptive elements of ecosystems and cultural systems alike, ultimate explanations for the evolution of ecosystems and culture change require a consideration of complex phenomenon that take place over varying spatial and chronological scales. The pollen remains and sedimentary descriptions described in the next chapter reflect long-term environmental fluctuations, short and long-term fluctuations in depositional environments/geomorphic processes, and fluctuations that may represent human impacts.

CHAPTER 3: PALEOENVIRONMENTAL ANALYSIS AND GENERAL RESULTS

This chapter describes the Mosquito Willies core, the methods I employed to retrieve pollen grains from the sediments, and the general results of the pollen analysis. The core's location and stratigraphy suggest that this core may contain important details about Holocene environments. Chronological control of the core comes from several radiocarbon dates, sedimentary evidence, and volcanic tephra, which are described alongside the results of the pollen analysis. I also use explorative statistics to discern dimensions of variability in the pollen represented in these samples and what these patterns reveal about variation in prehistoric plant communities.

The Mosquito Willies Core and Laboratory Methods

The core was collected by David Rhode, Joel Janetski, and David B. Madsen in June, 2003. They cored the south channel of the Mosquito Willies spring, approximately 50 m from the mouth of the spring which is located just below the Gilbert shoreline (Rhode, personal communication 2007). The spring itself is located not far from the Utah-Nevada border a little south of Wendover, Utah (Figure 3.1), sitting at 4260 feet (~1300 m). Modern vegetation at the coring site, much like the vegetation in the rest of the playa margin, is dominated by saltgrass, shadscale, greasewood, and iodinebush, with sagebrush-grass communities occurring on nearby alluvial terraces (Young et al. 2008). The core is 1.83m long, with silty lake deposits at the bottom, followed by layers of gray sand, laminated silty peat, and aeolian sand. Radiocarbon

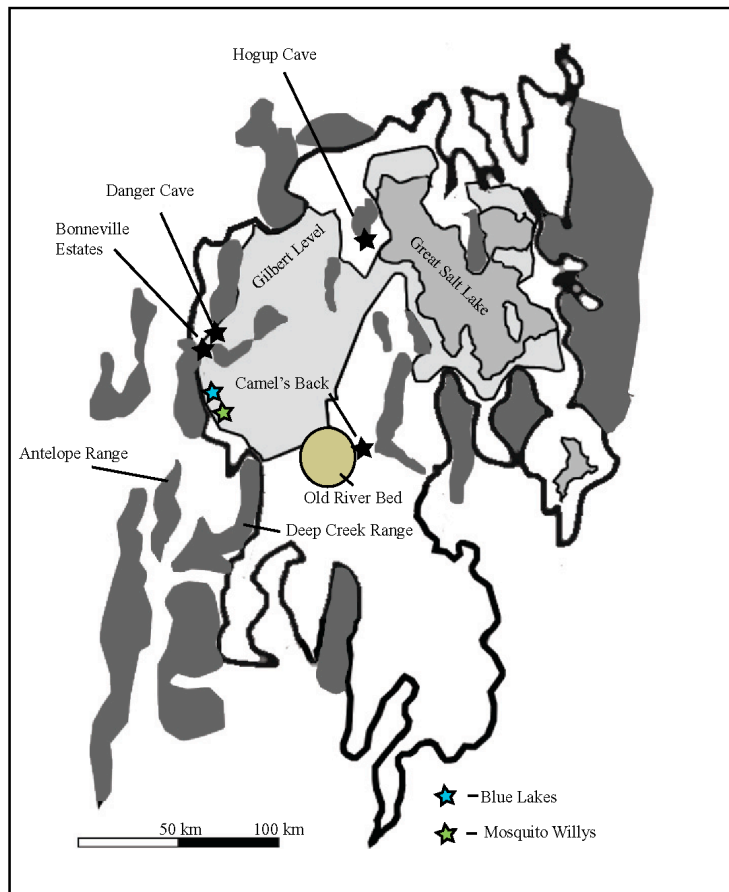


Figure 3.1 Map showing Bonneville Basin, a selection of Paleoarchaic-Archaic archaeological sites, the Old River Bed, local mountain ranges, and the location of the Blue Lake and Mosquito Willies springs.

dates of 7,150 +/- 40 (Beta 186789) and 7,630 +/- 50 ¹⁴C BP (Beta 186790) from depths of 120.5-121 cm and 142 cm respectively indicate that the strata contained in the core are dominated by Holocene deposits (Rhode, personal communication 2007.). I acquired the core from the Desert Research Institute in Fall, 2007 and brought it back to Washington State University for analysis in the Department of Anthropology's paleoenvironments laboratory, under the direction of Dr. John G. Jones.

A total of 31 pollen samples and seven radiocarbon dates were taken from the core and these are listed in Appendix A and Table 3.1. Samples were taken from the core at approximately

Mosquito Willies Samples and Radiocarbon Dates

Sample	cm	14C BP	calBP	lab #
1	155-156			
2	149-150			
3	144-146			
4	140-142	7630 +/- 50	8848	Beta 186790
5	132-134			
6	125-126			
7	120.5-121	7150 +/- 40	7979	Beta 186789
8	115-117			
9	110-111	7020 +/- 140	7847	AA78450
10	104-106			
11	99-100			
12	94-95			
13	90-91	-	-	AA78451*
14	84-85			
15	80-81			
16	74-75			
17	68-69			
18	64-65	3949 +/- 40	4406	AA78453
19	59-60			
20	54-55			
21	49-50			
22	44-45	3363 +/- 74	3605	AA78454
23	40-41			
24	37-38			
25	32-33			
26	24-25			
27	19-20			
28	15-16	1509 +/- 38	1417	AA78452
29	9-10			
30	4-5			

Table 3.1 Samples and radiocarbon dates from the Mosquito Willies sediment core. One sample (AA78451) failed to yield a reliable radiocarbon date and is marked with an asterisk (*).

5 cm intervals, but were adjusted to sample specific strata. A volume of each of those samples was mixed with a 10% HCl solution and a known quantity of the tracer spore *Lycopodium* sp. was added to quantify the concentrations and numbers of pollen grains in the sediments and also indicate potential errors during chemical processing of the sediments. For

Mosquito Willies Pollen Profile

Analyst: Chris Kiahtipes

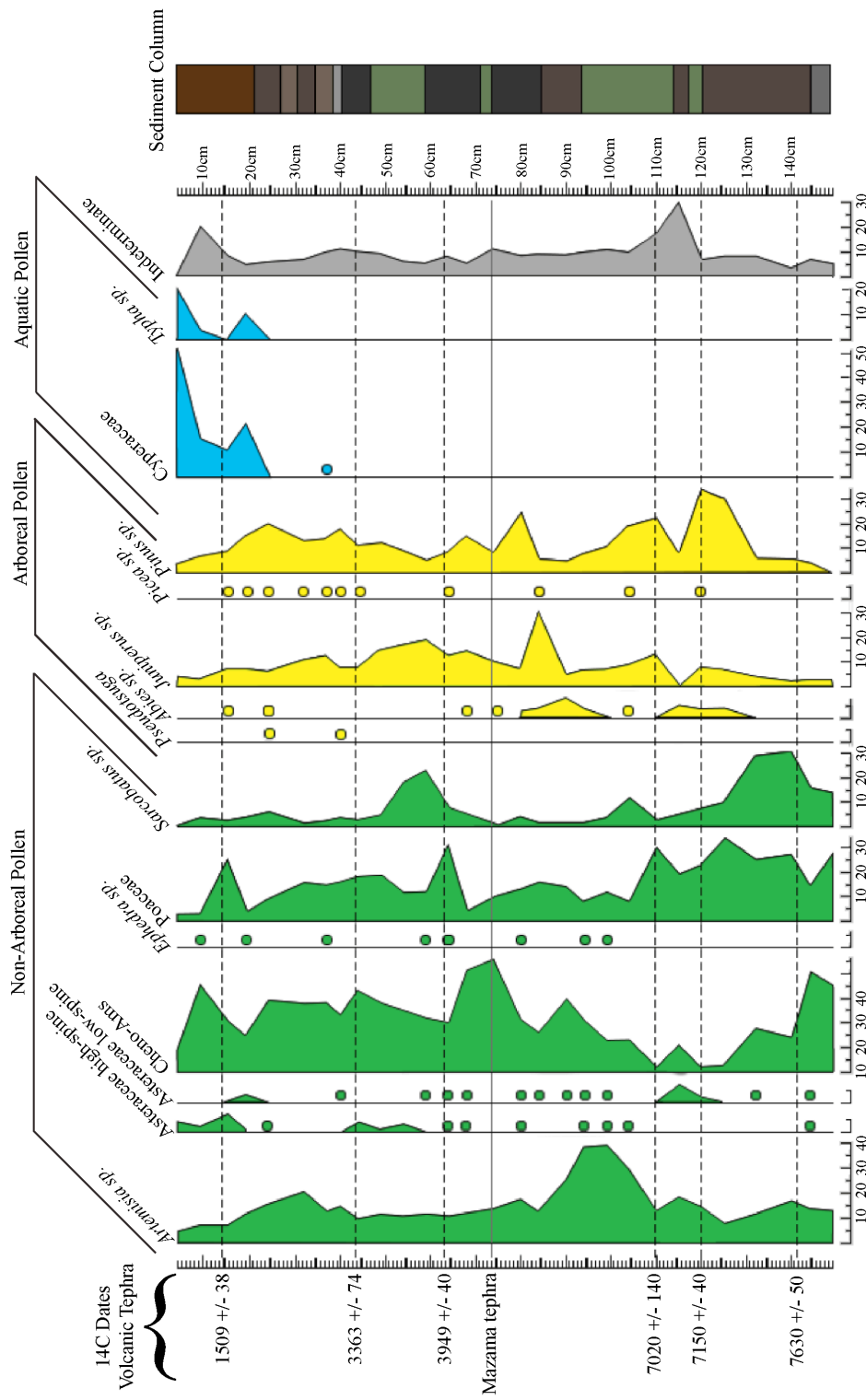


Figure 3.2. Pollen diagram showing relative percentages of non-arboreal pollen types (green), arboreal pollen types (yellow), aquatic pollen types (blue), and indeterminate grains. Trace amounts (<5%) are represented by dots. Radiocarbon dates (dashed lines) and volcanic tephras (solid grey line) are listed on the left side of the page and the sediment column is presented on the right-hand side.

Mosquito Willies Pollen Abundances, Pollen Concentrations, and Charcoal Counts

Analyst: Chris Kiahtipes

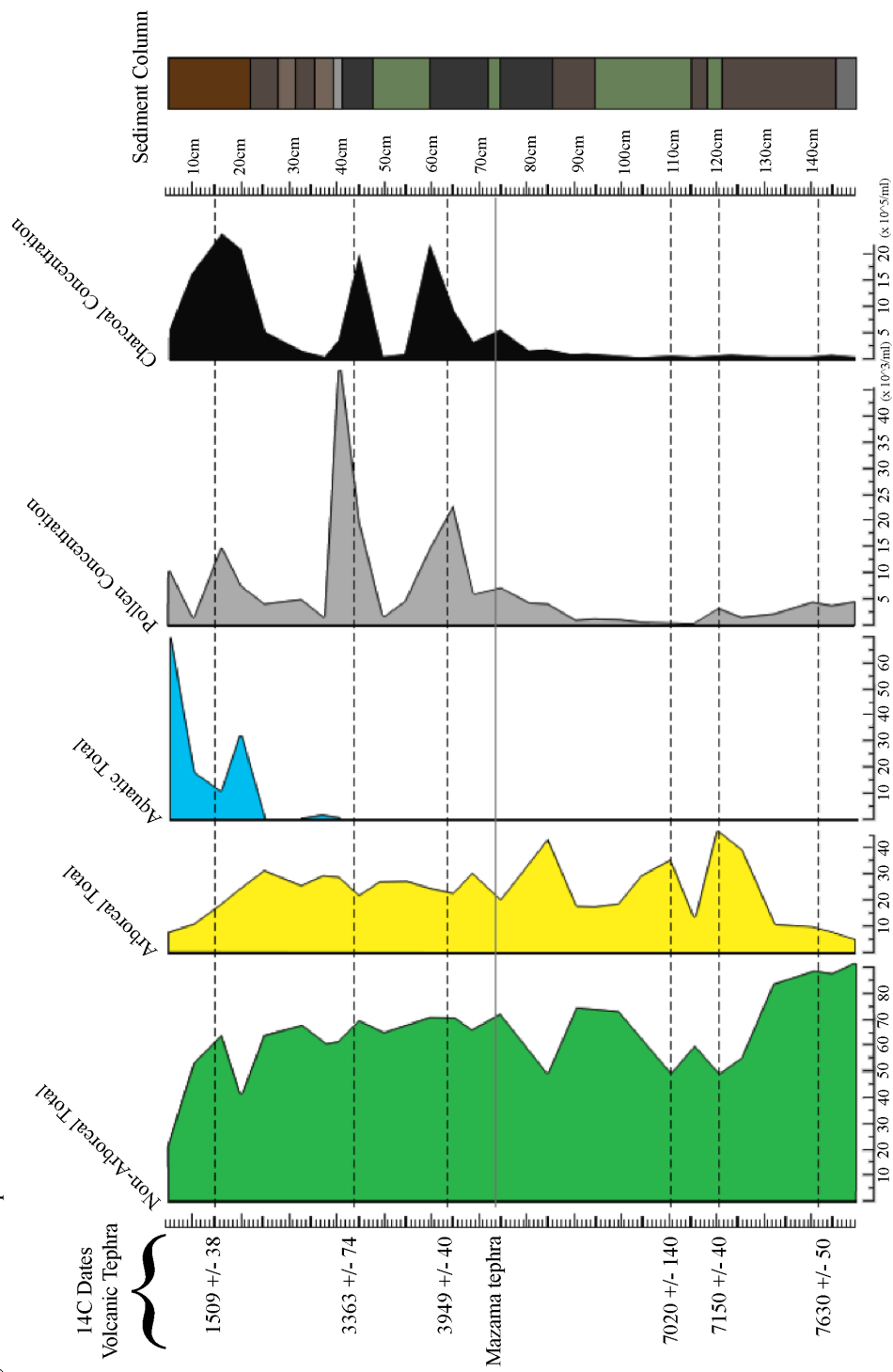


Figure 3.3 Diagram showing total percents of Non-Arboreal (green), Arboreal (yellow), and Aquatic (blue) pollen. Pollen concentrations (grey) and charcoal concentrations (black) are also included. Radiocarbon dates (dashed lines) and volcanic tephra (solid grey line) are listed on the left-hand side of the chart. The sediment column is represented on the right-hand side of the diagram.

instance, degraded *Lycopodium* sp. grains indicate that chemical treatment may have been too harsh and damaged ancient pollen grains. The samples were then washed, screened, and immersed in a 1% KOH solution to dissolve organic material. Samples containing abundant silicates were soaked overnight in a 48% HF solution. After rinsing the samples, H₂O was removed from them by adding glacial acetic acid (99.5%) before treating them with Acetolysis; a 9:1 solution of Acetic Anhydride and Sulfuric Acid. Samples are heated in the solution for six minutes, rinsed, and then the remaining pollen, charcoal, and other fine materials are separated out using Zinc Chloride. The pollen is then mounted on slides with glycerine. Chemical analysis was performed by myself and Dr. Jones.

Pollen grains and charcoal were counted on the slides using a light-microscope at a magnification of 40x. Grains were identified to the most reliable level possible, in some cases these levels are quite broad (e.g. Cheno-Ams), and others are more specific (*Sarcobatus* sp.) and counted until a total of 200 was reached. The tracer spores were counted separately and used to establish concentration values for the samples. Charcoal was counted separately, including only fine fraction (< ~5 µm). The results of the analysis are presented in Figures 3.2-3.3, which were generated using PSIMPOLL. Pollen counts used for this analysis are included in Appendix A. The results presented below describe changes in relative percents of identifiable pollen taxa and relevant chronological markers per sedimentary unit starting with the earliest (deepest) stratum, the reader should refer to Figures 3.2-3.3 for graphical representation. I draw comparisons between arboreal pollen, which is represented by conifers (*Abies*, *Juniperus*, *Picea*, *Pseudotsuga*, and *Pinus*) in this core, and non-arboreal pollen (*Artemisia*, Asteraceae high-spine, Asteraceae low-spine, Cheno-Ams, *Ephedra*, Poaceae, and *Sarcobatus*). Aquatic pollen plays less of a

prominent role in my discussion, because it appears late and is represented only by bulrush (Cyperaceae) and cattail (*Typha* sp.).

Taphonomic processes are indicated by fluctuations in pollen influx reflected in the pollen concentration values (Figure 3.3) and from the representation of indeterminate pollen grains. The number of indeterminate grains increases under conditions of poor preservation, which mask, distort, and/or destroy the diagnostic features of pollen grains. Furthermore, certain grains are more susceptible to damage than others (e.g. Poaceae), which may bias samples towards more durable pollen types (e.g. *Artemisia* or Cheno-Ams). If grains appeared to be unidentifiable, I classified them as indeterminate. I also classified unknown types as indeterminate if I could not otherwise identify the specimen. These changes in pollen influx and the preservation conditions indicated by indeterminate grains follow changes in the depositional environment indicated by the sediments in each of the strata from the core (Figure 3.2-3.3). The results of the pollen analysis are discussed by sedimentary strata, allowing a clear picture of the interaction between environmental change and taphonomic processes. I interpret these counts using the geological and depositional contexts in addition to comparing this data with other paleoenvironmental reconstructions in the next chapter.

Mosquito Willies: Palynological Results

156-145 cm

This layer is made up of gray sand and contained abundant gastropod shells and some small (~ 3 mm) pebbles. Samples 1 (155-156 cm), 2 (149-150 cm), and 3 (144-146 cm) came

from this stratum and the Desert Research Institute (DRI) sampled this section for radiocarbon dating at 142 cm (Beta 186790), which yielded a C¹⁴ date of 7,630 +/- 50 (8,448 Cal BP). Sample 1 did not yield reliable concentration values, so it is not considered here. Pollen from samples 2 and 3 contain an abundance of non-arboreal pollen (~90%) and relatively little arboreal pollen (~10%). Non-arboreal types are dominated by Chenopods and Grasses (~60%), with notable abundances of *Artemisia* and *Sarcobatus* (~30%). The abundance of Poaceae pollen decreases from ~30% at 150 cm to slightly above 10% at 145 cm, while chenopods and greasewood increase by around 10% and 5% respectively. *Juniperus*, Asteraceae high-spine, Asteraceae low-spine, and *Pinus* are all represented in samples 2 and 3, but their abundances are quite low (<5%). Charcoal concentrations from these samples increase slightly up the column, but are generally low (<200x10³ per ml). The sand-size grains and relatively high pollen concentrations (42,979 grains/ml) suggest that these sediments were deposited by the Great Salt Lake as it receded from the Gilbert shoreline (1,295 m) sometime after 10,500 ¹⁴C years BP (Benson et al. 1990; Oviatt et al.2005). This conclusion is supported by the basal sediments of the core (185-156 cm), which appear to be sub-aqueous near-shore deposits (Rhode pers. comm. 2007).

145-120.5 cm

This depositional unit is thick (24.5 cm) and made up of laminated peaty silts that are grey (5Y4/1) to very dark grey (5Y2.5/1) in color with some sections that appear to be burned (Rhode pers. comm.). Samples 4 (140-142 cm), 5 (132-134 cm), 6 (125-126 cm), and 7 (120.5-121 cm) come from this unit and DRI sampled this section for radiocarbon assay at

120.5-121 cm. The radiocarbon sample from this core (Beta 186789) yielded a C^{14} date of 7,150 +/- 40 (7,979 Cal BP). Because of a substantial shift in the frequency of pollen types in this section, I describe the samples 4 and 5 first, followed by 6-7. Non-arboreal pollen remains dominant (85-90%), although it decreases slightly in samples 4-5 (80%). Poaceae pollen rebounds from 10% to 20% in these levels alongside a substantial increase in *Sarcobatus* (~30%) and an overall decline in Cheno-Ams (<20%). *Artemisia* initially increases to almost 20% in sample 4, but drops down to almost 10% in sample 5. *Juniperus* and *Pinus* pollen are present in the samples and increase slightly in these samples, but their contribution to the total pollen remains small (~10%). Low-spine Asteraceae is also present but uncommon in these samples. Concentration values rise at 140-142 cm (~40x10³ grains/ml), but decline back to previous levels (20x10³ grains/ml) at 132-134 cm. Charcoal concentration values drop to around 150x10³ grains/ml at 140-142 cm, but rebound to slightly more than 260x10³ grains/ml by 132-134 cm.

Beginning at sample 6, non-arboreal pollen drops to below 50% of the total pollen and arboreal taxa increases to just under 40%, spiking at around 45% in sample 7. Though *Juniperus* pollen increases slightly from previous samples, it still makes up only 10% of the total pollen. *Pinus* pollen, on the other hand, dramatically increases from <10% to around 30% of the total pollen. Greasewood and Cheno-Am pollen decrease substantially in these samples, falling to around 10% each. Sagebrush increases slightly in sample 7, rising to just below 20%. The highest percentage for grass pollen in the core comes from sample 6 (~30%), but grasses are less abundant (~25%) by sample 7. *Abies* is present in small amounts (<2%) and *Picea* pollen is also present (<2%), but only in sample 7. Overall pollen concentration values continue to decrease, falling to around 100x10³ grains/ml. Charcoal concentrations increase slightly, rising

to almost 450×10^3 grains/ml in sample 6 and slightly more than 300×10^3 grains/ml in sample 7. Silty sediments and peat development in this stratum were likely deposited in a low energy system fed by local springs, but the declining concentration values in samples above 140-142 cm may indicate shifts in the regional hydrologic budget and the abundance of local plants.

120.5-118.5 cm

This thin (2 cm) layer is made up of an olive-gray (5Y4/2) clayey silt. No pollen or radiocarbon samples were taken from this stratum, but the sediments that lie above and below this layer are quite similar, suggesting that this layer is a brief discontinuity in an overall pattern visible between 145-114 cm. The lack of peat development and clayey silt texture indicate a very low-energy depositional environment.

118.5-114 cm

Sediments from this layer are peaty-silts and are very dark gray in color (5Y3/1), suggesting that these relatively thin deposits represent a resumption of peat development in a low energy spring system much like the one that deposited the sediments between 145-120.5 cm. Only sample 8 was collected from this stratum. Non-arboreal species are slightly more abundant in sample 8 than in sample 7, representing a little more than 50% of the total pollen and arboreal pollen is less abundant, representing less than 40% of the total pollen. The increase in non-arboreal pollen is driven by a continuing increase in the abundance of *Artemisia* (~17%) pollen and the rebounding of Chen-Ams from <5% in sample 7 to ~10% in this sample. *Sarcobatus* pollen increases slightly from previous samples, but remains at about 10%, while grasses

continue to decline, falling to around 20%. *Pinus* pollen is less abundant than in the previous sample, but it is still common (~30%). *Juniperus* pollen increases slightly, representing a little more than 10% of the total pollen. *Abies* and *Picea* are present, but rare, comprising < 2% of the pollen total.

Pollen concentration values are quite low (~1500 grains/ml) and charcoal concentrations are also modest (62×10^3 grains/ml) in sample 8. The broad similarities in the appearance of sediments between this stratum and the stratum at 145-120.5 cm suggest the samples were deposited in a low-energy spring-fed system. However, indeterminate pollen grains are more abundant in this sample than any others and pollen concentrations are well below the grains/ml required for reliable analysis apart from indicating what species were present. The abundance of pollen, particularly the increases in Cheno-Ams and *Artemisia* pollen, is likely a result of the durability of their exines and not their abundance on the landscape, as less durable pollen types are more likely to be damaged beyond recognition.

114-94 cm

This stratum is a fairly thick (20 cm) layer of mottled clayey silts that grades from a darker olive-gray color (5Y5/2) to olive-gray (5Y3/2). Samples 9 (110-111 cm), 10 (104-106 cm), 11 (99-100 cm), and 12 (94-95 cm). Sediments from 110-111 cm were also sampled for radiocarbon assay (AA78450) and yielded a C¹⁴ date of 7,020 +/- 140 (7,847 Cal BP). Non-arboreal pollen increases from slightly below 60% of the total pollen in sample 9 to more than 70% in sample 12. Arboreal pollen declines from about 35% in sample 9 to a little less than 20% in sample 10. Both *Artemisia* and Cheno-Am pollen become gradually more abundant in all

samples from this stratum, increasing from 20% to 35% and 10% to 20% respectively by sample 12. Poaceae pollen declines from around 15% to <10% between samples 9-10, rebounds to a little more than 10% in sample 11, and finally falls to <10% again in sample 12. *Sarcobatus* represents 10-15% of the total pollen between samples 9-10, but drops to <5% in samples 11-12. Low and High-spine Asteraceae are more abundant in samples from the upper portion of this stratum, but together they still represent less than 10% of the total pollen count. A single grain of *Ephedra* is also present in sample 12. *Pinus* pollen steadily declines from around 25% in sample 9 to a little more than 10% by 94-95 cm while *Juniperus* pollen holds at an abundance of around 10%. *Picea* and *Abies* are present in limited numbers (<2%) in samples 10-11 and the latter is also present in sample 12.

Concentration values are poor in the lower half of this stratum, falling to around 40×10^2 grains/ml in samples 9-10, but showing a moderate increase to almost 100×10^2 grains/ml in sample 12. Charcoal concentration values mirror this pattern, hitting a low of 65×10^3 grains/ml in sample 10 and rising to 702×10^3 grains/ml in sample 12. Sample 9 is considered with caution since almost 20% of the pollen recovered is too damaged to identify. The clayey silt texture, absence of peat development, formation of small peds at the base of this stratum, and low concentration values all point to a low-energy depositional environment and a greatly reduced hydrological budget, which may be linked to the increasing number of indeterminate grains in samples 9.

94-87 cm

Sediments from this stratum are grayish-brown (5Y5/2) laminated silty peats. One pollen sample (13) and one radiocarbon sample (AA78451) were both taken from 91-90 cm, but this sample failed to yield a reliable date. Non-arboreal pollen increases from the previous stratum, making up almost 80% of the total pollen with arboreal pollen contributing a little less than 20%.

Artemisia pollen is much less common in this stratum (~20%) than in sample 12 (~40%), but Chen-Am pollen is much more common, rising to almost 30% in this sample. Poaceae pollen increases from the previous stratum (<10%) to a little less than 15% of the total pollen. Low-spine Asteraceae and *Sarcobatus* pollen are present, but uncommon (< 10%). *Pinus* and *Juniperus* are not well-represented in this sample, representing around 15% of the total pollen. *Abies* pollen is much more abundant in this sample than in previous samples, but it contributes less than 10% to the total pollen. Concentration values drop back down to around 100×10^3 grains/ml and charcoal concentrations fall to 495×10^3 grains/ml. The development of peat in this stratum and the texture of the sediments suggests increased flow from the spring, while low concentration values suggests that the hydrologic budget is still low.

87-84 cm

This thin (3cm) stratum is made up of fine, dark gray (5Y4/1) silty sand. One pollen sample (14) was taken from 85-84 cm. Non-arboreal pollen is dramatically reduced in this sample (~50%) compared to the previous stratum, while arboreal pollen increases equally dramatically from around 20% in the previous sample to more than 40% in this sample. Reductions in both *Artemisia* (~15%) and Chen-Am pollen (~20%) compared to the previous

sample are the major contributors to the overall decline in non-arboreal pollen. Poaceae pollen is slightly more abundant, representing a little more than 15% of the total pollen. *Sarcobatus* and low-spine Asteraceae are still present, but rare (<2%). The spike in arboreal pollen mirrors the spike in *Juniperus* pollen, which increases to 30% in this sample. Although other arboreal types like *Pinus* (~10%) and *Abies* (~5%) are uncommon, *Picea* (~5%) is more common in sample 14 than any other. Pollen and charcoal concentrations increase to $\sim 370 \times 10^2$ grains/ml and $1,423 \times 10^3$ grains/ml respectively. The sudden shift in pollen representation, increased concentration values, and the shift in sediment particle-size indicate an increase in the energy of the depositional environment, which may be the result of an increased flow from the spring. The presence of subalpine conifers like *Picea* and *Abies* also points to an increase in the spring's catchment area, a result of an increased regional hydrologic budget.

84-74 cm

Black (5Y2/1) laminated silty peats characterize this stratum, but a lighter band at 77 cm represents a discontinuity in the depositional sequence, which I will discuss further after describing the sampling strategy and pollen data. Samples 15 and 16 were taken from 81-80 cm and 75-74 cm, respectively. Arboreal pollen is greatly reduced in each sample, representing slightly more than 20% of the total pollen sample 16. Almost 70% of the total pollen is non-arboreal, likely the result of an increase in Chenopodiaceae pollen from a little more than 15% in sample 15 to more than 30% in sample 16. Poaceae and *Artemisia* pollen gradually decrease in both samples, each type only representing around 15% of the total pollen in sample 16. Low-spine Asteraceae, *Sarcobatus*, and *Ephedra* are all represented by only a few grains from sample

15. *Pinus* pollen spikes at 81-80 cm, representing a little more than 20% of the total pollen sum, but drops again to around 10% in sample 16. *Juniperus* pollen is greatly reduced (10%) compared to the previous stratum (30%) in sample 15, but increases slightly to around 15% in sample 16. *Abies* and *Picea* are present, but are only represented by a few grains in these samples.

Pollen and charcoal concentrations change relatively little between samples 14-15, but both values are dramatically higher in sample 16 than all the previous samples, reaching $\sim 70 \times 10^3$ grains/ml and $5,243 \times 10^3$ grains/ml respectively. The dark silty-peats suggest an increased organic content in this stratum, but the depositional environment still seems to be characterized by low energy flow from a nearby spring. The lighter band at 77 cm appears to be subaqueous mud (Rhode, pers. comm. 2007) and given its position in the core, it is likely preserved tephra from the Mazama eruption at around 6,800 BP. Thompson's (1992:9) description of a similar situation in a core from Ruby Valley, Nevada lends support to this conclusion. The moderate increase in pollen concentration values in sample 16 also points to increasingly slow deposition rates.

74-71.5 cm

Sediments in this stratum form a thin (2.5 cm) band of light brown (5Y6/2) clayey silts. No pollen or radiocarbon samples were taken from this stratum, but given the evidence of standing water at 77 cm and the capping of this band of sediment with laminated silty peats suggests another possible period of ponding and subaqueous deposition.

71.5-59 cm

This stratum is relatively thick (11.5 cm) layer of black (5Y2/1) laminated silty peat. Samples 17 (69-68 cm), 18 (65-64 cm), and 19 (60-59 cm) were collected from this stratum in addition to radiocarbon sampling at 65-64 cm (AA78453), which yielded a ^{14}C date of 3,949 +/- 40 (4,406 Cal BP). Non-arboreal pollen drops to around 60%, but rebounds to ~70% samples 18-19, while arboreal pollen contributes 30% before falling to 20%. *Artemisia* and Cheno-Am pollen both slightly decrease in abundance in sample 17, contributing 12% and 40% respectively, but Cheno-Ams decrease dramatically in the samples 18-19. Poaceae pollen contributes only 5% to the pollen total in sample 17, but increases dramatically to 30% by sample 18 and falls to 10% by sample 19. *Sarcobatus* pollen makes a small rebound from less than 2% in sample 16 to 5% in sample 17, increases steadily in sample 18 to a little under 10%, and then spikes at 20% sample 19. *Pinus* and *Juniperus* pollen both increase from the previous stratum, contributing 15% each, with *Pinus* steadily decreasing in the next two samples to ~5% and *Juniperus* decreasing slightly in sample 18 and then increasing to almost 20% in sample 19. *Abies* and *Picea* are also present, but are only represented by a single grain samples 18-19. *Ephedra* is represented in samples 18-19 by a single grain. Asteraceae high-spine and low-spine are also present in very limited amounts (<5 grains) in all of the samples except sample 19, which contains only the low-spine variety.

Pollen and charcoal concentrations decline slightly (57×10^3 and $\sim 29 \times 10^5$) in sample 18 and rebound significantly (228×10^3 and 9×10^6) in sample 19. Charcoal surges again in sample 19, reaching a concentration of almost 21×10^6 . Pollen concentrations decline somewhat by sample 19, but remain higher than any of the samples below at 142×10^3 . These values and the

sedimentary evidence for ponding and low-energy deposition in previous strata may indicate a depositional hiatus or erosional event. The resumption of deposition is reflected in the dramatic increase in charcoal and pollen concentration values at sample 18. That the charcoal continues to increase in the last sample despite the decreasing pollen concentrations is interesting because it indicates that taphonomic processes may not be entirely responsible for this increase, which leaves climate change-induced changes in fire regimes or perhaps even anthropogenic burns as potential explanations. The radiocarbon date of 3,949 +/- 40 ¹⁴C BP date returned by sediments from 65-64 cm also indicates an erosional event/hiatus as the Mazama tephra is located at 77 cm, which suggests this record is missing almost 3,000 years of sediments between 71.5-64 cm. This is a dramatic change from the deposition rate from 77-109 cm, which is closer to 4 cm/year. After the hiatus, the surge in grass pollen and increase in charcoal may be related to a change in the frequency of natural or anthropogenic fires, which would support both increased representation of Poaceae pollen and an increased influx of charcoal while increased grass cover would stabilize soils and depress concentration values overall by improving soil development and stability.

59-47 cm

Starting at 59 cm and ending at 47 cm, the sediments are dominated by a olive gray (5Y4/2) sandy matrix with numerous gastropod shells. Samples 20 and 21 were taken from 55-54 cm and 50-49 cm, respectively. Non-arboreal pollen decreases slightly through these samples, reaching ~60% by sample 21. Arboreal pollen mirrors this pattern, steadily increasing to almost 25% of the pollen sum. *Sarcobatus* continues a dramatic drop off from almost 30% in

the previous stratum to <10% by sample 21, causing an the overall loss in non-arboreal pollen. However, the loss is mitigated by a steady increase in Chenopodiaceae pollen from 30% to around 40% by sample 21 and a relatively sudden increase in Poaceae pollen from around 10% in sample 20 to just short of 20% in sample 21. *Artemisia* continues to decline in abundance slowly, but still contributes > 10% to the total pollen sum. *Juniperus* pollen decreases steadily from almost 20% in sample 20 to about 15% in sample 21 while *Pinus* pollen makes a steady increase from < 10% to ~15% in the same samples. Asteraceae high-spine rises to ~5% in sample 20, but falls to 1% by sample 21.

Pollen and charcoal concentration values decline to levels similar to earlier strata (80-140 cm), falling to around 20×10^3 and 184×10^3 by sample 21. The sudden increase in sediment size and inclusion of gastropods point to an increased hydrological budget and increased sedimentation rates compared to the relatively slow rates of the previous stratum. The number of indeterminate grains increases slightly in these samples, suggesting a slight decrease in preservation. However, this doesn't seem to be significant enough to impact the diversity of taxa represented in these samples. What all of this does represent is a substantial departure in the depositional environment at the core, confirming the other signs of increases in the hydrologic budget.

47-40.5 cm

Sediments from this stratum are dominated by black (5Y2/1) clayey silts in a peat matrix. I collected samples 22 and 23 from this stratum at 45-44 cm and 40-41 cm. The latter sample straddles the next stratum, but this is because it represents a midpoint in what appeared to be a

gradual transition. I also sampled 44-45 cm for radiocarbon assay (AA78454), yielding a date of 3,363 +/- 74 ¹⁴C BP (3,605 cal BP). Non-arboreal pollen increases to 69% in sample 22 but declines slightly to 61% in sample 23, while arboreal pollen starts at 21% and rises to 28% in these samples. The initial gain in non-arboreal pollen is likely tied to a peak in Chenopodiaceae pollen at around 35%, which falls to 23% in sample 23. *Sarcobatus*, *Artemisia*, and Poaceae all decline in sample 22, but Poaceae continues to decrease in sample 23 while *Artemisia* increases to around 15%, although the former is still more abundant at 18%. Asteraceae high-spine rises to almost 5% and low-spines are represented by only a single grain in sample 22, but they switch positions in sample 23 with high-spines being represented by a single grain and low-spines reaching 2% of the total pollen abundance. *Pinus* and *Juniperus* pollen decline in sample 22, but *Pinus* resurges to 18% in sample 23. *Picea* is also present in both of these samples in trace amounts along with *Pseudotsuga*.

Both pollen and charcoal concentrations peak in this stratum. The former rises to 200×10^3 before peaking at 490×10^3 in sample 23 and the latter peaks at 20×10^6 in sample 22 before falling to 3×10^6 . The fine sediments and changes in pollen and charcoal concentrations points to a reduction in the rate of deposition, but the charcoal appears to fluctuate independently in the latter sample. Reduced sedimentation rates would have compressed the chronological record during their occurrence, while the gradual appearance of the transition between this strata and the next may indicate some mixing of the deposits laid down between samples 22 and 23.

Occupation of the nearby Mosquito Willies archaeological site did not intensify until after 2,000 ¹⁴C BP (Young et al. 2008), but Middle Archaic occupations of the site may be at least partially responsible for the sudden fluctuations in the deposition rates, pollen concentrations, and

charcoal influx starting sometime around 3,363 ¹⁴C BP. This possibility is explored further in the next two chapters.

40.5-39 cm

This layer is a 1.5 cm thick band of fine gray (5Y7/2) silt with silica spindles. This layer was partially sampled by sample 23, and the increased concentration values in that sample may be linked to the development of standing water at the coring site when these sediments were deposited.

39-31 cm

This stratum is made up of clean gray-brown (2.5Y5/2) aeolian sand with abundant broken gastropod shells that grades into a gray (2.5Y3/2) peaty sand at around 35 cm. I collected pollen samples 24 (38-37 cm) and 25 (33-32 cm) from this stratum. Non-arboreal pollen decreases somewhat before rising to around 60% of the total pollen in sample 24. Arboreal pollen increases slightly and then drops to around 30% of the total pollen in the same samples. Aquatic pollen appears in this portion of the core, but it only makes up around 1% of the total pollen. Roots intruding into these sediments may have introduced a small fraction of foreign pollen from overlying sediments. Chenopods and Poaceae both change relatively little in these samples, maintaining at around 28% and 18% respectively. *Atremisia*, on the other hand, increases rather dramatically by sample 25. *Juniperus* increases to around 15% in sample 24, but declines slightly with *Pinus* in sample 25 to 13% and 11% respectively. Some *Picea* grains were also present in both samples.

Concentration values for pollen and charcoal both increase slightly in both samples, but values are similar to those at 80 cm, reaching only as high as 45×10^3 for pollen and 12×10^5 for charcoal. The abrupt change in concentration values and sediment sizes may indicate some level of disturbance in these sediments, which may depress pollen concentrations by destroying pollen grains via reworking of the sediments. This process may also explain the damage to the gastropod shells. The pollen recovered from these sediments, however, did not show substantial damage, suggesting that rapid deposition of these sediments is the more likely cause for the shifts in pollen and charcoal concentrations. The resumption of peat development in the upper half of this stratum also points to a shift in depositional environments at the coring locality.

31-27 cm

This layer is another sudden interruption of grayish-brown (2.5Y5/2) aeolian sand into the sedimentary sequence. No samples were taken from this stratum, but this stratum is capped by sandy peats at 27-21 cm and appears to be another high-energy depositional phase (aeolian) followed by a relatively lower-energy peat development.

27-21 cm

This layer of gray (2.5Y3/2) peaty sand caps what appears to be a cycle of aeolian interruption between periods of peat development and I collected sample 26 from 25-24 cm. Non-arboreal pollen decreases to around 60% while arboreal pollen increases to 31% of the pollen sum. Although Chenopods are relatively stable at 29% and *Sarcobatus* increases slightly to 5%, Poaceae and *Artemisia* pollen declines substantially to 9% and 16% respectively.

Asteraceae high-spine and *Pseudotsuga* are also present, represented by 3 and 2 grains, respectively. *Juniperus* continues to decline, reaching 6%, while *Pinus* pollen increases to 20%. *Abies* and *Picea* are both present as single grains.

Pollen concentrations decline slightly to 38×10^3 , but charcoal increases to 4×10^6 . Despite this divergence, these concentrations are moderate compared to those in sample 23. These sediments, as described above, represent the resumption of peat development after a period of more rapid aeolian deposition. The incorporation of sand sized sediments in the peat from this layer and at 35-31 cm may indicate that peat development was sudden, and that the resumption of aeolian deposition was equally sudden. The overall slight increase in pollen concentration values compared to sample 24 suggests some limited reduction of the deposition rate during the periods of peat development.

21-0 cm

The stratum that extends to the present is a dark brown peat (5Y2/1) with numerous roots. Samples 27 (20-19 cm), 28 (16-15 cm), 29 (10-9 cm), and 30 (5-4 cm) were collected from this unit. A single radiocarbon sample (AA78452) from 16-15 cm yielded a ^{14}C date of 1,509 \pm 38 BP (1,417 cal BP). Pollen abundances are volatile in this stratum, with non-arboreal pollen falling dramatically to ~40% in sample 27, rising to 63% again in sample 28, and falling to 52% and 21% in samples 29-30. Arboreal pollen fluctuates less wildly, steadily declining to 24%, 18%, 10%, and 7%. The source of the fluctuations is two-fold. First, the inclusion of substantial amounts of aquatic pollen; which spikes to 32% in sample 27, declines to 18% and 10% from samples 28-29, and finally spikes again in sample 30 at 70%, distorts the local pollen signature

somewhat. Also, there is a surge in indeterminate pollen grains in samples 28-29 to 10% and 20%, which may indicate a period of poor preservation conditions like wet-dry cycles, so these samples must be considered with some caution.

The initial dramatic loss in non-arboreal pollen is also the result of moderate reductions in *Artemisia* and Poaceae to 12% and 4% and a sudden reduction in Chen-Ams to 15% in sample 27. Asteraceae low-spine increases to 3% and a single grain of *Pseudotsuga* and *Ephedra* are present in samples 27-28, and an additional *Ephedra* grain is present in sample 29. Poaceae and Chen-Am pollen rebounds in sample 28, rising to 25% and 21% respectively, but Poaceae falls again to 3% in samples 29-30. Chen-Am pollen continues to increase in sample 29, peaking at 36% and falling to 9% in sample 30. Asteraceae high-spine reaches 7% in sample 28 and 4% in sample 30. *Sarcobatus* remains a minor component at around 3% through the entire stratum. *Pinus* and *Juniperus* pollen decreases steadily through these samples from 15% and 7% to 3% and 4% by sample 30. Aquatic pollen is represented by Cyperaceae and *Typha*, which spike to 22% and 10% in sample 27, drop again to 10% and 0% in sample 28, rise slightly to 15% and 3% in sample 29, and finally spike again at 51% and 20% in sample 30.

Pollen concentrations rise in samples 27-28 to 72×10^3 and 146×10^3 , plunge to 4×10^3 in sample 28, and rise again to 102×10^3 by sample 30. Charcoal concentrations increase dramatically in sample 27 to 20×10^6 , rise again to $\sim 24 \times 10^6$ in sample 28, and then decrease in samples 29-30 to 16×10^6 and 4×10^6 respectively. The changes in Chen-Ams and Poacea in sample 29 may be related to their relative durability under harsh conditions, in which case Chen-Ams would be much better represented. The presence of aquatic types suggests that

wetlands formed at the coring site, but may have been interrupted by a pulse of high charcoal and Chen-Ams before wetland development expanded in sample 30.

Statistical Analysis

In order to better understand the ways in which plant taxa represented by the pollen recovered from the Mosquito Willies core vary, I performed a principal components analysis of pollen percentages for all terrestrial taxa (Table 3.2) and regional taxa (Table 3.3). I used the analytical software R to perform the analysis and draw the plots (Figures 3.4-3.5). What this analysis establishes is dimensions of variability in which the taxa themselves may positively or negatively co-vary, which indicates how the changes in the pollen abundances for each taxa may be related to each other and how they change through time.

Terrestrial taxa produced 12 principal components, the first two of which represent 58% of the variability in the terrestrial pollen results (Table 3.2). Component three represents 14% of the variability. Components 4 through 12 make up only 26% of the variance cumulatively, so they are left out of this discussion. The first component shows a tendency to have high percentages of *Pinus* and Poaceae pollen and low representation of Chen-Ams (Figure 3.4). The second component is made up of higher scores for *Artemisia* and *Pinus* with lower scores for *Sarcobatus* and Poaceae while the third component is defined by greater abundances of *Artemisia* and *Sarcobatus* pollen with as lesser representation of *Pinus* (Figure 3.4). The opposing loadings of *Pinus* and Poaceae compared to Chen-Ams on the first component may be because cool intervals favor increased representation of Poaceae and *Pinus*, while dry intervals

PRINCIPAL COMPONENTS: TERRESTRIAL TAXA

Importance of Components

	PC1	PC2	PC3	PC4
Standard Deviation	0.132	0.0990	0.0836	0.0657
Proportion of Variation	0.374	0.2120	0.1511	0.0933
Cumulative Proportion	0.374	0.5860	0.7370	0.8303

Component Loadings on Variables

	PC1	PC2	PC3	PC4
<i>Artemisia</i>	0.025534	0.552409	0.687632	-0.291433
Asteraceae High-spine	-0.017932	-0.001785	-0.032891	0.056916
Asteraceae Low-spine	0.004627	0.039626	0.070897	-0.020653
Cheno-Ams	-0.83828	-0.163408	-0.114596	-0.442904
Ephedra	-0.005794	0.016773	0.001371	0.008352
Poaceae	0.39335	-0.521607	-0.005297	-0.569134
<i>Sarcobatus</i> sp.	0.087427	-0.55963	0.506496	0.163567
<i>Pseudotsuga</i> sp.	-0.000947	0.003492	-0.00477	-0.006366
<i>Abies</i> sp.	0.020733	0.05694	0.015778	-0.045889
<i>Juniperus</i> sp.	-0.002083	0.004238	-0.252898	0.436863
<i>Picea</i> sp.	0.01001	0.022219	-0.044109	-0.00167
<i>Pinus</i> sp.	0.365179	0.27796	-0.430326	-0.414126
Standard Deviation	0.131569	0.099066	0.083647	0.065728

Table 3.2. Results of principal components analysis of terrestrial taxa. Bolded results are those that are incorporated into building plots for Figure 3.4 and interpretations of environmental variability represented by each component.

favor the growth of Cheno-Ams. The second component suggests a great deal of the variation is determined by the timing of rainfall, *Artemisia* and *Pinus* loading positively because they perform better with winter moisture, while *Sarcobatus* and Poaceae are more competitive in summer-dominated moisture regimes. Component three indicates that the amount of moisture is also relevant, though less important than temperature or timing of rainfall, with higher abundances of *Sarcobatus* and *Artemisia* being common in dry regimes and *Pinus* and *Juniperus* being more competitive wetter intervals.

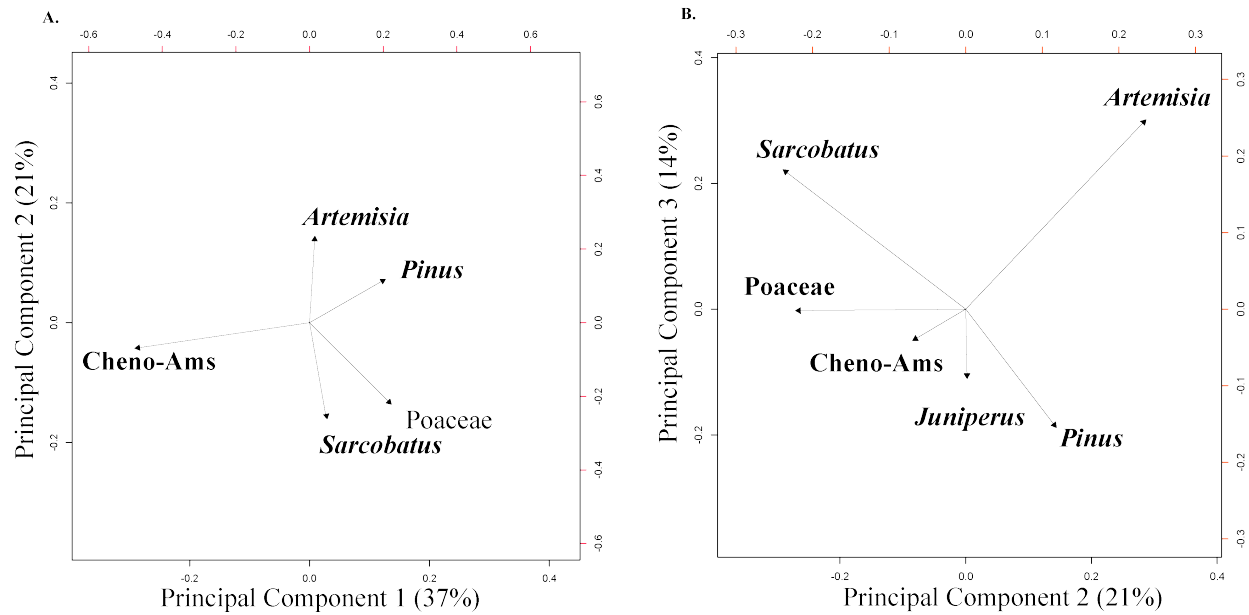


Figure 3.4 Plot of eigenvalue loadings on components 1-2 (A) and 2-3 (B) for terrestrial pollen taxa.

However, the importance of Poaceae and *Sarcobatus* in all three of the components may also reflect local disturbances in the vegetation, because these types distribute pollen locally. Drying cycles could inflate the importance of these types as the spring dried and grasses and greasewood colonize the area around the coring location. Anthropogenic burning could also be responsible for increased representation of these types, especially in the second component where *Artemisia* and *Pinus* would be less competitive under aboriginal burning regimes (Miller and Wigand 1994; Ulev 2008). I explore this possibility further in the next chapter.

A clearer picture of the development of modern plant communities might be possible by focusing on variability in regional taxa separately. This is especially important because it allows replication of analysis performed on the Blue Lakes core (Louderback and Rhode 2009), which used principal components analysis as well. I limited the taxa in the analysis to those used by Louderback and Rhode (2009), using their percent contribution to the regional pollen sum to

PRINCIPAL COMPONENTS: REGIONAL POLLEN TAXA

Importance of Components

	PC1	PC2	PC3	PC4	PC5
Standard Deviation	0.125	0.0849	0.0677	0.0613	0.01518
Proportion of Variation	0.498	0.2292	0.1457	0.1193	0.00733
Cumulative Proportion	0.498	0.7276	0.8733	0.9927	1.00000

Component Loadings on Variables

	PC1	PC2	PC3	PC4	PC5
Artemisia	0.115685274	-0.96413984	0.12459338	-0.19751579	0.05015257
Asteraceae high-spine	-0.015356793	0.0369938	-0.05176713	0.03972974	0.99720549
Cheno-am	-0.89974153	-0.04743399	0.43326601	-0.01932626	0.01105688
Juniperus	0.002305756	0.20007513	-0.01771504	-0.97920077	0.0285773
Pinus	0.420524612	0.16395083	0.890934	0.0191726	0.04611955
Standard Deviation	0.12519561	0.08490658	0.06771461	0.06126485	0.0151822

Table 3.3 Results of principal components analysis for regional pollen taxa. Bold numbers are results utilized in plotting taxa loadings on principal components.

perform another principal components analysis (Table 3.3), which defined five dimensions of variability. The first and second component explain 50% and 23% of the variance respectively. The other three components account for only ~27% of the total variance, with over half of that being in the third component (14%), so these components are not discussed below. Within the regional taxa, the first component is a negative covariance between increasing *Pinus* abundances and much lower abundances of Cheno-Ams. The second component is made up of moderate increases in the abundance of *Juniperus* and, to a limited extent, *Pinus*, with slight increases in *Pinus* and a much lower abundance of *Artemisia*.

Plotting the taxa based on their eigenvalue loadings (Figure 3.5) suggests that though *Pinus* and *Juniperus* are closely allied in modern plant communities the trees do not covary as a unit. The first component appears to indicate the impacts of temperature on the abundance of

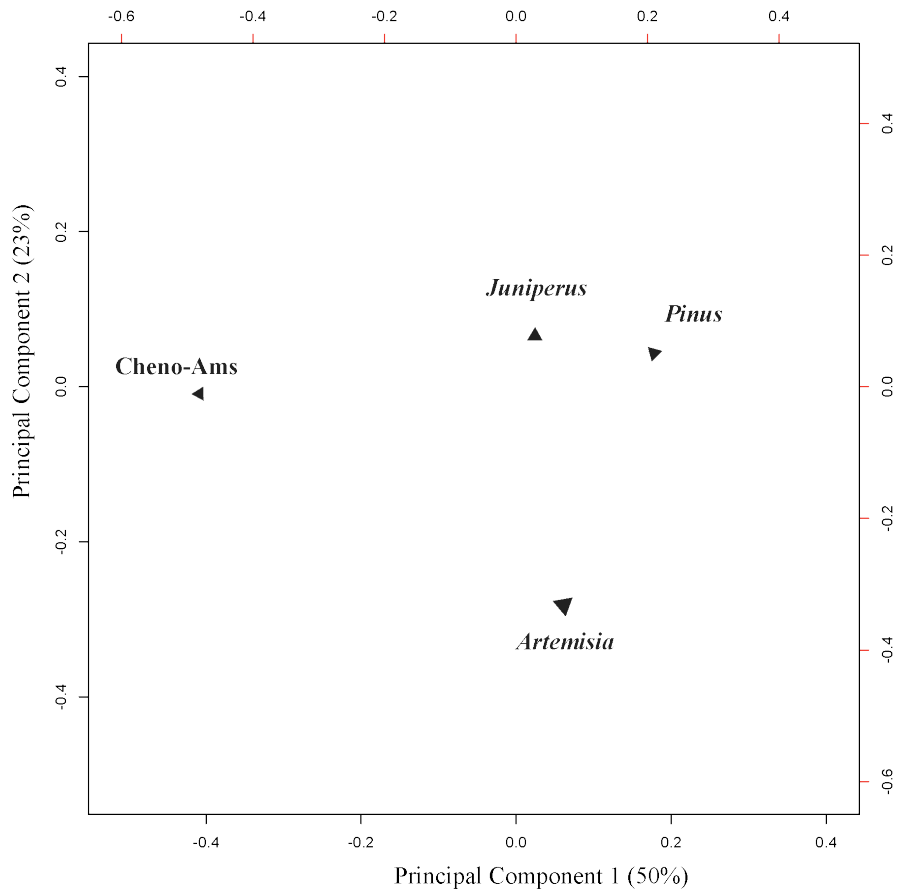


Figure 3.5 Plot of eigenvalue loadings on regional components 1-2 for regional pollen taxa.

Cheno-Ams and *Pinus*, primarily, with the latter and *Artemisia* being more competitive in cool regimes than Cheno-Ams. The second component illustrates the importance of moisture for regional taxa, favoring *Juniperus* primarily, though *Pinus* has a small positive loading on this component as well while *Artemisia*, which prefers drier conditions, is negatively loaded on this component. These dimensions aid in thinking of prehistoric environments and their relationship to climate change in multiple dimensions, where the vegetation expressed on the landscape is responding to a combination of temperature, moisture, timing of precipitation, and local processes like disturbance/colonization cycles.

Conclusions

The Mosquito Willies core contains a nearly 8,000 year record of vegetation change for the Bonneville Basin. Pollen, charcoal, and sedimentary evidence show fluctuations that are related to changes in the hydrologic budget of the region and depositional environment at the coring location. Principal components analysis of the pollen results shows that changes in the abundance of pollen taxa in the core are related to changes in three primary dimensions. The adaptations of plants represented in the principal components suggests that fluctuations in pollen from the time spans represented in the Mosquito Willies core are primarily driven by shifts in temperature and the seasonal timing of precipitation. Some variability in taxa seems to be responding to changes in the amount of precipitation, but this effect is marginal compared to the first two components. A probable exception to this trend is the depositional hiatus at around 70 cm, which is probably driven by drying.

In the next chapter, I utilize statistical methods to distinguish zones of variance and sub-patterns. Using these zones and the principal components established in this chapter, I describe changes through time in each zone and then compare these results in light of other paleoenvironmental records, especially the results from Blue Lakes (Louderback and Rhode 2009).

CHAPTER 4: SYNTHETIC RECONSTRUCTION AND DISCUSSION

This chapter uses the results from the previous chapter and other environmental records to create a synthetic reconstruction of Bonneville Basin environments through the Holocene. Paleoenvironmental interpretations of the pollen data require a consideration of local and regional pollen representation in addition to the depositional contexts and relative chronology of the samples. I identified three zones (I, II, and III) and two sub-patterns of variable lengths (*a*, *b*) using zonation methods available in PSIMPOLL. I discuss the general climatic features, chronology, and variability manifested in each zone that characterize specific changes in environmental variables. These broad patterns closely mirror standard chronological divisions within the Holocene (i.e., Early, Middle, and Late) but also identify variability within these periods, which I will refer to as early Middle Holocene and early Late Holocene. Individual samples are plotted based on their scores from the principal components described in chapter 3 (Figure 4.2) in order to monitor changes in dimensions of variability through time. Comparative data from additional paleoenvironmental records in other portions of the Great Basin, especially palynological evidence from a sediment core from nearby Blue Lake are utilized to support the synthetic reconstruction discussed below. Fluctuations in the influx of pollen and charcoal become a part of these discussions only after the Middle Holocene because charcoal concentrations are uniformly low during the Early Holocene. Finally, I discuss how these

changes relate to the development of modern plant communities through the Early, Middle, and Late Holocene.

Zonation Analysis

In order to ensure robust results, I used both CONCISS and Optimal Splitting (OS) methods for creating zones. CONCISS analysis uses clustering methods to group like samples,

Results of Zonation Analyses of Mosquito Willies Samples

<u>SAMPLE</u>	<u>Zones Defined</u>	<u>Increase in Dispersion</u>	<u>Within-Total Dispersion</u>	<u>Residual Variance</u>	<u>% of Total Variance</u>	<u>Zones and Sub-Patterns</u>
4cm	X-10	0.004173	0.015651	0.0553	0.0601	IIIb
15cm						
19cm						
24cm	X-9	0.002313	0.057575	0.0892	0.0970	IIIa
32cm						
37cm	X-8	0.014324	0.055565	0.1151	0.1252	IIb
40cm	X-7	0.004117	0.008280	0.1450	0.1578	
44cm	X-6	0.003198	0.011478	0.1830	0.1991	
49cm						
54cm	X-5	0.004392	0.020043	0.2049	0.2229	
59cm						
68cm						
74cm						
80cm	X-4	0.094258	0.152135	0.2743	0.2984	IIa
84cm						
90cm	X-3	0.008757	0.041241	0.3372	0.3669	I
94cm	X-2	0.012441	0.032484	0.4241	0.4614	
99cm	X-1	-	-	0.9192	1.0000	
101cm						
101cm						
120cm						
125cm						
132cm						
140cm						
144cm						
149cm						

Table 4.1 Results and selected summary statistics from CONCISS and Optimal Splitting methods and Zones in addition to the zones, sub-patterns, and the samples discussed in this chapter. Bolded numbers are associated with *p* values of < 0.05 in the CONCISS analysis.

Mosquito Willys Pollen Profile

Analyst: Chris Kiahtipes

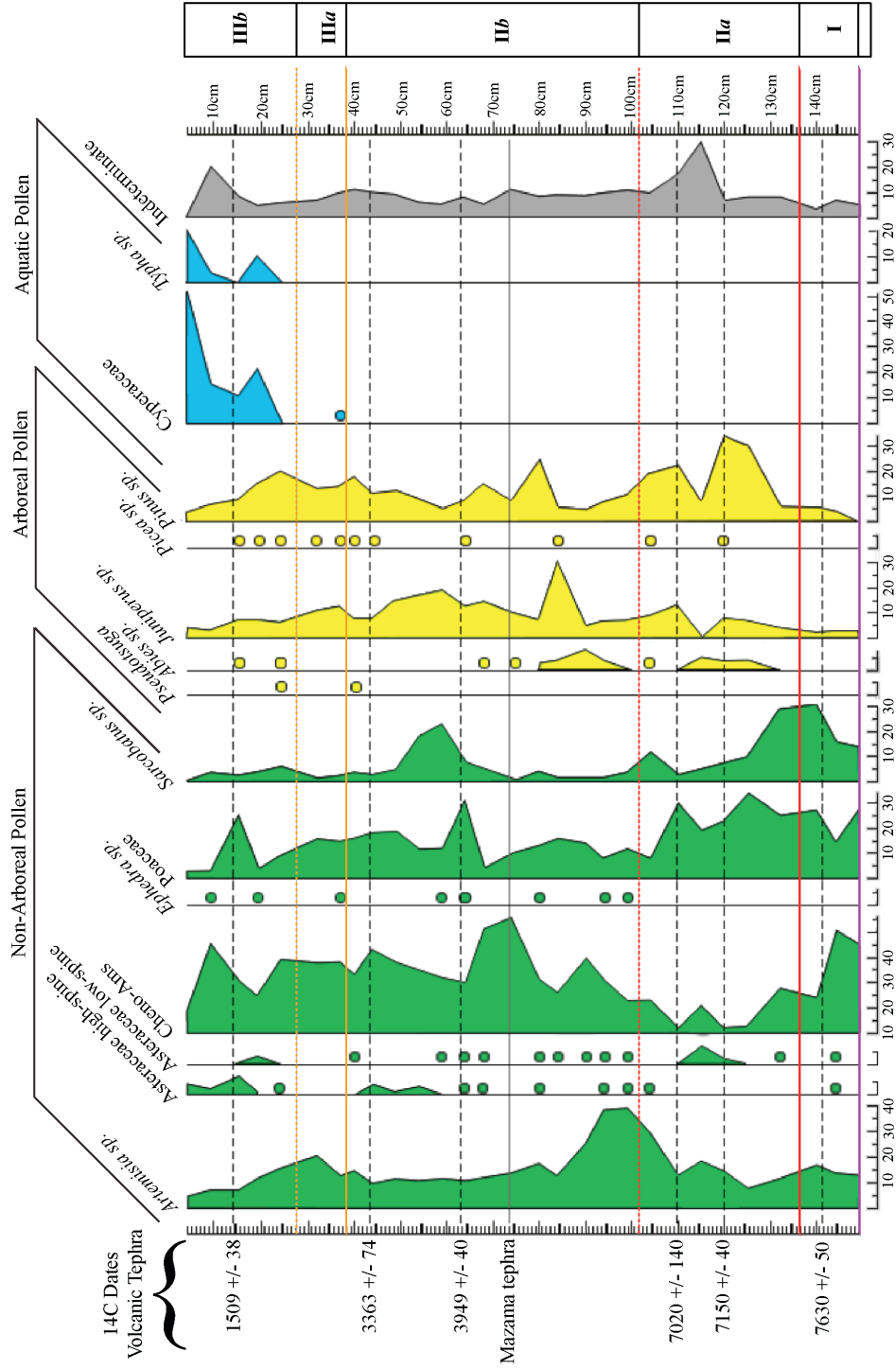


Figure 4.1 Pollen percentage diagram showing Non-Arboreal (green), Arboreal (yellow), and Indeterminate pollen abundances. Radiocarbon dates and tephras layers are presented on the left side, marked by dashed lines and a solid gray line. Zones (solid colored lines) and sub-zones (dotted colored lines) identified using PSIMPOLL are highlighted in purple (I), red (II), and blue (III) in addition to being listed on the right-hand side of the diagram.

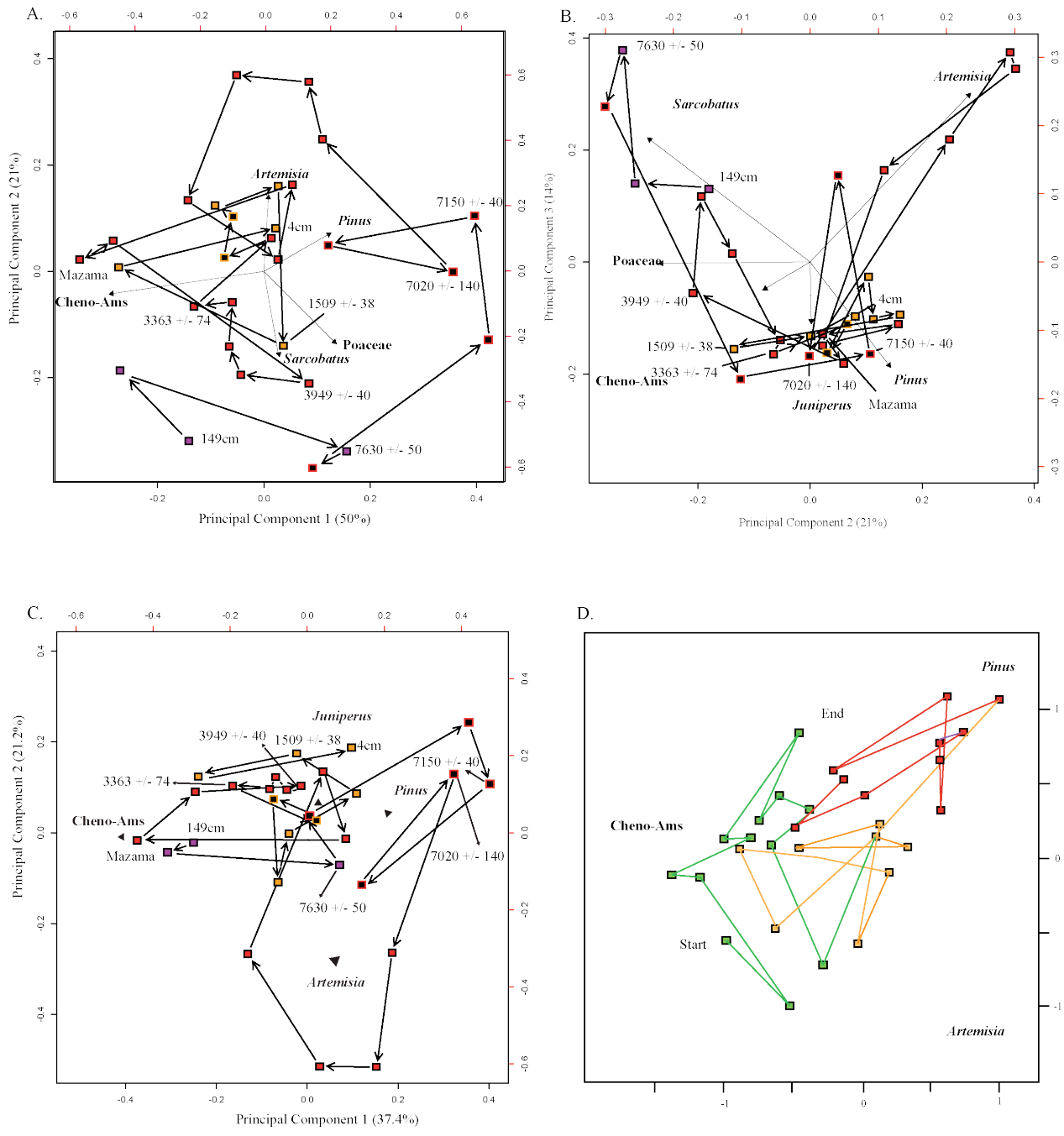


Figure 4.2 Plots of sample loadings on principle components 1-2 (A) and 2-3 (B) for terrestrial pollen taxa and 1-2 (C) for regional taxa from Mosquito Willies. Regional taxa from Blue Lakes (Rhode and Louderback 2009) are presented as a comparison (D). Taxa names are plotted based on their eigenvalue loadings (e.g. x = eigenvalue loading for principal component 1, y = eigenvalue loading for principal component 2) from Chapter 3. Individual samples (represented by colored squares) are plotted in a similar fashion, with associated chronological markers noted next to sample squares, in addition to assignments to zone I (purple), zone II (red), and zone III (orange) which are discussed in the text. Filled squares with colored borders represent sub-patterns IIa and IIb. Samples proceed upwards stratigraphically following the arrows. Assignments for D are based on chronology built by Louderback and Rhode (2009), representing 9,000 - 6,600 BP (green), 6,600 - 3,700 BP (orange), and 3,700 - 1,000 BP (red).

while OS uses a measure similar to the sum of squares to split samples into groups according to reductions in variance. Results from the analysis and summary statistics are presented in Table 4.1. Both methods were used to define 10 zones and CONCISS methods showed three significant ($p = 0.05$) clusters of samples, which match values for reductions in variance measured by the OS method. Both methods resulted in identical results for significant and non-significant zones alike, even when samples with questionable concentration values or indeterminate pollen grain percentages were included. Although the sub-zones I use here are not statistically significant, they do characterize the greatest reductions of variability (according to the OS analysis) by splitting zones. An overlay of the zones and sub-patterns I use in this reconstruction on the pollen diagram from the previous chapter is available in Figure 4.1. Additional detail is added to this reconstruction by plotting individual samples from each zone according to their loadings on components 1-2 (Figure 4.2:A) and components 2-3 (Figure 4.2:B) for terrestrial taxa. The same approach is used for components 1-2 for regional taxa (Figure 4.2:C), which facilitates a direct comparison with analysis of the Blue Lakes core (Figure 4.2:D) which utilized the same methods (Louderback and Rhode 2009).

Zone I

Zone I extends from 149 - 136 cm and is characterized by a dominance of non-arboreal pollen taxa. Chronologically, this pattern characterizes a time interval from the termination of Gilbert shoreline deposits ($< 10,000$ ^{14}C BP) to about 7,600 ^{14}C BP, which covers the Early Holocene - Middle Holocene transition. Zone I captures almost 70% of the variance in the

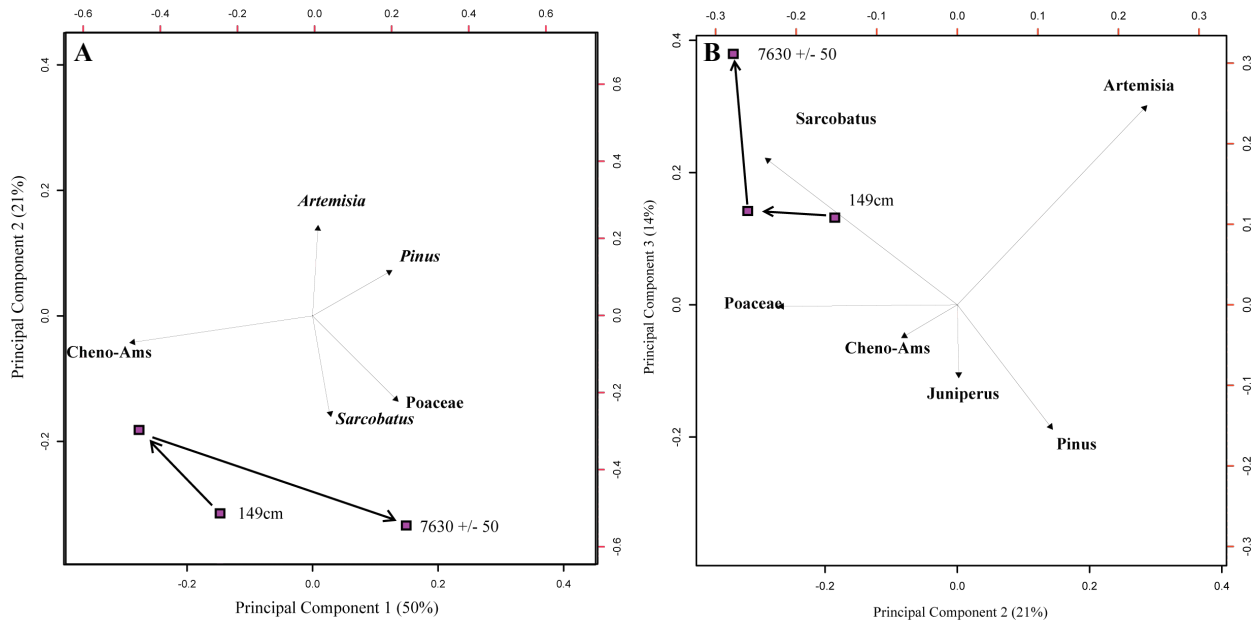


Figure 4.3 Sample loadings for zone I on principal components 1 (A) and 2 (B) for terrestrial taxa.

samples, despite the relatively few numbers of samples represented in this zone. Plots of the sample loadings on principal components shows that most of this variability takes place along component 1 for terrestrial taxa, which move to highly negative values initially and but move to positive values by 136 cm (Figure 4.3:A). These samples also show progressively higher loadings on component 3 for terrestrial taxa (Figure 4.3:B). Regional components show a similar pattern (Figure 4.2:C), with loadings on component 1 becoming gradually more positive. Although sample loadings from Blue Lakes shows more variability in both components 1 and 2, they show a similar trend towards lower loadings on component 1 (Figure 4.2:D).

Samples from zone I have component loadings that suggest expansions of grass cover and greasewood-scrub, which may reflect the colonization of habitats opened by the regression of the Great Salt Lake and the upward migration of limber-pine woodlands triggered by Early Holocene drying. These data generally match evidence for increasing aridity in the Homestead Cave fauna dating to this time interval (Grayson 2000a, 2000b; Hunt et al. 2000; Schmitt et al.

2002), and pollen records from the region (Louderback and Rhode 2009; Thompson 1992). Broughton et al. (2008) suggest that the Early Holocene temperature and precipitation distributions were highly variable, which depressed artiodactyl populations in the region until the Middle Holocene. This conclusion is supported by the results of the CONCISS and OS analyses, which show that samples from the Early Holocene to Middle Holocene transition (~9,000 – 7,500 ¹⁴C BP) are more variable than samples from later in the Holocene.

Zone II

Zone II is by far the largest zone, extending from 136 – 38.5 cm and dating to 7,500 – 3,300 ¹⁴C BP. However, the erosional event just after 6,900 ¹⁴C BP (~75 cm) created a nearly 3,000 year gap in the Mosquito Willies pollen record. In total, this zone captures around 22% of the variance in the core, with most of that falling into sub-pattern II*b* (~10%). Sub-pattern II*a* spans from 7,600 – 7,000 ¹⁴C BP, characterizing early Middle Holocene expansions of grasses, greasewood-scrub, and rocky mountain juniper in addition to the migration of pinyon pine into the region. Sample loadings on principle components 1-2 (Figure 4.4:A) suddenly shift to being positively loaded on both components, while component 3 (Figure 4.4:B) shows an equally sudden shift to negative values. Regional component loadings for samples falling into II*a* become highly positive on component one as well with slightly greater positive loadings on component two, similar to the results from Blue Lakes (Figure 4.2:C-D).

Regionally, shadscale-scrub and Chenopod-dominated scrub communities expand dramatically at the expense of sagebrush scrub and grass communities in the lowlands at the

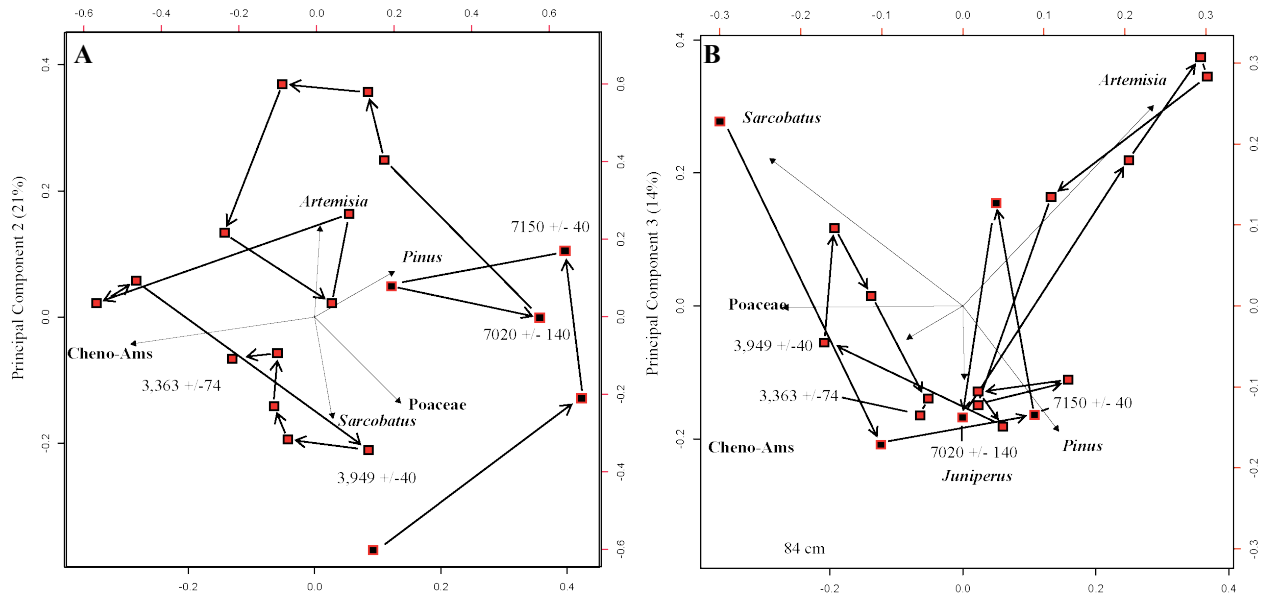


Figure 4.4 Sample loadings for zone II on principal components 1 (A) and 2 (B) for terrestrial taxa. Filled boxes with colored borders represent samples from sub-pattern IIa.

onset of the Middle Holocene (Rhode 2000; Thompson 1990; Wigand and Rhode 2001). Pinyon pine and Rocky Mountain juniper expand during the Middle Holocene, displacing subalpine conifers in Bonneville Basin uplands (Rhode 2000; Thompson 1990). These expansions of pinyon pine and Utah juniper took place at different times, with pinyon pine and Rocky Mountain juniper expanding early in the Middle Holocene, which Rhode (2000:157) interprets as an indication of increasing summer moisture (see also Thompson 1994; Wigand and Rhode 2001). Homestead cave flora and fauna show a marked drying trend during the early Middle Holocene (Madsen et al. 2001; Grayson 2000b). Together, these lines of evidence indicate a shift from cool wet conditions first to cool dry conditions, then to warm dry conditions by around 6,000 BP (Rhode 2000; Thompson 1984, 1990; Wigand and Rhode 2001), although Louderback and Rhode (2009:323) find more evidence for a sudden switch to dry and warm conditions in the Middle Holocene.

Sub-pattern *IIb* spans from 101.5 cm through the discontinuity at 69 cm and ends at 38 cm, just after 3,300 ¹⁴C BP. This sub-pattern defines a period of increasing aridity which may have reached a maximum at a little after 6,900 ¹⁴C BP, with the resumption of sedimentation at 3,900 ¹⁴C BP representing the return of monsoonal summer-storm patterns to the area. Charcoal and pollen concentrations spike at around 3,900 ¹⁴C BP in response to the increases in moisture and increased numbers of lightning strikes during summer storms, although anthropogenic burning may also be responsible. A second spike in pollen and charcoal concentrations at around 3,300 ¹⁴C BP takes place during the onset of cool conditions at the beginning of the neoglacial (Rhode 2000). The connection between charcoal fluctuations and human activity is discussed in more detail in the next chapter.

Sample loadings on principal components 1-2 for terrestrial taxa (Figure 4.4:A) show an almost cyclic pattern, with sample loadings moving from neutral to highly positive and back to neutral for component one. Loadings on component two move from being positive to neutral loadings near the Mazama tephra, and finally falling to moderately negative loadings by 3,900 ¹⁴C BP before adjusting to more neutral values at 3,300 ¹⁴C BP. Early in *IIb*, sample loadings on component three are fairly tightly clustered, but quickly move to highly positive values after 7,000. Regional component loadings (Figure 4.2:C) show a substantial drop to highly negative loadings on component 2 and neutral loadings on component 1. Although there is no one-to-one correlation between the samples analysed here and the Blue Lakes core, their samples show a similar shift in component loadings, indicating an expansion of sagebrush, followed by spikes in shadscale-scrub and greasewood-scrub vegetation cover followed by the erosional event triggered by increasing aridity.

This pattern agrees with a general trend towards increasing aridity and the emergence of modern environments visible elsewhere in the Bonneville Basin (Wigand and Rhode 2001; Thompson 1990). Additional evidence from throughout the Bonneville Basin indicates increased aridity during the early portion of the Middle Holocene, but temperatures appear to have cooled and precipitation increased after 6,000 ¹⁴C years BP until around 5,000 ¹⁴C years BP (Rhode 2000:157; Wigand and Rhode 2001:351), although this time span is not represented in sediments from Mosquito Willies. Increased representation of artidactyl fecal pellets at Homestead cave from this time period may support this conclusion (Hunt et al. 2000:55; Madsen et al. 2001:264) and indicate an increased influx in moisture. Increases in pine pollen in central Nevada at around 6,000 ¹⁴C BP (Madsen 1985:123) and sediment changes in Ruby Valley, Nevada (Thompson 1992) indicate a break in Middle Holocene aridity at ~ 6,000 BP, followed by another dry interval by 4,400 ¹⁴C BP (Madsen et al. 2001; Thompson 1984). The resumption of sedimentation at the coring location represents the onset of cool/wet conditions at the beginning of the neoglacial climatic episode, although Rhode (2000) suggests that conditions may have been “not quite so cool and wet as the Early Holocene itself” (p.159).

Zone III

Zone III characterizes samples from 38 - 4 cm, which fall between 3,300 ¹⁴C BP and present. The variance in zone III is less dramatic than the other zones (~6%), especially since aquatic pollen was not included in the zonation analysis because of the possibility that these types may be responding to anthropogenic impacts like diversion dams (described by Rhode,

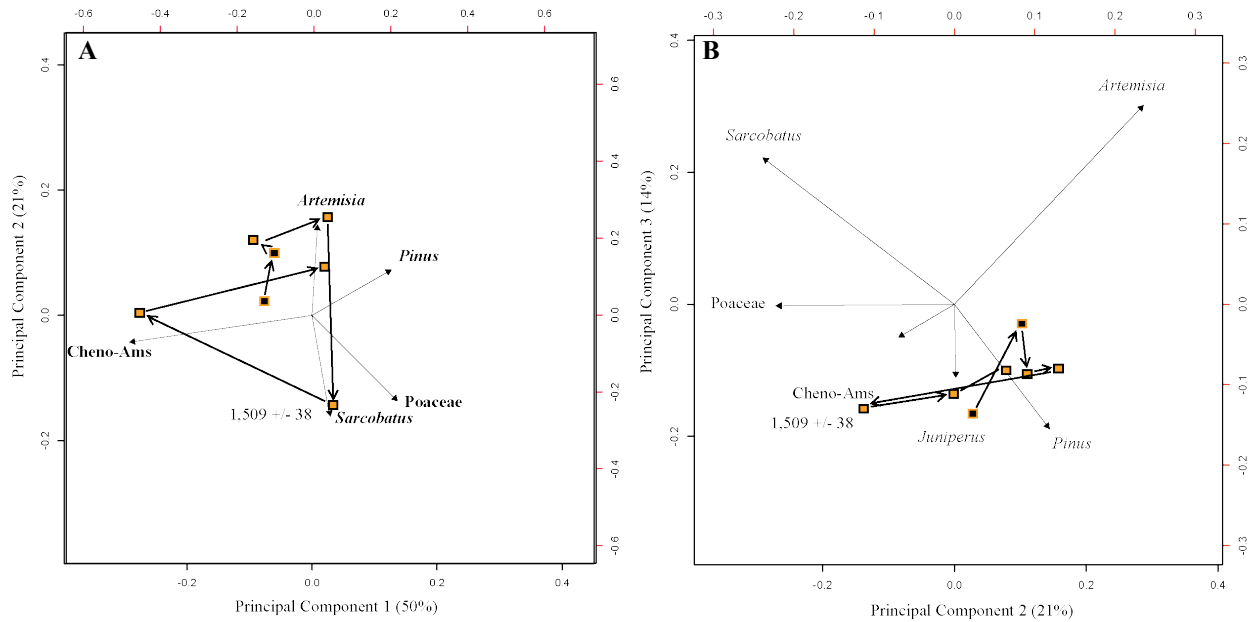


Figure 4.5 Sample loadings for zone III on principal components 1 (A) and 2 (B) for terrestrial taxa. Filled boxes with colored borders represent samples from sub-pattern IIIa.

pers. comm. 2007), although climatic events clearly encouraged the appearance of aquatic pollen in the core. Despite that qualification, the neoglacial cooling event is still well-represented by a general increase in arboreal pollen and reductions in thermophilic types. Sub-pattern IIIa captures this event best, extending between 38 - 28 cm, which appears to represent 3,300 - 2,000 ^{14}C BP. Utah juniper and pinyon pine increase in abundance and sagebrush-steppe expands, with simultaneous losses in grass and greasewood-scrub cover. Sample loadings are tightly clustered, but shift from neutral loadings to moderately positive values on component 2 and fluctuate between negative and neutral values for component 1 (Figure 4.5:A). Sample loadings on component 3 (Figure 4.5:B) show only minor fluctuations throughout zone III, with a small fluctuation towards neutral values during in sub-pattern IIIa. Sample loadings on regional components (Figure 4.2:C) show nearly uniformly neutral loadings on component 1 and fluctuate between slightly negative and slightly positive values on component 2. Modern plant

communities and distributions emerge in the Bonneville Basin because of the drastic environmental fluctuations during this time period (Wigand and Rhode 2001). Madsen et al. (2001) describe the latter portion of this period as “one of the most dramatic of any in the Bonneville basin during the Holocene” (p.266). These conditions encouraged the growth of Utah juniper at lower elevations than its present distribution (Rhode 2000:159; Wigand and Rhode 2001:351) and an increase in sagebrush-steppe vegetation in Great Basin lowlands (Louderback and Rhode 2009:324; Thompson 1992:12), indicating increases in effective moisture and cooler conditions as reflected by the low loadings on component 3 (Figure 4.5:B). The relationship between these samples and other Late Holocene environmental records is considered in more detail at the end of the next section.

Sub-pattern III*b* shows the greatest changes in sample loadings on principle components for terrestrial taxa and major fluctuations in pollen and charcoal concentrations. Charcoal concentrations are generally very high in these samples, persisting through dramatic vegetation changes before and after 1,500 ¹⁴C BP, which are certainly connected to human activity in the area, but also represent increases in summer storm activity at 1,500 ¹⁴C BP. Samples fluctuate between neutral and strongly negative scores on component 1, while scores on component 2 fluctuate between moderately positive and moderately negative values (Figure 4.5:A-B). Sample loadings on regional components fluctuate between slightly positive and moderately negative on component 1 and shift only slightly from neutral to slightly positive values on component 2 (Figure 4.2:C). Sample loadings from the Blue Lakes analysis show a similar pattern of more dramatic fluctuations along component 1 than component 2 (Figure 4.2:D). These shifts indicate

expansions of grass and greasewood cover followed by an expansion of shadscale-scrub after 1,500 ¹⁴C BP.

Pollen from Fossil pollen from the Blue Lakes core shows ponding episodes at ~2,600 cal BP and ~1,000 cal BP interrupted by a spike in Poaceae pollen (Louderback and Rhode 2009:320), which may match the spikes in aquatic pollen and Poaceae from IVb. Other records show the return of fish to raptor deposits at around 2,000 ¹⁴C years BP (Broughton 2000), increasing abundances of mesophilic fauna (Grayson 2000b), expansion of Bison populations (Grayson 2006b; Schmitt and Lupo 2005), and the expansion of mesophilic plants like hackberry and Utah juniper (Rhode 2000:159; Wigand and Rhode 2001). Increases in summer moisture are indicated by a shift to negative sample loadings on component 2 (Figure 4.6:A), supported by increasing artiodactyl fecal pellets in Late Holocene deposits in Homestead Cave and an increase in grassland cover as a result of increasing monsoonal moisture (Broughton et al. 2008; Grayson 2006b; Hunt et al. 2000:55), which may have supported the movement of agriculture into the region (Madsen et al. 2005; Rhode 2000; Simms 2008). Lake fluctuations occur in the Sevier basin at 2,500 ¹⁴C years BP (Benson et al. 1990:259) and in western Nevada at 2,600 ¹⁴C BP (Briggs et al. 2005). The Late Holocene fluctuates between warmer intervals at ~2,600 cal BP and ~1,800 cal BP and mesic intervals at ~2,200 cal BP and ~1,400 cal BP (Louderback and Rhode 2009:324). Although the last 1000 years have been characterized by relatively dry conditions (Madsen et al. 2001:267), the onset of the “Little Ice Age” at around 500 BP is associated with a short period of dramatic cooling that caused flooding in the vicinity of the Great Salt Lake and substantial changes in populations of prehistoric populations (Rhode 2000:161). The return to cooler conditions at around 500 BP associated with the little ice age

may be reflected in the higher positive loadings on component 2 for the 4 cm sample, but this conclusion is speculative.

Conclusions

The Mosquito Willies core shows distinct patterns of vegetation change through the Holocene including: Early Holocene drying, the migration of pinyon pine, early Middle Holocene aridity, a late Middle Holocene cool-wet cycle, and Late Holocene fluctuations in temperature and moisture. The shifts in plant taxa represent changes in local environments that favor attributes that are better matched for those conditions. Though pinyon-juniper woodland is a common Great Basin plant community, it appears to form through separate “pulses” of *Pinus* and *Juniperus* species that expanded during distinct climatic episodes. *Pinus* appears to have migrated into the region just after the Early Holocene, but sagebrush communities expand significantly during the early Middle Holocene, out-competing grasses, greasewood, and *Pinus* during what appears to be an extremely dry period with winter-dominated precipitation. Late Middle Holocene conditions are less dry and slightly cooler, favoring an expansion of Juniper early on, but quickly become warm and dry at around 6,800 ¹⁴C years BP, where the record is compressed as sedimentation rates slowed during a ponding episode.

After the ponding episode, sedimentation rates increase again after about 3,949 ¹⁴C years BP, capturing late Middle Holocene shifts from relatively dry conditions with summer-dominated precipitation to cool wet conditions with cycles of aeolian deposition capped by peat development. Vegetation seems to respond to these depositional fluctuations, with shadscale-

scrub and grass cover expanding during ponding episodes and woodland cover expanding between the ponding episodes, sometime between 3,363 +/- 74 ¹⁴C years BP and about 1,509 +/- 38 ¹⁴C years BP. Late Holocene sediments contain highly variable pollen concentrations, consistently high charcoal concentrations, and fluctuations in local pollen may be indicative of human impacts at the coring site. Though human impacts on local vegetation cover mask the responses of taxa to environmental factors, a Late Holocene environmental fluctuation from an early mesic interval to a xeric interval with summer-dominated precipitation sometime around 1,509 ¹⁴C years BP is apparent. The samples representing the last 1,000 years show the most evidence for depositional change, but may also suggest a shift towards cooler temperatures just before present. These changes closely match other paleoenvironmental records in the region, but the Blue Lakes core offers an especially interesting comparison to Mosquito Willies.

Both records show an Early Holocene - early Middle Holocene transition towards higher abundances of sagebrush and increasing representation of *Pinus*, late Middle Holocene transitions from warm to cool temperatures, and Late Holocene warm-cool cycles with a general trend towards increasing moisture. Though the abundance of pines in the Blue Lakes core seems to have a higher eigenvalue loading and *Juniperus* is absent from the second component, these two cores represent a coherent and complementary record of Holocene vegetation change in the Bonneville Basin. I use these records in the next chapter to discuss how these changes inform paleoecological research goals like the development of modern plant communities in addition to archaeological problems like the role of foragers in ecosystems, the emergence of agriculture in the Bonneville basin, and the evolution of human behavior.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

This chapter discusses implications of the results of the palynological analysis of the Mosquito Willies sediment core. The results contribute further detail to the history and dynamics responsible for the emergence of modern plant communities, including the migration of pinyon pine an important food resource for aboriginal groups. This record also has implications for the prehistoric record, especially shifts in land use patterns during the Middle Archaic (Madsen et al. 2005; Simms 2008) and Late Archaic (Bettinger 1999; Hocket 2005; Kelly 2001). These results also have implications for the history of agriculture in the Bonneville Basin. Some of these dynamics are reflected in 42To137 (Young et al. 2008), an archaeological site located in close proximity to the the coring location and offers a unique opportunity to consider the role of humans in the development of modern plant communities.

The Emergence of Modern Plant Communities

Results of the analysis shed light on the emergence of modern (i.e. Holocene) plant communities in the Bonneville Basin and by extension reflect the climatic patterns that influenced the region. Since individual plant species have different requirements and adaptations to deal with extreme temperatures, aridity, light restrictions, seasonality, etc., the association of plant taxa within plant communities should reveal important environmental factors that make

those relationships possible. Data suggest that modern vegetation emerged throughout the Great Basin at around 3,000 ¹⁴C years BP and were certainly in place by 2,000 ¹⁴C years BP (Rhode 2000). However, the Mosquito Willies core supports growing evidence that the specific combination of taxa that comprise modern plant communities did not suddenly appear as an integrated whole, but was assembled species by species over time.

Pinyon pine's journey into the Bonneville Basin is of particular interest because pinyon-juniper woodland dominates the vegetation cover in many areas of the Great Basin today (Miller and Wigand 1994). Pinyon was economically important to contact-era aboriginal groups (Steward 1938) and prehistoric foragers (Jennings 1957; Thompson 1982) alike. The rather late adoption of pinyon pine into forager diets in the western Great Basin (Bettinger 1999; Kelly 2001) is tied to the late arrival of pinyon into that region (circa 3,000 cal BP), but pinyon appears to arrive in the Bonneville Basin much earlier, as indicated by hulls in Danger Cave dating to around 6,600 BP if not earlier (Rhode and Madsen 1998).

The sudden expansion of *Pinus* pollen in sub-pattern IIa (7,500 - 7,150 ¹⁴C BP) is worth further consideration because it may indicate the movement of remnant populations of limber pine or the colonization of the region by Pinyon pine. The former possibility would require populations of limber pine expanding in north-facing slopes in mountain ranges near the coring locality such as the Deep Creek, Snake, or Gosiute mountain ranges. From these locations the pollen could disperse into the northeast-bound airstream. Although limber pine disappears from many packrat middens during this period, it is present in north-facing slopes of the Snake Range at 7,400 ¹⁴C years BP (Thompson 1990). The presence of *Pinus* nut hulls at 7,920 +/- 80 ¹⁴C years BP in Danger Cave suggests that pinyon may have been available to human foragers

in the region at this time (Madsen and Rhode 1990:99; but see also Rhode and Madsen 1998), despite not being present in other paleoenvironmental records at this time (Thompson 1990). Though estimates of transport costs indicate that pinyon can be transported long distances (>800 km) and still yield a net energetic gain (Jones and Madsen 1989), ethnographic observations of pinyon transport distances are considerably less (<100 km) than estimates based on energetic returns (Rhode 1990). Mosquito Willies lies between Danger Cave and several mountain systems containing pinyon as early as 6,000 years ago that may have served as migratory routes (Madsen and Rhode 1990; Rhode 2000). The sudden increase in *Pinus* pollen grains during the IIa sub-pattern is similar to patterns in other records (Louderback and Rhode 2009) and supports the general consensus of a northward migration of pinyon into the western margins of the southern Bonneville Basin at ~7,000 ¹⁴C BP.

Early pinyon-juniper woodlands were dominated by Rocky Mountain juniper until at least 5,100 ¹⁴C BP (Rhode 2000). Rocky Mountain juniper is more tolerant of cool temperatures and is less drought tolerant than Utah juniper. In the Mosquito Willies samples, *Juniperus* pollen expands during the Middle Holocene (IIb) and the early Late Holocene (IIIa), the latter is a warm dry interval with summer-dominant moisture, conditions that would allow Utah juniper to out-compete Rocky Mountain juniper. The early formation of pinyon-juniper woodlands and sagebrush-scrub cover during the early Middle Holocene were characterized by cool and dry conditions, while the movement of Utah juniper into these woodlands and the expansion of grasses and Chenopods during the late Middle Holocene points to warmer conditions with pulses of cool conditions creating a more thermophilic version of early Middle Holocene steppe-woodland plant cover sometime after 3,000 ¹⁴C BP.

Ephedra appears numerous times in the Mosquito Willies core and is generally associated with increases in arboreal pollen. The earliest appearance of *Ephedra* likely represents joint-fir (*Ephedra viridis*), which arrived in the Snake Range by the beginning of the Holocene (Thompson 1984). Later specimens may represent the movement of Mormon tea (*Ephedra nevadensis*) into the region, which likely did not take place until the Late Holocene (Madsen et al. 2001; Rhode 2000; Wigand and Rhode 2001). *Abies* and *Picea* show up periodically in many of the samples from Mosquito Willies as well, apparently fluctuating with the influx of arboreal pollen. Populations of white fir and Englemann's Spruce appear to have survived in some protected settings in the northeastern Great Basin as they are still present in the region (Thompson 1984), but their representation in the samples is limited.

Modern plant communities emerge from the collective responses of individual taxa to changes in temperature, seasonal precipitation distributions, and overall precipitation. This emergence is characterized by changes in environmental variables and plant taxa that occur independently. Pulses of pollen in the core reflect expansions of plant taxa during regimes where conditions favor their adaptations, followed by declining representations when conditions favor other species. Vegetation mosaics are shaped by climatic conditions and geologic factors that gradually, but continually alter the selective landscape. The movement of many plant and animal species is often explained by reference to Brown's (1987) island model (e.g. Grayson 2000b). The size of "islands" of vegetation cover fluctuated in response to environmental conditions that favor or inhibit the expansion of a species' territory. The island effect is particularly pronounced because regional landforms are broken by basin and range topography and elevational zonation of plant communities. Thus as climatic conditions grew unfavorable, some species retreated to

higher altitudes and disappeared from ranges. Great Basin plant and animal species also appear to shift their latitudinal distribution in response to climatic conditions. The combination of the dynamics of the expansion of “islands” of vegetation cover and north-south shifts provide the means for plant communities and ecosystems to be shaped by and redefined by selective processes acting on individual species. This cycle is broken by modern impacts, which cut off migration routes for plants as well as big game, waterfowl, and rodents, stranding them on shrinking islands with no route for escape (Grayson 2000b). Paleoenvironmental data suggests that the maintenance of migratory routes for species should be a crucial part of land management strategies (Madsen 2000). It is clear that modern humans have had a drastic impact on these dynamics, but paleoenvironmental and archaeological research suggests that prehistoric populations may have played a role in shaping these dynamics as well.

Archaeological Implications: Aboriginal Influences in Ecosystems

The use of fire to intentionally maintain stands of economic or medicinal plants (Downs 1967; Steward 1938) and to pursue small game (Steward 1938) is common in the Great Basin’s ethnographic record and is common in the ethnographic record in other parts of the world. However, the degree of impact that Precolumbian population had on past environments is very controversial and generally falls into three camps. Some argue that aboriginal populations were always intentional conservationists and portray these populations as primitive ecologists, adjusting their activities to maintain sustainable harvests (Alcorn 1993; Hill et al. 1997). Others view aboriginal populations as capable of substantial impacts on the environment (Alvard 1995;

Broughton 1994), and still others consider these impacts an inevitable outcome of human behavior (Penn 2003). This point is important because it sets up expectations for the timing and nature of impacts in the prehistoric Great Basin. Archaeologists have focused most of their attention on the impact of prehistoric humans on game populations (Janetski 2003; Broughton 1994) and vertebrate marine populations (Broughton 1997), but other research indicates that some resources may be actively conserved by prehistoric populations (Whitaker 2008). It is clear that the influence of human foragers on ecosystems is substantial, but the role of humans in ecosystems is complicated by species' responses to harvest pressures (Leach and Davidson 2001; Whitaker 2008), the intervening features of climatic changes (Broughton et al. 2008), and the specific needs and adaptations of the cultures that exist within them (Hill et al. 1997; Stahl 1996). What is clear is that foragers do not universally conserve or deplete resources. A more useful perspective requires a consideration of resource conservation and depletion as being emergent outcomes of individual decisions and goals within particular ecological and social circumstances.

Understanding the role of aboriginal burning in the prehistoric Bonneville Basin requires defining some clear expectations regarding the circumstances and outcomes of changes in fire frequency as a result of climate change and anthropogenic burning. Anthropogenic burning of plants could cause an increase in the influx of charcoal in the sediments, although fluctuations in charcoal concentrations in response to aboriginal burning may be masked by depositional processes and natural increases in fire frequency due to increasing probabilities of lightning strikes and higher fuel loads during summer-dominated precipitation regimes (Rhode 1999). The timing and nature of the changes in charcoal concentrations may yield some clues about

anthropogenic burning regimes in the prehistoric Great Basin. Fluctuations in charcoal concentrations in the core as a result of climate-induced changes in fire frequency should closely follow depositional sequences and pollen concentrations because both of these measures fluctuate with changes in the hydrologic budget. The outcomes of both climate-induced changes in fire frequency and aboriginal burning in terms of vegetation change should be generally similar. Burning of sagebrush stands with low levels of undergrowth typically reduces cover and hampers sagebrush reproduction by destroying young plants (Smith 2000; Uler 2008). Pinyon pine and Utah juniper are both especially intolerant of fire, expanding dramatically during low-frequency historic fire regimes (Miller and Wigand 1994). On the other hand, burning favors the colonization of open patches by grasses and Chenopods, while *Sarcobatus* responds to fire by flowering (Uler 2008). These responses in vegetation distributions should accompany increasing charcoal concentrations that fluctuate out of sync with pollen concentrations and sedimentary changes. Three major increases in charcoal concentrations are visible in the Mosquito Willies core, characterized by samples from sub-patterns IIb and IIIb. These sub-patterns also show fluctuations in pollen that meet the expectations outlined above, indicating a change in natural fire regimes or the appearance of anthropogenic burning in the Bonneville Basin.

Burning among desert foragers in Australia, for instance, is employed to improve the yield of small game, but also improves biodiversity and encourages the growth of forage for larger mammals (Bird et al. 2005). It is important to note that burning among Australian foragers is part of a larger pattern of broad-range foraging under conditions of restricted mobility (Bird et al. 2005). These circumstances appear to be an appropriate analogy for Bonneville Basin groups during the Late Holocene, a time period when mobility was restricted by population growth and

subsistence activities were broad and intensive. Other prehistoric environmental records and ethnographic data suggest that burning resources to improve returns and predictability would take place in advance of the adoption of agriculture (Bird and O'Connell 2006; Keely 1995). The goals that appear to be associated with aboriginal burning are improving small-game returns and improving the predictability of a localized subsistence base, which identifies some important differences between anthropogenic and climate-induced changes in burning regimes. Whereas natural fires are more frequent during dry conditions with summer-dominant precipitation regimes, aboriginal burning would most likely be employed under cool-wet conditions with more winter moisture.

These conditions are also associated with decreases in artiodactyl populations (Broughton 2000; Broughton et al. 2008) and losses productive stands of grasses and Cheno-Ams to encroaching sagebrush-steppe or pinyon-juniper woodland cover. Maintaining open vegetation cover is also particularly important to jackrabbit populations, which were also an important part of forager subsistence in the prehistoric Great Basin. Furthermore, evidence from other archaeological studies shows that small mammals may be a more sensitive indicator of population pressure and resource abundance (Hockett 2005), which corroborates the expectations of evolutionary models that foragers will only take small game as the abundance of larger game decreases (Simms 1987). The charcoal fluctuations from Mosquito Willies that are concentrated in sediments deposited during the last 4,000 years should be concentrated in cool-wet fluctuations if anthropogenic burning is the cause, especially those associated with decreases in artiodactyl abundances visible in other Holocene records. The shifts in pollen and charcoal concentrations at ~3,900 ¹⁴C BP (Figure 3.3) fluctuate in sync and take place during a xeric

period combined with summer-dominated precipitation regimes, indicating that these fluctuations are likely driven by natural changes in fire regimes. However, the charcoal spikes at ~3,300 ¹⁴C BP and ~2,000- 500 ¹⁴C BP fall in winter-dominated precipitation regimes.

An archaeological site (42To137) in close proximity to the coring location (Young et al. 2008) has Middle Archaic and Late Archaic components and the latter roughly coincides with the pulses in charcoal and sedimentation rates at *I**b*** and *III**b***. More intensive use of the site (42To137) emerged during the Late Archaic (Young et al. 2008), which probably coincides with the ponding episodes at *I**b*** and *III**b***, although the association between the latter sub-pattern, ponding episode, and archaeological occupation at the site (42To137) is much more reliable than the former. The period encompassed by *III**b*** is characterized by more intensive use of the landscape around the site, indicated by contemporaneous occupations at Buzz-cut dune, Camel's Back Cave and other Late Archaic sites (Madsen and Schmitt 2005; Young et al. 2008) in the Bonneville Basin. Both *I**b*** and *III**b*** show fluctuations of charcoal during relatively cool periods with less summer-moisture, which suggests that aboriginal burning may be responsible. In the case of the early spike in charcoal in *III**b***, this conclusion is a cautious one, but supports the suggestion that the roots of Late Archaic change may extend well into the Middle Archaic or beyond (Simms 2008). Further support comes from evidence from artiodactyl remains in Homestead Cave showing major declines artiodactyl representation after ~3,500 ¹⁴C BP and 1,500 ¹⁴C BP, which closely match the spikes in charcoal at Mosquito Willies.

Wetland development just prior to 1,509 ¹⁴C BP at the site and the continued influx of charcoal may be linked to continued occupation of the site and burning of nearby plant resources as a part of mass collecting small game during periods of reduced abundances of

larger game. Corn agriculture disappears from the region not long after this, as cool moist conditions set in at around 500 BP (Rhode 2000). The sudden decline in concentration values and the spike in abundance of aquatic pollen immediately after this may be linked to historic impacts at the site, disturbing the springs flow and causing a sudden influx of indeterminate pollen grains before wetland development expanded at 4 cm. Though no historic modifications of the spring itself are recorded by Young et al. (2008), they describe historic corral building near the site and laboratory logs from the collection of the Mosquito Willies core (Rhode, personal communication, 2007) describe modification of the north channel of the spring in the form of diversion dams.

The pattern that emerges after 2,000 ¹⁴C BP in the Mosquito Willies core suggests that humans may be directly involved in the formation of modern Bonneville Basin plant communities. Miller and Wigand (1994) report dramatic expansions of pinyon-juniper woodland starting after European contact, which interrupted aboriginal burning regimes that limited the extent of this vegetation cover. Prehistoric humans may also have been a vector for the migration of pinyon pine into the region, although this evidence is largely circumstantial. Late Archaic archaeological evidence and the charcoal fluctuations at Mosquito Willies indicate an increasing investment in the landscape (Simms 2008), in which the fortunes of prehistoric societies and the productivity of the landscape became even more intrinsically linked. The connection between increases in productivity to plant resources is worth further investigation, because evidence for increased investment in storage features, anthropogenic burning, and small game hunting techniques suggests that these practices become widespread in the Late Archaic

alongside the development of more permanent residences and a more diversified subsistence emphasis (Bettinger 1999; Hockett 2005; Madsen et al. 2005; Simms 2008).

Conclusions

The Holocene environmental changes in the Bonneville Basin captured by Mosquito Willies core indicate that Holocene climatic changes in the region is expressed in fluctuations in temperature, seasonal precipitation, and effective moisture. These fluctuations allow species to migrate to new territories during favorable regimes and isolate populations during less favorable regimes (Madsen 2000). The shifts in plant taxa represented in paleoenvironmental records provides detailed records of these movements, with taxa arranging and re-arranging themselves according to the conditions present on the landscape. Human populations play a more substantial role in vegetative change after 3,300 ¹⁴C BP as shifts in resource abundance push expanding population sizes towards more intensive use of the landscape, which triggers responses in local vegetation that encourage the growth of some economic plants. This conclusions warrants further research into the connections between resource structure, forager mobility, and environmental impacts.

The responses of human foragers changing environments were not homogenous, either. Clearer understandings of the dynamics that are responsible for ecosystem formation and change can give archaeologists and anthropologists a clearer picture of the different roles that humans play in ecosystems given the distribution of resources and conspecifics within those ecosystems. The evidence contained in the Mosquito Willies core suggests that changes in seasonality may

have important links to the productivity of the landscape, which may relate to the increasing importance of social dynamics in forager populations starting in the late Middle Archaic (Elston and Zeanah 2002; Kelly 1997; Hildebrant and McGuire 2002; Madsen et al. 2005; Simms 2008). Paleoenvironmental research is a critical part of understanding the evolution of modern environments and the dynamics of culture change by providing crucial information about the stage on which individuals carry out the drama of the everyday. As anthropologists and archaeologists engage in more sophisticated considerations of the dynamics of human behavior and cultural evolution (Eerkins and Lipo 2005; Smith et al. 2000; Zeanah 2004), environmental contexts have played a crucial role in understanding the dynamics of changes in forager mobility and subsistence patterns (Barlow and Metcalfe 1996; Elston and Zeanah 2002; Kelly 2001; Madsen and Schmitt 1989; Rhode 1999; Simms and Zeanah 1999). This project demonstrates the continuing value of paleoenvironmental research for contributing further details about prehistoric environments that make up a critical portion of the contexts of change for cultural and biological evolution alike.

Works Cited

- Aikens, C. M.
1970 *Hogup Cave*. University of Utah Anthropological Papers No. 93. Salt Lake City.
- Alcorn, Janis B
1993 Indigenous Peoples and Conservation. *Conservation Biology* 7(2):424-426
- Alvard, Michael S., John G. Robinson, Kent H. Redford, and Hillard Kaplan.
1994 The Sustainability of Subsistence Hunting in the Neotropics. *Conservations Biology* 11(4):977-982.
- Antevs, Ernst
1931 *Late-Glacial Correlations and Ice Recession in Manitoba*. Geological survey of Canada, Memoir No. 168, Ottawa.
- Beck, Charlotte and George T. Jones
2007 Early Paleoarchaic Point Morphology and Chronology. In *Paleoindian or Paleoarchaic?: Great Basin Human ecology at the Pleistocene-Holocene Transition*, edited by Kelly E. Graf and Dave N. Schmitt. University of Utah Press, Salt Lake City, pp. 23-41
- Benson, L. V., D. R. Currey, R. I. Dorn, K. R. Lajoie, C. G. Oviatt, S. W. Robinson, G. I. Smith, and S. Stine
1990 Chronology of Expansion and Contraction of Four Great Basin Lake Systems during the Past 35,000 Years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 78:241-286
- Bettinger, Robert L.
1999 What Happened in the Medithermal in *Models for the Millenium: Great Basin Anthropology Today*, ed. by Charlotte Beck. University of Utah Press, Salt Lake City. pp. 62-74
- Bird, Douglas W. and James F. O'Connell
2006 Behavioral Ecology and Archaeology. *Journal of Archaeological Research* 14:143-188
- Bird, Douglas W., Rebecca Bliege Bird, and Christopher H. Parker
2005 Aboriginal Burning Regimes and Hunting Strategies in Australia's Western Desert. *Human Ecology* 33(4):443-464.
- Bright, R. C.
1966 Pollen and Seed Stratigraphy of Swan Lake, Southeastern Idaho: Its Relation to Regional Vegetational History and to Lake Bonneville. *Tebiwa* 9:1-47

- Briggs, Richard W., Steven G. Wesnousky, Kenneth D. Adams
 2005 Late Pleistocene and Late Holocene Lake Highstands in the Pyramid Lake Subbasin of Lake Lahontan, Nevada, USA. *Quaternary Research* 64:257-263
- Broughton, Jack M.
 1997 Widening diet breadth, declining foraging efficiency, and prehistoric harvest pressure: Ichthyofaunal evidence from the Emeryville Shellmound, California. *Antiquity* 71:845-862
- 2000 The Homestead Cave Ichthyofauna. In *Late Quaternary Paleoecology in the Bonneville Basin*, edited by D.B. Madsen. Utah Geological Survey Bulletin 130. Salt Lake City. pp. 103-122
- Broughton, Jack M. and Frank E. Bayham
 2003 Showing Off, Foraging Models, and the Ascendance of Large-Game Hunting in the California Middle Archaic. *American Antiquity* 68(4):783-789
- Broughton, Jack M., David A. Byers, Reid A. Bryson, William Eckerie, and David B. Madsen.
 2008 Did Climatic Seasonality Control Late Quaternary Artiodactyl Densities in Western North America? *Quaternary Science Reviews* 27(19-20):1916-1937.
- Brown, J. H.
 1987 The Theory of Insular Biogeography and the Distribution of Boreal Birds and Mammals. In *Intermountain Biogeography: A Symposium*, edited by K.T Harper and J.L. Reveal. Great Basin Naturalist Memoirs, v. 2. pp. 209-227
- Byers, David A. and Jack M. Broughton
 2004 Holocene Environmental Change, Artiodactyl Abundances, and Human Hunting Strategies in the Great Basin. In *American Antiquity* 69(2):235-255
- Chamberlin, Ralph V.
 1911 The Ethno-Botany of the Gosiute Indians. *Proceedings of the Academy of Natural Sciences of Philadelphia* 63(1):24-99.
- Coltrain, Joan B. and Steven W. Leavitt
 2002 Climate and Diet in Fremont Prehistory: economic Variability and Abandonment of Maize Agriculture. *American Antiquity* 67(3):453-485
- Cummings, Linda Scott and Kathryn Puseman
 2005 *Pollen and Macrofloral Analysis of a Soil Column From Kelvin's Cave (Site 10LN93), South-Central Idaho, Compared to a Local Archaeoclimatic Model*. Paleo Research Institute Technical Report 04-97 prepared for the Bureau of Land Management. Shoshone, Idaho.

- Currey, Donald R. and Steven R. James
1982 Paleoenvironments of the Northeastern Great Basin and Northeastern Basin Rim Region: A Review of Geological and Biological Evidence, in *Man and Environment in the Great Basin*, ed. by David B. Madsen and James F. O'Connell. SAA Papers No.2 pp. 27-52
- Dalley, George F.
1970 Artifacts of Wood. In *Hogup Cave*, by C. M. Aikens, pp. 153-186. University of Utah Anthropological Papers No. 93. Salt Lake City.
- Downs, James F.
1966 The Significance of Environmental Manipulation in Great Basin Cultural Development. In *The Current Status of Anthropological Research in the Great Basin*, edited by W. L. d'Azevedo, W. A. Davis, D. D. Fowler, and W. Shuttles, pp. 39-56. Desert Research Institute, Technical Report Series S-H, Social Sciences and Humanities Publications No. 1. Reno, Nevada.
- Eerkins, Jelmer W. and Carl P. Lipo
2005 Cultural Transmission, Copying Errors, and the Generation of Variation in Material Culture and the Archaeological Record. *Journal of Anthropological Archaeology* 24:316-334
- Elston, Robert G. and David W. Zeanah
2002 Thinking Outside the Box: A New Perspective on Diet Breadth and Sexual Division of Labor in the Prearchaic Great Basin. In *World Archaeology* 34(1):103-130
- Faegri, Knut, Peter Emil Kaland, and Knut Krzwinski
1989 *Textbook of Pollen Analysis IV Edition*. The Blackburn Press, New Jersey
- Fowler, Catherine S.
1977 Ethnography and Great Basin Prehistory. In *Models and Great Basing Prehistory: A Symposium*, edited by Don D. Fowler. Desert Research Institute Publications in the Social Sciences No. 12. Reno, pp. 11-48
- Fremont, J.C.
1845 *Report of the Exploring Expedition to the Rocky Mountains in the Year 1842l and to Oregon and North California in the Years 1843- '44*. Reprinted in the *March of America Facsimile Series* no.79 University Microfilms, Ann Arbor.
- Fry, Gary F.
1976 Analysis of Prehistoric Coprolites from Utah. *University of Utah Papers* no. 67 University of Utah Press, Salt Lake City, Utah.

- Godsey, Holly S., Donald R. Currey, and Marjorie A. Chan
2005 New Evidence for an Extended Occupation of the Provo Shoreline and Implications for Regional Climate Change, Pleistocene Lake Bonneville, Utah, USA. *Quaternary Research* 63:212-223
- Goebel, Ted
2007 Pre-Archaic and Early Archaic Technological Activities at Bonneville Estates Rockshelter. In *Paleoindian or Paleoarchaic?: Great Basin Human ecology at the Pleistocene-Holocene Transition*, edited by Kelly E. Graf and Dave N. Schmitt. University of Utah Press, Salt Lake City, pp.156-184.
- Grayson, Donald K
1993 *The Desert's Past: A Natural Prehistory of the Great Basin*. Smithsonian Institution, Washington, D.C.
- 2000a Mammalian responses to Middle-Holocene climatic change in the Great Basin of the western United States. *Journal of Biogeography* 27:181-192.
- 2000b The Homestead Cave Mammals. In *Late Quaternary Paleoecology in the Bonneville Basin*, edited by D.B. Madsen. Utah Geological Survey Bulletin 130. Salt Lake City. pp. 67-90.
- 2006a The Late Quaternary biogeographic histories of some Great Basin mammals (western USA). In *Quaternary Science Reviews* 25:2964-2991
- 2006b Holocene Bison in the Great Basin, Western USA. *The Holocene* 16(6):913-925
- Grayson, Donald K and Michael D. Cannon
1999 Human Paleoecology and Foraging Theory in the Great Basin. In *Models for the Millennium: Great Basin Anthropology Today*. Edited by Charlotte Beck. University of Utah Press, Salt Lake City, pp.141-151.
- Hockett, Bryan
2005 Middle and Late Holocene Hunting in the Great Basin: A Critical Review of the Debate and Future Prospects. *American Antiquity*. 70(4):713-731.
- 2007 Nutritional Ecology of Late Pleistocene to Middle Holocene Subsistence in the Great Basin. In *Paleoindian or Paleoarchaic? Great Basin Human Ecology at the Pleistocene-Holocene Transition*. Edited by K.E. Graf and D.N. Schmitt, The University of Utah Press, Salt Lake City, pp. 204-230

Hughes, Malcolm K. and Gary Funkhouser

1998 Extremes of Moisture Availability Reconstructed from Tree Rings for Recent Millennia in the Great Basin of Western North America. In *The Impacts of Climate Variability on Forests* edited by M. Beniston and J.L. Innes. Lecture Notes in Earth Science no. 74. pp. 99-108

Hunt, Jeffrey M., David Rhode, and David B. Madsen

2000 Homestead Cave Flora and Non-Vertebrate Fauna. In *Late Quaternary Paleoecology in the Bonneville Basin*, edited by D.B. Madsen. Utah Geological Survey Bulletin 130. Salt Lake City. pp. 47-58

Hunt, Jeffrey M., David Rhode, Dave N. Schmitt, and David B. Madsen

2005 Hearth Morphology, Distribution, and Content. In *Camels Back Cave*, edited by Dave N. Schmitt and David B. Madsen. University of Utah Anthropological Papers No. 125, University of Utah Press, Salt Lake City pp. 59-91.

Janetski, Joel C.

1997 Fremont Hunting and Resource Intensification in the Eastern Great Basin. *Journal of Archaeological Science* 24:1075-1088.

Jenkins, Dennis L.

2007 Distribution and Dating of Cultural and Paleontological Remains at the Paisley Five Mile Point Caves in the Northern Great Basin. In *Paleoindian or Paleoarchaic?: Great Basin Human ecology at the Pleistocene-Holocene Transition*, edited by Kelly E. Graf and Dave N. Schmitt. University of Utah Press, Salt Lake City. pp.57-81.

Jennings, Jessie D.

1957 *Danger Cave*. University of Utah Anthropological Papers no. 27. University of Utah Press, Salt Lake City.

Jones, George T. and Charlotte Beck

1999 Paleoarchaic Archaeology in the Great Basin. In *Models for the Millennium: Great Basin Anthropology Today*. Edited by Charlotte Beck. The University of Utah Press, Salt Lake City, pp. 83-95.

Jones, Kevin T. and David B. Madsen

1989 Calculating the Cost of Resource Transportation: A Great Basin Example. *Current Anthropology* 30(4):529-534

- Keely, Lawrence H.
1995 Protoagricultural Practices Among Hunter-Gatherers: A Cross-Cultural Survey. In *Last Hunters-First Farmers: New Perspectives on the Prehistoric Transition to Agriculture*. Edited by T. Douglas Price and Anne Birgitte Gebauer. School of American Research Press, Santa Fe, New Mexico, pp. 243-272.
- Kelly, Isabel T.
1964 *Southern Paiute Ethnography*. University of Utah Anthropological Papers no. 69, University of Utah Press, Salt Lake City.
- Kelly, Robert L.
1997 Late Holocene Great Basin Prehistory. *Journal of World Prehistory*. 11(1):1-49

2001 *Prehistory of the Carson Desert and Stillwater Mountains: Environment, Mobility, and Subsistence in a Great Basin Wetland*. University of Utah Anthropological Papers no. 123. University of Utah Press, Salt Lake City.
- Kelly, Robert L. and Lawrence C. Todd
1988 Coming into the Country: Early Paleoindian Hunting and Mobility. *American Antiquity* 53(2):231-244.
- LaMarche, V.C.
1974 Paleoclimatic Inferences from Long Tree-Ring Records. *Science* 183:1043-1088
- Leach, F. and Davidson, J.
2000 The Use of Size-Frequency Diagrams to Characterize Prehistoric Fish Catches and to Assess Human Impact on Inshore Fisheries. *International Journal of Osteoarchaeology* 11:150-162
- Livingston, S. D.
2000 The Homestead Cave Avifauna. In *Late Quaternary Paleoecology in the Bonneville Basin*. Edited by D. B. Madsen. Utah Geological Survey, Salt Lake City. pp. 91-102
- Louderback, Lisbeth A. and David E. Rhode
2008 15,000 Years of Vegetation Change in the Bonneville Basin: the Blue Lake Pollen Record. *Quaternary Science Reviews* 28(3-4):308-326
- McGuire, Kelly R. and William R. Hildebrandt
2005 Re-Thinking Great Basin Foragers: Prestige Hunting and Costly Signaling During the Middle Archaic Period. In *American Antiquity* 70(4):695-712

Madsen, David B.

1982 Get it Where the Getting's Good: A Variable Model of Great basin Subsistence and Settlement Based on Data from the Eastern Great Basin. In *Man and Environment in the Great Basin*, edited by D. B. Madsen and J. F. O'Connell, SAA Papers No. 2. Society for American Archaeology, Washington, D. C. pp. 207-226.

1983 *Black Rock Cave Revisited*. Bureau of Land Management Cultural Resource Series No. 14.

1985 Two Holocene Pollen Records From the Central Great Basin, in *American Association of Stratigraphic Palynologists Series* No. 16:113-126

1999 Environmental Change During the Pleistocene-Holocene Transition and Its Possible Impact on Human Populations, in *Models for the Millennium: Great Basin Anthropology Today*, University of Utah Press, Salt Lake City. pp. 75-82

2000 *Late Quaternary Paleoecology in the Bonneville Basin*. Utah Geological Survey Bulletin 130. Salt Lake City.

2007 The Paleoarchaic to Archaic Transition in the Great Basin. In *Paleoindian or Paleoarchaic? Great Basin Human Ecology at the Pleistocene-Holocene Transition*. Edited by K.E. Graf and D.N. Schmitt, The University of Utah Press, Salt Lake City, pp. 3-20

Madsen, David B. and David Schmitt

1998 Mass Collecting and the Diet Breadth Model: A Great basin Example. In *Journal of Archaeological Science* 25:445-455

2005 *Buzz-Cut Dune and Fremont Foraging at the Margin of Horticulture*. University of Utah Anthropological Papers No. 124.

Madsen, David B. and David Rhode (editors)

1994 *Across the West: Human Population Movement and the Expansion of the Numa*. University of Utah Press, Salt Lake City.

Madsen, David B. and David Rhode

1990 Early Holocene Pinyon (*Pinus monophylla*) in the Northeastern Great Basin. *Quaternary Research* 33:94-101

Madsen, David B. and Donald R. Currey

1979 Late Quaternary Glacial and Vegetation Changes, Little Cottonwood Canyon Area, Wasatch Mountains, Utah. *Quaternary Research* 12:254-270

- Madsen, David B. and Michael S. Berry
1975 A Reassessment of Northeastern Great Basin Prehistory. In *American Antiquity* 40(4): 391-405
- Madsen, David B and Steven R. Simms
1998 The Fremont Complex: A Behavioral Perspective in *Journal of World Prehistory* 12(3): 255-336
- Madsen, David B., Charles G. Oviatt, and Dave N. Schmitt
2005 A Geomorphic, Environmental, and Cultural History of the Camels Back Cave Region. In *Camels Back Cave* edited by D.N. Schmitt and D. B. Madsen. University of Utah Anthropological Papers no. 125. University of Utah Press, Salt Lake City, pp. 20-45.
- Madsen, D.B., D. Rhode, D.K. Grayson, J.M. Broughton, S.D. Livingston, J. Hunt, J. Quade, D.N. Schmitt, M.W. Shaver III
2001 Late Quaternary Environmental Change in the Bonneville Basin, Western USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 167:243-271
- Mehring, Peter J. Jr.
1977 Great Basin Late Quaternary Environments and Chronology. In *Models and Great Basin Prehistory: A Symposium*, edited by D.D. Fowler. *Desert Research Institute Publications in the Social Sciences* 12:113-167.
- Miller, Richard F. and Peter E. Wigand
1994 Holocene Changes in Semiarid Pinyon-Juniper Woodlands. In *Bioscience* 44(7):465-474
- Oviatt, Charles G., D. R. Currey, and D. Sack
1992 Radiocarbon Chronology of Lake Bonneville, Eastern Great Basin, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 99:225-241
- Oviatt, Charles G., David M. Miller, John P. McGeehin, Cecile Zachary, and Shannon Mahan
2005 The Younger Dryas Phase of the Great Salt Lake, Utah, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 219:263-284
- Oviatt, Charles G., David B. Madsen, and Dave N. Schmitt
2003 Late Pleistocene and Early Holocene Rivers and Wetlands in the Bonneville Basin of Western North America. *Quaternary Research* 60:200-210
- Rhode, David
1990 Transportation Costs of Great Basin Resources: An Assessment of the Jones-Madsen Model. *Current Anthropology* 31:413-419.

- 1999 The Role of Paleoecology in the Development of Great Basin Archaeology and Vice-Versa. In *Models for the Millennium: Great Basin Anthropology Today*. Edited by Charlotte Beck. University of Utah Press, Salt Lake City, pp. 29-49.
- 2000 Holocene Vegetation History in the Bonneville Basin. In *Late Quaternary Paleoecology in the Bonneville Basin*, edited by D.B. Madsen. Utah Geological Survey Bulletin 130. Salt Lake City. pp.149-164
- 2007 Personal Communication.
- 2008 Dietary Plant use by Middle Holocene Foragers in the Bonneville Basin, Western North America. *Before Farming* 3(2):1-17
- Rhode, David and David B. Madsen
 1995 Late Wisconsin/Early Holocene Vegetation in the Bonneville Basin. *Quaternary Research* 44:246-256
- 1998 Pine Nut Use in the Early Holocene and Beyond: The Danger Cave Archaeological Record. *Journal of Archaeological Science* 25:119-1210
- Rhode, David and Lisbeth A. Louderback
 2007 Dietary Plant Use in the Bonneville Basin During the Terminal Pleistocene/Early Holocene Transition. In *Paleoindian or Paleoarchaic? Great Basin Human Ecology at the Pleistocene-Holocene Transition*. Edited by Kelly E. Graf and Dave N. Schmitt. University of Utah Press, Salt Lake City, pp. 231-247.
- Rhode, David, David B. Madsen, and Kevin T. Jones
 2006 Antiquity of Early Holocene Small-Seed Consumption and Processing at Danger Cave. In *Antiquity* 80:328-339
- Rudy, S. S.
 1957 Textiles. In *Danger Cave*, by J. D. Jennings, pp. 235-264. University of Utah Anthropological Papers No. 27. Salt Lake City.
- Schmitt, Dave N. and Karen D. Lupo
 2005 The Camels Back Cave Mammalian Fauna. In *Camels Back Cave*, edited by Dave N. Schmitt and David B. Madsen. University of Utah Anthropological Papers no. 125 pp. 136-176.

- Schmitt, Dave N, David B. Madsen, Charles G. Oviatt, and Rachel Quist
 2007 Late Pleistocene/Early Holocene Geomorphology and Human Occupation of the Old River Bed Delta, Western Utah. In *Paleoindian or Paleoarchaic? Great Basin Human Ecology at the Pleistocene-Holocene Transition*. Edited by K.E. Graf and D.N. Schmitt, The University of Utah Press, Salt Lake City, pp. 105-119
- Schmitt, Dave N., David B. Madsen, and Karen D. Lupo
 2002 Small-Mammal Data on Early and Middle Holocene Climates and biotic Communities in the Bonneville Basin, USA. In *Quaternary Research* 58:255-260.
- Simms, S.R.
 1977 A Mid-Archaic Subsistence and Settlement Shift in the Northeast Great Basin. In *Models and Great Basing Prehistory: A Symposium*, edited by Don D. Fowler. Desert Research Institute Publications in the Social Sciences No. 12. Reno, pp. 195-210
- 1987 *Behavioral Ecology and hunter-Gatherer Foraging: An Example from the Great Basin*. BAR International Series 381. British Archaeological Reports, Oxford, England.
- 2008 *Ancient Peoples of the Great Basin & Colorado Plateau*. Left Coast Press, California.
- Smith, Felisa A., and Julio L. Betancourt
 2003 The Effect of Holocene Temperature Fluctuations on the Evolution and Ecology of *Neotoma* (woodrats) in Idaho and northwestern Utah. *Quaternary Research* 59(2):160-171.
- Smith, J. Kapler (editor)
 2000 *Wildland Fire in Ecosystems: Effects of Fire on Fauna*. Gen. Tech. Report RMRS-GTR-42-vol. 1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.
- Smith, G.R., W.L. Stokes, and K.F. Horn
 1968 Some Late Pleistocene Fishes of Lake Bonneville. *Copeia* 1968(4):807-816.
- Spaulding, W.G., Julio L. Betancourt, Lisa K. Croft, and Kenneth L. Cole
 1990 Packrat Middens: Their Composition and Methods of Analysis. In *Packrat Middens: the Last 40,000 Years of Biotic Change*, edited by J. L. Betancourt, T. R. Van Devender, and P.S. Martin, pp. 59-84 University of Arizona Press, Tucson.
- Stahl, Peter
 1996 Holocene Biodiversity: An Archaeological Perspective from the Americas. *Annual Review of Anthropology* 25:105-126.

- Steward, Julian H.
1938 *Basin-Plateau Aboriginal Sociopolitical Groups*. Bureau of American Ethnology Bulletin 120. Washington D.C.
- Thompson, Robert S.
1984 *Late Pleistocene and Holocene Environments in the Great Basin*. Ph.D. dissertation, University of Arizona, Tucson.
- 1990 Late Quaternary Vegetation and Climate in the Great Basin. In *Packrat Middens: The Last 40,000 Years of Biotic Change*, edited by J. L. Betancourt, T. R. Van Devender, and P. S. Martin, pp. 200-239. University of Arizona Press, Tucson.
- 1992 Late Quaternary Environments in Ruby Valley, Nevada. *Quaternary Research* 37:1-15
- Ulev, Elena, compiler.
2008 Effects of fall and spring prescribed burning in sagebrush steppe in east-central Oregon. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/> [2009, February 28].
- Weide, David L., and Margaret L. Weide
1977 Time, Space, and Intensity in Great Basin Paleoecological Models. In *Models and Great Basin Prehistory: A Symposium*, edited by D.D. Fowler. *Desert Research Institute Publications in the Social Sciences* 12:79-111
- Wells, Philip V.
1983 Paleobiogeography of Montane Islands in the Great Basin since the Last Glaciopluvial. *Ecological Monographs* 53(4):341-382
- Whitaker, Adrian R.
2008 Incipient Aquaculture in Prehistoric California?: Long-Term Productivity and Sustainability vs. Immediate Returns for the Harvest of Marine Invertebrates. *Journal of Archaeological Science* 35:1114-1123.
- Wilde, J.D. D.E. Newman, and A. E. Godfrey
1986 *The Late Archaic/Early Formative Transition in Central Utah: Pre-Fremont Corn from the Elsinore Burial Site 42Sv2111, Sevier County, Utah*. Brigham Young University Museum of People and Culture Technical Report No. 86-20.
- Winter, J.C.
2001 *Tobacco Use by Native Americans: Sacred Smoke and Silent Killer*. Norman: University of Oklahoma Press. 185-201

Wigand, Peter E., and David Rhode

2001 Great Basin Vegetation and Aquatic Systems: The last 150,000 Years. In *Great Basin Aquatic System History*, edited by Robert Hershler, David B. Madsen, and Donald R. Currey, pp. 309-368. Smithsonian Contributions to the Earth Sciences 33. Smithsonian Institution Press, Washington D.C.

Young, Craig D., Kimberly Carpenter, Daron Duke, Eric Wohlgemuth, and Teresa Wriston

2008 *Mosquito Willies (42To137) Prehistoric Data Recovery in Locus 3, Tooele County, Utah*. Report submitted to Select Engineering Services Inc. Far Western Anthropological Research Group, Inc.

Zeanah, David W.

2004 Sexual Division of Labor and Central Place Foraging: a Model for the Carson Desert of Western Nevada. *Journal of Anthropological Archaeology* 23:1-32

APPENDIX A: PALYNOLOGICAL DATA

	149 cm	144 cm	140 cm	132 cm	125 cm	120 cm	115 cm
Artemisia	27	28	37	23	16	29	5
Asteraceae High Spine	1	2	0	0	0	0	0
Asteraceae Low Spine	2	5	0	4	0	4	2
Cheno-Am	72	82	30	35	6	3	3
Ephedra	0	0	0	0	0	0	0
Poaceae	56	27	58	49	67	45	5
Sarcobatus	26	29	62	55	18	14	1
Zea mays	0	0	0	0	0	0	0
Abies	0	0	0	0	5	6	1
Juniperus	7	6	6	7	14	16	0
Picea	0	0	0	0	0	3	0
Pinus	1	7	13	12	59	67	2
Scirpus sp.	0	0	0	0	0	0	0
Typha sp.	0	0	0	0	0	0	0
Indeterminate	11	14	7	15	15	13	8
Arboreal	8	13	19	19	78	92	3
Non-Arboreal	184	173	187	166	107	95	16
Aquatic	0	0	0	0	0	0	0
Pollen Total	203	200	213	200	200	200	27
Lycopodium	123	70	62	124	190	172	330
Sample ml	2	2	2	2	2	2	3
Sample charcoal	280	645	265	415	717	815	154
Lycopodium (ch)	20	21	22	20	20	20	21
Lycopodium (n)	25084	25084	25084	25084	25084	25084	25084

110 cm	104 cm	99 cm	94 cm	90 cm	84 cm	80 cm	74 cm	68 cm	25
6	60	79	78	53	26	36	28	25	
0	1	3	1	0	0	1	0	2	
0	0	6	6	5	2	3	2	3	
1	26	25	41	62	33	42	91	87	
0	0	1	2	0	0	3	0	0	
14	15	23	16	29	32	25	20	9	
1	21	6	2	2	3	5	0	10	
0	0	0	0	0	0	0	0	0	
0	1	0	5	15	6	3	1	2	
6	17	14	13	10	63	14	20	29	
0	3	0	0	0	7	2	0	0	
10	37	22	16	10	10	48	16	32	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
8	19	21	20	18	19	18	22	11	
16	58	36	34	35	86	67	37	63	
22	123	143	146	151	96	115	141	136	
0	0	0	0	0	0	0	0	0	
46	200	200	200	204	201	200	200	210	
125	429	254	219	331	138	121	36	46	
2	3	2	2	2	2	2	2	2	
347	155	710	1120	870	2270	1930	8780	5310	
20	21	25	20	22	20	20	21	23	
25084	25084	25084	25084	25084	25084	25084	25084	25084	

64-65 cm	59-60 cm	54-55 cm	49-50 cm	44-45 cm	40-41 cm	37-38 cm	32-33 cm	24-25 cm
22	24	22	24	21	31	26	44	34
1	2	6	2	9	1	1	0	3
2	2	1	2	1	4	0	1	1
39	45	51	57	68	47	56	59	61
1	2	0	0	0	1	2	0	1
61	24	24	39	37	34	31	33	19
14	45	35	8	5	7	5	3	11
0	0	0	0	1	2	0	0	2
0	0	0	0	0	0	0	0	3
25	39	35	30	17	16	27	23	12
4	0	1	1	5	5	2	3	8
15	11	19	24	22	37	29	27	43
0	0	0	0	0	0	3	0	0
0	0	0	0	0	0	0	0	0
16	11	12	18	20	22	20	15	13
44	50	55	55	44	58	58	53	66
140	144	139	132	142	127	121	140	132
0	0	0	0	0	0	3	0	0
200	205	206	205	206	207	202	208	211
11	18	39	132	13	11	320	57	70
2	2	3	3	2	2	3	2	2
14260	34820	1520	440	11100	1420	400	1920	7900
20	20	20	20	7	5	20	20	20
25084	25084	25084	25084	25084	25084	25084	25084	25084

19-20 cm	15-16 cm	9-10 cm	4-5 cm	
24	17	4	11	
3	17	1	9	
6	1	0	0	
31	48	22	20	
2	1	1	0	
9	59	2	6	
6	4	2	1	
1	0	0	0	
0	2	0	0	
15	17	2	9	
2	2	0	0	
32	21	4	6	
45	24	9	112	
21	0	2	43	
11	21	12	3	
49	42	6	15	
82	147	32	47	
66	24	11	155	
208	234	61	220	
36	20	97	56	
2	2	2	2	
33080	3800	13060	7660	
20	2	10	20	
25084	25084	25084	25084	