ASSESSING DIET AND SEASONALITY IN THE LOWER PECOS CANYONLANDS: AN EVALUATION OF COPROLITE SPECIMENS AS RECORDS OF INDIVIDUAL DIETARY DECISIONS

A Dissertation

by

TIMOTHY E. RILEY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2010

Major Subject: Anthropology

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Approved by:

Chair of Committee,	Vaughn M. Bryant
Committee Members,	Alston Thoms
	Lori Wright
	Andreas Holzenburg
Head of Department,	Donny Hamilton

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ABSTRACT

Assessing Diet and Seasonality in the Lower Pecos Canyonlands: An Evaluation of
Coprolite Specimens as Records of Individual Dietary Decisions. (December 2010)
Timothy E. Riley, B.A., The College of the University of Chicago
Chair of Advisory Committee: Dr. Vaughn M. Bryant

This dissertation presents an evaluation of coprolite specimens from the Lower Pecos canyonlands as records of individual dietary decisions. Prior studies of coprolites from this region have greatly expanded our knowledge of Archaic subsistence patterns, but have not taken full advantage of the record of individual dietary decisions recorded in each coprolite specimen. The menu, or dietary combinations, reflected in individual coprolite specimens are assessed through the identification of several congruent botanical components derived from the same food resource, phytoliths, fiber ultimates, and epidermal sheets. The data is analyzed with hierarchical cluster analysis, an exploratory statistical technique. The resultant menus reflected in these clusters are evaluated with reference to the diet-breadth model developed for the known staple resources of the canyonlands as well as the seasonal subsistence patterns observed in the ethnohistoric record of modern-day Mexico and Texas. This same technique is also applied to the coprolite data available from previous studies in the Lower Pecos canyonlands.

Overall, the combined dietary data available for the Lower Pecos canyonlands presents a similar dependence on desertic plant resources throughout the Archaic. Three main menus are apparent in the specimens. The first menu consists of prickly pear (*Opuntia* sp.) cladodes, or nopales, and was principally, although not exclusively, consumed in the late spring. This menu is primarily consumed when other resources were not readily available and may be considered a dependable but undesirable meal. The second menu consists of pit-baked lechuguilla (*Agave lechuguilla*) and sotol (*Dasylirion* sp.) caudices, or hearts, common throughout the cool season. This menu entails high processing costs, but would provide a reliable caloric return. The third menu exhibits a monolithic reliance on prickly pear fruits, or tunas, during the summer. The ease of harvest and consumption is reflected in the seasonal dominance of this resource, which was assuredly a highly desirable meal. The dietary patterns recorded in the coprolite specimens from the Lower Pecos canyonlands demonstrate a seasonally variable diet-breadth that incorporated low-ranked resources during times of seasonal scarcity as well as a monolithic dependence on high-ranked resources when they were available in the local landscape.

DEDICATION

To Janet, Lita and Cecily. A mother, a wife, a daughter. I would not be the man I am today without these three women in my life. To my mother, Janet, who raised me with a boundless curiosity that informs my research to this day. To my wife, Lita, for her patience, love, and understanding over the course of my graduate career. To Cecily Rosemary Riley, my inspiration and hope for the future.

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I would like to thank my committee chair, Dr. Bryant, and my committee members, Dr. Thoms, Dr. Wright, and Dr. Holzenburg, for their guidance and support throughout the course of this research. This dissertation would not have been possible without their guidance and support during my graduate career.

Thanks also go to my friends and colleagues and the faculty and staff of the Anthropology department. The camaraderie and collegial atmosphere I encountered throughout the department was vital to my personal and professional development over the past seven years. While I am indebted to too many people to thank them all individually here, I want to specifically mention several cohorts. First, the archaeological faculty of the department. Each of you have been incredibly helpful and encouraging throughout this process. Second, the Palynology/Ecological Archaeology graduate students. I have learned a great deal from each of you over my graduate experience and I hope you can say the same. Having a group of other scholars interested in related topics of subsistence and microbotanical analysis has greatly enriched my research and personal perspective. Third, all of the students who I taught in graduate labs in Paleoethnobotany. Helping each of you develop an independent paleoethnobotanical research project has been the most rewarding and challenging aspect of my teaching career to date. I would also like to thank Phillip Johnson and Charlotte Pevny, dear friends and wonderful colleagues. I look forward to continued collaboration with both of you in the decades to come.

This dissertation would not have been possible without the efforts of prior researchers. This includes the crew who excavated Hinds Cave in the mid-seventies, previous coprolite specialists both at TAMU and beyond, and the ongoing efforts of researchers such as Steve Black, Phil Dering, and the SHUMLA School. Finally, thanks to my mother and father for their encouragement in pursuing my academic interests and to my wife for her love.

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CHAPTER I

DIET AND SEASONALITY IN THE LOWER PECOS CANYONLANDS

This study uses dietary data from coprolite specimens to assess questions of diet-breadth and seasonality of occupation for the human populations occupying Hinds Cave (41VV456) and the Lower Pecos canyonlands of Texas. Previous cultural reconstructions of the canyonlands, centered around the confluence of the Pecos River and the Rio Grande, suggest a consistent cultural exploitation of the region throughout the Holocene (Bement 1989; Collins 1974; Hester 1989; Prewitt 1983; Shafer 1986; Story and Bryant 1966; Turpin 1991a, 2004). The hunter-gatherers occupying this area practiced a conservative foraging adaptation to the semi-arid environment consisting of small, nomadic social groups with a broad-based subsistence economy (Sobolik 1996b).

Previous research has shown that the human populations exploiting the canyonlands were heavily dependent on sotol (*Dasylirion texanum* Scheele) caudex (heart), lechuguilla (*Agave lechuguilla* Torr.) caudex, prickly pear (*Opuntia sp.*) fruits (tunas) and cladodes (nopales) as dietary staples (Bousman and Quigg 2006; Bryant 1974b, 1977a; Dering 1979, 1999; Edwards 1990; Huebner 1991; Poinar et al. 2001; Shafer 1986; Shafer and Holloway 1979; Sobolik 1988b; Sobolik 1991a, c, 1996a, b; Stock 1983; Turpin 1991a; Williams-Dean 1978; Woltz 1998).

This dissertation follows the style of *American Antiquity*.

A similar dependence on these xeric resources is recorded in the early ethnohistoric accounts of colonial New Spain (De Leon 1971; Krieger 2002; Wade 2003).

Hinds Cave is a limestone solution rockshelter located approximately ten miles upstream from the confluence of the Pecos River and Rio Grande (Figure 1) (Shafer and Bryant 1977). The fill in the cave is almost entirely the result of human activity and contains an abundance of organic material including plant and animal remains (Shafer and Bryant 1977). Hinds Cave excavations by Shafer and Bryant of Texas A&M University resulted in the largest collection of coprolites (desiccated or mineralized feces) from a single hunter-gatherer site in North America (Dean 2006). Several thousand coprolites were recovered from a variety of contexts during the two field seasons spent excavating the site (Shafer and Bryant 1977). Coprolite specimens were recovered from excavation contexts that span the Holocene, providing a framework to address changes in the subsistence strategies employed by these hunter-gatherer populations. Four previous studies have been conducted on coprolites recovered from Hinds Cave (Edwards 1990; Reinhard 1989; Stock 1983; Williams-Dean 1978). Each of these studies has added to our knowledge of diet and nutritional health of the hunter-gatherer groups that populated the canyonlands. However, they provide only limited identification of the major plant constituents recovered from these specimens, namely epidermal cells, fiber cells, and calcium oxalate phytoliths, which are correlated indicators of staple resource exploitation. This is rectified in the current study, which uses these three congruent datasets to assess the diet-breadth of the meals represented in each coprolite as well as the seasonality of deposition. This novel approach relies on the temporally precise window into individual decision making that is recorded in coprolite specimens.

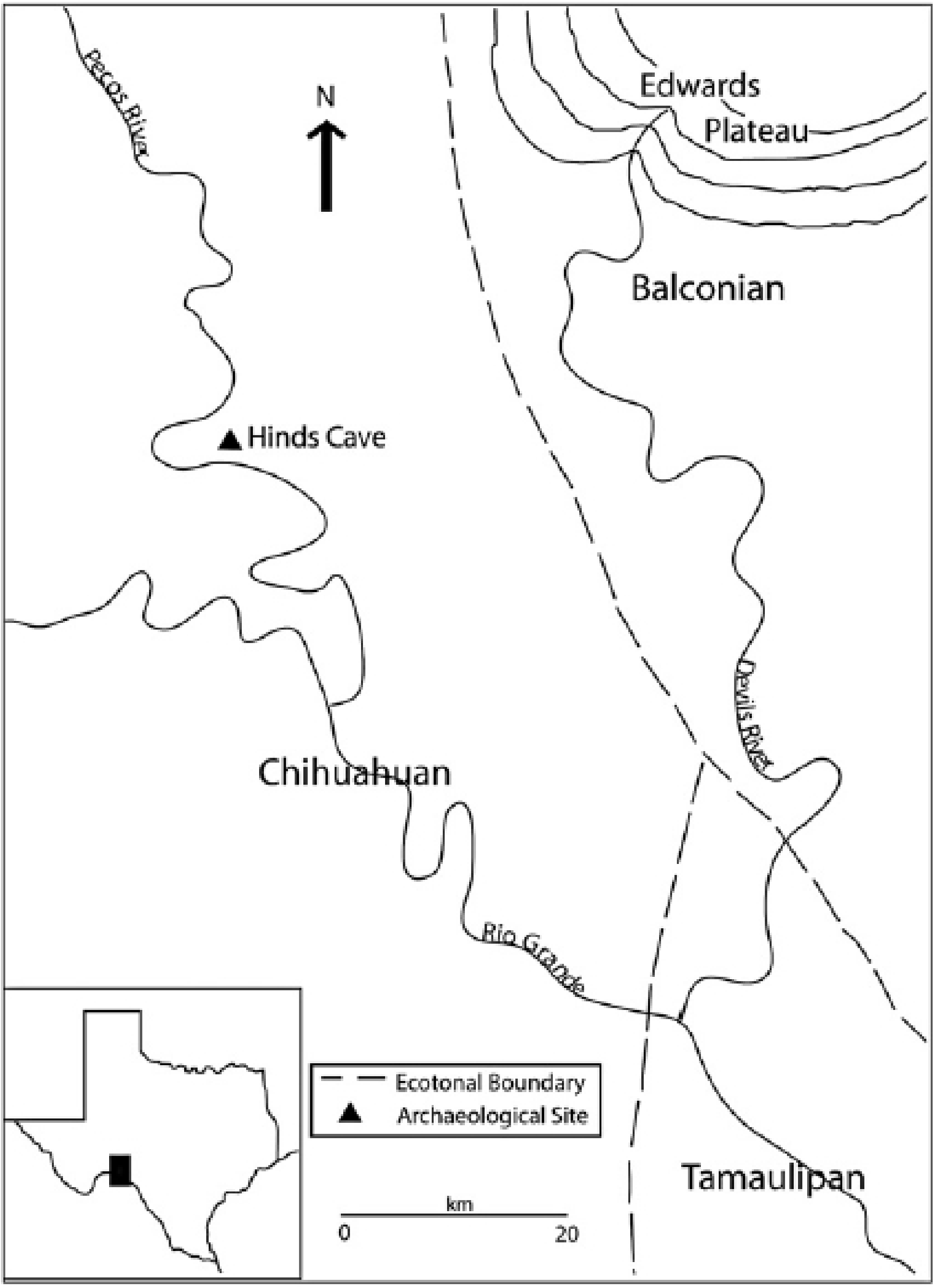


Figure 1. Map of Hinds Cave (adapted from Sobolik 1996)

Coprolites provide a unique perspective within the archaeological record, as they record the dietary choices of a single individual over a single day, or possibly, several days. This precise temporal record of diet allows for the direct application of diet-breadth models derived from optimal foraging theory, as each coprolite represents a related suite of subsistence decisions by an individual actor in the archaeological record. A diet-breadth model ranking these previously identified staple plant resources is applied to the available coprolite data from the region. This model is derived, in part, from earth-oven experiments developed by Dering (1999) and views the optimization of caloric return as the objective of the archaeological actors. This simplified model of the previously identified staple resources of the Lower Pecos canyonlands provides some important insight into the dietary decisions of hunter-gatherers in the region.

A total of thirty coprolites were examined for macroscopic and microscopic residues of plant resources in this analysis. These samples were taken from a set of three associated lenses chosen because they contain the oldest specimens excavated in area B, which has been interpreted as a latrine feature re-used throughout the Holocene (Shafer and Bryant 1977). The data from these specimens were assessed with hierarchical cluster analysis to assign groups of specimens based on overall similarities of constituents. The resultant clusters were examined with reference to the diet-breadth model generated for the known staple resources of the canyonlands and the seasonal round reconstructed from the ethnohistoric literature.

This same statistical method is applied to the previously available coprolite data from Hinds Cave and four other sites. While there are certain limits in the identification of the major components of specimens in some of these studies, they provide a useful record of some aspects of diet-breadth. The four other sites with coprolite data are spread across and beyond the Lower Pecos canyonlands. Conejo Shelter (Bryant 1974b) and Parida Cave (Riskind 1970) are located near the mouth of the Pecos River, while Baker Cave (Sobolik 1991a) is located east of the Devils River in a more mesic environment. Frightful Cave (Fry 1975), located in the center of the modern state of Coahuila, Mexico, provides an external point of comparison in evaluating the Lower Pecos canyonlands as a distinct cultural area.

The combined coprolite data provide a robust set of data to explore the subsistence strategies employed by the Holocene hunter-gatherer populations in the Lower Pecos canyonlands. There are a total of 224 coprolite specimens from Hinds Cave, ranging from the Early Archaic to the Late Archaic, and another 124 coprolite specimens from the other four sites. Three major menus, or dietary combinations, account for the meals represented in the majority of the coprolites from the canyonlands.

The first menu is dominated by the consumption of roasted sotol or lechuguilla caudex. Both of these resources were available year round, although the ethnographic evidence indicates that they were primarily consumed during the early spring or late winter. The caloric return for both of these resources compares favorably with other seasonally available resources, indicating that this menu would have been a preferential cold-season meal, despite the relatively high processing costs.

The second menu indicates a diet of nopales supplemented with onion bulbs (*Allium* sp.). The ethnohistoric literature observes that nopales were an important resource only during seasons of scarcity. This is corroborated by the diet-breadth model developed in Chapter II. The caloric return for both of these resources is extremely limited and suggests that they would only be incorporated into the diet-breadth during times of nutritional stress.

The third menu commonly observed in coprolite specimens from the canyonlands reflects the importance of prickly pear tunas as a seasonal staple. Tunas have low processing costs and a caloric return that surpasses the other plant staples of the canyonlands. This suggests that tunas would become the primary focus of the regional subsistence strategy whenever they are available and abundant. This is exactly the pattern of exploitation seen in the ethnohistoric record. Multiple ethnohistoric sources attest to the seasonal dominance of this resource across modern day Northern Mexico and Texas (De Leon 1971; Krieger 2002; Wade 2003). This abundant and highly-ranked resource formed the major component of the diet for several months every summer, providing a seasonal caloric surplus that supported the formation of large inter-ethnic gatherings and trade fairs.

Overall, the data indicate that many of the meals represented by these coprolite specimens were dominated by one or two staple plant resources. While this is frequently supplemented with trace amounts of secondary resources such as hackberry fruits (*Celtis* sp.) and other small fruits and seeds, the data indicate a stable exploitation of the four major resources considered in this study that spans the Holocene. This fits well with the ethnohistoric observations, which indicate that the diet of native groups tended to be focused on the exploitation of one or two preferred resources (De Leon 1971; Krieger 2002; Thoms 2008b).

The data presented in this study show that the human populations living along the northern fringe of the Chihuahuan Desert were dependent on fructan-based plant resources for the majority of their carbohydrate intake (Darbyshire and Henry 1981; Lopez and Urias-Silvas 2007b; Mancilla-Margalli and Lopez 2006). The temporal depth and spatial breadth of this strategy across most of arid North America has some important dietary implications for modern populations exhibiting high levels of diet-induced health issues, such as obesity and diabetes (Archer et al. 2002; Fogg 2010; Wiedman 2005). Soluble dietary fibers generally, and specifically fructans, have been shown to have a positive, ameliorating effect on lipid and glucose metabolism (Beylot 2005; Daubioul et al. 2002; Daubioul 2005; Delzenne and Daubioul 2000; Roberfroid 1999; Williams and Jackson 2002). Studies have shown that the fructan components of both *Agave* sp. and *Dasylirion* sp. have similar effects on metabolic function as the commercially available fructans derived from chicory root (*Cichorium intybus* (LINN.)) (Ur et al. 2008). This research suggests that attempts to address the high prevalence of obesity and diabetes among modern indigenous populations through diet should focus on the promotion of neglected, tradititional food resources, both as whole foods as well as a source of fructans for the commercial food industry. The incredible temporal depth of fructan consumption by human populations in the Chihuahuan desert has already been noted by some researchers (Leach 2007; Leach and Sobolik 2010) and, it is hoped, may inform on the community health strategies applied in the borderlands today.

CHAPTER II

OPTIMAL FORAGING THEORY AND DIET-BREADTH MODELS

Coprolites are the most direct evidence of diet available from an archaeological context (Reinhard and Bryant 1992; Sutton et al. 2010). While the differential digestibility of dietary components hinders a complete reconstruction of diet from coprolites (Fry 1985), these rarely preserved specimens have the unique potential to inform on the past dietary choices of both individuals and populations. Each coprolite reflects the dietary consumption patterns of an individual over one to several days. This window into individual behavior over such a short temporal period is unparalleled in archaeology. The discrete temporal record of diet recorded in a coprolite is an appropriate context for the application of models based upon individual decision making, such as those derived from optimal foraging theory (OFT) (Broughton 2002; Gremillion 2002; Yesner 1985). This chapter begins with an analysis of the potential for applying models derived from OFT to coprolite data sets from Hinds Cave. This will include a review of other applications of OFT models to anthropological datasets as well as a brief history of human behavioral ecology. This will be followed by an overview of diet-breadth models in OFT and the development of such a model for the coprolite data from the Lower Pecos canyonlands.

The Hinds Cave Assemblage and Optimal Foraging Theory

The Hinds Cave excavation presents an excellent opportunity to study prehistoric subsistence with diet breadth models for several reasons. Human habitation of the site extends to the Late Pleistocene, which is verified by both the radiocarbon record (Valastro et al. 1979) and diagnostic artifacts (Saunders 1986; Shafer 1986; Shafer and Bryant 1977). The temporal depth of this site, along with the well documented paleoenvironmental record for the Lower Pecos canyonlands, provides an ideal context for the accurate assessment of change in subsistence across the Holocene. The human populations occupying the Lower Pecos canyonlands during the Holocene engaged in a hunting and gathering subsistence strategy. This common subsistence strategy allows for the direct comparison of diet breadth between the different occupations of the site.

A number of prior studies of the site's assemblage dealt directly with issues of subsistence. These include the analyses of coprolites (Edwards 1990; Reinhard 1989; Stock 1983; Williams-Dean 1978) and macrobotanical (Dering 1979; Sobolik 1991a; Woltz 1998) and faunal (Lord 1984) components of the excavation, as well as studies of organic residues on stone tools (Shafer and Holloway 1979; Sobolik 1996a), experimental studies on cooking technology (Dering 1999)and a regional resource procurement survey (Saunders 1992) related to this archaeological site. The coprolite studies, combined with the organic residue analyses and experimental processing studies, provide a fairly comprehensive picture of prehistoric diet and food processing for the Lower Pecos region.

Another factor that makes Hinds Cave a wonderful site for examining prehistoric resource strategies is the excellent preservation of the assemblage. The assemblage from Hinds Cave includes uncharred leaves, fibers, and dried soft plant tissue throughout the matrix, as well as seeds, charcoal, and wood (Dering 1979, Shafer and Bryant 1977).

This assemblage is much more representative of the original residues of human activity deposited by the site occupants than almost any other type of archaeological site, excluding submerged and frozen contexts (Gorham and Bryant 2001; Monsalve et al. 2008; Poinar and Stankiewicz 1999). These two factors: 1) complementary research into coprolites, organic residues, and experimental plant processing and 2) incredible organic preservation make the Hinds Cave assemblage a good candidate for assessing subsistence strategies with testable predictions generated from diet breadth models.

Optimal Foraging Theory

Optimal foraging theory was developed by evolutionary ecologists interested in addressing a number of issues relating to animal subsistence (Macarthur and Pianka 1966; Pianka 1974; Smith and Winterhalder 1985). This approach consists of a set of models addressing time and energy allocation for food procurement, resource selection and habitat migration (Winterhalder and Smith 2000). Early advocates for the incorporation of these models into anthropology suggested that this approach was a promising avenue of development in the search for general rules of economic organization among foraging cultures (Smith 1983). Optimal foraging was one of the first successfully integrated human behavioral ecological methods in anthropology (Winterhalder and Smith 2000). While there are certain limitations of this approach in understanding human behavior (Martin 1983), the strength of foraging theory is that it consists of a unified set of models and concepts that allow for debate and revision (Smith and Winterhalder 1985). This strength is also an aspect of the underlying human behavioral ecology approach to understanding past human behavior.

There are some fundamental assumptions underlying the application of behavioral ecology, and specifically foraging theory, to studies of human behavior. Foraging theory makes an assumption of constrained optimization (Kaplan and Hill 1992). This is due to the adoption of concepts from micro-economics and evolutionary biology, which also assume optimization (Winterhalder 2001). Constrained optimization assumes that the archaeological actors in the model are skilled hunters and gatherers (Winterhalder 2001), who have a fairly stable return rate from their activities. Foraging theory is also reductionist in its modeling assumptions (Winterhalder and Smith 2000). The models developed in this approach are inherently simple, focusing on specific elements of the foraging strategy (Winterhalder 2001). Many anthropologists are uneasy with this approach, because it runs contrary to the holistic approach considered by many to be the major strength of anthropology (Winterhalder 2001). Human behavioral ecologists would counter that any holistic explanation of human behavior must be founded in the type of explanatory detail that can only be provided by isolating and examining the variables underlying the behavioral patterns. Winterhalder and Smith (2000) suggest that human behavioral ecologists share field methods with the rest of anthropology, but rely on different theoretical and epistemological frameworks to interpret the data generated from these methods.

Applications of Optimal Foraging Theory in Archaeology. A number of archaeological, cultural, and physical anthropologists have utilized OFT in their research. This section presents some of the applications of optimal foraging theory to archaeological data that have been conducted over the last twenty years. This will be followed by a brief section on some of the limitations in applying human behavioral ecology to archaeological data sets.

Zooarchaeologists have applied models derived from optimal foraging theory to the vertebrate and invertebrate faunal assemblages recovered from archaeological sites (Broughton 2002; Jones 2004; Madsen 1993; Madsen and Schmitt 1998; Nagaoka 2002; Speth 1991; Stiner 2002; Stiner et al. 2000). Beyond the focus on the faunal assemblages of archaeological sites and the use of optimal foraging theory, there is little common ground in these articles. Some are concerned with the evolution of modern humans and the broad-spectrum revolution (Stiner 2002; Stiner et al. 2000), while others focus on issues of protein selection (Speth 1991). Some studies utilize data to evaluate hypotheses (Nagaoka 2002), while others utilize data to refine and test the models (Broughton 2002; Jones 2004).

Surprisingly, very few paleoethnobotanists have adopted the theoretical tenets of optimal foraging theory in their research (Gremillion 1996; Gremillion and Sobolik 1996). Even detailed paleonutritional studies of coprolites have not approached the data from this theoretical perspective (Sobolik 1991a). Perhaps this is due to the limited inferences that can generally be derived from a macrobotanical assemblage resulting from depositional and preservational biases. However, many of these same taphonomic biases impact the conclusions derived from faunal assemblages as well. There has been some recent research on the methodological problems of testing the macrobotanical assemblage with optimal foraging theory (Gremillion 2002), which will be explored in the next section.

The application of optimal foraging theory in archaeology has not been limited to cultural groups that practice a hunter-gatherer adaptive strategy. There have been several applications of foraging models to issues of resource procurement and investment in agricultural and horticultural societies (Dominguez 2002; Gremillion 1996; Keegan 1986).

Although the hypotheses derived from foraging models all deal specifically with the acquisition of food, the resultant hypotheses have been used to inform larger social issues that impact foraging strategies such as the sexual division of labor (Elston and Zeanah 2002), risk avoidance (Speth 1991), and population dynamics (Boone 2002; Stiner et al. 2000). I suggest that habitat modification or disturbance is another issue that could be addressed through diet breadth modeling.

Limitations of Optimal Foraging Theory in Archaeology. A number of scholars have addressed the limitations of applying human behavioral ecology, specifically optimal foraging theory, to archaeological data sets (Gremillion 2002; Murray 2002; Yesner 1985). Others have compared the application of evolutionary ecology to similar approaches such as Dunnell's selectionist archaeology (Broughton and O' Connell 1999). The primary limitation in applying optimal foraging theory to archaeological data is an aspect of the data itself. Direct testing of diet breadth models requires data of individual behavioral decisions (Winterhalder and Smith 2000). The archaeological record cannot generally meet this requirement, since it is an aggregation of material from a number of individuals involved in a host of decisions (Winterhalder and Smith 2000). Post-depositional taphonomic processes complicate the situation.

There has been some effort to generate predictions consistent with the archaeological data (Grayson and Delpech 1998), as well as efforts in ethnoarchaeology to bridge the gap between the material record and the behaviors that create it (Bird 2000; Bird 2009; Kelly et al. 2005; Lupo 2006; Thomas 2002, 2007).

Yesner (1985) suggests that applying optimal foraging theory to the archaeological record simply requires appropriate selection of analytical units for currencies, constraints, and time frame. While some solutions to these issues have been illustrated in recent research on archaeological foraging theory (Gremillion 2002), it should be noted that these problems are primarily methodological and do not suggest a theoretical incompatibility between optimal foraging and archaeology. It can be argued that the Hinds Cave coprolite assemblage overcomes many of the issues in applying diet breadth models to an archaeological context. Coprolites do represent a temporally discrete set of behaviors by an individual actor that allows a direct application of the diet breadth models developed in behavioral ecology.

Every coprolite specimen reflects a discrete set of individual dietary choices. This direct evidence of a single individual's behavioral decisions over a very constrained timeframe is unique in the archaeological record. In prior studies, the individual nature of each specimen has been seen as a limitation of dietary reconstruction, since the precise relationship of the meals represented in a single coprolite specimen to overall patterns of subsistence among a human population cannot be determined (Reinhard and Bryant 1992). Prior studies have addressed this by examining a large number of specimens from a single context. The current study examines diet breadth and seasonality with a view that each specimen is an individual context of analysis. The ability to examine a temporally limited set of dietary decisions by an individual is exceptional in the archaeological record and a major strength of coprolite studies. This links the archaeological record to decisions of individual actors, overcoming a major weakness in the application of optimal foraging models to archaeological settings (Winterhalder and Smith 2000).

Diet-Breadth Models. Diet breadth models are among the most widely utilized optimal foraging models in ecology and anthropology (Winterhalder and Smith 2000). This is partly due to the fact that these were among the first fully developed models in behavioral ecology (Winterhalder 2001). These models deal with a biological necessity, food acquisition that humans share with all other animals, perhaps another reason for the successful introduction of these models in anthropology. Like all human behavioral ecology models, diet breadth models consist of four major components: 1) a goal (generally to optimize the net energy acquisition rate); 2) a currency to measure the relative costs and benefits; 3) constraints modeling the social and environmental contexts; and 4) alternative behavioral decisions (Kaplan and Hill 1992). Constructing such limited models allows researchers to approach complicated situations in a very explicit and formalized fashion. This makes models easier to refine as well as flexible enough to apply in diverse socioenvironmental circumstances.

There are two major classes of diet breadth model, the encounter-contingent type (also known as prey choice) and resource patch types (Winterhalder 2001). These models differ primarily in the distribution of resources in the landscape. Prey choice models suppose a random distribution of resources and, hence, a random encounter rate with different resources (Kaplan and Hill 1992). Patch models suppose the presence of patches of resources with intervening spaces empty of resources (Winterhalder 2001). While both of these models are simplifications of any ecological community, they both can be utilized to generate hypotheses of resource acquisition that encompass testable predictions. Kaplan and Hill (1992) suggest that these simple approaches can be elaborated in a number of ways, either to incorporate more complex models of resources or to account for human behavioral complexity. In the following section, an encounter-contingent model is proposed for the major plant staples of human populations in the Lower Pecos canyonlands.

Diet-Breath and Dietary Staples of the Lower Pecos Canyonlands

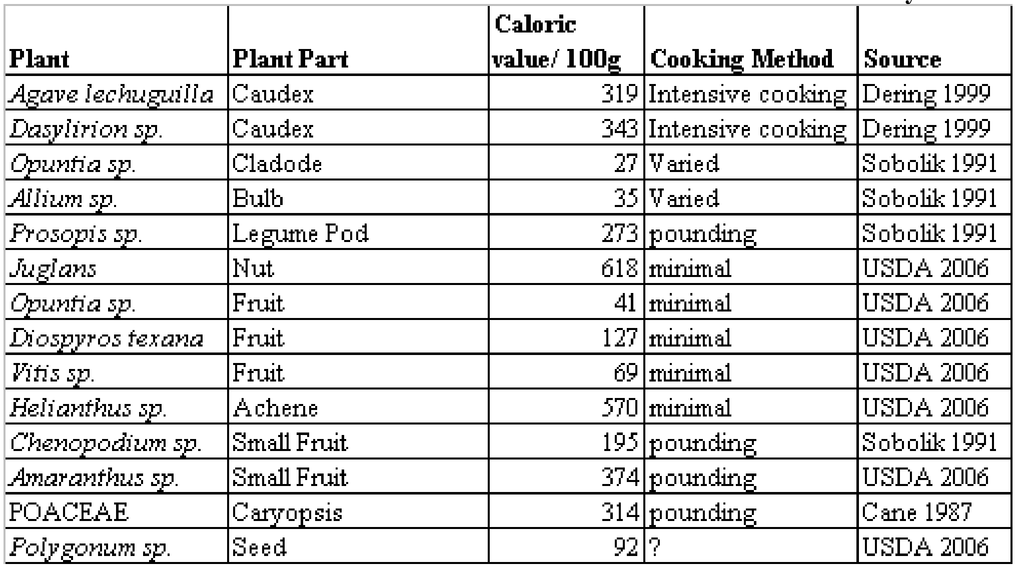
Previous research, as noted, has shown that the human populations exploiting the Lower Pecos region were heavily dependent on sotol caudex, lechuguilla caudex, prickly pear tunas and nopales as dietary staples throughout the Holocene (Bousman and Quigg 2006; Bryant 1974a, 1977b; Dering 1979, 1999; Edwards 1990; Huebner 1991; Poinar et al. 2001; Shafer and Bryant 1979; Shafer 1986; Sobolik 1988a, b, c, 1991a, b, 1996a, b; Stock 1983; Turpin 1991; Williams-Dean 1978; Woltz 1998). For the purposes of this study, a resource which is consumed on a daily basis during its seasonal availability or which provides the bulk of caloric intake in a menu is considered a staple resource. This model ranks these resources according to their potential return rates. Diet breadth modeling suggests that less productive resources would only be incorporated into a diet when the energetic returns from higher ranked resources dropped to the level of the lower resources due to seasonal limitations or scarcity (Kaplan and Hill 1992). This approach underlies the classification of survival and famine foods presented by Turner and Davis (1993) and Cotton (1996). However, the approach taken by those authors is not explicit or quantifiable, though it is still a useful way to classify the relative importance of food resources (Cotton 1996; Turner and Davis 1993). The four major components of the diet-breadth model will be presented, followed by a synthesis of the available data and expectations for diet-breadth derived from the model.

Goal. The goal of this model is to optimize the net energy return rate (kCal/hr of work) of a human population dependent on these staple resources. This requires an evaluation of the net caloric return each of these major resources as well as a consideration of the energetic costs associated with acquiring and processing these resources. This will be followed by an examination of the environmental constraints influencing these costs and the generation of a mathematical model from these data. It should be noted that while maximizing caloric return rates was the goal of this simplified model, there are other reasons for consuming dietary resources. This model can indirectly inform on this by observing when and how caloric return rates fail to account for observed dietary breadth.

Currency. The caloric value of lechuguilla, sotol, onions, and prickly pear nopales is primarily derived from fructan, a storage polysaccharide composed of long branched chains of fructose with a single glucose molecule (Darbyshire and Henry 1981; Huazano-Garcia 2009; Leach and Sobolik 2010; Lopez and Urias-Silvas 2007a, b; Mancilla-Margalli and Lopez 2006; Ur et al. 2008). Fructan cannot be broken down in the human digestive tract directly and requires lengthy hydrolysis to degrade the compounds and form smaller carbohydrate molecules (Leach and Lopez ; Lopez and Urias-Silvas 2007b; Wandsnider 1997). Unaltered fructans function as soluble dietary fiber, or prebiotics, fermentable substrates that promote bacterial populations in the hindgut (Lopez and Urias-Silvas 2007b). Short chain fatty acids are produced as a byproduct of this fermentation process (Leach and Lopez ; Lopez and Urias-Silvas 2007b). Recent research suggests that this process produces significantly less caloric yield than direct digestion of carbohydrates (Leach 2009). Leach (2009) argues that experimental earth ovens do not reach a high enough temperature to substantially depolymerize fructans into digestible carbohydrates, leading him to conclude that the previous caloric values utilized for these desert succulents are set too high (Dering 1999). Leach does not account for the presence of other carbohydrates in the tissue of these species, which typically make up between 15% and 35 % of the water-soluble carbohydrates and occasionally account for over half of all carbohydrates in a specimen (Mancilla-Margalli and Lopez 2006). For the purposes of this diet breadth model, the traditional values of 4 Kcal/gram of carbohydrate will be utilized rather than the 1.5 Kcal/gram suggested by Leach (2009). This is due to the uncertainty of the degree of depolymerization achieved in rock lined earth ovens as well as the inability to account for the relative frequency of fructans to digestible carboyhydrates in the plant material consumed. Ethnographic accounts frequently reference the sweet taste of roasted agave and sotol hearts (Castetter et al. 1938), suggesting that the fructans were depolymerized with traditional earth oven cooking methods. This is corroborated in a study evaluating the hydrolysis of fructans in *Agave tequilana* using traditional tequila production processes (Waleckx et al. 2008). Samples from the process indicate that 98% of the fructans were converted into simple sugars, dominantly fructose, after 25.5 hours of cooking in the oven (Waleckx et al. 2008).

Table 1 presents the caloric values of plant resources identified in previous coprolite studies (Edwards 1990; Stock 1983; Williams-Dean 1978). The nutritional value of sotol and lechuguilla is many times that of nopales and tunas by weight (Dering 1999; Riley 2008; Sobolik 1991a). It should be noted that prickly pear tunas contain starch and oil in their abundant seeds. As these seeds are generally recovered intact in the coprolite specimens, this source of calories has not been incorporated into the caloric value presented in Table 1.

Table 1. Caloric Values for Known Food Resources from the Lower Pecos Canyonlands



Plant	**Plant Part**	**Caloric value/ 100g**	**Cooking Method**	**Source**
Agave lechuguilla	Caudex	319	Intensive cooking	Dering 1999
Dasylirion sp.	Caudex	343	Intensive cooking	Dering 1999
Opuntia sp.	Cladode	27	Varied	Sobolik 1991
Allium sp.	Bulb	35	Varied	Sobolik 1991
Prosopis sp.	Legume Pod	273	pounding	Sobolik 1991
Juglans	Nut	618	minimal	USDA 2006
Opuntia sp.	Fruit	41	minimal	USDA 2006
Diospyros texana	Fruit	127	minimal	USDA 2006
Vitis sp.	Fruit	69	minimal	USDA 2006
Helianthus sp.	Achene	570	minimal	USDA 2006
Chenopodium sp.	Small Fruit	195	pounding	Sobolik 1991
Amaranthus sp.	Small Fruit	374	pounding	USDA 2006
POACEAE	Caryopsis	314	pounding	Cane 1987
Polygonum sp.	Seed	92	?	USDA 2006

Costs. The desert succulents so prevalent in coprolites from the region require intensive cooking to depolymerize the fructan type carbohydrates into shorter chain digestible polysacchrides. This hydrolysis is achieved through the use of rock as heating elements in buried earth ovens (Dering 1999; Leach et al. 2005). Dering (1999) has estimated the handling costs required to construct such an oven, as well as the amount of plant material that could be baked in a 1.5 m^2 earth oven (Table 2). While prickly pear nopales and wild onions can be processed in a number of ways, ethnohistoric evidence suggests that nopales were usually baked in an earth oven like lechuguilla and sotol (De Leon 1971; Krieger 2002; Thoms 2008b). This long term roasting method would be necessary to extract the maximum caloric value from these fructan-based carbohydrate resources. Thus, the processing costs would be similar for the lechuguilla, sotol, and prickly pear nopales, as all three resources require intensive hydrolysis to render digestible carbohydrates.

Prickly pear tunas can be eaten with minimal processing. Processing may be used to transform these sugar rich resources into storable cakes or to remove minute glochids (spines), but there is no need to process this resource to render it digestible. Because of the occurrence of all of these staple resources in dense stands near the canyon rims, search costs have not been calculated (Dering 1999). I contend that differences in the reproductive ecology and growth habits of these three species may impact resource availability in the immediate vicinity of a consistently re-occupied habitation site such as Hinds Cave. This is discussed further in the constraints section that follows.

Constraints. It has been suggested that the staple resources presented above fall into two broad categories based on growth habits and reproduction (Dean 2004). One category consists of those resources that exhibit slow growth habits and only reproduce at an advanced age. This category of resources could be stripped from a local environment by a small foraging population. Ecologists have documented the suppression of slowly growing species through frequent disturbance using Lotka-Volterra computer simulations (Huston 1994). The decline of sotol, a slow growth species in the local plant community, would be directly related to the intensity of resource procurement as hunter-gatherer populations would harvest the calorically valuable mature specimens before florescence (Dean 2004).

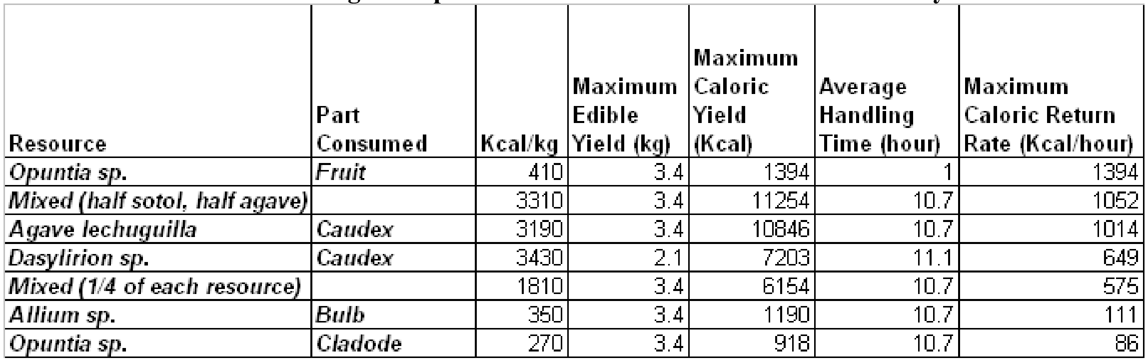
The other category consists of those resources that exhibit fast growth habits and frequent flowering, such as prickly pear, or reproduce asexually, such as lechuguilla (Nobel 1988). It would require a greater intensity of disturbance to remove this resource type from a local resource cachement area. Most agave species, including lechuguilla, grows in clusters of young rametes attached by rhizomes to a mother rosette (Nobel 1988). This vegetative reproduction can account for 95% of all offspring in an agave population (Nobel 1988). Mature mother plants can be harvested with little impact on the surrounding rametes, which are too small and carbohydrate deficient to be utilized as a food or fiber resource (Castetter et al. 1938; Gentry 1982) This situation creates a continuous supply of newly mature plants, since harvest patterns do not interfere with population reproduction (Flannery 1986a). If Hinds Cave was occupied on a semi-annual basis, the slow growth resources should be less available for harvest and less important in the diet than the renewable resources. If there are long periods of abandonment between the occupations, there should be a greater availability of and associated dependence on slow growth resources.

While Dering (1999; 2005) has done an excellent job developing processing cost and caloric return experiments associated with sotol and lechuguilla (Table 2), the resultant data categorize the aforementioned staples as high-input, low-return food sources primarily by comparison to the returns from animal resources rather than other plant foods, particularly those available in the Lower Pecos canyonlands. I argue that comparing plant and animal resources directly based on return rates is less productive than considering each class of food resource separately since they generally represent two distinct groups of activities, namely, hunting and gathering. When considered from this vantage, very few plant foods in the Lower Pecos have a higher caloric value than sotol and agave (Riley 2008). The only resources that surpass the caloric yield of these succulents are seasonally limited and inconsistent mast resources, such as walnuts and acorns, and sunflower achenes. By contrast, desert succulents are potentially available year round, are not subject to much interannual variation in production and frequently occur in dense communities allowing for mass harvesting and processing. There does appear to be some differences in caloric content associated with the inflorescence of these species (Bell and Castetter 1941; Castetter et al. 1938; Mancilla-Margalli and Lopez 2006). This is not considered in this model due to a lack of nutritional data addressing this difference. While this initial ranking based on caloric return does not take into account the costs associated with procuring and preparing these resources, it suggests that both sotol and lechuguilla would have been preferred resources, particularly mature specimens with large quantities of energy stored to grow their inflorescence.

A Model of Lower Pecos Diet Breadth

The following model uses the data from Dering (1999) with some additions and modifications. Dering's (1999) earth oven experiments varied in the amount of plant material initially cooked. Lechuguilla ovens contained 30 hearts and sotol ovens 25, due to size differences. Surprisingly, lechuguilla yields more calories than a sotol plant of comparable size, probably due to the thicker leafbase and caudex of the lechuguilla plant (Dering 1999). The edible yield (kg) for an oven loaded with lechuguilla is higher than an oven loaded with same weight of sotol, while the amount of inedible plant refuse is higher for the oven containing sotol (Dering 1999). It should be noted that this is not entirely secure, as some sotol ovens returned higher yields than some lechuguilla ovens (Dering 1999). For the purposes of this model, only the upper yields have been generated for each resource. There is no experimental data available for the edible yield of roasted nopales or onions. Because neither of these resources would produce a large amount of vegetal refuse, the higher cooked return values of lechuguilla have been used for both. The returns for two mixed resource earth ovens are also presented, one half sotol and half lechuguilla and the other composed of equal parts of all four resources. The returns from these six earth ovens are also compared to the returns generated by collecting tunas. For the purposes of this study, it is assumed that the same amount of edible material generated by each oven could be collected in one hour for tunas.

Table 2. Diet Breadth Ranking of Staple Plant Resources of the Lower Pecos Canyonlands



Resource	Part Consumed	Kcal/kg	Maximum Edible Yield (kg)	Maximum Caloric Yield (Kcal)	Average Handling Time (hour)	Maximum Caloric Return Rate (Kcal/hour)
Opuntia sp.	*Fruit*	410	3.4	1394	1	1394
Mixed (half sotol, half agave)		3310	3.4	11254	10.7	1052
Agave lechuguilla	*Caudex*	3190	3.4	10846	10.7	1014
Dasylirion sp.	*Caudex*	3430	2.1	7203	11.1	649
Mixed (1/4 of each resource)		1810	3.4	6154	10.7	575
Allium sp.	*Bulb*	350	3.4	1190	10.7	111
Opuntia sp.	*Cladode*	270	3.4	918	10.7	86

This simplified model of the previously identified staple resources of the Lower Pecos canyonlands provides some important insight into the dietary decisions of hunter-gatherers in the region. Despite having a relatively low caloric return by unit weight, prickly pear tunas have the highest caloric return rates of any resource considered in this model. This is due, primarily, to the low processing costs associated with this easily digestible resource. Tunas should be the dominant component of the diet when they are seasonally available. Both agave and sotol provide a decent return on the time and energy spent constructing an earth oven, but neither provides the surplus of calories necessary to store resources for future consumption. The return rates for onions and nopales suggest they should only be incorporated into the diet when most other resources are not available in abundance due to seasonality or localized overharvesting. This model will be used to assess the diet breadth of a number of coprolite studies from across the Holocene (Bryant 1969, 1974b; Edwards 1990; Fry 1975; Riskind 1970; Sobolik 1988b; Sobolik 1991a; Stock 1983; Williams-Dean 1978).

CHAPTER III

SUBSISTENCE AND COPROLITES IN ARCHAEOLOGY

The reconstruction of prehistoric subsistence has been a major goal of archaeology (Boone 2002; Broughton and O' Connell 1999; Bryant 1974c; Sobolik 1988a; Sobolik 1991a, b, c, 1996b; Sutton et al. 2010; Winterhalder and Smith 1992). This includes research in fields as diverse as tool form and function, stable isotope analysis of bones and teeth, iconographic evidence, and the analysis of botanical and zoological remains from archaeological deposits (Reinhard and Bryant 1992). While these approaches to reconstructing subsistence all have merit, none are direct evidence of the specific resources incorporated into past human diet. Coprolites are a direct line of evidence for diet (Sutton 1998; Sutton et al. 2010). This chapter presents a brief historical review of archaeological coprolite research, followed by an examination of the data sets potentially available from coprolite specimen. This section is organized into three broad categories of analysis: macroscopic, microscopic, and biochemical.

A Brief History of Coprolite Research

The study of fecal material has a long history in such diverse disciplines as medicine, biology, paleontology, and archaeology (Fry 1985; Sutton et al. 2010). The word “coprolite” was coined by Buckland in 1829 as a term for mineralized dinosaur feces (Buckland 1829). The definition has been expanded to include desiccated feces or intestinal contents in addition to actual “poop stones.” A small number of studies were conducted throughout the first half of the twentieth century, but there was no standardized method for sample preparation and analysis (Eames 1930; Laudermilk 1938a, b; Wakefield and Dellinger 1936).

This all changed with the pioneering work of Eric O. Callen, the first archaeological coprolite specialist (Callen 1963, 1965, 1967, 1973; Callen and Cameron 1960; Callen and Martin 1969). Callen's primary contribution was adopting a rehydration technique for dried zoological specimens (Van Cleave and Ross 1947) and herbarium specimens (Benninghoff 1947) that required soaking the specimen in a solution of trisodium phosphate until disaggregation of the components occurred (Callen and Cameron 1960). Prior to the establishment of this technique, researchers attempted to separate constituents in a number of ways, including screening the dry specimen, breaking it open with a hammer, and teasing the coprolite apart by hand (Bryant and Dean 2006). The advent of a viable rehydration technique allowed researchers to recover a much broader range of data with which to evaluate past human diet, nutrition, health, and ecology.

Following the development of this rehydration technique, Callen and others began a systematic study of the pollen, plant and animal macrofossils, and parasitological remains recovered from these unique human (Bryant 1969, 1974b, c, 1975; Callen 1963; Callen and Martin 1969; Colyer 1965; Dickson et al. 2003; Fry 1970; Fry and Moore 1969; Heizer 1967; Martin and Sharrock 1964; Moore 1969; Riskind 1970; Robbins 1971; Watson and Yarnell 1966; Yarnell 1969). While the recovery of macrofossils, pollen, and parasitological data has been the main focus of coprolite studies, recent research has also extended into areas of biochemical analysis including

DNA studies (Gilbert et al. 2008; Gilbert et al. 2009; Goldberg 2009; Hofreiter et al. 2000; Iniguez 2006; Leles 2008; Loreille et al. 2001; Luciani et al. 2006; Poinar et al. 2009; Poinar et al. 2003; Poinar et al. 1998; Poinar et al. 2001; Rasmussen et al. 2009; Reinhard et al. 2008; Rollo et al. 2002; Stokstad 2000; Sutton et al. 1996), protein residue (Chin et al. 2003; Lambert 2000; Marlar 2000; Newman et al. 1993; Reinhard 2006; Toker et al. 2005), sterol analysis (Gremillion and Sobolik 1996; Lin and Connor 2001; Lin et al. 1978; Toker et al. 2005), and the determination of organic compounds through IR spectroscopy and various chromatographic techniques (Wales and Evans 1988).

These interdependent data sets have been used to address research questions including subsistence strategy (Bryant 1974b, c; Clary ; Cummings 1994; Euler 1982; Faulkner 1991; Gremillion 1996; Heizer 1967; Holden 1991; Horrocks et al. 2004; Leach and Sobolik 2010; Minnis 1989; Poinar et al. 2001; Sobolik 1991a; Sutton et al. 2010), medicinal plant usage (Chaves and Reinhard 2006; Dean 1993; Kelso and Solomon 2006; Reinhard et al. 1991; Sobolik 1988a; Sobolik and Gerick 1992), community health (Andrews 1979; Confalonieri et al. 1991; De Candanedo Guerra Rde 2003; Dittmar and Steyn 2004; Evans et al. 1996; Fry and Moore 1969; Goncalves et al. 2002; Guerra et al. 2001; Guerra et al. 2003; Jouy-Avantin et al. 1999; Le Bailly et al. 2003; Leles 2008; Loreille et al. 2001; Mart et al. 2010; Ortega and Bonavia 2003; Reinhard 1987; Reinhard 1992; Reinhard and Bryant 1992; Westoni 2009), and seasonality of site occupation (Riley 2008; Yll et al. 2006).

Deconstructing Coprolites

Coprolites are biochemically complex specimens that contain residues derived from multiple sources. Fry (1985) lists six major components: 1) undigested dietary compounds; 2) intestinal secretions of the individual; 3) minerals and other substances excreted into the digestive tract; 4) hindgut bacteria and their metabolic derivatives; 5) cellular components, including parasites and pathological evidence; 6) enteroliths, gallstones, pancreatic calculi, and fecal spherulites (Canti 1997, 1998, 1999; Sutton et al. 2010). While each of these major classes can inform on past human nutrition and health, the majority of coprolite studies have focused on the identification of food residues and parasites. Because coprolites are the result of the digestive process, the remaining residues of dietary items do not necessarily reflect the entire breadth of the meals consumed (Reinhard and Bryant 1992; Williams-Dean 1978).

Dietary reconstruction based on coprolite specimens makes five basic assumptions about the nature of the components recovered (Sutton et al. 2010). First, the materials in the specimen were intentionally consumed by the individual who deposited the sample. Second, these materials can be identified. Third, the identified materials were consumed for the purpose of subsistence and represent at least part of the overall dietary choices made by the individual prior to deposition. Fourth, the materials identified in a specimen were consumed in the day or two prior to elimination. Thus, specimens may represent more than one meal, but are relatively precise windows into the suite of dietary decisions made by the individual. Fifth, each coprolite is the result of a unique elimination of one individual.

Macroscopic Analysis. The most abundant components of many coprolite specimens are macroscopic plant remains such as seeds, nut shell, epidermal cells and other plant fragments (Callen and Martin 1969; Reinhard and Bryant 1992) as well as animal components including bone, shell, feathers, hair, and scales (Reinhard et al. 2007; Sobolik 1993; Sutton et al. 2010). These remains include both undigested and indigestible tissues (Sutton et al. 2010). These components can inform on diet, but may not accurately reflect the relative importance of different food items (Holden 1994; Reinhard and Bryant 1992). This is particularly true of easily digestible plant and animal components, such as the soft tissue of fruits, geophytes (underground storage organs), skeletal muscle and other tissue from animals, or plant foods that are heavily processed before consumption, such as milled seed resources (Sutton et al. 2010). This is also impacted by the selective discard of harder components of a resource, including shell, bone, fiber, and seeds. This is seen throughout the Lower Pecos canyonlands, where fiber quids derived primarily from sotol and lechuguilla were encountered in abundance at many sites (Irving 1966). While many coprolite studies identify botanical components such as seeds, fruit fragments and nutshells, most neglect what are often the dominant components of many specimens, plant epidermal and sclerid (fiber) cells (Bell and King 1944; Catling and Grayson 1998; Sobolik 1991a; Sobolik 1992). This creates a significant gap in the ability to reconstruct vegetal components of the meals represented in the coprolites, as many staple plant resources, including geophytes, cladodes and caudices, are underrepresented while reproductive structures such as fruits, nuts and seed resources are elevated above their actual contribution to the diet.

This is a particularly important issue in the Lower Pecos canyonlands, where previous studies have shown that the bulk of the diet was composed of fibrous vegetal resources (Bryant 1974b; Edwards 1990; Fry 1975; Leach and Sobolik 2010; Sobolik 1991a; Stock 1983; Williams-Dean 1978). Many of these staple resources can only be confirmed by reference to microscopic features of the macroscopic remains in coprolites or ancient DNA (aDNA). Fiber ultimates and epidermal sheets require special reference collections and expertise to properly identify (Bell and King 1944; Catling and Grayson 1998; Sobolik 1992). Combining the thorough analysis of plant macrofossils with microscopic plant remains such as phytoliths, as well as biochemical and DNA evidence, can furnish a more complete picture of the botanical component of past human diet and nutrition.

Common vertebrate remains encountered in many coprolites include small bones and bone fragments, hair, feathers, scales, and eggshell (Backwell et al. 2009; Reinhard et al. 2007; Reinhard and Bryant 1992; Sobolik 1993). While this is a broad range of potential data, large animals are frequently underrepresented in the record because the bone and other durable components were removed prior to the consumption of the edible portions such as meat and organs (Reinhard et al. 2007; Sobolik 1993). Combining the study of these macroscopic remains with protein residue and DNA studies of the coprolite specimens as well as traditional zooarchaeological studies from the same site can provide a more complete picture of the animal component of the diet.

Evidence of insect and other invertebrate consumption is another macroscopic component frequently encountered in coprolite specimens (Bryant and Dean 2006;

Callen 1963; Johnson et al. 2008; Reinhard and Bryant 1992; Sutton et al. 2010). The evidence generally consists of the remains of the chitinous exoskeletons of insects and the calcium carbonate shell fragments of gastropods. It is important to note that unidentified chitin fragments recovered from specimens may represent the remains of coprophagous insects rather than dietary consumption (Reinhard and Bryant 1992).

Microscopic Analysis. Analysis of the microscopic fraction of specimens is an important part of coprolite studies. Most of this work has focused on the identification of pollen grains, which can inform on diet, seasonality of deposition, and medical practices (Carrion et al. 2005; Carrion et al. 2001; Dean 1993, 2006; Horrocks et al. 2003; Horrocks et al. 2004; Horrocks et al. 2002; Kelso and Solomon 2006; Reinhard et al. 2006; Reinhard et al. 1991; Riskind 1970; Sobolik 1988a). The second most common microscopic component identified in coprolite studies are ova and other evidence of parasites (Confalonieri et al. 1991; Dittmar and Steyn 2004; Evans et al. 1996; Fry and Moore 1969; Fugassa et al. 2006; Horrocks et al. 2004; Jouy-Avantin et al. 1999; Ortega and Bonavia 2003; Shin et al. 2009; Toker et al. 2005). To date, little attention has been focused on the identification of phytoliths and starch granules from coprolites, although there are some exceptions (Danielson and Reinhard 1998; Horrocks et al. 2003; Horrocks et al. 2004; Horrocks et al. 2002; Reinhard 2006; Reinhard and Danielson 2005). Analysis of these microscopic components provides corollary lines of evidence to interpretations based on the macroscopic and aDNAcomponents.

Since the first studies of coprolite pollen by Paul Martin in the 1960s (Fry 1985; Martin et al. 1961; Martin and Sharrock 1964), pollen analysis has become a routine part of both human and animal coprolite studies (Bryant 1974a, c, 1975; Bryant and Holloway 1985; Carrion et al. 2005; Carrion et al. 2001; Chaves and Reinhard 2006; Horrocks et al. 2003; Horrocks et al. 2004; Horrocks et al. 2002; Horrocks et al. 2008; Irwin et al. 2004; Kelso and Solomon 2006; Reinhard et al. 2006; Riskind 1970; Williams-Dean 1978), because it is preserved remarkably well in fecal matter (Reinhard and Bryant 1992). The pollen spectrum of a coprolite is often the primary data set used to assess seasonality of consumption (Gremillion and Sobolik 1996; Reinhard and Bryant 1992; Williams-Dean 1978). While these types of data are not without fault, the congruence of the pollen spectrum with other indicators such as seasonally limited fruit or juvenile faunal remains provide some of the strongest evidence of seasonality of site usage. It is also an important, if biased, source of evidence used for past environmental reconstruction (Carrion et al. 2001). Pollen recovered from coprolite specimens can inform on aspects of dietary intake not evident in the macroscopic plant remains (Dean 1993; Fry 1985; Holloway 1983; Sobolik 1988a). This is perhaps most useful in identifying potential medicinal ingestion of plants (Holloway 1983; Reinhard et al. 1991; Shafer et al. 1989; Sobolik and Gerick 1992).

Pollen data recovered from coprolites have limitations in inferring dietary intake. Experimental studies demonstrate that pollen types can appear in fecal samples days or even weeks after the recorded ingestion of that type (Dean 2006; Kelso and Solomon 2006; Williams-Dean 1978). There is also an ongoing debate about the importance of concentration values in a coprolite specimen to better establish the purposeful ingestion of pollen (Dean 1993, 2006; Reinhard et al. 2006; Reinhard et al. 1991). This is explored further in the results of the present study.

Pollen can inform on multiple aspects of past diet and environment, due to its varied dispersal and ingestion (Fry 1985). Some pollen is anemophilous (airborne) and would be primarily ingested through aspiration, from water sources, or as an atmospheric contamination of food (Fry 1985). These pollen types would inform on seasonality of deposition as well as changes in vegetative communities and, potentially, climate through correlation with pollen samples recovered from dated stratigraphic sequences (Fry 1985; Reinhard and Bryant 1992). Other pollen types are zoophilous (animalt-borne) and are usually directly correlated with ingestion of flowers as food or drink (Bryant and Dean 2006; Chaves and Reinhard 2006; Dean 1993, 2006; Fry 1985; Kelso and Solomon 2006; Reinhard et al. 2006; Reinhard et al. 1991; Sobolik 1988a). While some scholars (Fry 1985) suggest that pollen could enter the digestive tract from grains adhering to various foodstuffs, studies of pollen dispersal have shown that pollen rarely accumulates on or near the fruit and other digestible components of major food resources such as nopales, though there are some exceptions (C*henopodium sp.*) (Adams 1988a; Adams 1988b; Bohrer and Adams 1977). Little pollen would be expected to accumulate on the sotol and lechuguilla staples of the Lower Pecos, since harvesting these resources negates the development of the inflorescence.

Evidence of parasitism is one issue frequently addressed with microscopic analysis of coprolites (Confalonieri et al. 1991; Dittmar and Steyn 2004; Evans et al. 1996; Faulkner 1991; Fry 1985; Guerra et al. 2003; Holiday et al. 2003; Jouy-Avantin et al. 1999; Reinhard et al. 1985). It generally consists of the ova and larvae of both ectoparasites and endoparasites (Reinhard 1992). It should be noted that interpretations of these remains must be made with caution, as many parasite ova are difficult to classify or are not exclusive to humans (Fry 1985). Evidence of parasitic infestation can provide an excellent means by which to evaluate changes in community health with the development of agriculture or increasing population density (Fry 1985; Reinhard 1989; Reinhard 1992; Reinhard et al. 1985).

Reinhard (1988) utilized the combined macrobotanical, faunal and parasitological data from coprolite specimens from across the Southwest to evaluate the maize dependency hypothesis, which suggests that high levels of anemia should be observed (through skeletal markers such as porotic hyperostosis (El-Najjar et al. 1975; Karl and Fink 1994; Walker et al. 2009; Wright 1998)) in populations with a singular dependence on maize. There was no observed relationship between high levels of maize consumption and skeletal markers of anemia (Reinhard 1989). In this analysis, Reinhard (1988) observed a strong correlation between the presence of helminth remains, mostly pinworm (*Enterobius vermicularis*), in coprolites and porotic hyperostosis lesions on skeletons from the same sites. While this does not infer a causal relationship, it does suggest that the same sanitation factors that promote the growth of pinworm would also lead to microparasite infections that cause anemia (Reinhard 1989).

Other microfossils have also been recovered from coprolite specimens, including bacteria, fungal spores, diatoms, and phytoliths (Horrocks et al. 2003; Horrocks et al. 2002; Reinhard and Bryant 1992). Phytoliths are the most frequently studied of these microfossils (Danielson and Reinhard 1998; Fox 1994; Horrocks et al. 2003; Horrocks et al. 2004; Horrocks et al. 2002; Reinhard and Danielson 2005; Williams-Dean and Bryant 1975). These silica and calcium structures are found in a wide variety of plants, particularly from areas where water sources are rich in dissolved silica and calcium carbonate (Ball 1992; Piperno 2006). While not all phytoliths are diagnostic, the proportions of different shapes of phytoliths can inform on the ingestion of certain plant resources (Ball 1992; Piperno 2006). In addition, a number of cacti and other succulent genera and species do have distinctive phytolith morphologies (Danielson and Reinhard 1998; Jones and Bryant 1992). Phytolith data from dental calculus has also had important inferences for dietary reconstruction, particularly when combined with concurrent studies of dental microwear (Boyadjian et al. 2007; Buchet 2001; Danielson 1993; Danielson and Reinhard 1998; Fox 1994; Gugel et al. 2001; Hardy et al. 2009; Henry and Piperno 2008; Lalueza Fox et al. 1996; Mainland 2003; Middleton 1994; Philippe 2010; Reinhard and Danielson 2005; Rovner 2001; Sanson et al. 2007).

Digestion and Starch Recovery from Coprolites. To my knowledge, there is only one published study of starch recovered from coprolite specimens (Horrocks et al. 2004). This line of evidence, if recovered, would strengthen and expand the dietary reconstruction based on the macroscopic and other microscopic evidence from specimens. Starch granules are often interpreted as direct evidence of past diet, since the starch itself is the nutrient being consumed. Starch is fundamentally different from other microbotanical components such as pollen and phytoliths, which are not always direct evidence of food consumption. However, a recent study suggests that natural starch rain may be a more common environmental contaminant than has been previously realized in archaeological starch research (Laurence 2010). While this remains unresolved, it is clear that starch frequently enters the atmosphere through pollen grain rupture associated with precipitation and other weather patterns (Currie et al. 2000; D'amato et al. 2007; Erpenbeck et al. 2005; Garcia 2010; Kuang et al. 2005; Pacini 2006; Schappi 1999; Schappi et al. 1999; Wang et al. 2004; Zona 2001).

The role of starch in human nutrition is one possible reason few researchers have investigated coprolites for starch. Starch is a highly digestible carbohydrate in the human gastrointestinal system, and it would not necessarily be expected to escape digestion in an identifiable manner (Asp et al. 1996; Autio 2001; Dreher et al. 1984; Englyst et al. 1992; Faisant 1995; Franco et al. 1992; Samuel 2006). While it was once assumed that all starch was fully hydrolysed and absorbed in the small intestine portion of the human gastrointestinal tract, research has shown that there is a great deal of variability in the digestibility of starch, influenced by the molecular structure of the starch itself, the complex interaction of starch with other cellular components of the food resource as well as the rest of the meal, and the processing techniques involved in meal preparation (Englyst et al. 1992).

Nutritionists divide starch into three categories based upon the potential digestibility of the granule (Englyst et al. 1992). These categories are: 1) rapidly digestible starch (RDS); 2) slowly digestible starch (SDS); and 3) resistant starch (RS). Rapidly digestible starch includes most freshly cooked starchy foodstuffs and is readily digested in the small intestine (Englyst et al. 1992). This nutritional class of starch should not be recovered in coprolite specimens since normally it would be entirely digested before reaching the colon. Slowly digestible starches include most raw cereal grains and are generally slowly but completely hydrolysed and absorbed in the small intestine. These granules would generally not be present in a coprolite specimen except under circumstances of rapid passage through the gastrointestinal tract. Resistant starch includes all starch granules which are not expected to be fully digested in the small intestine, leaving a potential starch residue that may be fermented in the colon, or possibly incorporated into fecal material (Englyst et al. 1992).

This category of resistant starch, can further be divided into three sub-categories based upon the intrinsic factors of starch that reduce digestibility (Asp et al. 1996; Englyst et al. 1992). The first factor leading to the resistance of some starches to the human digestive system is the physical makeup of the food. Some starch grains are physically inaccessible due to the presence of cellulose or other indigestible material co-occurring in the starchy food (Englyst et al. 1992). This includes starch grains that are embedded in cells or structures such as seeds. This also occurs when starch is densely packed, limiting the exposure of some interior granules to pancreatic amylase, retarding digestion (Asp et al. 1996). The second factor impacting the resistance of starch to digestibility is the structure of the starch grain itself. Storage of starch is accomplished in plants through the formation of a granule, a partially crystalline intercellular body (Banks and Greenwood 1975). The crystal structure of the amylopectin component of the granule occurs in one of three patterns distinguishable by x-ray diffraction patterns, which tend to correlate with botanical sources (Czaja 1978). The A-type diffraction occurs predominately in starches from cereals, granules from tubers generally show the B-type pattern, and the C-type pattern is a combination of the A and B type crystalline arrangements (Banks and Greenwood 1975; Copeland et al. 2009; Evers 1979; Moss 1976; Thomas and Atwell 1999). Both the B and C type patterns tend to be resistant to digestion, although this varies with the plant source itself (Asp et al. 1996). This is particularly true of B and C type starches that are consumed raw, such as bananas, or when the starch has been incompletely gelatinized through processing (Englyst et al. 1992). The third factor affecting starch resistance to digestibility is retrograded starch. This occurs when a starch that has been gelatinized and dispersed then cools, reforming into a partially crystalline structure (Englyst et al. 1992). This process of retrogradation generally occurs with the linear amylase structures rather than the branched amylopectin fraction of starch (Englyst et al. 1992; Franco et al. 1992). Retrograded starch exhibits B-type diffraction patterns, which may explain the resistance to digestibility observed in these granules. Other intrinsic factors, such as the size of the starch granule, have been suggested to affect differences in starch digestibility (Franco et al. 1992).

The differential digestibility of starch based on its intrinsic physical qualities is further complicated by a number of extrinsic factors associated with eating that will alter the susceptibility of starch to hydrolysis in the small intestine. These include such factors as the extent of chewing practiced by an individual or culture, the transit time of food through the gastrointestinal tract, the amount of starch present, the concentration of the necessary enzyme amylase in the gut, and the presence of other food components in the meal that might reduce starch hydroloysis (Franco et al. 1992). This is particularly true of compounds like dietary fiber, which impact starch digestion both chemically and physically (Dreher et al. 1984). The digestibility of starch is also affected by different processing techniques (Autio 2001; Babot 2003; Baker and Hobson 1952; Henry et al. 2009). Starch that is gelatinized in the presence of heat and water is initially easier to digest before it retrogrades as discussed above (Dreher et al. 1984). Storage techniques such as drying and freezing, which are both traditionally used among potato cultivators in the Andes (Johns 1988, 1996), can significantly decrease starch granule digestibility (Dreher et al. 1984; Szymonska 2000).

Biochemical Analysis of Coprolites

The dietary data derived from the macroscopic and microscopic residues of coprolites is unparalleled in the archaeological record. Concordant lines of evidence inform on the dietary decisions underlying the several meals represented in the specimen. This extreme detail into the decisions of an individual actor in the past is furthered by a range of molecular techniques that have been applied to these biochemically complex specimens.

Wakefield and Dellinger's (1936) elemental analysis of specimens recovered in the Ozark Mountains was the first attempt to evaluate the chemical composition of coprolites. However, only in the last several decades have coprolite researchers begun applying the full range of analytical techniques that could be useful in reconstructing aspects of past dietary health. Reinhard and Bryant (1992) reported on a series of studies from the 1970's and 1980's that established the difficulty of evaluating the chemical composition of coprolites, due to the complex nature and molecular alteration in the post-depositional environment. Further work discovered that the Maillard reaction is an important post-depositional process that degrades complex organic molecules (Evershed et al. 1997). Nevertheless, some research has shown that plant components can be detected with a modified gas chromatography procedure (Moore et al. 1984). Other early research established the presence of steroids and amino acids, but failed to detect bilirubin, hydrolyzed fat, or blood (Reinhard and Bryant 1992). During the last fifteen years, new research has focused on attempts to recover and interpret various chemical constituents of coprolites in terms of dietary choices (Sutton et al. 2010).

The Chemical Makeup of Coprolites. Coprolites have a complex chemical composition (Wales and Evans 1988). They contain a range of organic and inorganic substances, as well as compounds in varying stages of digestive breakdown. There are three main categories of organic chemical compounds found in coprolites (Wales and Evans 1988). The first type are nitrogenous substances, primarily proteins and amino acids. The second group, lipids, can be further classed into simple lipids (such as fats, oils, and waxes), complex lipids (phospholipids and glycolipids), and derived lipids (including cholesterol, steroids, and vitamins). Carbohydrates, such as sugars, starch, fructans, and cellulose, make up the third class of compounds. Wales (1988) followed procedures already successfully employed in the analysis of organic residues from pottery in his preliminary study. The study utilized infra-red spectroscopy (IR) but could not reach any conclusions for three major reasons (Wales and Evans 1988). One, the chemical composition of the specimens was incredibly complex despite the presumably limited diet. Two, a suitable reference collection of plant materials for the region of origin has not been analyzed, although preliminary results suggested that the chemical spectra of different species are quite distinctive. Third, post-depositional chemical degradation and contamination had not been explored in any systematic fashion. Nonetheless, the study was able to show the presence of some triglycerides and free fatty acids, suggesting that future research should focus on cuticular waxes and seed oils. Wales (1988) anticipated that this research would help to identify archaeologically "invisible" food resources, particularly underground storage organs that are staples in many regions of the world (Hillman et al. 1993).

More recently, IR has been employed to study the chemical composition of mineralized human feces (Allen et al. 2002; Marshall et al. 2008; Shearer 1988; Sutton et al. 2010). One study detected apatite consistent with bone in all the coprolites analyzed (Allen et al. 2002). Other possible techniques for characterizing chemical compounds include gas chromatography (GC), Fourier Transform Infrared Spectroscopy (FTIR), and gas chromatography- mass spectrometry (GC/MS), which also has the ability to monitor the isotope ratios of individual compounds (Degano and Colombini 2009; Evershed 1993; Gilbert et al. 2008; Gill et al. 2009; Poinar et al. 2009; Rasmussen et al. 2009). GC/MS has the potential for wide application in paleodietary and coprolite studies, as it allows for the characterization of individual components visible in the specimen and a more precise isotope analysis of composite artifacts such as coprolites (Evershed 1993).

Protein Residue Analysis. Protein residue analysis has received considerable attention in the archaeological community as a method for determining stone tool use

(Leach 1998; Leach and Mauldin 1996; Lombard 2004; Newman et al. 1993; Shillito 2009). Only rarely has this technique been applied to non-lithic archaeological materials. Some preliminary work has been performed on some coprolite specimens as well as site soils with promising results (Newman et al. 1993). This technique could render the dietary contribution of meat visible in coprolite analysis, allowing for a better understanding of past human diet.

Protein residue analysis utilizes an immunological technique, cross-over electrophoresis (CIEP), to evaluate the antigen-antibody reaction in a substance (Newman et al. 1993). This reaction is extremely sensitive and specific, allowing for the characterization of very small amounts of protein (Newman et al. 1993). This technique has been primarily employed in medico-legal settings for characterizing bloodstains, but it can be applied to any research involving protein detection. It has been demonstrated that antigens can survive harsh conditions in a post-depositional context and retain their antigenicity and biological activity, making this technique potentially useful in archaeological contexts (Newman et al. 1993).

Immunosorbent Assay. This is a technique that is frequently applied to modern fecal specimens (Gonclaves et al. 2004; Neill 1995). The technique is fairly simple, and can be used to detect a number of antigen proteins, depending on the research goal (Goncalves et al. 2002). It has been used primarily to detect evidence of parasitic infection (Goncalves et al. 2002; Gonclaves et al. 2004). This is particularly important since differential preservation of identifiable parasitic remains, along with the lack of distinguishing features for many parasite larvae and ova, limits the conclusions based upon visual identification (Fry 1985; Reinhard 1989). This technique has also been used to confirm the consumption of human flesh associated with evidence of human butchery at Cowboy Wash, Colorado (Koon et al. 2010; Lambert 2000; Lambert et al. 2000; Reinhard 2006).

Preparation methods for immunoassay follow standard coprolite procedures (Goncalves et al. 2002). A sub-sample is examined microscopically for parasite remains. A commercially available immunoassay kit is used following the manufacturers instructions. The results are assessed with a visual inspection of color change and verified by measuring the absorbance of each sample at 450 nm with a spectrophotometer (Gonclaves et al. 2004). This technique seems to provide a relatively straightforward corollary line of evidence for assessing aspects of parasitic infection and community health.

DNA Analysis. Ancient DNA analysis has become a controversial topic due to the potential for contamination throughout the deposition, recovery, and analysis of the specimen (Bryant and Dean 2006; Gilbert et al. 2008; Gilbert et al. 2009; Goldberg 2009; Hofreiter et al. 2000; Kemp et al. 2006; Lindahl 1997; Luciani et al. 2006; Poinar et al. 2009; Poinar et al. 2003; Poinar et al. 1998; Poinar and Stankiewicz 1999; Rasmussen et al. 2009; Reinhard et al. 2008; Stokstad 2000; Sutton et al. 1996; Yang and Watt 2004). This review focuses on the analysis of non-human DNA from coprolites, which have less potential for contamination during recovery and analysis (Hofreiter et al. 2000; Leles 2008; Loreille et al. 2001; Poinar et al. 1998; Poinar et al. 2001; Reinhard et al. 2008). DNA recovered from parasites has been commonly explored, but will not be considered further here (Iniguez 2006; Leles 2008; Loreille et al. 2001).

Many of the studies of ancient DNA have focused on mtDNA (mitochondrial) since preservation of nuclear DNA seems to require a more rigorous set of preservation requirements (Lindahl 1997). DNA preservation should never be assumed (Poinar and Stankiewicz 1999). Rather, it should be assessed by verifying the preservation of other molecular structures, particularly proteins (Poinar and Stankiewicz 1999). Flash pyrolysis with gas chromatography (GC) or mass spectrometry (MS) has been suggested as a quick and effective method for evaluating the potential for DNA and other molecule preservation (Poinar et al. 1998). mtDNA from coprolites can provide direct evidence of past movement of human populations and other questions of paleodemography through the evaluation of the common haplotype groups among Native American populations (Leblanc et al. 2007) (Gilbert et al. 2008; Luciani et al. 2006; Poinar et al. 2001).

Much of the work on coprolite DNA has focused on nuclear and chloroplast DNA, since non-human mtDNA has limited capacity to inform on dietary intake (Iniguez 2006; Leles 2008; Loreille et al. 2001; Luciani et al. 2006; Poinar et al. 2003; Poinar and Stankiewicz 1999). There are some exceptions to this, such as the identification of turkey domestication in the American Southwest through mtDNA markers (Speller et al. 2010). Since many nuclear DNA fragments cannot be identified below the family level, paleovegetation/ faunal studies and corollary evidence from macroremains and micro remains can improve the resolution of the resulting interpretations (Hofreiter et al. 2000; Reinhard et al. 2008). Nonetheless, aDNA studies of coprolites may reveal the consumption of food resources undetected with the traditional methods of analysis and identification (Poinar et al. 2001; Reinhard et al. 2008).

Steroid Analysis. Prior to the advent of aDNA research, steroid analysis was the most commonly employed chemical technique in coprolite studies (Bull et al. 2003; Goodfellow et al. 1977; Lin and Connor 2001; Rhode 2003; Sobolik et al. 1996). Steroids are a class of lipid that perform a variety of biochemical functions within plants and animals. The analysis of these compounds can be utilized to address a number of research questions. Since humans produce species-specific sterols in their feces, the analysis of these compounds can inform on the presence of human fecal material in water (Goodfellow et al. 1977), soil (Bull et al. 2003), or verify a coprolite as human in origin. Hormonal steroids in coprolites have also been used to determine the sexual status of primates (Rhode 2003). Sex is assessed by measuring the relative abundance of testosterone to estrogen (Rhode 2003). Fecal steroids have also been applied in the analysis of endocrine function and hormone metabolism research in modern human samples (Sobolik et al. 1996). Determining sex has been the primary focus of fecal steroid studies in human coprolite research (Rhode 2003; Sobolik et al. 1996). There may also be some potential for distinguishing between the follicular phase and the luteal phase in coprolites deposited by women (Sobolik et al. 1996).

Stable Isotope Analysis. While stable isotope studies are routinely conducted on preserved skeletal material from archaeological sites, there are no published studies of stable isotope data derived from human coprolites. Staple isotopes could potentially inform on the differential use of plant resources with differing photosynthetic pathways ($\delta^{13}C$) as well as the role and source of animal protein ($\delta^{15}N$). There is an abundance of literature on fecal studies of African herbivores that incorporate stable isotope data (Codron et al. 2006; Codron et al. 2007a; Codron et al. 2007b; Codron et al. 2008; Deniro and Epstein 1978; Smith et al. 2002; Sponheimer et al. 2003a; Sponheimer et al. 2003b). These studies are considered in the following section of the relationship between the $\delta^{13}C$ value of diet and fecal remnants of that diet. $\delta^{15}N$ is not considered in any detail here.

There is not a one-to-one relationship between the $\delta^{13}C$ value of diet and the $\delta^{13}C$ values of the resultant animal tissue (Deniro and Epstein 1978). Many studies have evaluated the relationship between diet and the most studied tissue types, namely bone collagen, bone apatite, and dental enamel (See Smith et al. (2002) for an example), but fewer studies have included soft tissue that is unlikely to be recovered archaeologically. Experimental studies have shown that the relationship between dietary $\delta^{13}C$ values and the $\delta^{13}C$ values of various tissues are constant, if not directly one-to-one (Ambrose and Norr 1993; Deniro and Epstein 1978; Tieszen and Fagre 1993). This relationship is not uni-directional for all tissue types, with some organs exhibiting increased discrimination and others exhibiting decreased discrimination (Deniro and Epstein 1978). This complex relationship suggests that any dietary reconstruction based on less commonly recovered tissues in the record should be formulated on prior experimental work (Codron et al. 2006; Codron et al. 2007a; Codron et al. 2007b; Codron et al. 2008; Smith et al. 2002; Sponheimer et al. 2003a; Sponheimer et al. 2003b).

This relationship between dietary $\delta^{13}C$ values and the resulting $\delta^{13}C$ values of feces is even more complex, since fecal material represents a combination of indigestible dietary residue, the bacterial flora of the gastrointestinal tract, and cells of multiple tissue types of the animal under consideration (Sutton et al. 2010). Thus, different diets could contribute different amounts of each of these categories to the fecal specimen, with this complex relationship creating a less secure link between dietary $\delta^{13}C$ values and fecal $\delta^{13}C$ values. As other researchers have pointed out, the coarse, undigested component of the diet may be over-represented in the feces relative to diet (Codron et al. 2005; Sponheimer et al. 2003b). However, one major advantage of fecal δ13C values is that they can be used to ask questions about changes in diet over much shorter time periods than the record found in bone and teerh, which represent a dietary average over a longer timespan (Sponheimer et al. 2003b).

There have been a number of studies linking dietary $\delta^{13}C$ values and fecal $\delta^{13}C$ values, mostly focused on wild animals (Codron et al. 2005; Codron et al. 2006; Codron et al. 2007a; Codron et al. 2007b; Codron et al. 2007c; Deniro and Epstein 1978; Hwang et al. 2007; Sponheimer et al. 2003a). Most species studied exhibit a slight fractionation between diet and feces ($\Delta\delta^{13}C$ between –0.3 and –1.3 ‰) (Sponheimer et al. 2003b). In this study, fractionation appears to vary slightly with differences in dietary δ13C values. On average, herbivores fed a C3 plant diet (alfalfa) had a $\Delta\delta^{13}C$ of –0.6‰ while those same species fed a C4 plant diet (coastal Bermuda grass) had a $\Delta\delta^{13}C$ of –1.0‰ (Sponheimer et al. 2003b). Digestive anatomy does not seem to play an important role in differences in fractionation, although hindgut fermentors were limited to two samples

(Sponheimer et al. 2003b). Other researchers have argued that the data from Sponheimer et al. (2003) cannot be extrapolated to all herbivores, since the majority of the animals studied were medium to large bodied, and metabolic associations with body size were not taken into account (Hwang et al. 2007). Hwang et al. (2007) studied a number of small rodents (all hindgut fermentors) and concluded that the $\Delta\delta^{13}C$ values were much larger (-2.7 to –5.9‰). This may be due to higher mass-specific metabolic rates of smaller animals, but it seems equally likely to be influenced by research design. Unlike previous studies based on the consumption of complete plants (C3 or C4), this study used a commercially prepared food that contained a combination of C3 and C4 plants, probably with differing degrees of digestibility. This suggests that the larger fractionation may be due to the more complete digestion of the C4 component and a resulting increase in the proportion of C3 plant material in the undigested food residue represented by the fecal material (Sponheimer et al. 2003b).

It also seems likely that humans should also show a very slight fractionation between diet and feces. Relative to herbivores, humans have a generalized digestive physiology that exhibits significantly shorter passage times. The inclusion of hindgut fermenting herbivores in the study suggests that the results are broadly applicable to other hindgut fermentors including humans. Previous studies of baboons (Codron et al. 2008) have successfully applied a $\Delta\delta^{13}C$ of –0.9‰, derived from the previously mentioned herbivore studies, to dietary reconstruction. Baboons are ecological generalists who exploit a wide variety of resources (Codron et al. 2008). While they may not be direct analogs for reconstructing human paleodiet, this study does indicate that the fractionation values developed for herbivores can be applied to broader classes of mammals, including humans. However, as previous studies have suggested, the $\delta^{13}C$ of fecal remains may be biased towards the undigestible residue of the diet, such as dietary fiber, and may not reflect the $\delta^{13}C$ compostion of the entire diet, especially meat and other readily digestible components. This bias is not limited to stable carbon isotopes and is true of all coprolite constituents (Reinhard and Bryant 1992; Sutton et al. 2010). This should not be a limiting factor in research designed to evaluate the dietary contributions of items with similar composition, such as the staple food resources previously identified for the Lower Pecos canyonlands. Sponheimer et al. (2003) suggest that differential digestibility is unlikely to bias field studies, since most wild foods have high levels of fiber and other indigestible components such as lignin.

AMS C-14 Radiocarbon Dating of Coprolites

Coprolite specimens can be directly dated using Accelerator Mass Spectrometry (AMS) radiocarbon methods (Dean 2004; Gilbert et al. 2008; Hofreiter et al. 2000; Luciani et al. 2006; Poinar et al. 2003; Poinar et al. 1998; Poinar et al. 2001). This is particularly important in the Lower Pecos canyonlands, where many sites still contain coprolite specimens that have been disturbed and impacted by artifact collectors, looting and animal grazing. This previously neglected data set can be temporally associated using AMS radiocarbon dating. While coprolites do provide enough carbon to be dated directly using traditional radiocarbon methods (Williams-Dean 1978), there is the potential of external contamination and admixture of components within the specimen. AMS dating allows for the direct sub-sampling of either visible components or the general residue in the specimen without destroying a large portion of the specimen. To date, seven specimens recovered from the Hinds Cave excavation have been directly dated using AMS radiocarbon methods.

Summary

Coprolites are among the most biologically complex evidence of past human activity recovered in the archaeological record. One specimen can yield multiple lines of congruent evidence on an individual's dietary choices, as well as information on seasonality of site occupation, overall health, parasite load, potential sex through sterol analysis, and even individual identity through mtDNA. This wealth of information focused on the actions of one individual over a day or two requires different frames of analysis than the archaeological palimpsest that results from the actions of multiple individuals over years and decades.

CHAPTER IV

THE LOWER PECOS CANYONLANDS

Located on the eastern periphery of the Chihuahuan desert (Figure 2), the Lower Pecos canyonlands have a long history of archaeological investigation, due primarily to the remarkable preservation conditions on its numerous rockshelters and its distinctive rock art styles. This chapter first presents an environmental overview and geographic delineation of the region. It includes a reconstruction of past environment during the Holocene based on pollen and other paleoenvironmental data. The overview of archaeological research is presented in three temporal phases. The first phase consists of the initial excavations and rock art research during the 1930s. The second phase coincides with the damming of the Rio Grande and the creation of the Amistad Reservoir (now the Amistad National Recreation Area). This phase primarily consists of studies through the Texas Archaeological Salvage Project. The third phase entails primarily academic excavations and laboratory analysis of existing museum collections done after the completion of the Amistad Reservoir. The chapter concludes with a chronological reconstruction of human occupation in the region derived from the eighty years of archaeological research.

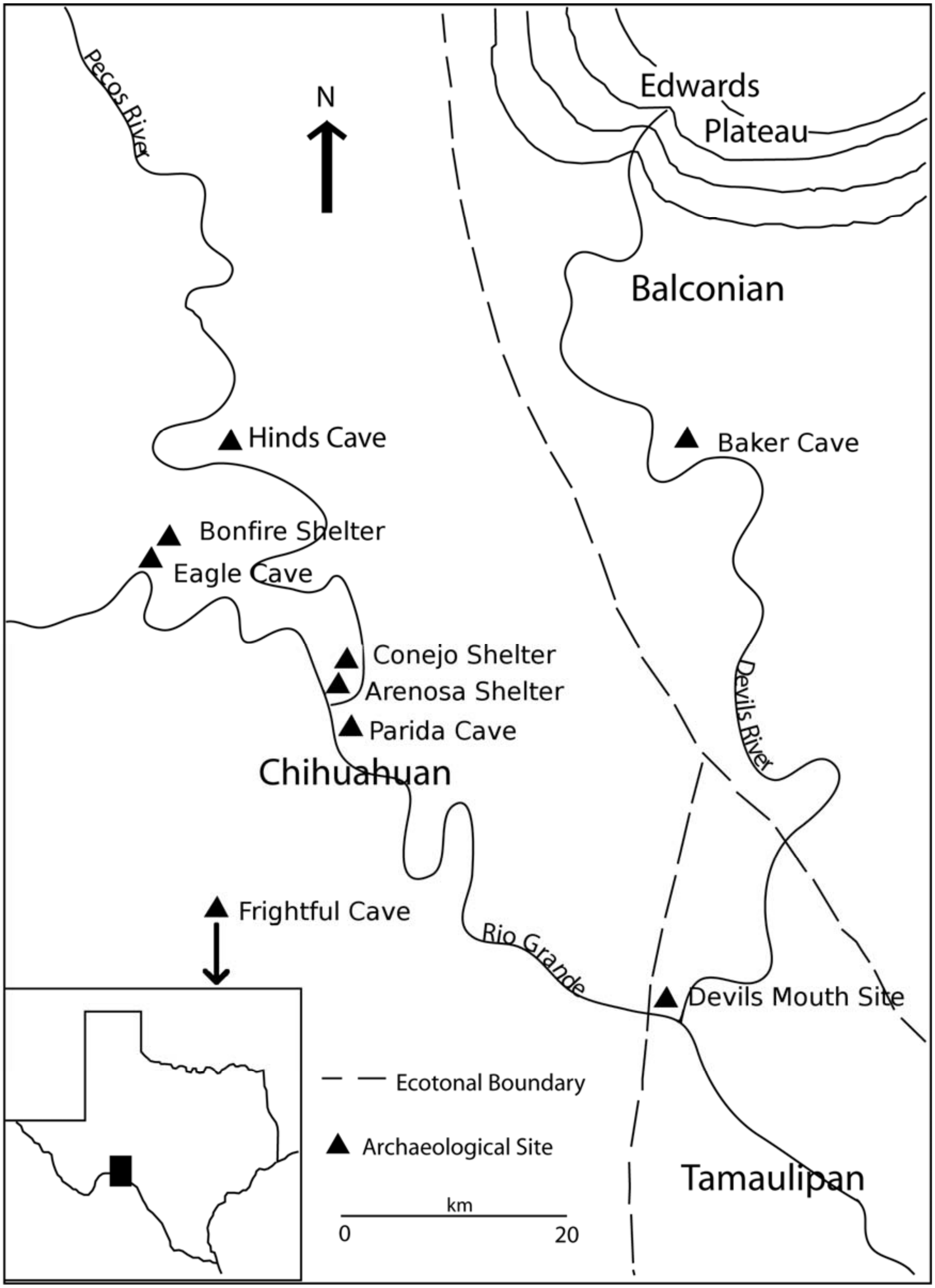


Figure 2. Map of the Lower Pecos Canyonlands

Defining the Lower Pecos Canyonlands

The Lower Pecos canyonlands were originally recognized as a unique archaeological research area based on the several styles of rockart that occur in rockshelters and other protected settings of the region (Jackson 1938; Kirkland 1939). The distribution of the most distinctive of these styles, the Pecos River style, has been the basis for the geographic boundaries assigned to the region (Turpin 2004). These boundaries are reinforced by the similarity among material culture recovered from the rockshelters of the region, partly a result of the incredible preservation of organic remains noted above (Turpin 2004). This region encompasses the southwestern edge of the Edwards Plateau, the eastern edge of the Stockton Plateau, and the northern edge of Coahuila, Mexico (Saunders 1992). This region is bisected by the middle Rio Grande basin, as well as the tributary Pecos and Devils Rivers (Dering 2002). The topography of the region is hilly and dissected by numerous canyons associated with the rivers and seasonal tributaries (Dering 2002). Elevation in the Lower Pecos canyonlands varies from 265 m above sea level along the Rio Grande to 620 m above sea level in the North Central portion of the county (Dering 1979).

While the northern limits of the region are fairly well-defined, extending approximately 75 km up the Devils and Pecos Rivers, the southern half (located in the modern nation-state of Mexico) has been poorly explored (Turpin 2004). There are few permanent water sources south of the Rio Grande and north of the Serrañias del Burro mountains, suggesting that human populations utilizing this landscape would have engaged in different mobility strategies than those closer to the incised riverine systems in the northern half (Turpin 2004). Rock art and material culture studies from the southern part of the region do suggest that the inhabitants as far south as the Sierra del Carmen mountains shared both adaptive strategies and beliefs with their more intensively studies northern neighbors in the region (Turpin 1997; Turpin and Eling 2002).

Geology. The exposed bedrock in the Lower Pecos region is Cretaceous in age and is predominately bedded limestone (Maslowski 1978). Outcrops of Boquillas and Eagle Ford (Upper Cretaceous) and Salmon Peak (Lower Cretaceous) are common (Dering 2002). These outcrops provide a plentiful source for the rock heating elements used in earthen ovens. Gravels of Miocene-Pliocene age (Uvalde gravels) are an important geological surface feature found throughout the southern portion of Val Verde County (Dering 2002). These gravels are frequently associated with prehistoric lithic quarry sites (Dering 2002)

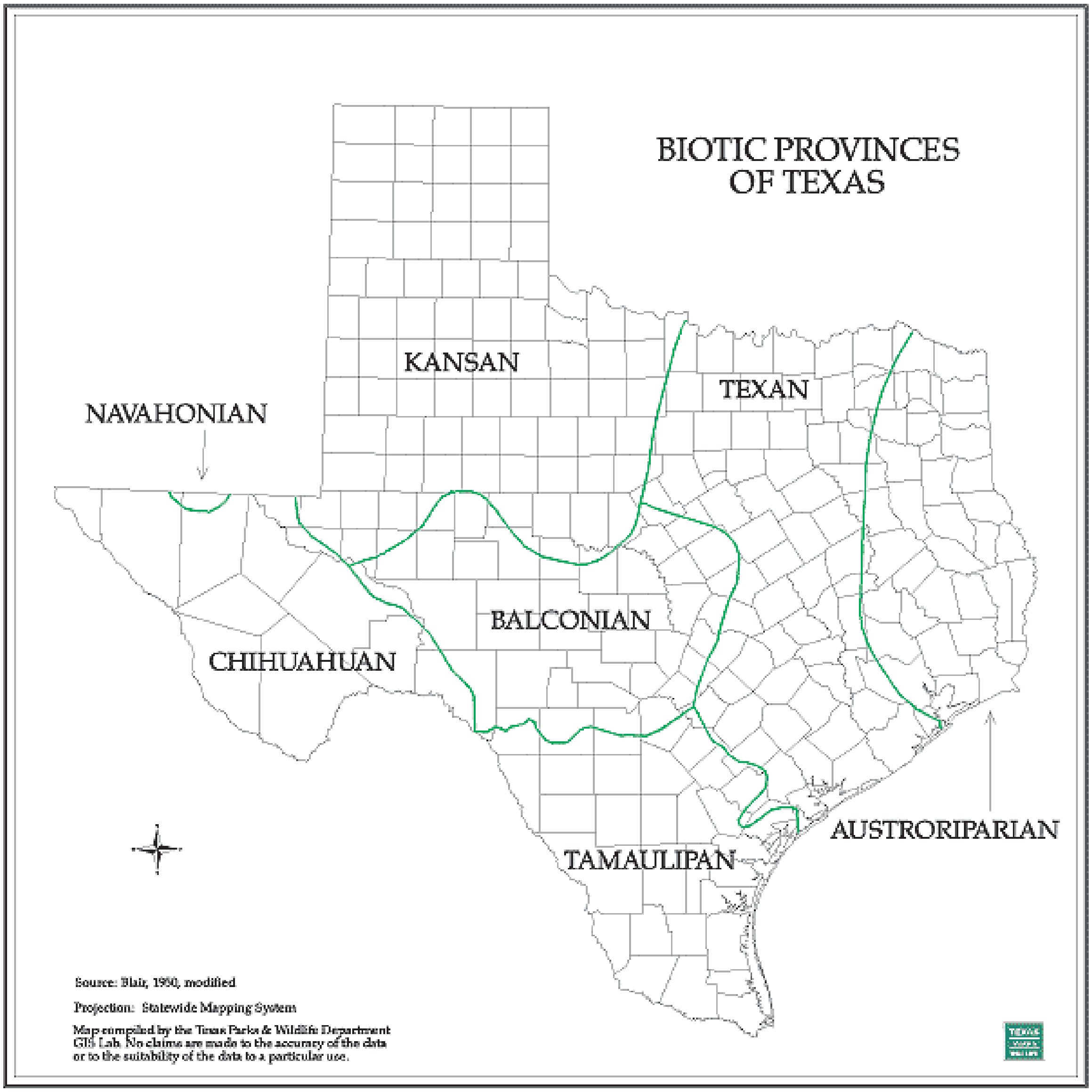
The soils in the Lower Pecos region are dominated by outcrops of limestone bedrock and associated weathered material (Golden et al. 1982). The soil surrounding the archaeological site of Hinds Cave as well as most of the uplands in the southern portion of the county are characterized as the Langtry-rock-outcrop complex, a very shallow, rocky soil with 45-70 percent exposed bedrock (Dering 2002). All of the soils in the area can be characterized as either Calcids (Aridsol) or Ustolls (Molisol) (Staff 1999, 2010).

These shallow, rocky soils provide a favorable habitat for lechugilla, sotol,, yucca *(Yucca sp.),* and prickly-pear cactus. The archaeological evidence suggests that these plant resources were the primary components of the local subsistence strategy (Bryant 1974b; Danielson and Reinhard 1998; Shafer 1986). The region is subject to flash flooding during rainstorms due to the karst topography and associated shallow soils (Kochel et al. 1982; Patton and Dibble 1982).

Modern Climate. The climate of the Lower Pecos can be characterized as a dry midlatitude grassland in the Köppen climate classification system (BSh) (Peel and Mcmahon 2007). This climate classification holds for the immediate vicinity of Hinds Cave and the Lower Pecos, but quickly grades into Dry Midlatitude Steppe (BSk) and Dry Tropical Desert (BW) to the west and Moist Continental Deciduous Forest (Cfa) to the east, again suggesting the ecotonal nature of the region (Peel and Mcmahon 2007).

The mean annual temperature for the Laughlin Airforce Base near Del Rio, TX is 21˚C (69.8˚F). The warmest month, July, has an average temperature of 30.3˚C (86.5˚F). The coldest month, January, has an average temperature of 10.3˚C (50.5˚F) (Rivas-Martínez 2010) Rainfall data recorded at the Laughlin Airforce Base yielded a mean annual rainfall of 548.6 mm (21.6 in). The highest average monthly rainfall occurs in September (76.2 mm [3 in]) and the lowest average monthly rainfall occurs in January (19.1 mm[0.75 in]) (Swanson and Fipps 2007).

Characterizing the Vegetation. The Pecos River is considered an important ecotonal boundary between the wetter climates of Central and Eastern Texas and the semi-arid regions to the west known as the Trans-Pecos (Dering 1979). The Lower Pecos region is bounded by the mesquite-chaparral zone of the Tamaulipan biotic province to the southeast, the oak-cedar zone of the Balconian biotic province to the northeast, and the sotol-lechuguilla zone of the Chihuahuan biotic province to the west (Figures 2 and 3) (Blair 1950; Dering 2002). Following the Bailey eco-region system, the Lower Pecos is in the Chihuahuan Desert province (321), although the northern portion extends into the Southwest Plateau and Plains Dry Steppe province (315) According to the Omernik eco-region classification, the Lower Pecos includes parts of the Chihuahuan Basins and Playas (24A), the Semi-arid Edwards Bajada (31B), and the Semi-arid Edwards Plateau (30B). In the Kuchler potential natural vegetation types, the region in mostly made up of the Southwest Shrub-Steppe, although it extends into the Texas Savannah. In the Major Land and Resource Area classification, the region is incorporated into the Edwards Plateau (MLRA 81)). In the Nature Conservancy Vegetation Classification, the region is classified as an extremely xeromorphic deciduous subdesert shrubland with succulents (III.C.3.N.a). As this brief statement indicates, the area is considered an ecotonal boundary regardless of which modern vegetation classification system is utilized. The mosaic of habitats in the Lower Pecos provided a remarkably diverse environment for the prehistoric hunter-gatherers (Dering 1979). The diversity of habitats allowed the human populations in the area to engage in an extremely broad-based subsistence strategy, with many seasonally available resources supplementing the cactus and succulent staples (Dering 1999).



Source: Blair, 1950, modified

Projection: Statewide Mapping System

Map compiled by the Texas Parks & Wildlife Department GIS Lab. No claims are made to the accuracy of the data or to the suitability of the data to a particular use.

Figure 3. Map of Physiographic Biotic Provinces (Blair 1950). Taken from Texas Parks and Wildlife

The abrupt topography of this canyon country also influences the ecological diversity of the Lower Pecos region (Flyr 1966). The major impact of this topography is the creation of closely situated microenvironments with a range of exploitable resources. The plant communities of these microenvironments have been divided into four major types, each associated with a particular topographic context. Flyr (1966) suggested the following division: 1) Vega Terrace Vegetation occurs on the sandy soils of the river terraces and the bottom of the many canyons in the region; 2) Cliff-Canyon Vegetation occurs in the upper areas of canyon walls, such as the location of Hinds Cave; 3) Upland Vegetation (flats) occurs on the plateaus and flat uplands that separate the canyons; and 4) Upland Vegetation (hills) occurs on the rolling hills further back from the canyon lands. Each of these microhabitats would have provided a different set of available food resources for the human populations in the area (Table 3). Table 3 provides a list of available food resources mentioned by Flyr (1966) and Williams-Dean (1978) for each of the four microhabitats encountered in the canyonlands.

The Vega Terrace Vegetation is the richest plant community in terms of productivity, but it is also characterized by very low diversity of species due to the frequent disturbances caused by flooding in these incised riverene environments (Flyr 1966). A number of seasonally-available resources such as mesquite (*Prosopis glandulosa* Torr.), Texas persimmon (*Diospyros texana* Scheele), several acacias including catclaw (*Acacia greggii* Gray) and guajillo (*Acacia berlandieri* Benth.), and walnut (*Juglans microcarpa* Berl.) are important components of this community (Williams-Dean 1978). This community is characterized as weedy due to the frequent disturbances of runoff and flooding (Flyr 1966). The Cliff-Canyon community is dominated by dense yucca, sotol, and lechugilla stands along the upper slopes, providing important patches of high resource density (Flyr 1966). Both upland communities have fairly sparse growth and were probably not very important for plant harvesting, although the staples of sotol, lechugilla, and prickly pear cactus all occur (Flyr 1966). It is important to recall that the modern vegetational community has been heavily impacted by invasive species and modern range management practices in the region (Bray 1901, 1905; Havard 1885; Williams-Dean 1978).

Table 3. Occurence of Edible Plant Species by Lower Pecos Microhabitat. Derived from Flyr (1966) and Williams-Dean (1978)

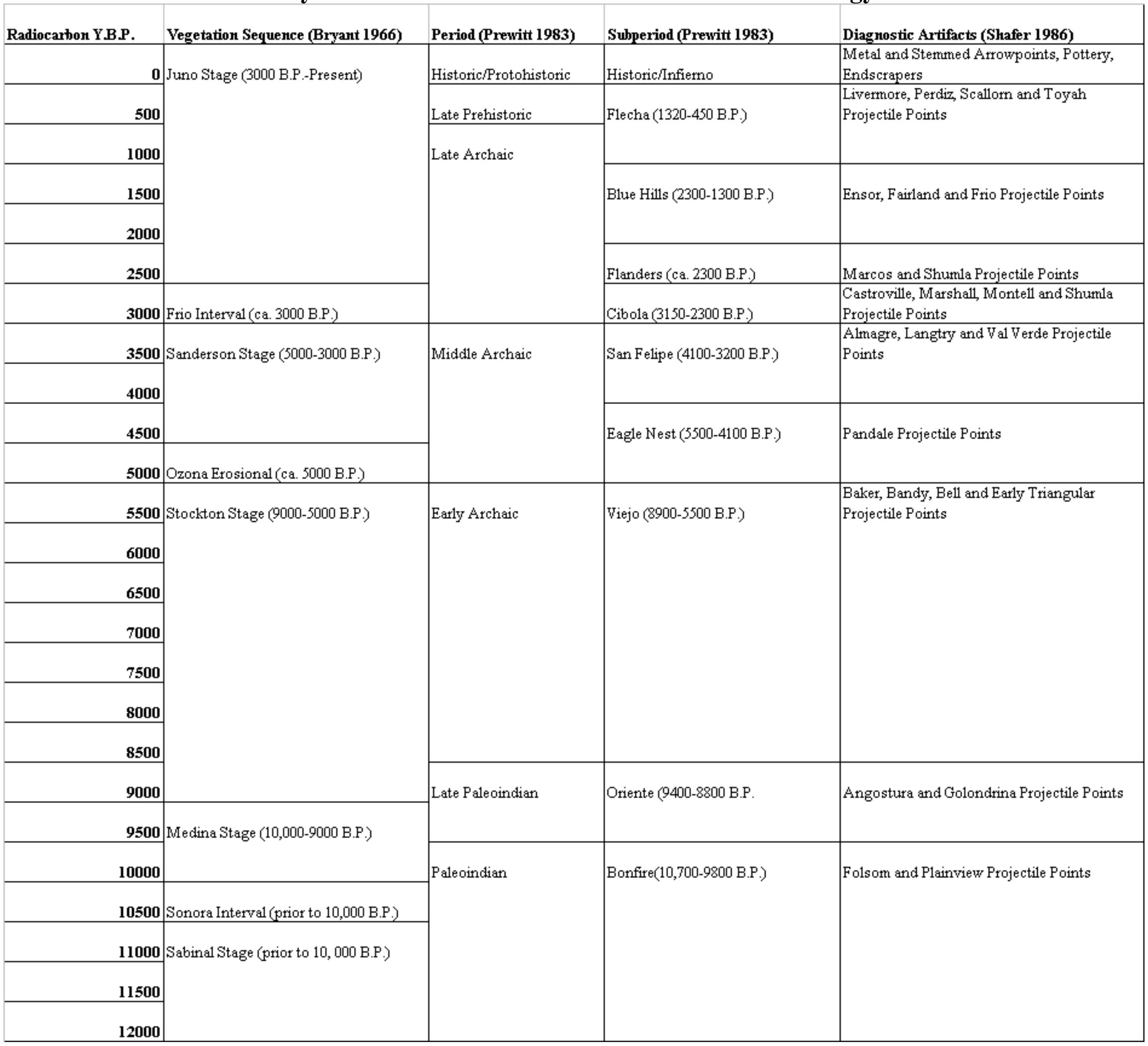
Genus	Species	Vega-Terrace	Cliff-Canyon	Upland Flats	Upland Hills
Acacia	*sp.*		present	present	dominant
Agave	*lechuguilla*		present	present	present
Aster	*spinosus*	abundant			
Baccharis	*glutinosa*	abundant			
Berberis	*trifoliolata*			present	rare
Bumelia	*sp.*		minor		
Carya	*sp.*	present			
Celtis	*sp.*		present	Prominent	
Dasylirion	*sp.*		present	present	present
Diospyros	*texana*		present	present	present
Ephedra	*sp.*		present	present	
Fraxinus	*sp.*		minor		present
Juglans	*microcarpa*		present		
Juniperus	*ashei*		rare		rare
Leucaena	*sp.*		minor		
Lycium	*berlandieri*			present	
Morus	*sp.*	present			
Nolina	*sp.*				present
Opuntia	*linderheimeri*	present		present	
Opuntia	*leptocaulis*	present		present	
Pinus	*cembroides*				rare-relic stand
Pistacia	*texana*		minor		
Prosopis	*glandulosa*	rare	rare	Prominent	
Quercus	*sp.*		present		
Rhus	*virens*		present		rare
Salix	*sp.*	present	rare		
Salvia	*ballotaeflora*			present	
Sophora	*secundiflora*		present		present
Yucca	*sp.*		present	present	present
Chenopodium	*sp.*			very rare	
Amaranthus	*sp.*			very rare	
Vitis	*monticola*		present		
Rubus	*trivialis*		rare		
CYPERACEAE			present		
Echinocereus	*enneaocanthus*			present	
Mammillaria	*sp.*			present	
Epithelantha	*micromeris*			present	
Hesperaloe	*parviflora*			present	

Paleoenvironmental Overview for the Lower Pecos Canyonlands

The similarities in human exploitation of the Lower Pecos canyonlands across the Holocene has been attributed to the fairly stable ecological conditions in the region (Bryant and Holloway 1985; Turpin 1991a). This section references the nomenclature of Bryant (1966d) (Table 2) but limits the paleoenvironmental reconstruction to the broader framework utilized in Bryant and Holloway (1985) for reasons examined below. While later studies do not continue this nomenclature, it was utilized here due to its temporal association with the cultural chronology presented at the end of this chapter (Table 2) (Prewitt 1983; Turpin 2004).

Bryant (1966d) utilized pollen data from Bonfire Shelter, Devils Mouth Site and Eagle Cave to develop his initial paleoenvironmental model, which he has continued to refine (Bryant 1966d, 1969, 1977b; Bryant and Holloway 1985; Bryant and Riskind 1980). This review of the paleoenvironmental sequence incorporates all of the primary pollen data available for the Lower Pecos canyonlands, regardless of shortcomings (Bryant 1966b, c, d, 1967, 1969, 1977c; Bryant and Holloway 1985; Bryant and Larson 1968; Bryant and Riskind 1980; Bryant and Shafer 1977; Dering 1979; Hevly 1966; Johnson 1963; Mcandrews and Larson 1966).

Table 4. Lower Pecos Canyonlands Cultural and Environmental Chronology



Radiocarbon Y.B.P.	Vegetation Sequence (Bryant 1966)	Period (Prewitt 1983)	Subperiod (Prewitt 1983)	Diagnostic Artifacts (Shafer 1986)
0	Juno Stage (3000 B.P.-Present)	Historic/Protohistoric	Historic/Infierno	Metal and Stemmed Arrowpoints, Pottery, Endscrapers
500		Late Prehistoric	Flecha (1320-450 B.P.)	Livermore, Perdiz, Scallorn and Toyah Projectile Points
1000		Late Archaic		
1500			Blue Hills (2300-1300 B.P.)	Ensor, Fairland and Frio Projectile Points
2000				
2500			Flanders (ca. 2300 B.P.)	Marcos and Shumla Projectile Points
3000	Frio Interval (ca. 3000 B.P.)		Cibola (3150-2300 B.P.)	Castroville, Marshall, Montell and Shumla Projectile Points
3500	Sanderson Stage (5000-3000 B.P.)	Middle Archaic	San Felipe (4100-3200 B.P.)	Almagre, Langtry and Val Verde Projectile Points
4000				
4500			Eagle Nest (5500-4100 B.P.)	Pandale Projectile Points
5000	Ozona Erosional (ca. 5000 B.P.)			
5500	Stockton Stage (9000-5000 B.P.)	Early Archaic	Viejo (8900-5500 B.P.)	Baker, Bandy, Bell and Early Triangular Projectile Points
6000				
6500				
7000				
7500				
8000				
8500				
9000		Late Paleoindian	Oriente (9400-8800 B.P.	Angostura and Golondrina Projectile Points
9500	Medina Stage (10,000-9000 B.P.)			
10000		Paleoindian	Bonfire(10,700-9800 B.P.)	Folsom and Plainview Projectile Points
10500	Sonora Interval (prior to 10,000 B.P.)			
11000	Sabinal Stage (prior to 10, 000 B.P.)			
11500				
12000				

It should be noted that the pollen data from the Lower Pecos canyonlands has some major limitations that preclude any fine grained paleoenvironmental reconstruction based on these records. All of these pollen profiles were recovered from repeatedly occupied archaeological sites and are significantly influenced by human activities. Most of the records contain high levels of zoophilous pollen types that reflect the human-derived nature of these pollen assemblages. Any paleoenvironmental reconstruction of the region is also hindered by the mosaic of microhabitats observed by Flyr (1966). The very nature of this mosaic limits the extrapolation of pollen data from a single site to the entire canyonlands. Finally, much of this work was done in the infancy of archaeological palynology. Many of the researchers were graduate students engaged in their first palynological study and this may be reflected in the overall quality of the work. Nevertheless, the multitude of studies for the region do provide a relatively robust framework for reconstructing the paleoenvironment of the canyonlands across the Holocene. This reconstruction is further corroborated with reference to several non-anthropogenic records from the surrounding area (Hall 2005; Hall 2010; Van Devender and Spaulding 1979).

Macrobotanical assemblages (Alexander 1974; Dering 1979; Irving 1966; Sobolik 1988b; Sobolik 1991a) from rockshelters in the region will not be considered in this section, as they represent purposeful accumulations of vegetation by humans and other actors. The macrobotanical data from Hinds Cave (Dering 1979; Sobolik 1991a) will be incorporated into the cultural chronology section. The anthropogenic accumulation of this vegetal debris closely correlates with the subsistence strategies and material acquisition choices of the human populations occupying the rockshelters and provides a rough picture of changes in the relative importance of different resources across the Holocene. This will be considered further in conjunction with the coprolite data in the results.

During the post-glacial period (10,000 years B.P. to present) there has been a shift from a mosaic of woodlands, parklands and scrub grasslands to an environment dominated by scrub grasslands (Bryant and Holloway 1985). The increasing xerification of the Lower Pecos landscape continued during the Holocene with only one brief period around 2,500 years B.P., when pollen records suggest a cooler and more mesic environment (Bryant and Holloway 1985). More recent paleoenvironmental reconstructions based on snail shell stable isotope data suggest that the mid-Holocene may have been characterized by relatively moist conditions followed by a drying trend peaking around 3500 cal yr BP (Goodfriend and Ellis 2000). Altogether, the paleoenvironmental reconstructions suggest a relatively stable environment for the Lower Pecos canyonlands across the Holocene (Bryant 1967, 1969, 1977b, c; Bryant and Holloway 1985; Bryant and Larson 1968; Bryant and Riskind 1980; Dering 1979; Goodfriend and Ellis 2000; Hevly 1966; Johnson 1963; Mcandrews and Larson 1966; Meyer 1973). In the following section, the general trends in vegetational change interpreted by Byrant and Holloway (1985) are presented within the framework proposed by Bryant (1966d).

Sabinal Stage (Prior to 10,000 B.P.). The only pollen record from the Lower Pecos canyonlands that spans the Early Holocene comes from the Bonfire Shelter study (Figure 4) (Hevly 1966). Bonfire Shelter is located in a side canyon off the Rio Grande, just west of the mouth of the Pecos River (Figure 2) (Dibble 1965; Dibble and Dessamae 1968). These strata are older than 10,000 B.P., but do not have any directly associated radiocarbon dates. The pollen counts from this stage are characterized by high levels of pine (*Pinus* sp.) and grass (*Poaceae*) pollen. The stratigraphically younger samples from this stage show an increased percentage of pine and decreases in grass and herbaceous pollen types. It is unlikely that the area was covered with conifer forest, but was instead

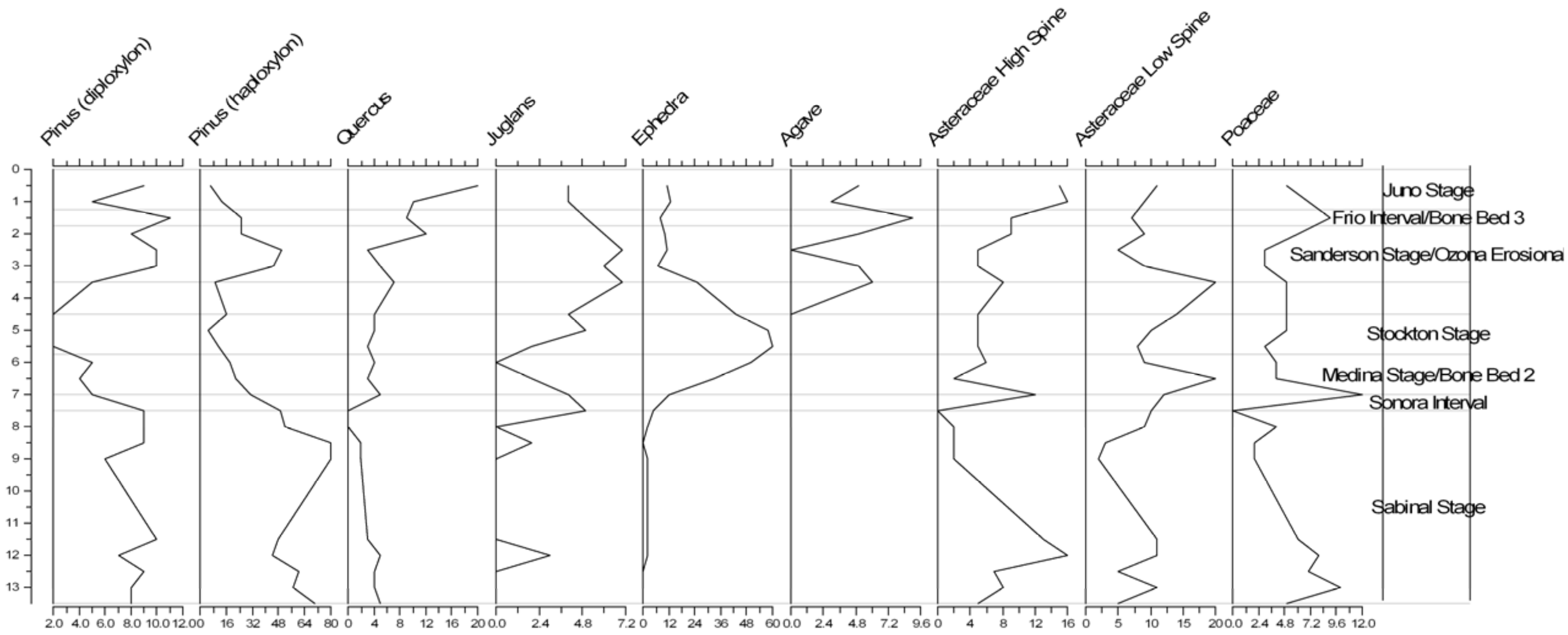


Figure 4. Pollen Diagram from Bonfire Shelter (Hevly 1966)

a mosaic of woodlands, pinyon parklands and scrub grasslands during this time(Bryant and Holloway 1985).

Sonora Interval (Prior to 10,000 B.P.). This climatic interval is represented in the pollen record from two sites in the Lower Pecos, Bonfire Shelter and Eagle Cave (Figures 4 and 5) (Hevly 1966; Mcandrews and Larson 1966). Much like the preceding Sabinal stage, the Sonora interval is poorly dated. Based on radiocarbon dates associated with the Bone Bed 2 deposits in Bonfire Shelter, this interval ended just prior to 10,000 B.P. but the transition between the prior Sabinal stage and this interval is not dated (Bryant 1966d; Hevly 1966). Bryant and Holloway (1985) have assigned this transition to approximately 14,000 B.P. based on the presence of rock spalls created by ice wedging, which indicates the Wisconsin Full-Glacial Period.

The pollen spectra suggest that many of the woodlands and parklands in the region were being replaced by expanded scrub grasslands and riparian woodlands during the Sonora Interval interval (Bryant and Holloway 1985). This trend was gradual and continued into the next two intervals as well. The landscape was still a mosaic of different communites, but the scrub grasslands were continuing to expand and replace the woodlands and parklands more common during the Sabinal Stage.

These vegetational changes reflect a climate with less available moisture than the preceding stage. This is most likely due to the northward retreat of the continental glaciers and associated changes in wind patterns (Bryant and Holloway 1985). This is also reflected in the desiccation of the pluvial lakes across West Texas and the Lower Pecos (Kochel et al. 1982).

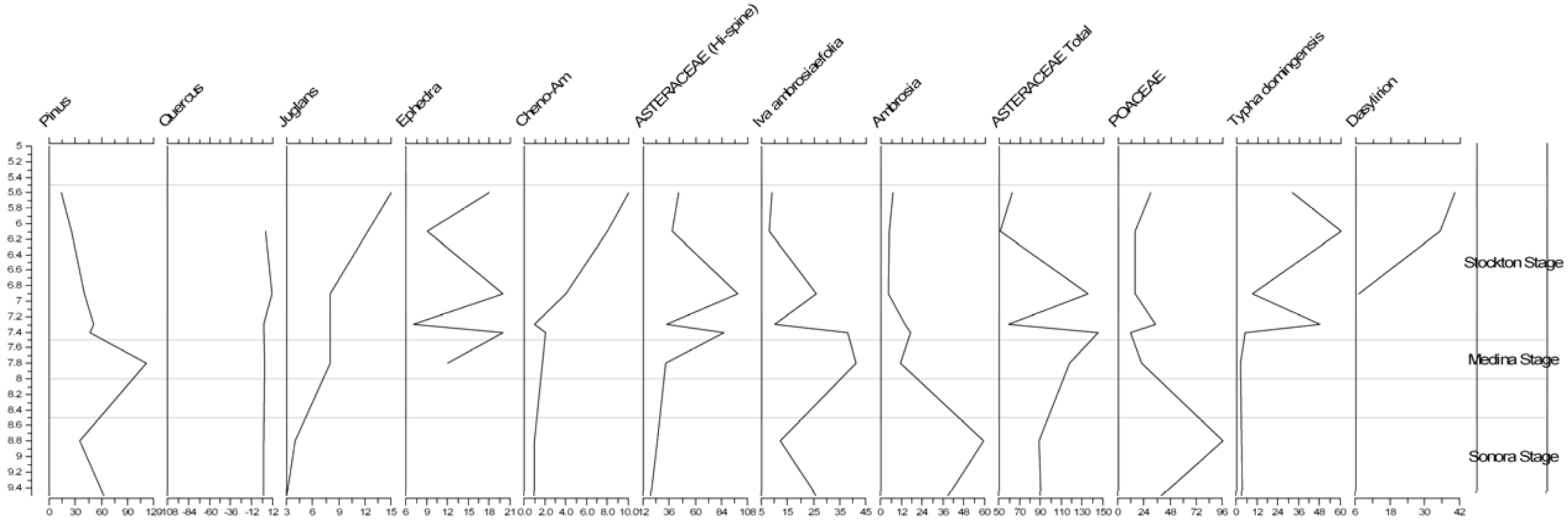


Figure 5. Pollen Diagram from Eagle Cave (McAndrews and Larson 1966)

Medina Stage (10,000 B.P.- 9000 B.P.). Three sites have pollen data from this period: Bonfire Shelter, Devils Mouth Site (Bryant 1966b) and Eagle Cave (Figures 4-6). All of these sites show an increase in arboreal pollen types and declines in grass, but there is a fair amount of variation between the three sites as well. The easternmost site is the Devils Mouth site, located on the west bank of the Devils River near its confluence with the Rio Grande (Figure 2), was a large open-air site on an alluvial terrace with deeply stratified cultural components (Figure 4). At Bonfire Shelter, the pollen spectra from this stage is characterized by decreasing levels of pine with a corresponding increase in pecan, ephedra and low-spine asteraceae pollen types (Figure 4). Eagle Cave, located in close proximity to Bonfire, exhibits a continued decline in pine pollen types across the Medina Stage (Figure 5). The pollen spectra from this stage also exhibit an increase in ephedra, hackberry, and asteraceae pollen types across this stage.

The pollen spectra suggest a scrub grassland habitat with riparian woodlands. This is a continuation of the trend observed in the preceding Sonora Interval. These three data sets suggest that the strong east-west influence seen in the modern plant communities of the Lower Pecos canyonlands were already established by the early Holocene (Figures 2-4). Later reconstructions corroborate the view that the Medina Stage was a period of scrub grassland expansion (Bryant and Holloway 1985).

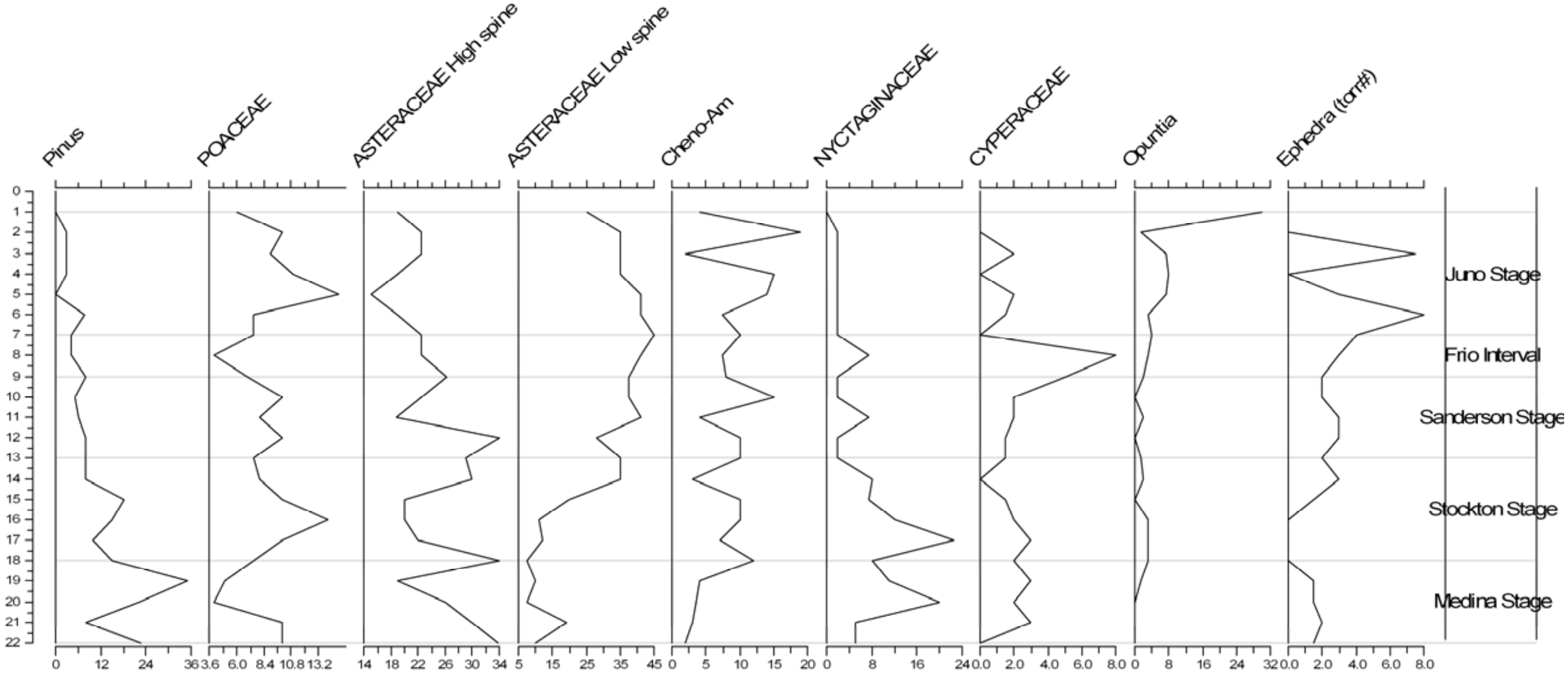


Figure 6. Pollen Diagram from the Devils Mouth Site (Bryant 1966)

Stockton Stage (10,000 B.P. – 5000 B.P.). This long climatic stage is represented in the pollen spectra of four sites in the Lower Pecos canyonlands. Pollen data are available from Bonfire Shelter, the Devils Mouth Site, Eagle Cave, and two different excavation areas in Hinds Cave (Bryant 1977c; Dering 1979). The spectra from the Devils Mouth Site show a continued decline in pine pollen and most other arboreal pollen types (Figure 6). The exception to this trend is oak (*Quercus sp.*), which exhibits a distinct peak during this stage. Grass, cheno-am and asteraceae pollen types are common in strata from this stage.

Hinds cave is located on a side canyon on the eastern bank of the Pecos River (Figure 2). The pollen data from Dering (1979) show a sharp decline in both pine and oak pollen during this stage (Figure 7). Grass is recovered at relatively low levels until the last one thousand years of this stage, but high levels of asteraceae pollen types are common throughout the strata associated with this stage. Agave (*Agave sp.*) pollen is first noted in strata dating to 8000 B.P. and rises sharply, peaking between 7000 B.P. and 5500 B.P. The presence of quantities of this zoophilous pollen type is certainly the result of human activity, but it does indicate that the Chihuahuan desert vegetation that characterizes the modern environment was present at this point in the Holocene. The pollen study conducted by Bryant (1977) on Hinds Cave samples show a similar pattern to the study by Dering (1979) (Figure 8). Overall the dominant pollen from this study are grass and asteraceae pollen types (Bryant 1977c). There is evidence of both agave and sotol (*Dasylirion sp.*) in the lower samples from this study.

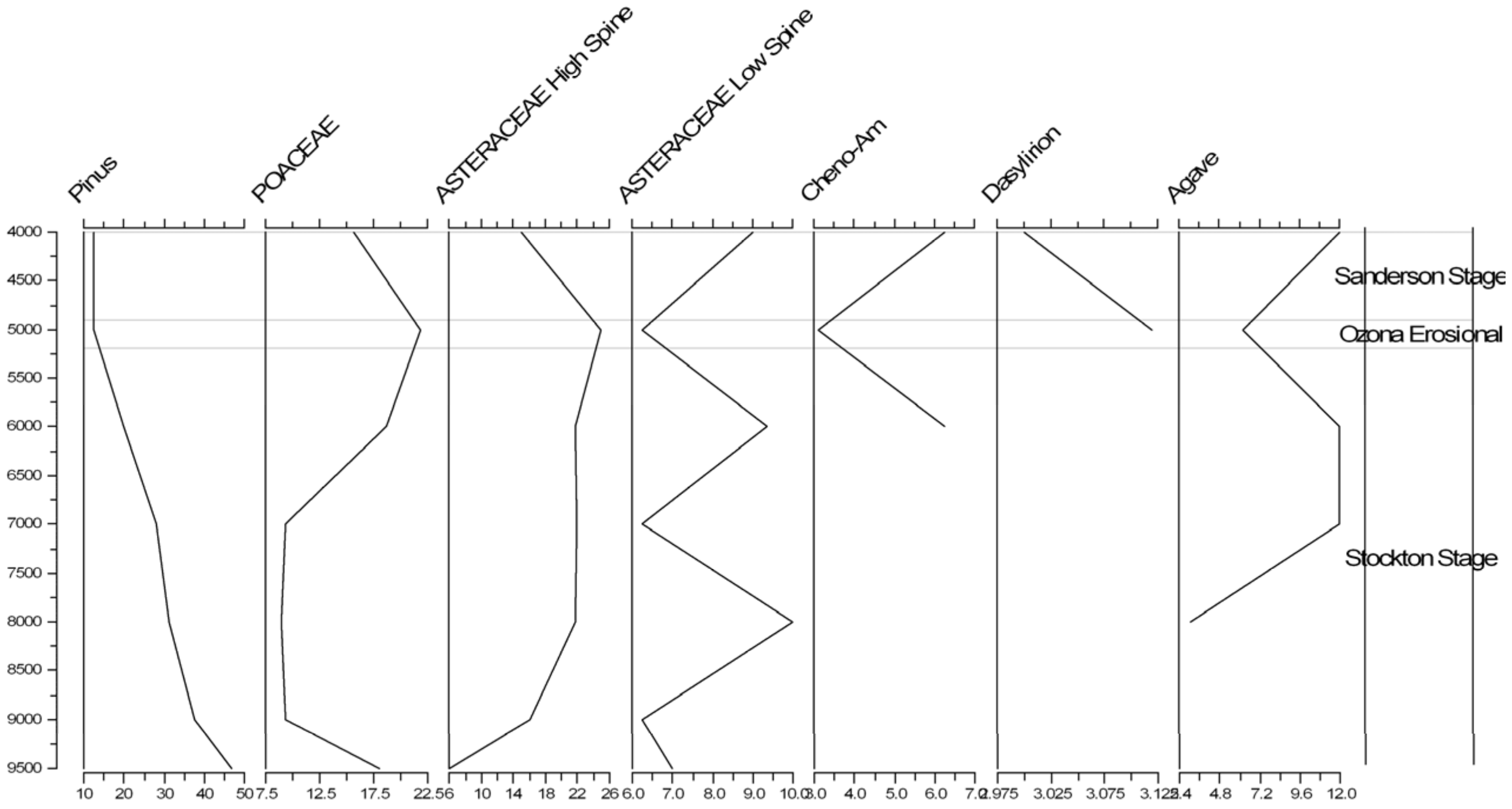


Figure 7. Pollen Diagram from Hinds Cave (Dering 1979)

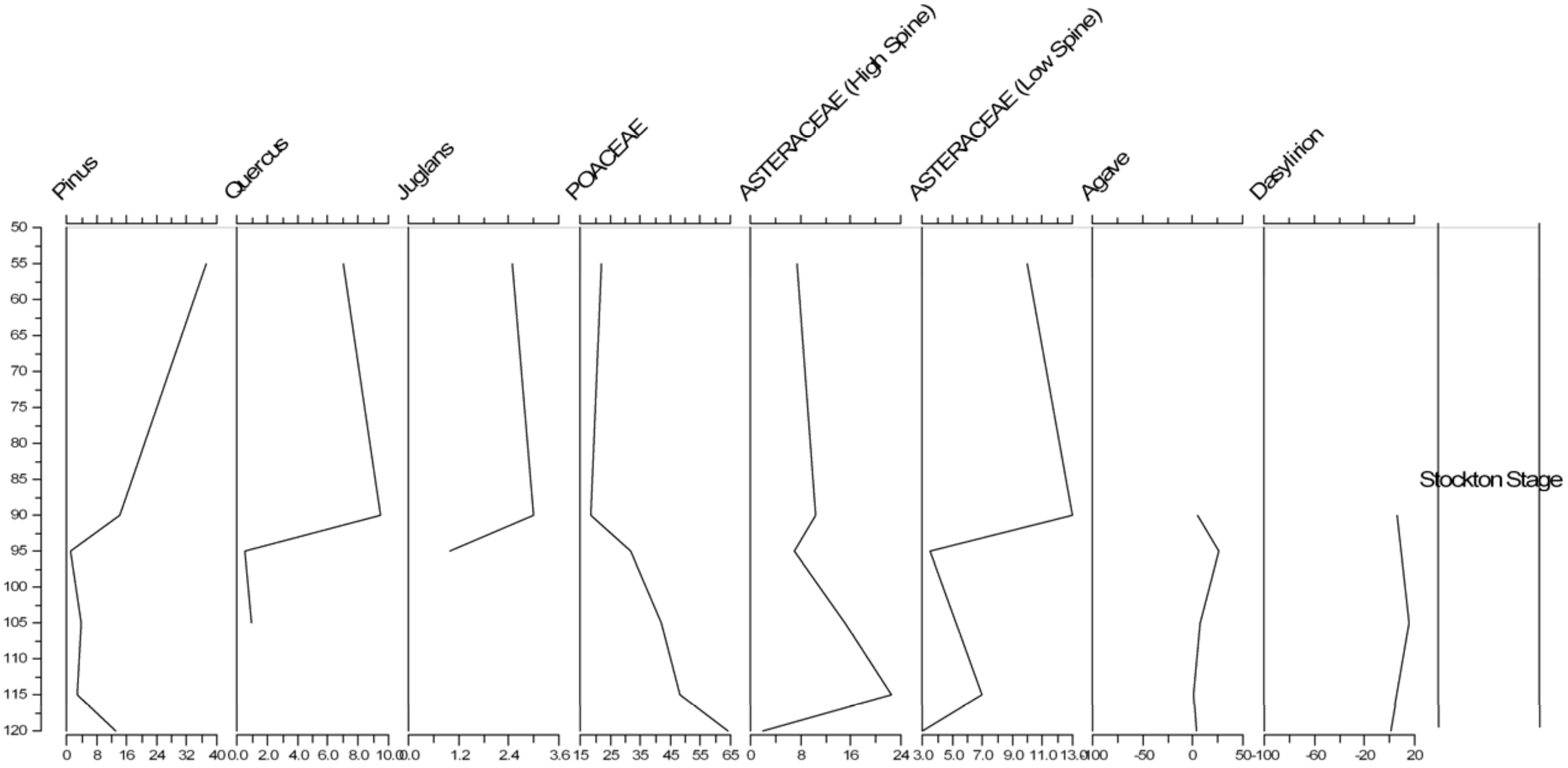


Figure 8. Pollen Diagram from Hinds Cave, Area D (Bryant 1977)

The spectra from Bonfire Shelter show a high level of ephedra pollen during this stage, as well as other types indicative of scrublands such as asteraceae pollen types (Figure 4). Pine levels in these strata are the lowest encountered in the Bonfire Shelter pollen profile. The spectra from Eagle Cave show a similar elevation of ephedra pollen from this stage, which is also associated with higher levels of cheno-am pollen (Figure 5). Sotol first appears in this pollen profile at the beginning of this stage and exhibits a significant increase over time, being one of the prominent types in the youngest sample in the profile. Clearly, human habitation of these sites markedly influenced the pollen spectra recovered during excavation. While this limits any paleoenvironmental interpretation for the region based on this data, it does indicate that these desert succulents that dominant the historically documented vegetation of the canyonlands were present in the region and being exploited by human populations across the Stockton Stage.

Overall, these five pollen profiles suggest that the xerification of the Lower Pecos canyonlands observed in the earlier periods continues across the Stockton Stage. Increases in ephedra and other desert shrubs, along with the low levels of grass and arboreal pollen types, indicate the development of a scrubland-desert type vegetation. This suggests that the environment was similar to the sotol-lechuguilla zone of the Chihuahuan biotic province currently found.

Similar to the data from the Medina Stage, the pollen profile from the Devils Mouth site shows some significant differences from the other records from sites near the Pecos River (Figure 6). The Devils Mouth site record does not exhibit the same high frequency of desert shrubs and instead suggests an open oak woodland that a scrubland or desert environment throughout much of the region. Located much further east than the other sites included in this review, the spectra from the Devils Mouth site reflect a more mesic environment that the other sites, which are all securely within the Chihuahuan biotic province (Figure 2) (Blair 1950).

Ozona Erosional (5000 B.P.). This climatic period is only represented in two pollen records from the region, Bonfire Shelter and Hinds Cave. This period is referred to as the Ozona Erosional Period because many of the sites excavated during the Texas Archaeological Salvage Project exhibited disconformities in their stratigraphic profile for this period (Bryant 1966d; Bryant and Holloway 1985). The pollen record from Dering (1979) for this period contains high levels of grass and high-spine asteraceae pollen types (Figure 7). Agave, creosote bush, and sotol pollen types are present in the sample from this period. This supports the reconstruction of the continued expansion of the Chihuahuan biotic community into the region from the south and west.

The pollen data from Bonfire Shelter for this period suggest a similar trend of increasing xerification of the landscape (Figure 4). Desert shrub species are common in the samples from this period, along with small amounts of pollen from riparian species such as walnut and pecan. Overall, the Ozona Erosional is characterized as a desert scrubland with reduced ground cover. The region appears to be increasingly dry and prone to episodes of flooding and erosion during the Ozona Erosional (Bryant 1966d; Bryant and Holloway 1985; Kochel et al. 1982; Patton and Dibble 1982).

Sanderson Stage (5000 B.P. – 3000 B.P.). The Sanderson stage of Bryant's (1966) climatic reconstruction is represented in pollen spectra from four sites in the region. These include Arenosa Shelter (Bryant 1967), Bonfire Shelter, the Devils Mouth Site and Hinds Cave. These will be presented in the same east to west format used for previous climatic stages.

The Devils Mouth site pollen data from this climatic stage show similar trends as the preceding strata associated with the Stockton stage (Figure 6). Asteraceae pollen types are the dominant component of the assemblage. Cheno-am and ephedra pollen remain a visible component of the spectra, but at low levels

Arenosa Shelter is a limestone overhang located on the Pecos River near the confluence with the Rio Grande (Figure 2) (Dibble 1967; Jurgens 2005). This location of this site exposed it to flooding episodes observed in the recent historic period (Dibble 1967; Jurgens 2005). The stratigraphic contexts assigned to the Stockton climatic stage exhibit high levels of pine, grass and asteraceae pollen types (Figure 9). Cheno-am, opuntia, and ephedra pollen types are also present in relatively high levels.

Only one of the pollen profiles from Hinds Cave has data assigned to this stage (Dering 1979). This data set shows a decrease in grass, high-spine asteraceae, and sotol across this climatic stage (Figure 7). Agave, oak, mesquite, ephedra, low-spine asteraceae and cheno-am pollen types all exhibit an increase in prevalence across this same stage.

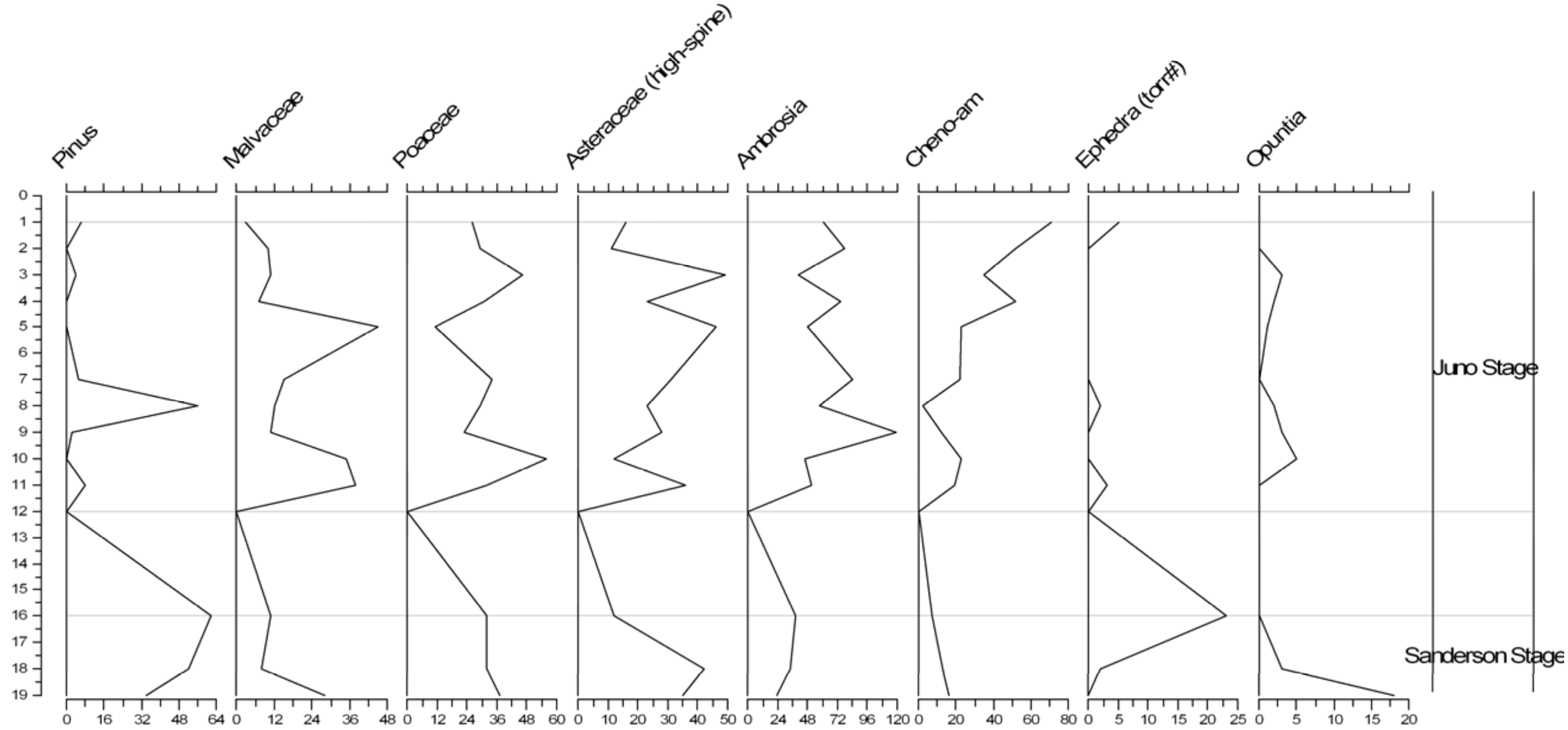


Figure 9. Pollen Diagram from Arenosa Shelter (Bryant 1967)

The data from Bonfire Shelter show an increase in pine and other arboreal pollen during the Stockton climatic stage (Figure 4). Ephedra, grass, and asteraceae pollen types all decline relative to the previous stage.

Overall, the Stockton Stage is a continuation of the xeric trend started in the Sanderson Stage. The pollen record reflects a plant community composed of many desert shrub species and weeds. Grass pollen continues to decline in the record at many of the sites in the region. The pollen record from this stage marks the first appearance of opuntia and ephedra in the spectra from the Devils Mouth site. This suggests that the sotol-lechuguilla zone of the Chihuahuan biotic province continues to extend to the east as xeric conditions prevail in the region.

Frio Interval (3000 B.P.). This short interval has pollen records from two sites in the region, Bonfire Shelter and the Devils Mouth Site. The pollen spectra from both sites exhibit an increase in grass during this interval, as well as an upward trend in asteraceae pollen types. There is an increase in arboreal pollen types, particularly pine. Overall, these spectra suggest an increase in available moisture during this interval. Grasslands and oak motts would have interfingered with the desert scrublands more common in early stages (Bryant and Holloway 1985). This is further corroborated by the presence of Bison in the canyonlands during the Frio Interval (Dibble 1965, 1970; Dibble and Dessamae 1968).

Juno Stage (3000 B.P. – Present). The Juno climatic stage represents a return to the xeric conditions prior to the more mesic Frio Interval. Pollen spectra are available from three sites in the region: Arenosa Shelter, Bonfire Shelter, and the Devils Mouth Site. The spectrum from the Devils Mouth site exhibit spikes in grass and ephedra pollen during this stage (Figure 6). *Opuntia* sp. pollen follows an upward trend to a maximum in the youngest stratum of the profile. The Arenosa Shelter profile shows an overall increase in arboreal pollen types compared to the discontinuous older strata from the Sanderson climatic stage (Figure 9). This is consistent with the continous pollen records from the other two sites presented here. These arboreal pollen types include juniper and mesquite. Pollen from grass and asteraceae types remain a substantial component of the spectra. The spectra from Bonfire Shelter exhibit a similar increase in arboreal pollen (Figure 4). Grass and asteraceae pollen types continue to constitute the bulk of each spectrum. The pollen spectra available from this stage indicate a region of xeric scrubland and riparian woodlands, much like the modern environment observed by Flyr (1966) and Williams-Dean (1978).

Prior Research in the Lower Pecos Canyonlands

The first excavations in the region were conducted in the 1930's by the University of Texas (Pearce 1933) and followed shortly thereafter by excavations led by the Witte Museum (Davenport 1938; Martin 1933) and the Smithsonian Institution (Setzler 1932, 1933, 1934). These excavations were primarily aimed at the recovery of museum quality artifacts, as was most archaeological research in this time period (Shafer and Bryant 1977). The majority of these studies focused on the excavation of artifacts from large rockshelter contexts along the major drainages in the region (Davenport 1938, 1941; Martin 1933; Pearce 1933; Setzler 1932, 1933, 1934). These sites tended to have highly visible accumulations of past human habitation as well as incredible preservation of perishable artifacts such as sandals and baskets as well as ecofacts (Davenport 1938; Martin 1933; Pearce 1933; Setzler 1932, 1933, 1934). Despite this, very few examples of perishable remains outside of textiles were collected during this period. This period also saw the first scientific recovery of human remains from the region (Setzler 1934). Very little was published on these excavations, although later researchers used these museum collections as the basis of descriptions of the regions material culture (Schuetz 1956, 1961, 1963). These reports are generally descriptive in nature, without much attempt to reconstruct prehistoric lifeways (Davenport 1938; Martin 1933; Pearce 1933). There are few controls on artifact provenience or stratigraphic association from these early excavations, which were generally concerned with the recovery of complete or rare artifacts. This can be very frustrating for current researchers working with these museum collections. Pevny et al. (2010) conducted a joint usewear and microscopic residue study on flake tools that the Witte Museum recovered from Shumla Cave and Eagle Cave that exposed some of these limitations. There was no way to link specific tools with the site stratigraphy or a generalized chronology of the region. This lack of modern excavation method and recording, along with the limited collection agendas, of these early explorations of the canyonlands limit the potential of these collections.

This period also saw the first professional interest in the rock art of the region, primarily by Forrest Kirkland (Jackson 1938; Kirkland 1939). Much of this rock art was preserved by the limestone overhang of the numerous rockshelters of the region, frequently in very large and complex panels. This distinctive art quickly became the hallmark of the region and one of the defining characteristics of the Lower Pecos as an archaeological region. Much like the archaeology from this period, the rock art research was primarily descriptive in nature, with Kirkland faithfully recording many of the larger panels in the region (Kirkland 1939; Kirkland and Newcomb 1967). These early researchers recognized that there were at least three different styles of rock art in the region, but it remained unclear if these were temporal or cultural differences (Boyd 1998; Gebhard 1960; Grieder 1966; Jackson 1938; Kirkland 1939; Kirkland and Newcomb 1967).

In addition to the formal excavations and rock art research from this period, there was a good deal of looting from these highly visible sites in very rural settings (Shafer and Bryant 1977). It is unclear how much damage was caused by this looting activity, but nearly every major rockshelter site recorded by the Texas Archaeological Salvage Project and later projects had some evidence of looting (Shafer and Bryant 1977). This activity created an even more confusing depositional pattern for later archaeologists, as most looting resulted in the reworking and admixture of stratigraphically distinct deposits as the looters attempted to recover human remains and rare textile artifacts (Turpin 2004). This looting remains unabated to this day in the region (Dering 2002).

The first attempts to generate a cultural chronology for the region occurred after World War II (Taylor 1949a, b). These attempts were admittedly tentative, but they represent the first research in the region to approach the archaeological record with explicit questions of human occupation of the Lower Pecos. Despite this effort to establish a cultural chronology for the area in the 1940’s and 50’s (Lehmer 1960;

Schuetz 1956, 1961, 1963; Taylor 1949a, b), the decades after the initial explorations in the 1930's saw very little active research in the region. The most intensive archaeological investigation of the region occurred from 1958-1969 (Alexander 1970, 1974; Anderson 1974; Bryant 1966a, b, c, d, 1967, 1969; Bryant and Larson 1968; Collins 1969; Dibble 1965, 1970; Dibble and Dessamae 1968; Epstein 1963; Flyr 1966; Gebhard 1960; Graham and Davis 1958; Greer 1966, 1968; Hevly 1966; Irving 1966; Johnson 1963, 1964, 1967; Mcandrews and Larson 1966; Nunley et al. 1965; Parsons 1965; Prewitt 1966, 1970; Riskind 1970; Ross 1965; Shafer 1969, 1970; Sorrow 1967, 1968; Story and Bryant 1966; Taylor and Rul 1961; Word and Douglas 1970) . This research was conducted as a salvage operation prior to the construction of the Amistad Reservoir. In addition to a large amount of survey and test excavation (Collins 1969; Dibble 1967; Graham and Davis 1958; Nunley et al. 1965; Shafer 1969, 1970; Taylor and Rul 1961), this salvage project conducted a number of major excavations on both rockshelter sites (Alexander 1970, 1974; Dibble 1965; Dibble and Prewitt 1967; Epstein 1963; Johnson 1963; Parsons 1965; Ross 1965), as well as open air sites (Greer 1966, 1968; Johnson 1964; Sorrow 1967, 1968). Although there was excellent preservation of botanical material in the majority of the rockshelter sites selected for excavation, none of the research designs included a systematic collection and analysis of these materials (Shafer and Bryant 1977). Rather the focus was on building chronologies from the projectile point types and other artifacts recovered in the excavations.

As the salvage work progressed, the focus changed from developing cultural chronologies to paleoecological studies (Bryant 1966a, b, c, d, 1967; Bryant and Larson

1968; Flyr 1966; Hevly 1966; Irving 1966; Johnson 1963; Mcandrews 1966; Mcandrews and Larson 1966; Riskind 1970; Story and Bryant 1966). This was due in part to a general shift in archaeological research questions across the U.S., associated with the "new" archaeology (Dering 1979) as well as the incredible preservation of the region. Beginning around 1965, researchers in the Amistad Reservoir salvage project realized the preservation of biological components of the archaeological record in the area created a unique opportunity to address questions of subsistence and human-environmental relationships (Story and Bryant 1966). Unfortunately, this research was severely limited by the collection strategies applied during excavation (Dering and Shafer 1976). Very few excavators from the salvage project recovered and collected the ecofacts required to properly address questions of human ecology. Although coprolites were encountered in the majority of rockshelter excavations, they were collected for analysis in only two cases, Conejo Shelter (Alexander 1974; Bryant 1969) and Parida Cave (Alexander 1970; Riskind 1970). In many cases, the coprolites encountered in the screens during excavation were "frisbeed" out over the canyon during lunch breaks as a form of entertainment for the crew (Bryant and Dean 2006). Most of these major rockshelter sites were flooded after the completion of the dam, resulting in the permanent loss of the largest collection of coprolite data in North America and possibly the world.

The primary result of this focus on paleoecology was the generation of a number of pollen analyses from both open air and rockshelter habitation sites (Bryant 1966b, c, d, 1967; Bryant and Larson 1968; Hevly 1966; Johnson 1963; Mcandrews 1966;

Mcandrews and Larson 1966; Story and Bryant 1966). This paleoecological focus also resulted in the study of the macrobotanical remains from seven of the excavated sites from the salvage project (Alexander 1974; Irving 1966).

Work in this region ceased after the completion of the Amistad Reservoir, and did not resume until both the Hinds Cave and Baker Cave projects began in 1974 (Brown 1991; Hester 1978; Shafer and Bryant 1977; Shafer et al. 1975). Both of these excavations were designed to take advantage of the ecofact preservation in these dry rockshelters and produced an incredible amount of excavated material. While the Hinds Cave excavation generated a great deal of new research, including studies of the macrobotanical (Dering 1979), coprolite (Edwards 1990; Stock 1983; Williams-Dean 1978) and faunal components (Lord 1984), the results of the Baker Cave project were less thoroughly examined (Hester 1978). The Hinds Cave excavation also resulted in the publication of one of the first studies of microscopic residue from lithic tools (Shafer and Holloway 1979) as well as a volume on the textile artifacts recovered during excavation (Andrews and Adovasio 1980). The excavated materials from Hinds Cave continue to generate new scholarly inquiries into past human lifeways in the Lower Pecos (Dean 2004, 2006; Goodfriend and Ellis 2000; Poinar et al. 2001; Reinhard et al. 2007; Reinhard et al. 2008; Riley 2008; Saunders 1986; Sobolik 1996b). The systematic recovery of a wide-range of material culture in these excavations, as well as a increased focus on the ecology of human habitation of the Lower Pecos, allowed researchers to more thoroughly investigate past human lifeways in the region than prior excavations. A new generation of scholars had research interests in the region, although much of the research focuses on the analysis of previously excavated materials (Brunnemann 1988; Danielson and Reinhard 1998; Mailloux 2003; Mcgregor 1992; Sobolik 1996a; Williams-Dean 1978) and the documentation and interpretation of rock art in the region (Boyd 2003; Boyd and Dering 1996; Chippindale and Taçon 2000; Greco 1984; Mock 1987; Turpin 1990a; Turpin 1992; Turpin and Eling 2002). This continues today, as the region has received renewed attention from both rock art specialists and archaeologists (Bousman and Quigg 2006; Boyd 1998; Boyd and Dering 1996; Boyd 2006; Steelman et al. 2004; Turpin 1991a, b, 1997, 2004; Turpin et al. 2002).

Human Habitation and Cultural Chronology of the Lower Pecos Canyonlands

Despite the considerable biotic diversity of the region, most cultural reconstructions suggest a remarkably similar use of the region by human cultures across the Holocene (Bement 1989; Collins 1974; Hester et al. 1989; Prewitt 1983; Shafer 1986; Story and Bryant 1966; Turpin 1991a, 2004). The populations occupying this area practiced a conservative foraging adaptation to the semi-arid environment (Sobolik 1996b). This adaptation consisted of small, nomadic social groups with a broad-based subsistence economy (Sobolik 1996b). The lack of storage features associated with archaeological sites in the region suggests a primary dependence on seasonally available foodstuffs with no long-term storage of dietary staples (Williams-Dean 1978). The dietary staples of these populations were desert succulents and cactus (Williams-Dean 1978). This dependence on plants from xeric environments extends back to at least 8,500 years B.P. (Dering 1979; Stock 1983).

The large amount of archaeological research in this geographically constrained area has yielded a very robust collection of radiocarbon dates (Turpin 1991b, 2004). This abundance of data has been used to generate a regional chronology of human habitation (Turpin 2004). While there have been multiple nomenclatures proposed for the different time periods of this chronology (Bement 1989; Collins 1974; Hester 1989; Prewitt 1983; Shafer 1986; Story and Bryant 1966; Turpin 1991b, 2004), the overall picture of cultural occupation of the region is well agreed upon. Following Turpin (1991:2004), this study uses the nomenclature first proposed in Prewitt (1983). All dates are presented as uncalibrated radiocarbon years before present (B.P.).

Paleoindian Period

Aurora Subperiod (pre-12,000 B.P.). There is very limited evidence of human occupation in the Lower Pecos canyonlands from this early subperiod (Table 4). There are only two sites with dates from this subperiod. Cueva Quebrada is a small rockshelter that contains faunal remains exhibiting evidence of burning (Lundelius 1984). The oldest bone bed from Bonfire Shelter also dates to this period and has been interpreted as representing butchered megafauna, but the lack of artifacts from the context makes this claim tenuous (Bement 1986; Bement 2007; Byerly et al. 2007; Byerly et al. 2005; Dibble and Dessamae 1968). These butchered animal remains are primarily Pleistocene megafauna and are associated with specialized big-game hunters, as are most early Paleoindian sites (Turpin 2004).

Bonfire Subperiod (10,700 to 9800 B.P.). This subperiod is named for Bone Bed 2 of Bonfire Shelter (Table 4). This large collection of bison (*Bison bison antiquus*) bone associated with Plainview and Folsom dart points has been interpreted as the result of a series of bison jumps and subsequent butchery by human populations occupying the canyonlands. This is the oldest known example of a animal jump as well as the southernmost. This has recently been thrown into doubt through a re-examination of the site using GIS, which suggests that the accumulation pattern is more consistent with secondary processing of high-utility portions of bison initially killed elsewhere (Bement 2007; Byerly et al. 2007; Byerly et al. 2005). Regardless of the method of accumulation, this bone bed and associated lithic artifacts indicate that the Lower Pecos canyonlands were utilized by Paleoindian big game hunters. The paleoenvironmental records suggest that this rare occurrence of bison in the Lower Pecos faunal record is associated with a mesic period (Medina stage in Bryant 1966d) in the region's climate (Bryant 1966d; Patton and Dibble 1982).

Oriente Subperiod (9400 to 8800 B.P.). This subperiod is the equivalent of the Late Paleoindian period, particularly with reference to the lithic technology utilized by the region's inhabitants (Table 4) (Turpin 2004). However, Lower Pecos archaeological sites from this time period exhibit a blend of Late Paleoindian and Early Archaic traits that was first observed by Johnson (1964) at the deeply stratified Devil's Mouth Site. These traits suggest a broad based economy that was not focused on big game hunting (Johnson 1964). This view was corroborated further by excavations at Baker Cave, which recovered a great diversity of subsistence resources associated with a hearth feature, and suggest the sites inhabitants had a much broader diet breadth than is typically postulated for Late Paleoindian populations (Hester 1983). Further, there are a wide variety of fiber artifacts recovered from this period, suggesting that the human populations in the region were utilizing local plant resources to a degree unseen in most Late Paleoindian archaeological contexts (Andrews and Adovasio 1980; Turpin 2004). While this may be an artifact of the uncommon preservation of perishables in this region, it is telling that this broadening of diet breadth visible in the archaeological record coincides with the onset of the drying trend identified by Bryant (1966d) as the Stockton stage.

Early Archaic Period

Viejo Subperiod (8900 to 5500 B.P.). This broadly defined subperiod encompasses the entire Early Archaic Period and provides archaeological evidence for the florescence of many of the cultural traits that have come to define the Lower Pecos canyonlands (Table 4). Associated with the increasing xerification of the landscape (Bryant 1966d, 1977b, c; Bryant and Holloway 1985; Bryant and Riskind 1980) during the drying trend noted above, rockshelters become more intensively occupied during this subperiod and even exhibit the delineation of shelter space into activities areas (Lord 1984; Shafer 1986). The earliest coprolites analyzed from the region date from this period (Stock 1983; Williams-Dean 1978) and, along with other evidence of plant use including macrobotanical remains and earth oven cooking features (Figures 10 and 11) (Dering 1979; Sobolik 1991), show a human population engaged in a subsistence pattern and material culture focused on Chihuahuan desert plant resources such as lechuguilla and sotol.

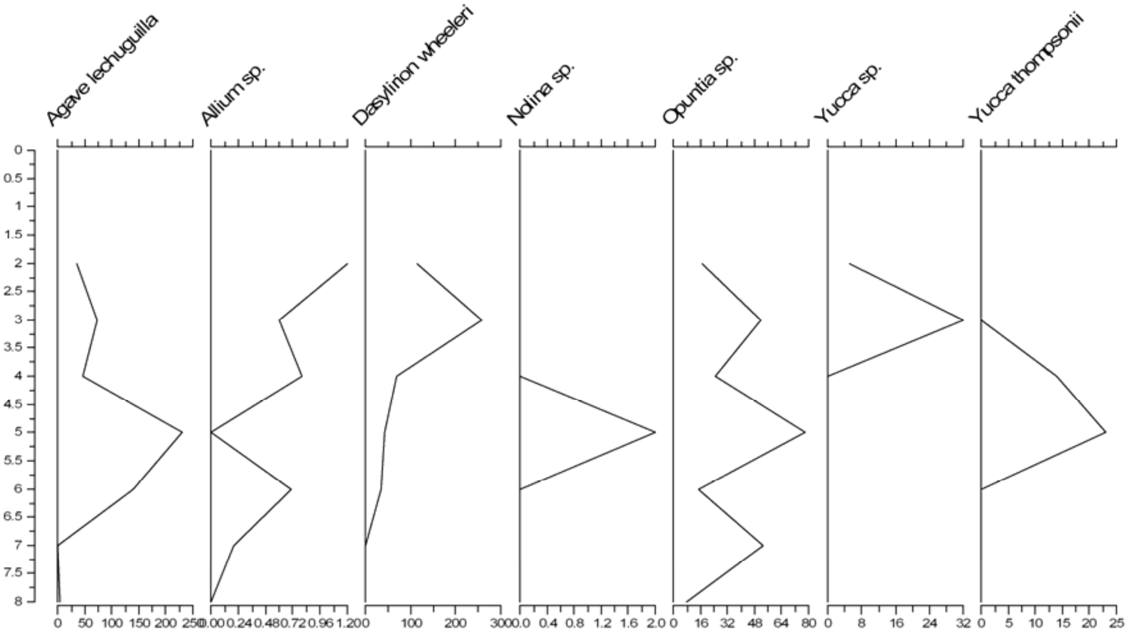


Figure 10. Stems and Bulbs from Hinds Cave, Area A (Dering 1979)

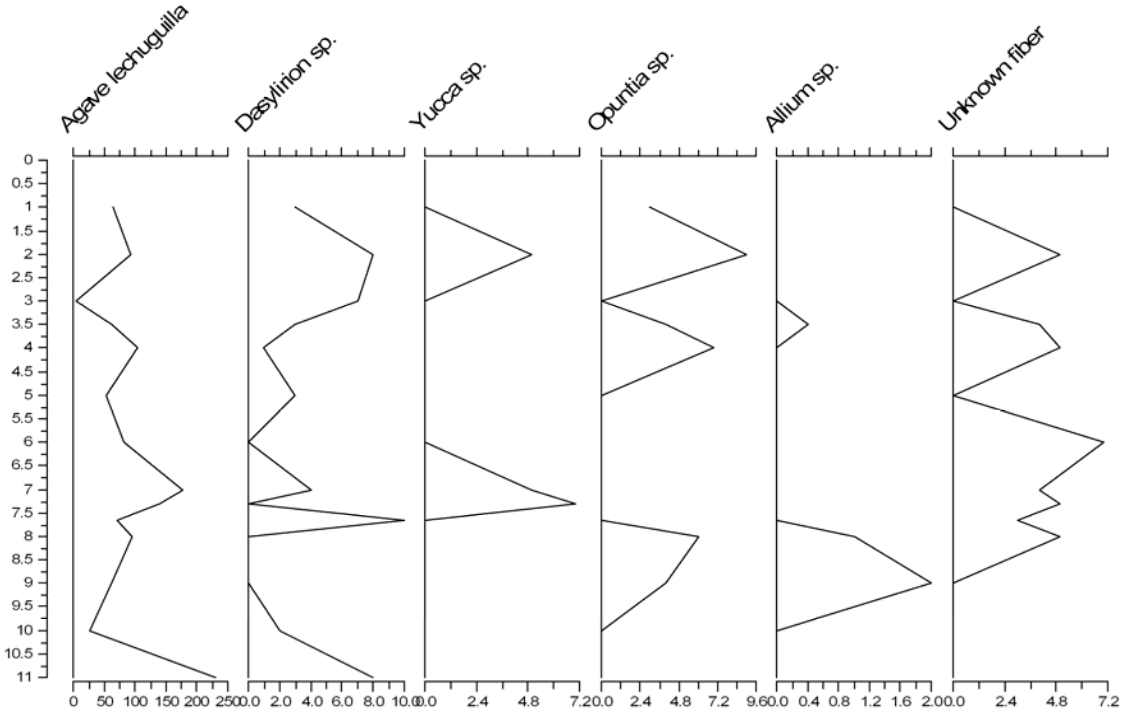


Figure 11. Stems and Bulbs from Hinds Cave, Area B (Sobolik 1991)

The oldest human skeletal remains from the region are also from this period (Turpin 1988). The Seminole Sink ossuary has multiple individuals who date directly to the Early Archaic (Bousman and Quigg 2006). The ossuary contains both male and female individuals of a variety of ages, which suggests an egalitarian society with little differentiation of social status (Turpin et al. 1986). These skeletons exhibit temporary nutritional stress that may be seasonal in nature, but have no evidence of prolonged malnourishment (Alvarez 2005a, b; Marks et al. 1988; Sobolik 1991a). This suggests that Early Archaic human populations in the region had adapted remarkably well to a very arid landscape through expanded diet breadth. These Early Archaic human populations incorporated labor intensive staple resources with a relatively low caloric return, such as lecheguilla and sotol (Dering 1979; Stock 1983). This is further corroborated by a high frequency of tooth loss and dental pathology on these same individuals, suggestive of a diet high in sugars and other carbohydrates (Hartnady 1988; Marks et al. 1988; Turpin et al. 1986). The dietary data derived from these skeletal remains will be discussed in greater detail in the dietary reconstruction section of the interpretation chapter.

Finally, excavated contexts from this period contain the earliest known artwork in the Lower Pecos canyonlands. Painted pebbles have been recovered from at least one Early Archaic context (Turpin and Middleton 1998). Other painted pebbles and unfired clay figurines have been recovered from unknown archaic contexts that may include this subperiod (Chandler et al. 1994; Mock 1987; Parsons 1986; Shafer 1975). Both portable art forms are considered hallmarks of the Lower Pecos canyonlands (Chandler et al.

1994; Mock 1987; Parsons 1986). Researchers have suggested that this long subperiod provided the watershed for the development of a Lower Pecos cultural adaptation distinct from surrounding regions that peaks in the next two subperiods (Turpin 2004).

Middle Archaic Period

Eagle Nest Subperiod (5500 to 4100 B.P.). This period is primarily defined by the presence of a distinctly beveled projectile point style known as Pandale (Turpin 2004). This is the earliest projectile point style that has a regional distribution that coincides with the geographic boundaries of the Lower Pecos canyonlands (Turpin 2004). Other researchers have suggested that the development of the Pandale projectile point coincides with an increased dependence on the labor intensive processing of sotol, lecheguilla, and yucca for subsistence (Brown 1991). The increased dependence on these intensive resources has been seen as an economy of scale response to the increasing aridity of the region observed by Bryant (1966d).

This same subperiod shows an increase in flooding (Patton and Dibble 1982), as the xeric conditions of the region intensified. This hot and dry period, labeled the Ozona Erosional, is reflected as disconformities in the stratigraphy of open air sites in the region, such as Devil’s Mouth Site and Arenosa Shelter (Dibble 1967; Johnson 1964). Human populations in the region responded with a least-risk strategy that saw them invest large amounts of energy in food production and may have also resulted in the expansion of diet breadth, increased mobility, and changes in community structure to accommodate the decreased availability of food resources on the landscape (Brown 1991; Dering 1999). It is important to note that the macrobotanical studies of Dering

(1979) indicate that lechuguilla was already important resource in the preceding Viejo subperiod, although there is a marked increase during the Middle Archaic (Figure 10). The oldest evidence for peyote use in the Americas also comes from this period, a trend which will be elaborated on in the following section (Bar 2007; Terry et al. 2006).

San Felipe Subperiod (4100 to 3200 B.P.). This period marks the development of the earliest rock art style in the region, the Pecos River style (Boyd 1998; Kirkland 1939; Kirkland and Newcomb 1967; Turpin 1982). This subperiod is associated with regionally circumscribed projectile point styles such as Langtry, Val Verde and Arenosa, further suggesting that the development of a regionally distinct cultural adaptation was well underway (Turpin and Eling 2002). The primary focus of archaeological research in this period had primarily been on the large, polychromatic rock art panels (Boyd 1998). Most of these panels are centered around large anthropomorphic figures. These figures were first recognized by Newcomb as portrayals of shamen engaged in ritual behavior (Kirkland and Newcomb 1967). Boyd has convincingly argued that these panels have parallels with the Huichol peyote ceremonies recorded ethnographically (Boyd 1998). This is further corroborated with the macrobotanical evidence from the rockshelters (Boyd and Dering 1996).

The desertification of the region may have led to a shift in settlement and mobility patterns, as populations focused around the reliable water in the major drainages (Turpin 2004). Upland sites from this period are more prevalent as well, which may indicate the reorganization of mobility towards a more logistically oriented mobility pattern, with task-oriented workgroups exploiting the increased density of desert succulents on the uplands and returning them to home bases tethered to the canyon systems (Saunders 1986; Saunders 1992). Researchers have suggested that this reorganization of populations into more densely packed communities along the rivers with sparse uplands may have driven the development of new social institutions, including the ritual acts reflected in the Pecos River style rock art (Turpin 1990b). These hypotheses are suppositional and have yet to be fully modeled or tested for the region. Tests of return rates by Dering (1999) have suggested that the dependence on labor intensive, low yield plant resouces, which extends back into the Early Archaic, created constraints on population density and mobility that would have rendered the logistically oriented mobility strategy proposed above an improbable strategy at any time.

Late Archaic Period

Cibola Subperiod (3150 to 2300 B.P.). This period is associated with a major mesic shift in the region, first noted in Bryant (1966d) as the Frio Interval, and characterized by a shift away from a desert environment towards a grassland. This is further supported by the renewed presence of Bison in the region, which are absent from the faunal record between the Paleoindian period and the Late Archaic (Dibble 1970; Dibble and Dessamae 1968; Turpin 2004). The clearest evidence of this is the youngest bone bed of Bonfire Shelter, which consists of eight hundred bison as well as dart points generally considered as Central Texas types (Dibble and Dessamae 1968). There is also a proposed shift in settlement patterns, as projectile points from this period are less common in rockshelter deposits and much more frequently encountered at open air sites such as Devil's Mouth (Turpin 2004). These patterns suggest a reorganization of subsistence during this subperiod, away from low yield desert succulents and towards the large herds of bison now available in the region (Dibble 1965, 1970; Dibble and Dessamae 1968; Turpin 2004). Turpin (1990: 2004) has also correlated the rock art style known as Red Linear with this subperiod. This is due to the presence of bison and atlatls among the motifs of this style. This period has been seen as a time of great cultural change in the region, as new resource distributions and human migration forced the extant human populations to adjust (Turpin 2004).

Flanders Subperiod (2300 B.P. to ?). As the grasslands that characterized the region in the previous subperiod retreated, Turpin (2004) suggests that new human populations familiar with desert resources would have entered the region from other parts of what is now northern Mexico. This argument is based on a combination of paleoecological and lithic data. The dominant point style of this subperiod is the Shumla dart point, which has many similarities with points from earlier contexts in the modern Mexican states of Coahuila and Nuevo Leon (Turpin 2004). This is associated with a xeric interval identified by Bryant (1966d) as the Juno Interval, which would have led to an increase in the distribution of the desert succulent resource so prevalent in the Early and Middle Archaic. Very few sites with components from this period have been excavated to date, which limits any further interpretation of human lifeways during this shift back to more desertic conditions.

Blue Hills Subperiod (2300 to 1300 B.P.). This subperiod is characterized by a material culture that is shared with a much broader expanse of modern day Texas than the previous Middle and Late Archaic subperiods. While the previous periods have projectile point styles that are either regionally circumscribed or have similarities with styles recovered in Northern Mexico. The dominant points of this period, Ensor and Frio, are found throughout much of Texas (Prewitt 1995). This subperiod also sees an increase in upland sites with these point types and unifacial tools considered to be plant processing tools (Marmaduke 1978; Turpin 1990a). This has been interpreted as an increased reliance on the desert staples previously mentioned as the environment became more arid during this period (Turpin 2004). The macrobotanical data from Hinds Cave (Figures 10 and 11) do support an interpretation of increased reliance on sotol during this period (Dering 1979; Sobolik 1991a). However, there is little evidence that the suite of desert resources (lechuguilla, prickly pear, and sotol) was more important to the subsistence economy than it had been during the Middle and Early Archaic (Figures 10 and 11) (Dering 1979; Sobolik 1991a). In many ways, this subperiod is seen as a return to the broad based desert foraging economy of the Middle and Early Archaic with associated increases in mobility and more intensive reliance on different environmental niches for seasonal subsistence requirements (Turpin 2004).

Late Prehistoric Period

Flecha Subperiod (1320 to 450 B.P.). This subperiod, characterized by the introduction of the bow and arrow to the region, is poorly understood due to the lack of well-stratified contexts (Turpin 2004). This is partly due to the frequent disturbance of upper levels of rockshelter deposits by grazing and looting activities. While many of the same staple resources were utilized during this period, there seems to be a shift in the locus of these activities away from rockshelters and to open sites closer to stands of the resources and firewood (Brown 1991). The first examples of both the Red Monochrome and Bold Line Geometrics style occur during this period as well (Boyd 1998; Turpin 1982). Researchers suggest that these styles appear as fully developed art styles, which could be the result of new human populations migrating into the region during this period (Turpin 1982, 1990b; Turpin and Eling 2002). Most of the more common Red Monochrome style pictographs occur in isolated, high overhangs with little cultural debris, avoiding many of the larger rockshelters with large panels of Pecos River style art (Kirkland and Newcomb 1967; Turpin 2004).

Infierno Phase (Estimated 450 to 250 B.P.). This phase is uncommonly encountered in the Lower Pecos, with less than two dozen sites reported (Turpin 2004). These sites are generally located on high points overlooking water sources and are characterized by circles of stones interpreted as tipi rings and a very simple and distinctive toolkit including ceramics (Bement and Turpin 1987; Turpin 2004; Turpin and Robinson 1998). Only one of these sites has been excavated (Turpin and Bement 1989). Artifacts recovered include plainware ceramics but no material suitable for radiocarbon dating (Turpin and Bement 1989).

Historic Period (350 B.P. to Present)

Very little is known archaeologically about the historic period in the Lower Pecos canyonlands. There are a number of rock art sites that incorporate European elements such as horses and crosses (Boyd 1998; Kirkland and Newcomb 1967; Turpin 1982) or have affinities to Plains Indian art styles (Turpin and Bement 1989), but the material record is scarce. Beyond a handful of metal arrowpoints, only one site has been reported to have historical components (Kirkland 1942). This lack of evidence is due partly to the frequent disturbance of the upper levels of rockshelter deposits, but is also due to shifts in mobility patterns both necessitated by the changing social landscape and facilitated by the Colonial era incorporation of horse husbandry in the region (Turpin 2004). Much more is known about this period from the ethnohistoric record of northern Mexico presented in Chapter V.

The cultural chronology presented above provides a brief overview of the changes in material culture observed in the Lower Pecos canyonlands across the Holocene. Despite the stylistic variation in rock art, sandals, projectile points and other manufactured items observed in the archaeological record, the human populations occupying the canyonlands focused on a similar exploitation of xeric plant resources throughout the Archaic (Dering 1979). The relatively stable vegetative community observed in the paleoenvironmental reconstruction suggests that the major staples of lechuguilla, sotol, and prickly pear would always have occurred in abundance. The following chapter describes some ecological characteristics of these major staple resources relevant to their harvest and consumption as a food resource. This is followed by a review of subsistence patterns recorded by early European observers of native cultures in the northern Chihuahuan Desert. Most of this information is from a much broader region than the canyonlands, demonstrating the widespread importance of these staple resources.

CHAPTER V

ECOLOGY AND ETHNOHISTORY OF THE STAPLE PLANT RESOURCES OF THE LOWER PECOS CANYONLANDS

This chapter presents a review of the relevant ecological and ethnohistoric data for the staple plant resources previously identified in the Lower Pecos canyonlands. These versatile plants provided for many of the material needs of human cultures across much of Northern Mexico and the US southwest (Bell and Castetter 1941; Castetter et al. 1938; Colunga Garcia Marin 1996; Gentry 1982; Martinez et al. 1995) and are still important resources today (Mayorga-Hernandez 2004; Mcdaniel 1985; Mclaughlin and Schuck 1991; Nobel 1986; Pando-Moreno 2004, 2008; Quero 1987; Ur et al. 2008; Waleckx et al. 2008). This review focuses solely on the use of these plants as food resources. Prickly pear (*Opuntia* sp.), sotol (*Dasylirion* sp.), and lechuguilla (*Agave lechuguilla*) have been identified as important dietary constituents across the greater Southwest in both the ethnographic (Bean and Saubel 1972; Bell and Castetter 1941; Castetter 1935; Castetter et al. 1938; Felger 1970) and archaeological literature (Danielson and Reinhard 1998; Dering 1999; Fish et al. 1985; Leach and Sobolik 2010; Phippen 1999; Venner 1982). Archaeological research in the Lower Pecos canyonlands has demonstrated that these three plant resources were important food resources for human populations during most of the Holocene (Bousman and Quigg 2006; Bryant 1974b; Sobolik 1991a; Williams-Dean 1978). After an introduction to the ecology and biology of each of these staple resources, this chapter presents an overview of photosynthetic pathways and the role it plays in the differential fractionation of stable carbon isotope values. This demonstrates a potential line of evidence to evaluate the presence of these different plant resources in the diet of the Lower Pecos canyonlands that will be revisited in the results of the current study. This is followed by a brief statement on the types of carbohydrates utilized by these plants for energy storage and the processing costs associated with rendering these resources digestible. Finally, early European explorer and settler accounts of the use of these foodstuffs, including aspects of seasonality and intensity of use, are presented.

Environmental Background

Agave. Agave was a vital resource across much of pre-Columbian Mesoamerica and the northern deserts of modern-day Mexico (Flannery 1986b); (Gentry 1982). This relationship has been described as a symbiosis. Members of this genus were cultivated prehistorically in both the Mesoamerican Highlands and the deserts of the greater Southwest. It is possible that this genus represents the earliest domesticate of the New World (Gentry 1982; Sauer 1965) although lack of differentiation between wild and domesticated specimens hinders proper evaluation. Regardless, this genus was of early importance to human populations occupying this arid landscape during the Holocene (Callen 1965, 1973) and occupies an important role in the cosmology of Mesoamerica, as reflected in several codices (Gonclaves De Lima 1956). This section will review the *Agave* genus generally, with applicable references to the species, *Agave lechuguilla*, common in the Lower Pecos canyonlands.

Agave plants are perennials that require several years to bloom. These plants exhibit a thick, abbreviated shoot or caudex surrounded by a rosette of generally fleshy leaves. This thick stem and associated leaf bases store a great deal of water and nutrients in the fibrous, meristematic tissue. The imbricated spiral nature of the leaf arrangement serves several purposes, among which is the redirection of rain water to the center of the plant, giving the fibrous root structure underneath the caudex access to the often limited and unpredictable precipitation. The rosette growth habit of this genus also serves a defensive function to keep most animals away from the soft and easily palatable florescence and caudex. The leaves themselves are thickened and generally succulent, storing the nutrients used by the plant to grow the inflorescence in specialized spongy parenchymous tissue. Leaf succulence is also a xerophtytic adaptation, losing turgidity and form with severe drought. Most of the species in this genus are monocarpic, flowering only once at the end of their life history. The flowers are synoecious, exhibiting both male and female components within the same flower. The large showy inflorescence can produce both seeds as well as bulbils, a type of vegetative reproduction. Many species in this genus also exhibit vegetative reproduction through rhizomatous suckers extending outward from the base of the caudex (Gentry 1982).

Lechuguilla is a small plant variety of agave, with the largest range of any known species in the genus (Gentry 1982). It is generally considered a type species for the Chihuahuan desert and its distribution is used to mark the boundaries of the desert (Muldavin 2002). This species is widely reproduced by suckering and often occurs in dense patches as a result (Gentry 1982). The rosettes tend to be open, with leaves numbering from twenty to fifty. These leaves, like most agave species, are incredibly long lived, persisting for as many as fifteen years (Gentry 1982). A latitudinal study of this species suggests that the specimens in the south grow larger than their northerly counterparts (Silva-Montellano and Eguiarte 2003).

The inflorescence of this species is a spike-like panicle that grows as much as 20 cm daily. This causes a major shift in the distribution of biomass within the specimen, from 85% in the leaves and 15% as the basal mass to 40% in the inflorescence and 50% in the leaves. This necessitates the depolymerization of complex carbohydrates into smaller, easily transported sugars. Most specimens were observed flowering in May and June, suggesting that human use of this resource would optimally take place in the early Spring before mature individuals develop an inflorescence.

The mature lechuguilla plant dies after flowering, replaced by one of its many clonal pups. Reproduction for this species is predominately through these clonal pups, as seedlings are rarely observed. Lechuguilla exhibits a shallow, fibrous root system that can be rapidly expanded during precipitation abundance. Only 4% of the plant's dry biomass is underground, again highlighting both the plant's preference for shallow soils as well as the importance of the caudex and leaf bases for water and nutrient storage.

This species is well-adapted and partial to limestone soils and tends to be limited to areas with rocky and shallow, well-drained soils on broken and sloped terrain (Gentry 1982). It can also occur as a dominant component of the vegetative community on sediments with abundant caliche deposits, common on mountain slopes and bajadas of the Southwest. Bray (1905) observed the co-dominance of lechuguilla in the Lower

Pecos canyonlands. The densest stands occur on sharply sloping rocky hillsides or near the top of canyon walls, while sotol is the most abundant plant form on the broad divides between canyons (Bray 1905).

This species occurs in great abundance, with dense stands numbering up to 30,000 rosettes per hectare (Martinez 1936). Other studies have shown that lechuguilla has much higher environmental productivity than other plant species in the Chihuahuan desert, measured as biomass accumulation over time, (Nobel 1986). This suggests that lechuguilla use could be intensified without impacting the reproductive population of a local region. This is further corroborated by the use of this plant as a fiber source by over half a million rural workers in Mexico (Pando-Moreno 2004, 2008; Quero 1987). Despite this heavy commercial use, lechuguilla remains the dominant plant across much of the Chihuahuan desert (Gentry 1982). Interestingly, modern studies have demonstrated that the central bud of the lechuguilla can be removed from a specimen without killing the plant. The removal of the folded leaved and upper caudex stimulates clonal growth from rhizomes as well as the redevelopment of the specimen's central bud. Plants treated by this removal exhibited an increase in bio-mass accumulation, with no discernable difference between treated and untreated specimens after six months.

Dasylirion. Sotol (*Dasylirion* sp.) was not nearly as important to pre-Columbian human populations as the genus agave due, in part, to a much more restricted geographic range for this genus (Bogler 1994). Largely confined to the northern Chihuahuan desert, sotol was an important food and fiber resource wherever it occurred in abundance (Bell and Castetter 1941; Leach and Sobolik 2010; Mancilla-Margalli and Lopez 2006; Thoms

2008a). While the use of these species today is generally confined to the production of alcoholic beverages and as cattle fodder, it remains an important wild-harvested resource in the state of Chihuahua (De La Garza et al. 2010; Garza-Toledo et al. 2008; Olhagaray Rivera et al. 2004; Tunnell and Madrid 1988).

The genus *Dasylirion* contains as many as twenty species distributed throughout Northern Mexico and the American Southwest. All of these plants have dense rosettes of fibrous leaves surrounding a bulb-like caudex or crown (Bogler 1994). The root structure of sotol is fibrous and ephemeral, easily broken to dislodge the caudex in harvest (Bogler 1994). Only one species (*Dasylirion simplex*) exhibits the type of rhizomatous vegetative reproduction so common among the agave (Bogler 1994). This particular sotol is quite small in size and very limited in distribution (Bogler 1994). This size of the caudex increases with the age of the plant, sometimes resulting in a woody, arborescent habit (Bogler 1994). While these larger specimens frequently exhibit a corky periderm beneath the rosette of leaves, the younger, more tender parts of the caudex remains edible when cooked properly (Bogler 1994).

Unlike the *Agave* genus, sotol species are polycarpic, flowering multiple times over the life history of an individual plant (Bogler 1994). Flowering among sotol populations is highly variable, and seems to be associated with precipitation patterns, although the exact relationship is not clear (Bogler 1994; Fay 2009; Patrick et al. 2009; Robertson et al. 2009). There may be a six year cyclic pattern to flowering, but this is only speculative (Bogler 1994). Blooming is highly variable, sometimes occurring for nearly every plant in a population and sometimes for a small proportion of the total population (Bogler 1994). The genus is dioecious, suggesting that the entire population should flower in unison to maximize reproductive potential (Bogler 1994). For the species common in the Lower Pecos canyonlands, *Dasylirion texanum* and *Dasylirion wheeleri*, blooming peaks from May to July and continues sporadically until the end of August (Bogler 1994). The peak season for humans to harvest these plants for roasting would be in the Spring, in order to maximize caloric return (Bogler 1994; Dering 1999; Mancilla-Margalli and Lopez 2006).

While the distribution of this plant is generally limited to rocky hillsides and canyon walls, it can occur in immense populations in these areas (Mata-Gonzalez et al. 2002). Much like *Agave lechuguilla*, this plant is a dominant part of the open plant community type known as “izotal”, which is limited to the aforementioned gravelly, well-drained sites (Bogler 1994). The earliest botanical accounts of the sotol country, which includes the Lower Pecos canyonlands, remark on the restriction of the sotol-lechuguilla community to the shallow, rocky soils along the upper canyon walls and uplands, with the finer-grained sediments of the larger floodplains maintaining a grassland community with few, if any, succulent species (Bray 1905, 1906). *Dasylirion* species are extreme xerophytes due, in part, to the ability to store large amounts of nutrients and water in their caudex and leaf bases (Bogler 1994). Other xerophytic features include expendable and easily re-grown roots, fibrous and sclerified leaves, and the development of cuticular wax (Bogler 1994). While there are undoubtedly physiological mechanisms to help conserve water, plants of this genus are C3 plants and do not exhibit CAM photosynthesis (Bogler 1994; Sternberg et al. 1984). The lifespan of *Dasylirion* is not known, but greenhouse cultivation suggests a minimum estimate of 150 years (Bogler 1994).

The rich package of nutrients and water contained in the caudex has been a source of food for animals other than humans (Bogler 1994). There are reports of bears tearing apart sotol plants to eat the sweet caudex, particularly before the development of the inflorescence. Horses will willingly eat the leaves of sotol, and goat and cattle will also graze the mature plants, if not as willingly. However, juvenile plants are much more palatable and are frequently pulled up and eaten by deer as well as cattle and goats. In addition to the use of sotol as forage, it has frequently been chopped up and used as fodder for domesticated animals (Mondragon-Jacobo and Perez-Gonzalez 2002). Early reports suggest that intensive grazing (or harvesting by humans) of sotol could cause a significant decline in the local populations of sotol (Bell and Castetter 1941; Bray 1905).

Opuntia. While prickly pear (*Opuntia* sp.) is a part of plant communities across most of the contiguous United States, the greatest diversity and density of these cacti is in the Chihuahuan Desert Region (Powell and Weedin 2004). The genus *Opuntia* is generally considered as one of the more primitive forms of cactus and is the most widespread, growing across almost the whole contiguous United States (Weniger 1984). Within this genus are two major subgenus designations, the cholla (Cylindropuntia) and the prickly pear (Platyopuntia). This paper considers only the role of the prickly pear types as a food resource, as the ethnohistoric (Krieger 2002; Thoms 2008b), ethnographic (Castetter 1935) and archaeological (Dering 1979, 1999; Williams-Dean 1978) literature indicate it was a major food resource across much of the Chihuahuan

Desert and surrounding regions. There are at least 52 species or distinguishable varieties of prickly pear found across Texas (Weniger 1984). Due to the difficulty of identification beyond the subgenus level in both the archaeological and ethnohistoric record, no attempt was made to distinguish among prickly pear species or varieties.

Experimental evidence has confirmed that almost 98% of cactus utilize CAM photosynthesis (Nobel 1988; Powell and Weedin 2004). This, along with the shallow root system, thick stems of water storing parenchyma, and thick cuticular lining exhibited by most cactus, indicates an adaptation to arid environments with poor or shallow soils (Nobel 1988; Powell and Weedin 2004; Weniger 1984). All of these characteristics suggest that prickly pear should be a major part of any vegetative community with shallow soils, limited precipitation, high annual temperatures and limited grass cover (Bowers 2005; Cui 1994; Mata-Gonzalez et al. 2002; Nobel 2002). This is clearly indicated in the relationship between grass density, grazing, and cactus density observed in both the Trans-Pecos region of the Chihuahuan Desert and the Tamulipan Biotic Province of South Texas (Lundgren et al. 1981; Powell and Weedin 2004).

Prickly pear cactus reproduce both sexually and vegetatively (Nobel 1988; Powell and Weedin 2004). Most species produce large, showy flowers that attract a great number of pollinators on an annual basis (Powell and Weedin 2004). Each individual plant produces many hundreds of seeds every year (Powell and Weedin 2004). Vegetative propagation requires nothing more than part of a pad with a meristem to be removed and dropped to the ground (Powell and Weedin 2004). Prickly pear cactus is considered a major problem for the range livestock industry in Texas (Lundgren et al. 1981). Over 25.5 million acres of rangeland in Texas was considered “infested” with prickly pear in 1980. This accounts for over a quarter of all rangeland in the state. Over 40% of this “infested” acreage occurs in the Edwards Plateau (10.2 million acres), while 17% occurs in the Tamulipan Plains (4.35 million acres) (Figure 3). This data suggests that prickly pear would have been an easily accessible and readily renewable food resource for human populations. The short reproductive cycle of a prickly pear individual, combined with vegetative reproduction, would make this plant an ideal resource to utilize under conditions of environmental or demographic stress since any established community would be virtually impossible to overharvest.

Photosynthesis and Stable Isotopes

Stable carbon isotopes studies of animal tissue have been shown to successfully reflect the isotopic composition of diet (Deniro and Epstein 1978; Schwartz and Schoeninger 1991; Smith et al. 2002; Sponheimer et al. 2003b). Underlying this dietary application of stable carbon isotopes are the differences in the fractionation of atmospheric CO_2 by plants utilizing different photosynthetic pathways (Van Der Merwe 1982). Atmospheric carbon dioxide contains approximately 1.1% of the heavier isotope ^{13}C (O'leary 1988). This carbon isotope is discriminated against during photosynthesis due to the small differences in mass between this heavier isotope and the dominant (98.9%) form of carbon, ^{12}C (Van Der Merwe 1982). These differences in mass cause ^{13}C to form stronger chemical bonds and diffuse at a slower rate (O'leary 1988). The amount of discrimination against ^{13}C in plants is influenced by a number of factors, but is principally controlled by the photosynthetic pathway utilized by a plant.

This requires a brief review of the three major types of photosynthesis, and the underlying diffusional and chemical processes that result in differential fractionation between the pathways. The evolutionary importance of these pathways (decreasing evapotranspiration, influence on CO_2 utilization) will not be discussed in detail. Prior to industrial human activity , the $\delta^{13}C$ value of atmospheric CO_2 was –8‰ (O'leary 1988). Early studies of plant $\delta^{13}C$ values found that most plants fell between –25‰ and –35‰ (O'leary 1988). This value did not show any species or environmental relationships. These early studies occurred before the discovery of the C4 photosynthetic pathway in the 1960s and therefore did not take this into account. Later studies showed that C3 plants had an average $\delta^{13}C$ of –28‰ and that C4 plants had an average $\delta^{13}C$ of –14‰ (O'leary 1988). The $\delta^{13}C$ values of these two pathways have little overlap.

C3 (Calvin Cycle) photosynthesis fixes CO_2 through the action of the enzyme ribulose biphosphate carboxylase (RuBisCo) (O'leary 1988). Atmospheric CO_2 is transported through the stomata into an internal gas space. The CO_2 in this gas space dissolves into cell sap and diffuses to the chloroplast. The RuBisCo controlled carboxylation of ribulose biphosphate occurs in the chloroplast. This step, unlike the previous diffusionary processes, is irreversible, and is the major determinant in fractionation of ^{13}C (O'leary 1988). O'Leary (1988) presents a table of the $\Delta\delta^{13}C$ effect of each step in both C3 and C4 photosynthetic pathways. These data are used to infer the principle limiting step in both pathways. For plants utilizing C3 photosynthesis, diffusion ($\Delta\delta^{13}C$ 4.4 ‰) seems to play a minor role in fractionation, while the RuBisCo catalyzed reaction ($\Delta\delta^{13}C$ 29.0 ‰) is the principle process responsible for the large fractionation of atmospheric CO_2 observed in C3 photosynthesis (Griffiths 1992; O'leary 1988).

The C4 (Hatch-Slack) photosynthetic pathway involves the sequential operation of two carboxylase reactions. Initially, CO_2 is fixed through the carboxylation of phosphoenolpyruvate (PEP) in the mesophyll (O'leary 1988). This product is then converted to malate or aspartate, transported to the bundle sheath cells (Krantz anatomy -a feature found only in C4 plants) and cleaved to yield CO_2 (Van Der Merwe 1982). The resultant CO_2 molecules are taken up by RuBisCo in a manner similar to C3 plants. Although the RuBisCo chemical process does occur in C4 photosynthesis, it does not influence the fractionation of the overall pathway because it is preceded by a prior irreversible step (O'leary 1988).

O'Leary (1988) suggests that the two potential limiting processes for fractionation are stomatal diffusion and the carboxylation of PEP. However, the average observed values for most C4 plants (~14‰) are more negative than the range of values predicted by the model (O'leary 1988). There is some indication that this difference is due to the loss of CO_2 from the bundle sheath cells during uptake by RuBisCo. This is supported by evidence that $\delta^{13}C$ values of C4 plants vary with bundle sheath permeability, with more negative values observed for plants with greater permeability (O'leary 1988).

Many xeric adapted plants absorb CO_2 with a third type of photosynthesis known as Crassulacean acid metabolism (CAM) (Osmond et al. 1973). This photosynthetic method is actually a temporal coupling of the processes observed in the two major photosynthetic pathways (Griffiths 1992). CAM is a unique ecological adaptation that probably evolved as a survival mechanism in extreme habitats (Griffiths 1992). During the night, CAM plants open their stomates and produce high levels of malic acid through the carboxylation of PEP, followed by a process involving malate dehydrogenase (Phase I) (Griffiths 1992). This step is very similar to the initial carboxylation process seen in C4 plants. This malic acid is stored overnight until the stomates close the next morning. At that point, the malic acid is decarboxylated (Phase II) and the resultant CO_2 is taken up by RuBisCo in a process similar to that of the bundle sheath cells in C4 (Phase III) (Griffiths 1992). Many CAM plants also engage directly in C3 photosynthesis using RuBisCo during the late afternoon, when water loss from open stomates is lower (Phase IV) (Griffiths 1992).

Most CAM plants yield a $\delta^{13}C$ value similar to C4 plants (as low as -11‰ when CO_2 is only absorbed at night) (Griffiths 1992). This is due to the dominance of nighttime carboxylation most CAM plants exhibit under their natural environmental conditions. CAM plants can be experimentally manipulated to engage primarily in daytime (C3) photosynthesis which is reflected in their $\delta^{13}C$ value (-26‰) (Griffiths 1992). However, the majority of biomass derived from constitutive CAM plants will have a similar isotopic signature to C4 plants (Griffiths 1992).

Any dietary reconstruction based on stable carbon isotope values of animal tissue must account not only for the proportions of plant foods utilizing C3, CAM, and C4 photosynthetic pathways, but also the fractionation factor between the diet and the resultant tissue (Deniro and Epstein 1978; Hwang et al. 2007; Smith et al. 2002; Sponheimer et al. 2003b). This tissue fractionation was discussed in greater detail in the Chapter III. As noted above, both lechuguilla and prickly pear utilize CAM photosynthesis, while sotol is characterized as a C3 plant (Sternberg et al. 1984). Sternberg et al. (1984) present staple carbon isotope values for samples of all three plant resources. These samples were collected in the Lower Pecos canyonlands, near the mouth of the Pecos River. The lechuguilla sample exhibits a δ^{13}C value of -11.0 ‰, while the four specimens of prickly pear range have δ^{13}C values that range from -11.5‰ to -13.8‰. This is consistent with the expected values for a plant resource utilizing either CAM or C-4 photosynthesis. The sotol sample collected for the study had a δ^{13}C value of -22.2‰ (Sternberg et al. 1984). This provides another congruent line of evidence to evaluate the relative importance of these three staple resources in the Hinds Cave coprolite collection, as well as the skeletal remains from the Lower Pecos canyonlands.

Carbohydrate Storage and Food Value

All three of these plant resources (lechuguilla, sotol, and prickly pear) store the majority of their caloric content as carbohydrates (Lopez and Urias-Silvas 2007b; Mancilla-Margalli and Lopez 2006). Plants sequester energy in one of three primary reserve carbohydrates: starch, sucrose and fructans. While earlier studies assumed that starch was the main storage polysaccharide in these resources (Gentry 1982), more recent work has demonstrated that all of these species use fructans as their primary reserve carbohydrate (Lopez and Urias-Silvas 2007b). In addition, another resource commonly consumed in the Lower Pecos, *Allium* sp. also stores most of its energy as fructans (Darbyshire and Henry 1981). Fructans, which occur in approximately 15% of vascular plant species, are water soluble fructose polymers with a single glucose moiety. Fructans can be linear or branched (Wang et al., 1999). Vijn and Smeekens (1999) classified fructans in five major groups based on degree of polymerization (DP) and branching patterns: (i) linear inulin, reported in some Asteraceae, (ii) levan, which is found in some grasses, (iii) graminans, mixed fructans containing type i and ii linkages, also found in some grasses, (iv) inulin neoserie, characterized in onion and asparagus, and (v) levan neoserie, which has been reported in oat.

Fructans are usually present in plants as a heterogeneous mixture with different DP and branched structure. The type of fructans found in plants are species specific and highly influenced by the environmental conditions and developmental stage of the plant (Sims 2003; Sims et al. 2001). There is some evidence to suggest that fructans provide an added benefit of drought tolerance to plant species, but this remains poorly understood despite empirical observation. The fructans in agave and sotol have been classed as branched neo-fructans termed agavins (class iv) and gramanins (class iii) based on the degree of polymerization and linkage-type abundance. These fructans are synthesized and stored in the caudex or stem of these plants, whose primary function is nutrient storage. The fructan structure in opuntia has not been classified to date, but it has been suggested to contain neo-type fructans (class iv and v) similar to agave and sotol. The only direct study of the carbohydrate content of sotol indicates that this species has much higher concentrations of mono- and di- saccharides such as glucose (27%) and fructose (38%) than fructans. The low level of fructans in *Dasylirion* is most likely due to the presence of the floral organ on the specimen examined, as the energy stored in the fructans was depolymerized to meet the high energy demand of this developmental process. Thus, depolymerization and mobilization of fructans have been observed to cover energy-demanding activities such as regrowth (Amiard et al. 2003), sprouting (Machado De Carvalho and Dietrich 1993), and inflorescence development (Bieleski 1993). The inflorescence emergence in *Dasylirion* plants might have caused a drop in the fructan content and associated increase in sugars to supply the energy required for this event (Mancilla-Margalli and Lopez 2006). This has implications for the harvesting strategies of hunter-gatherers dependent on sotol and lechuguilla (Dering 1999). Harvesting an individual at the onset of this ontogenetic event would result in a food resource with higher levels of readily digestible sugars and less need for the hydrolysis processing described below. Ethnohistoric and ethnographic literature corroborate the preference native groups displayed for harvesting sotol and agave resources at this time in their life history (Castetter et al. 1938; De Leon 1971).

The human digestive system does not contain the enzymes necessary to degrade fructans (Vijn and Smeekens, 1999). In the large intestine , these undigestable carbohydrates serve as a substrate for colonic bacteria and are for this reason considered as prebiotics (Gibson et al., 1995; Wang and Gibson, 1993). A prebiotic is a nondigestible food ingredient that positively affects the host by selectively stimulating the growth, and/or the activity of one or a limited number of bacteria types in the colon (Gibson and Roberfroid, 1995). The fructan component of agave and sotol have higher prebiotic activity than commercially available sources of inulin, while the fructans from opuntia was similar to commercial inulin. This suggests that diets high in these plant resources would result in very healthy and robust populations of colonic bacteria.

The fermentation of fructans in the colon generates short chain fatty acids (SCFAs) such as lactic acid, and gases including H_2, CO_2 and CH_4 as a product of an anaerobic metabolism (Roberfroid, 1993). Their fermentation is an important process, since it favors the maintenance and development of the bacterial flora as well as colonic epithelial cells (García Peris et al., 2002). This contributes greatly to fecal mass, as the healthy bacterial population deposits cellular components to the fecal material through population turnover. The SCFAs produced by this fermentation are absorbed by intestinal cells to produce energy, allowing humans to receive some caloric benefit from these prebiotic dietary fibers. This has been calculated as a return of 1.5 Kcal/g of ingested material (Leach 2009). While this is significantly lower than the return rate for fully digestible carbohydrates, the return nonetheless provides an additional source of energy.

Nonetheless, most traditional preparations of these resources expose the material to long periods of hydrolysis (Wandsnider 1997). This processing step breaks the indigestible fructans into smaller carbohydrate fractions, especially sugars, that can be digested by the human gastrointestinal tract. While Leach (2009) makes the point that it is unclear how much of the fructan fraction gets reduced, it is clear from both historical accounts remarking on the sweetness of agave and sotol as well as the use of these resources as the sugar source in alchohol production that a sizeable amount of the fructan is converted into digestible carbohydrates using traditional earth ovens (Dering 1999). This is corroborated in a study evaluating the hydrolysis of fructans in *Agave tequilana* using traditional tequila production processes (Waleckx et al. 2008). Samples from the process indicate that 98% of the fructans were converted into simple sugars, dominantly fructose, after 25.5 hours of cooking in the traditional wood-fired brick oven (Waleckx et al. 2008).

Seasonality of Resource Use and Ethnohistoric Accounts

This section is a gathering of ethnohistorical source material documenting the use of lechuguilla, prickly pear and sotol as foods in Texas and the surrounding region. Other relevant wild plant resources mentioned in the sources are also included. In order to save time and space, the researcher has summarized much of the seasonality data in Table 5 The taxa presented are based on those recovered in three previous coprolite studies from Hinds Cave (Edwards 1990; Stock 1983; Williams-Dean 1978) and the seasonality data is derived from a variety of ethnohistorical and ethnographic sources (Bean and Saubel 1972; Bell and Castetter 1941; Castetter 1935; Castetter et al. 1938; De Leon 1971; Griffen 1969; Krieger 2002; Taylor 1972; Thoms 2008b). This is followed by a brief recount of the seasonal subsistence patterns noted in the earliest reports of native lifeways in the general region. Most of the available literature is based on early Spanish reports of the nomadic hunter-gatherers of the modern states of Nuevo

Leon and Coahuila, Mexico as well as south Texas. Although a number of secondary sources were consulted (Beals 1973; Campbell 1979, 1983; Griffen 1969; Hester 1989; Kenmotsu and Wade 2002; Maslowski 1978; Newcomb 1961; and Taylor 1972), most of the data about the region presented in these sources is based upon Don Alonso de Leon's First Discourse (De Leon 1971) or the account of Cabeza de Vaca (Krieger 2002).

This review of ethnohistoric accounts from the region follows a broadly chronological approach, presenting details about seasonality and intensity of use for each resource. This review will be followed by a brief overview of the more recent ethnographic literature on the use of each of the three previously identified staples across the Greater Southwest. Finally, the Lipan Apache, geographic Coahuiltecans, and the Jumano will be used as case studies of the subsistence strategies of a major ethnic grouping from each of the three biotic provinces bordering the Lower Pecos canyonlands (Foster 2008b; La Vere 2004).

Table 5. Seasonality of Plant Use based on Ethnographic Sources

Plant	**Plant Part**	**Winter**	**Spring**	**Summer**	**Fall**
Agave lechuguilla	**Caudex**	Heavy Use	Heavy Use	Available	Available
Dasylirion sp.	**Caudex**	Heavy Use	Heavy Use	Available	Available
Opuntia sp.	**Cladode**	Available	Heavy Use	Heavy Use	Available
Allium sp.	**Bulb**	Available	Heavy Use	Available	Available
Prosopis sp.	**Legume Pod**			Heavy Use	Heavy Use
Juglans	**Nut**				Heavy Use
Opuntia sp.	**Fruit**		Heavy Use	Heavy Use	Available
Opuntia leptocauli	**Fruit**		Available	Available	Available
Echinocerus sp.	**Fruit**			Available	
Celtis sp.	**Fruit**			Available	Available
Dasylirion sp.	**Fruit**			Available	
Diospyros texana	**Fruit**	Available			Available
SOLANACEAE	**Fruit**			Available	
Vitis sp.	**Fruit**			Available	
Yucca sp.	**Fruit**		Available	Available	
Coryphantha sp.	**Fruit**			Available	
FABACEAE	**Legume**			Available	
Chamaecrista sp.	**Fruit**			Available	Available
***Helianthus* sp.**	**Achene**			Available	Available
Chenopodium sp.	**Small Fruit**		Available	Available	Heavy Use
Amaranthus sp.	**Small Fruit**		Available	Available	Heavy Use
POACEAE	**Caryopsis**			Available	Available
Sporobolus sp.	**Caryopsis**			Available	Available
Panicum sp.	**Caryopsis**			Available	Available
Cenchrus sp.	**Caryopsis**			Available	Available
CYPERACEAE	**Seed**			Available	
Carex sp.	**Seed**			Available	
Polygonum sp.	**Seed**			Available	Available

Cabeza de Vaca. The account of Cabeza de Vaca provides the earliest record of Native lifeways across parts of South Texas (Krieger 2002; Thoms 2008b). For the sake of brevity, the reports of coastal lifeways near Galveston Bay will be ignored, as the environment there is very different from the Lower Pecos canyonlands. Upon moving to stay with bands in the area surrounding the lower reaches of the modern-day San Antonio and Guadalupe Rivers, Cabeza de Vaca provides an account of pecans as an important fall staple (Krieger 2002; Thoms 2008b). Along with an unidentified "little grain", these nuts formed the majority of the diet for several months during years of good yield. Preperations methods are not recorded. During the winter, these inland groups, including the Mariames and Yguazes, subsisted almost entirely on geophytes from several unidentified species (Krieger 2002). This is the earliest European account of earth oven cookery in North America (Thoms 2008b). From the description of the several day cooking necessary to render them edible, it is clear that it must be a fructan-based storage organ. However, there is no mention of rock elements in the construction of these ovens.

The use of the prickly pear nopales and green tunas as a food is mentioned by Cabeza de Vaca in the year following his trek across the Tamulipan plain and the winter spent with the Avavares (Krieger 2002). Cabeza de Vaca references the cooking of green fruit and pads in earth-ovens, recording that the pads are left to steam overnight in the earth oven. Again, there is no mention of a rock heating element, which may change the energetic costs of building such an oven. It is made clear in the account that this is not a highly desirable resource. Nopales were a marginal food resource designed to satiate until the tunas were ripe. This corresponds with the low caloric return rate of this resource. However, for the Avavares, a group who lived entirely in the Tamulipan plains province, nopales and green tunas were the major staple recorded by Cabeza de Vaca (Krieger 2002). The account stresses that these people, and other groups in South Texas were highly dependent on the pads of prickly pear for sustenance during much of the year.

The late summer and fall was a time of abundance, with ripe prickly pear tunas serving as a major staple (Krieger 2002; Thoms 2008b). This seasonal abundance of tunas provided a caloric surplus that encouraged bands to congregate at large tuna grounds in the Tamulipan Plains province. Prickly pear fruits or tunas were a productive resource across the plains province and were the focal point of the largest inter-ethnic gatherings observed by de Vaca in Texas (Krieger 2002). Large thickets of prickly pear drew native groups from the Coastal Prairie onto the South Texas Plains for a period of abundant food, celebration, and trade. According to Cabeza de Vaca, this resource was the major dietary staple of these groups for three months in late summer/early fall (Krieger 2002; Thoms 2008b). While staying with the Mariames and Yguases, Cabeza de Vaca and his companions planned to use the upcoming tuna season as an opportunity to move on with other Native groups in an attempt to reach the Spanish-occupied areas of central Mexico. It appears that tunas were an important seasonal resource for all of the Native groups that occupied the Tamulipan Plains province, as Cabeza de Vaca mentions them as the major food resource among the Native groups (Avavares, Cutalches [Cutalchiches], Malicones, Coayos, Susolas, Arbadaos) encountered from the time of their fleeing from the Mariames and Yguases in September until reaching groups near the Rio Grande that consumed mesquite (*Prosopis sp.*) flour (Krieger 2002). The tuna continued to be noted as an important dietary constituent among these groups near the river, as well as other groups further west that had access to maize (Krieger 2002). This indicates that tunas were a seasonally important resource in the basin and range province along the southwestern margin of the Tamulipan plain, and was probably an important resource wherever it occurred in abundance.

The ripe tuna was important both as a fresh and dried fruit, as well as a source of water in the dry interior of the Tamulipan Plains (Krieger 2002). Cabeza de Vaca recounts that many of the groups mentioned above were sharing dried or ground tunas with them after the season of tuna availability (Krieger 2002). This practice suggests that many Native groups engaged in at least short-term storage of a seasonally available resource.

While this very brief review does not account for the marked environmental variation of the Tamulipan Plains Biotic Province, it is clear that groups living around the margins of this area (which includes the Lower Pecos canyonlands) were highly mobile and willing to move great distances for a productive and dense resource stand such as prickly pear tunas. Cabeza de Vaca and his companions clearly travelled through parts of the northern Chihuahuan desert, but there is no mention of any resources resembling agave or sotol in the account.

De Leon the Elder. De Leon, the elder, also provided an early account of native lifeways based on decades of observation. An early settler of the modern-day state of

Nuevo Leon, Alonso de Leon recounted many ethnographic details of native populations living near the western margin of the Tamulipan Plains Biotic province from 1580 to 1649 (De Leon 1971). The Native groups of Nuevo Leon and Tamaulipas living near the early Spanish settlements in the interior mountain ranges depended primarily on gathered plant resources for the majority of their diet, particularly in times of seasonal stress (Taylor 1972). De Leon claimed that the natives subsisted on three major staples throughout the year (De Leon 1971). In the winter, the major food utilized was the caudex and basal leaves of lechuguilla. During the spring and much of the summer, prickly pear was the foundation of the diet, both as green and ripe tunas. Mesquite beans were an important staple during the late summer and fall, first as an edible raw "green bean" and then as a source of ground meal and dry bean once the pods dry. These Native populations also ate unnamed seasonally available fruit and geophyte food resources.

De Leon briefly recounted the cooking or "barbequing" of lechuguilla hearts over the course of two days and three nights. While there is no explicit mention of an earth oven, the length of time mentioned in the account suggests that the native groups described were using rocks as heating elements. Regardless of cooking method, the account clearly indicated that barbequed lechuguilla is the bulk of the diet across most of the cold season (De Leon 1971).

As the prickly-pear blossoms in the spring, first the flowers (buds?) and then the young tunas (fruit) were gathered and pit roasted (barbequed) (De Leon 1971). De Leon claimed that there are great quantities of prickly pears in the region, allowing the natives to utilize the barbecued young tunas as the primary food supply without impacting the later tuna harvest (De Leon 1971). When the tunas ripened, the local populations subsisted almost entirely on these fruits (both fresh and dried) (De Leon 1971). There is no indication in this account of the use of the pads as a food resource. It is possible that de Leon did not distinguish green buds from the succulent young pads of the many prickly pear species.

Later Spanish and French Accounts. While no other sources provide the level of detail presented in the two previous accounts, there are some passing mentions of prickly pear, sotol and lechuguilla in later accounts that suggest they continued to be important dietary resources for Native populations in South Texas and neighboring regions (Foster 1998; Wade 2003). In January of 1674, Friar Larrios reported the staples of the native groups meeting with him at Mission San Ildefonso in Modern-day Coahuilla as subsisting on mescal, prickly pear tunas, acorns, small nuts, fish, deer, and buffalo (Wade 2003). Mescal may reference any agave species whose caudex was roasted for food (Castetter et al. 1938; Gentry 1982). Another account of this same expedition in 1674 mentions mescal as the staple food at the establishment of the Mission Santa Rosa de Santa Maria along the Rio Sabinas (Wade 2003). During the ceremony establishing the mission, Captain Elizondo asked the natives to share food with the friars, who were subsisting solely on mescal (Wade 2003).

Reports from later in the spring of 1674 referenced mescal as the primary food resource. Friars at these two mission sites reported that they and the congregated natives had only mescal and unidentified geophytes for food (Wade 2003). The location of this site about 50 miles south and west of modern-day Eagle Pass, TX suggests that it was probably lechuguilla. This is corroborated by reports from the military commander, Captain Barbarigo. In his report from that same spring, Captain Barbarigo recorded that the friars subsisted on the roots of lechuguilla, "tule", and sotol once the stored maize and other resources had been exhausted (Wade 2003). "Tule" may refer to a species in the bulrush genus *Scirpus* or another such aquatic resource such as cattails (*Typha* sp.). There is no mention of the method of preparation of these resources. The small nut in the accounts may be little walnut (*Juglans microcarpa*), which is common in the archaeological record of the Lower Pecos canyonlands, but this is purely speculative. The gathered natives at this mission establishment numbered upward of 600 individuals from at least nine separately identified bands (Wade 2003). The account also mentions that many other people affiliated with these bands were engaged in logistic forays for bison and other resources (Wade 2003). These statements hint at a very flexible social organization characterized by dispersal and congregation around seasonal resources.

Wade (2003) mentions the importance of prickly pear tunas in the dispersal of Native groups from the mission Santa Rosa during the harvest season, which began in June in this region. The friars had congregated over three thousand natives at the mission, who were subsisting on the large tuna grounds that abounded in the immediate vicinity of the mission (Wade 2003). The friars realized that the native populations would have to disperse once the tuna supply was exhausted and were desperate for supplies to keep the congregation together at the mission (Wade 2003). This account extends the recorded seasonal use of tunas as a staple to the western margins of the Tamulipan plains.

Friar Larrios also presents an interesting account of band mobility during this period. The friar suggests that native bands had to move on an approximate bi-weekly schedule, as the large numbers of individuals in each band would quickly strip the available foodstuffs from the immediate vicinity of the band's homebase (Wade 2003). Wade (2003) suggests that the external pressures of the encomienda system as well as inter-ethnic conflict may have forced human populations in the region to consolidate into larger ethnic entities for defense. There is also evidence that many of these groups defended specific territory, including the harvesting of resources (Wade 2003).

Griffen (1969) presents an overview of native lifeways recorded in Early Spanish accounts from the Bolsón de Mapimí of Central Northern Mexico. This closed drainage system is located to the west and south of the Lower Pecos canyonlands, in the modern-states of Chihuahua, Coahuila, Durango, and Zacatecas. The majority of these accounts are from the Parras and La Laguna districts, which were bettered watered and became the center of Spanish colonial life in the region (Griffen 1969). The Spanish accounts from the late 16th and 17th centuries record a number of wild plant resources utilized as staple foods. For most of the groups in the region, mescal, tunas and mesquite were recorded as the major wild plant resources (Griffen 1969).

There are several reports of other terms for agave, including maguey and noas, as well as specific mention of lechuguilla use by natives in the area of modern-day Parras, Coahuila (Griffen 1969). The term "maguey" today references any of the large, thick leaved *Agave* species (Gonclaves De Lima 1956; Parsons and Darling 2000; Parsons and Parsons 1990). However, the use of the term on the Spanish colonial records suggest that it is generally used as sub-grouping of mescal (Griffen 1969). Noas is another type of mescal, that is less fibrous than those species classed as maguey (Griffen 1969). Nopales are mentioned as a food resource for two groups in the region as well. At least two different aquatic resources were used by native groups in the region, "espadaña" (probably *Typha* sp.) and "tule", described in more detail below. Flour made from the roots of these resources, as well as mesquite, tunas, and mescal were all used to make solid loaves. Griffen (1969) also reports bread made from a small seed he tentatively identifies as *Phalaris canariensi*s, which grows in such abundance that it resembles a wheat field. The accounts also indicate that native groups made wine out of the staples of mescal, tunas and mesquite (Griffen 1969). The above accounts are centered on the relatively well-watered La Laguna district and may not be reflective of the region as a whole. Accounts recorded as early as 1598 characterize the diet of groups located in regions with minimal water as composed wholly of lechuguilla, mesquite, maguey, and tunas (Griffen 1969). This is re-emphasized in later accounts as well, indicating that some groups were entirely dependent on lechuguilla and wild maguey for the bulk of the caloric needs (Griffen 1969).

Foster (1998) includes a report from Henri Joutel of the LaSalle expedition indicating the difficulty an inexperienced Frenchman had in utilizing the nutritious but well protected tuna of the prickly pear (Joutel 1714). Unaware of the many small glochids located on the skin of the tuna, one of the soldiers ate enough unskinned tunas to close his trachea through inflammatory response (Foster 1998). While this account is not very informative in terms of native use, it does indicate a continued use of this resource in the 17th century.

There are two references to the Lipan Apaches incorporating prickly pear into their seasonal round. In 1761, the Lipan captain El Cabezón requested a military escort from Presidio de las Amarillas on the San Saba River during the prickly pear season (Wade 2003). In the following year, the captain of the Presidio agreed to establish a mission for another Lipan captain, El Turnio. El Turnio made it clear that his group would abandon the mission during the prickly pear season (Wade 2003). The accounts of this mission from 1762 suggest that groups of Lipanes interrupted bison hunting to participate in the tuna harvest. Reports from the friars at the mission indicate that much of the mission population left in June to hunt bison, in August to gather tunas, and again in the fall to hunt bison again (Wade 2003). These two accounts recorded during the founding of the San Saba mission in 1756 (Wade 2003), along with the group name "Come Nopales", which is Spanish for the "nopale eaters", suggest that the prickly pear was an important seasonal resource for the Lipan Apache. The name "Come Nopales" suggests that the use of the pads as food was also encountered in the region, since only the pads of the prickly pear are referred to as nopales (Powell and Weedin 2004). This account has a dual importance in the current study. First, it indicates that the pattern of prickly pear dependence described for the Tamulipan plains by earlier accounts may also be an important component of the subsistence strategy of Native groups in the Edwards Plateau. Second, it suggests that the productivity of this resource was great enough that displaced groups migrating from areas with a low density of this prickly pear, such as the Southern High Plains, would adopt this subsistence strategy in areas with a sufficient density of prickly pear. It appears that the drier areas of the Edwards Plateau have a high enough resource density to facilitate this shift to a seasonal dependence on prickly pear tunas by the Lipan and other Apache bands.

Ethnographic Data from the Greater Southwest

Agave sp. Agaves are widely used as a food resource by native groups across the majority of arid North America (Basehart 1974; Beals 1973; Bean and Saubel 1972; Castetter et al. 1938; Gentry 1982; Parsons and Darling 2000; Parsons and Parsons 1990). Despite this, there are no modern ethnographic records of agave being used as a food resource. Castetter and Bell (1938) make the assertion that Lipan Apaches utilized lechuguilla as a food resource, but it is unclear whether this is based on ethnographic or archaeological data. While still important across much of Northern Mexico as fiber for the ixtle cottage industry, a regionally important source of coarse fibers for brushes and other material items (Mayorga-Hernandez 2004; Pando-Moreno 2004, 2008; Quero 1987), the use of lechuguilla for food seems to have disappeared or been greatly reduced before the advent of detailed ethnobotanical studies in the Southwest.

Agave species are one of the most common wild plant foods in the literature, with Castetter and Bell reporting the utilization of this resource for at least ten tribes, including agriculturalists, in the Greater Southwest (Castetter 1935; Castetter et al. 1938) and Beals reporting at least twenty native groups from central Mexico north into modern-day Colorado (Beals 1973). This resource was once of such importance that it was a major trade item between the Apache and the Hopi and other agricultural groups (Castetter 1935). Castetter and Bell (1938) present data from observations of several different native groups which give a good deal of data on the seasonality, harvest selection, and processing of agave. Preferred harvest occurred in the late spring and early summer, as individual plants were beginning to send up an inflorescence (Castetter et al. 1938). This is particularly true for accounts of native groups that have been re-settled and no longer depend on wild harvesting for most of their subsistence (Castetter et al. 1938). These accounts indicate that native harvesters preferred to harvest plants with a budding inflorescence, even going so far as to assign gender and taste differences among the plants based on this trait (Castetter et al. 1938). All of these accounts indicate that the agave caudex and inflorescence were roasted in earth ovens with rock heating elements (Castetter et al. 1938). Some of the accounts describe the cut leaves were also being cooked and eaten, although this seems unlikely for the small leaved *Agave lechuguilla* species (Castetter et al. 1938). The size of these ovens ranged up to 12 feet in diameter and 4 feet deep, and contained an abundance of large flat rocks (Castetter et al. 1938). The caudex is cooked with these heated rocks for 1-2 days in a sealed environment. Once the caudices are sufficiently roasted to be rendered both palatable and digestible, they are either eaten immediately or pounded into pulp and dried for future storage (Castetter et al. 1938). Mid-19th century Anglo-American accounts cited by Castetter and Bell (1938) indicate that this resource was the major staple of many bands, including Apache and Southern Comanche, across most of the cold season and occasionally as a year round staple (Castetter et al. 1938). Ethnographic summaries for the Mescalero suggest that agave was such a prized food because it is available in great quantity and does not exhibit seasonal variation in availability (Basehart 1974). While spring harvest was considered ideal and fall harvest a close second, mescal could be gathered at anytime of the year if other food resources were not available (Basehart 1974).

These accounts all indicate the significant role of agave as a source of carbohydrates across much of the Southwest. Native groups would make logistical forays to regions with dense agave growth in order to harvest this resource for both feasting and storage (Castetter 1935). This gives credence to the idea that this resource could be harvested with greater efficiency with an economy of scale. This has not been considered in the development of the diet-breadth models presented in Chapter II. While Castetter and Bell (1938) acknowledge agave as a major staple, they caution that reports of it may be exaggerated due to the high visibility of both the foodstuffs as well as the earth oven processing method. They include a list of other resources that may have been as important, such as mesquite pods, sotol caudex, pinyon nuts, and tunas (Castetter et al. 1938). This view is not supported by either the archaeological (Dering 1979, 1999; Evans 1992; Fish et al. 1985; Leach and Sobolik 2010; Minnis 1976; Phippen 1999; Thoms 2008a) or ethnohistoric (De Leon 1971; Griffen 1969; Taylor 1972; Wade 2003) evidence, which both confirm that agave resources were the major dietary staple across the Northern Chihuahuan Desert.

Sotol. While sotol is poorly represented in the early Spanish accounts of Northern Mexico, the ethnographic literature stresses a much greater dependence on the caudex of these plant species, especially among native hunter-gatherer groups located on the periphery of the Chihuahuan desert (Basehart 1974; Bell and Castetter 1941; Castetter 1935; Dennis 1977). Much like agave, sotol had a preferred harvest season during the spring, but was harvested year round if necessary (Basehart 1974; Bell and Castetter 1941). This was particularly true during periods of severe drought. Basehart (1974) considers these desert succulent resources as “hard food,” meaning foods with a high energetic investment in processing. While mescal was the preferred resource for the Mescalero, sotol was frequently cooked both with it or instead of it (Basehart 1974; Bell and Castetter 1941). This preference was reported as being due to the smaller size of sotol relative to mescal. This is not the case when comparing lechuguilla and sotol. Castetter and Bell (1935) report that only the youngest and most tender parts of each sotol specimen was prepared for consumption, since much of the older stem is woody and unpalatable. The harvesting, processing and consumption of this resource parallels that of agave. One interesting note recorded for this resource is the occasional use of its inflorescence as a source of honey (Basehart 1974), which corroborates recent studies indicating a high level of sugar available from this species during the development of the inflorescence (Arrizon et al. 2010).

Prickly Pear. The tunas of these species were an important food resource across most of modern-day Mexico and the Greater Southwest. This remains true today, with cultivated varieties grown across the globe for human consumption (Albuquerque and Santos 2006; Felker 2002; Kabas et al. 2006; Mondragon-Jacobo and Perez-Gonzalez 2002; Nobel 2002; Rodriguez 2005; Touil et al. 2010). While consumption of nopales remains an important dietary component across Mexico, this use of the resource is not as common or as important calorically, as the tunas.

Throughout the Southwest, native groups, including agriculturalists, gathered tunas for use as both a fresh fruit and dried preserve. Castetter and Bell (1935) also report groups grinding the dried fruit, including the large and abundant seeds, into flour with maize, which is eaten as a gruel. These large and sweet fruits do not appear to have been a staple for the agricultural groups studied by Castetter and Bell (1935), but rather, a seasonal supplement and sweet treat. The Mescalero did not make logistical forays to acquire this resource (Basehart 1974). This is due to the inconsistent production of tunas at any one locality, as well as the minimal processing required for this resource (Basehart 1974). This is contrasted with the importance of this species in Mexico, where varieties with larger fruit are an important commercial crop. Regardless of the degree of importance, it is certain that most or all native groups living in the greater Southwest utilized the fruits of prickly pear (Beals 1973).

Nopales were much less important as a food resource across the southwest than tunas (Basehart 1974). Accounts indicate that nopales were primarily used during the winter or as a starvation resource by native groups (Castetter 1935). It appears likely this resource had lost its importance to native groups in the recent past (Basehart 1974). The pads, and occasionally unripe tunas, were generally roasted directly in coals and used to supplement cornmeal or other resources (Castetter 1935).

The relatively minor role of both tunas and nopales reported in the ethnographic literature of the Southwest is in sharp contrast with the importance of both of these resources recorded in the earliest Spanish accounts of the Tamulipan plain. This may be due to differences in prickly pear density or species differences between the regions or a change in lifeways over the centuries separating the accounts. Both sets of documents make it clear that tunas were an easily processed and highly desirable resource during its seasonal availability. Nopales were generally regarded as a food resource for times of scarcity.

Ethnohistoric Subsistence Patterns

Coahuiltecans. There is ample evidence that prickly pear tunas were an important component of the seasonal round across Tamaulipas, Nuevo Leon and the South Texas Plain (Duaine 1971; Krieger 2002; Salinas 1990). This fruit was one of the major staples of this population, along with lechuguilla, sotol, mesquite, and geophytes (De Leon 1971; Krieger 2002; Thoms 2008b; Wade 2003). The innumerable cultures that subsited in this area consisted of small, highly mobile hunter-gatherer bands who congregated seasonally around productive patches of prickly pear (Duaine 1971; Krieger 2002). Population density was probably higher along the Rio Grande Delta and other productive localized environments (Salinas 1990), but this area overall had a low population density, with each band exploiting a large geographic area and sharing productive resource patches such as the tuna fields (Duaine 1971; Krieger 2002). Hunting seems to have been an important source of protein, but there is no reference to bison this far south in the 16th century. Cabeza de Vaca describes a deer drive where many deer were driven into a bay and drowned (Krieger 2002), but there is also indication that these populations were not picky about the source of their protein, eating everything from grubs and lizards to deer (Duaine 1971; Krieger 2002).

Lipanes. The Lipan Apache were one of the Athabascan speaking groups who pushed down into Texas and the Southwest from the Great Plains during the 16th and 17th centuries (Opler 2001). While they ranged over much of Texas and northern Mexico in the ensuing centuries, many of the encounters with the Lipanes occurred in the Edwards Plateau north of San Antonio (Wade 2003). The Lipanes may have been the Querechos, bison hunters encountered by Coronado in the Panhandle of Texas. There is no doubt that bison were a major focal point of the Lipan subsistence strategy (Opler 2001l; Wade 2003). Other important food resources include lechuguilla and sotol crowns, geophytes, small seed resources, tunas, and nuts (Opler 2001). The Lipanes were also noted as green corn farmers when settled along streams with good bottomland (Opler 2001). Regardless of the importance of plant foods, it appears that much of the seasonal movements of the Lipan was dictated by bison herds (Opler 2001). Like the geographic Coahuiltecans, the Lipan Apaches lived in dispersed highly mobile bands which congregated in times of abundance (Opler 2001). The importance of the prickly pear to the Lipanes in the Edwards Plateau can be seen in the aforementioned 18th century accounts from Wade (2003).

Jumanos. The Jumanos provide an interesting contrast to the first two ethnic groups presented. While it is still unclear if the term, derived from the Spanish word for “Human”, refers to an ethnic identity or a physical description, recent work by Hickerson (1994) suggests that this term does refer to a recognizable cultural entity. The

Jumano were important as intermediaries between the Southwest farming tradition along the Rio Grande and further west and the Caddo of the Piney Woods of East Texas (Kelley 1955). This role later expanded to include the Spanish in Coahuila in their network of exchange (Kelley 1955). The Jumano consisted of two sub-divisions who engaged in complementary subsistence strategies. The groups along the Rio Grande and the Rio Concho occupied permanent farming communities of some size (Hickerson 1994). These groups were full time farmers utilizing the entire suite of Mesoamerican domesticates (Hickerson 1994). The Plains Jumano consisted of highly mobile bison hunters who lived along the rivers in an impermanent fashion, frequently leaving to gain access to bison herds. It remains unclear if this division was a recognized ethnic split or simply a system of labor specialization. Maize and bison formed the staples of both groups, although wild plant resources and other animals were also important (Hickerson 1994). The population density of the La Junta area was quite high, with most of the bottomlands used for farming (Hickerson 1994: 36). It appears that this area served as a base for congregation and exchange for both the farming and bison hunting Jumanos. While there are some references to wild plant foods such as mescal and mesquite (Hickerson 1994: 37, 40, 43, 133), most references to food in the accounts compiled by Hickerson (1994) indicate that bison and cultivated crops were the dietary mainstays of the Jumano. There were only two references two prickly pear or cactus in Hickerson (1994). The first reference is taken from Cabeza de Vaca and mistakenly places his interactions with the Mariames in the Edwards Plateau (Hickerson 1994: 8). The second mention of prickly pear is made by Hickerson herself (1994: 221) in her summary of the place of the Jumano among the prehistoric and historic Native landscape. While the fresh tunas were undoubtedly consumed by the Jumano and related groups, there does not seem to be a primary seasonal dependence on this resource similar to the Lipanes and Coahuiltecans. Perhaps this is related to the lower densities of prickly pear in the western Trans-Pecos (Lundgren et al. 1981).

Ethnographic Expectations and the Archaeological Record

Reconstructing the importance of specific food resources in the archaeological record is a daunting task. In order to examine the importance of subsistence resources in the past, it is necessary to establish what lines of evidence could be expected for each of the different resources mentioned above. For lechuguilla, sotol, and nopales, the use of this resources should result in the accumulation of a burnt rock midden from spent heating stones (Black et al. 1997; Collins 2004; Hall et al. 1986; Mallouf 1985; Thoms and Mandel 2006). These resources require long intensive cooking to render the fructans into simple sugars digestible by humans. Unfortunately, many other plant resources, including geophytes, also utilize the same cooking technology. The presence of burned rock middens is not enough. The midden fill must have some botanical evidence. Even statements about this seemingly direct evidence must be limited, since prickly pear was frequently used as a packing material in earth ovens and not as a food resource (Dering 1991). Evidence for the use of fresh and dried tunas is even more limited, since this processing leaves little recognizable traces in the archaeological record.

The best and most direct evidence for consumption comes from coprolites. The dry rockshelters in the Lower Pecos and the Trans-Pecos preserved thousands of these specimens although many have been lost to looting, development and inadequate sampling during excavation. These specimens provide a wealth of knowledge about prickly pear processing, allowing researchers to ask questions about the importance of pounding or grinding the tuna seeds as a source of oil and starch, or various methods of heat processing reflected in the seeds, fiber and epidermal cells recoverable from these specimens. To date, this has not been addressed through coprolite research. Other lines of evidence include the recovery of genus specific phytoliths from the dental calculus and microwear patterns in teeth (Danielson and Reinhard 1998). A final line of evidence is staple carbon isotope data from both skeletal remains and directly from coprolites. This technique can only inform on the importance of broad photosynthetic classes of plant foods such as CAM, but this could be quite useful in coprolite studies, in conjunction with the congruent lines of evidence presented above.

Prickly pear, lechuguilla and sotol were important food resources in the ethnographic data available for the macroregion considered in this chapter. Both the environmental and ethnohistoric data gathered suggest that these resources should be seasonally dominant staples of human populations in the Lower Pecos canyonlands. Human populations preferentially exploited prickly pear tunas when seasonally available. Sotol and lechuguilla were important resources during the cool season, despite the high processing costs. Nopales were consumed during seasons of scarcity and as a stop-gap while waiting for the more productive tuna resources to ripen.

CHAPTER VI

THE HINDS CAVE EXCAVATION

The Hinds Cave (41VV456) excavation by Shafer and Bryant of Texas A&M University resulted in the largest collection of coprolites from a single hunter-gatherer site in North America (Dean 2006). Several thousand coprolites were recovered from a variety of contexts during the two field seasons spent excavating the site (Shafer and Bryant 1977). Recent work re-accessioning the coprolites in the collections of Texas A&M University has corroborated this number and resulted in an estimate of 2300 to 2400 coprolite specimens that have not been analyzed to date. Despite the long history of excavation in the Lower Pecos canyonlands, few sites in the region have had systematic research programs designed to recover perishable artifacts such as coprolites and macrobotanical remains (Shafer and Bryant 1977). In many sites excavated during the Texas Archaeological Salvage Project, thousands of coprolites were noted during excavation but not collected, except in rare cases near the end of the salvage project (Alexander 1970, 1974; Bryant 1974c; Bryant and Dean 2006).

Hinds Cave was the first site in the Lower Pecos region to be excavated with a research design that included the systematic collection of biological components of the archaeological record (Shafer and Bryant 1977). The primary focus of the excavation was five-fold: 1) to collect a well-controlled sample of human coprolites from the site; 2) to collect a well-controlled sample of plant macrofossils; 3) to determine the depth of cultural deposits at the site; 4) to conduct a preliminary environmental resource study of the area around the site; and 5) to collect a well-controlled sample of material culture elements of the site (Shafer and Bryant 1977). This study was initiated in 1974 with a limited survey of the site, both to assess its potential for a large-scale excavation and to assess the disturbance of the site by modern relic hunters (Shafer et al. 1975). This survey resulted in the formulation of the research plan above, which was carried out during the summers of 1975 and 1976 (Shafer and Bryant 1977). There was some continuing fieldwork in 1977 and early 1978 to finish the open excavations (trench A-C) and clarify stratigraphy, but the bulk of excavation and material culture collection ended with the 1976 field season (Saunders 1986; Shafer 1986).

Hinds Cave is a large limestone solution cave in the west wall of Still Canyon, approximately one-half kilometer above the confluence with the Pecos River (Shafer and Bryant 1977). This east-facing overhang is located very high on the canyon wall and is difficult to access. Hinds Cave is located in the sotol-lechuguilla zone of the Chihuahuan biotic province within close proximity of the ecotonal boundary between this province and the the oak-cedar zone of the Balconian biotic province to the east (Figures 2 and 3) (Blair 1950; Dering 1979).

The protected area of the site measures about 37 meters North-South and is about 23 meters in depth (Shafer and Bryant 1977). The fill in the cave, almost entirely the result of human activity, is 3 meters deep in some parts of the cave and contains an abundance of perishable organic material including plant and animal remains as well as artifacts such as matting and sandals (Shafer and Bryant 1977). While there was evidence of extensive disturbance of the upper layers of the site by relic hunters, this was easily observed and did not impact the excavation of contextual samples (Shafer and Bryant 1977). During these field seasons a number of excavation areas within the larger site were selected to address the specific research goals presented above (Shafer and Bryant 1977). Based on the exploratory survey of the site in 1974, the excavation strategy was focused on two major areas (A and B) and several smaller areas (C, D, E, F, and G) (Figure 12).

Before excavation, both vertical and horizontal controls were established for the site. The main site datum was established along the backwall of the rockshelter and given an arbitrary elevation of 100 meters. All other vertical measurements were tied back to this main datum. Rather than establish a Cartesian grid coordinate system for horizontal control, the excavation areas were placed independent of each other. This allowed the researchers to orient each area relative to the patches of undisturbed cultural deposits at the site. Excavation units were excavated according to the natural stratigraphy of the deposit when exposed profiles made it possible or in arbitrary levels of 10 or 20 cm when the archaeologists did not have good profiles for stratigraphic control. One excavation unit, designated as a block, was excavated by natural stratigraphy in both areas A and B. Excavated matrix was treated in one of two ways: If plant macrofossils were being collected, the sample was screened through a doubled set of screens of ¼” and 1/16”; In all other cases, the matrix sample was screened through a ¼” screen only. In those cases where the double screen system was used, all material from both screens was bagged after the removal of visible artifacts and brought to Texas A&M University for curation and analysis. Otherwise, the material on the screen was scanned for faunal and artifactual content, which was collected for futher analysis. Bulk matrix samples were also collected from most lenses excavated in the Block B excavation unit and from every other lens encountered in the Block A excavation unit (Shafer and Bryant 1977).

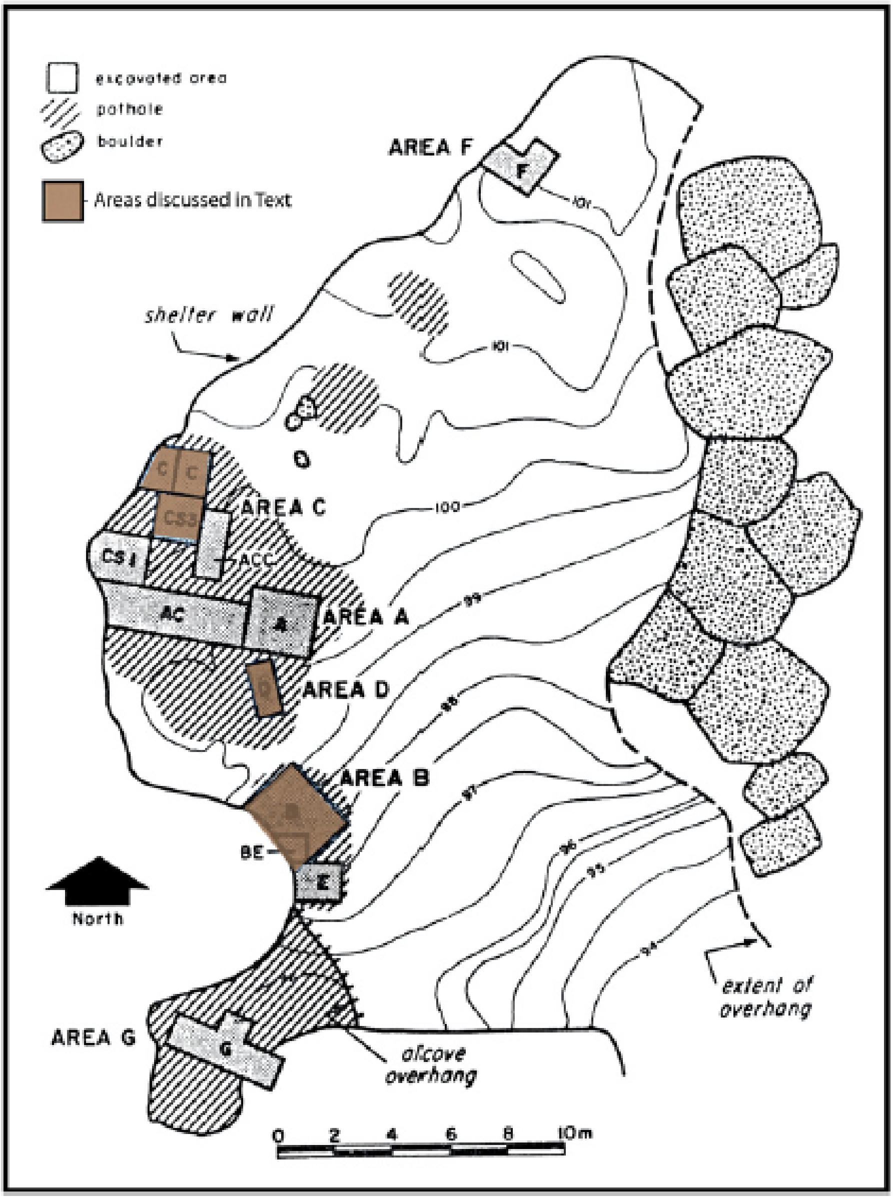


Figure 12. Site Map of Hinds Cave (41vv456). Modified from Shafer and Bryant (1977)

Excavation Units

The first major area, designated as Area A, was selected as the primary focus of the plant macrofossil sampling strategy. This area was selected for the plant macrofossil recovery due to the well-stratified nature of the matrix in this area of the cave as well as its relation to what was considered the primary living area of the rockshelter (Figure 12). The archaeologists located this area to take advantage of profiles exposed from previous uncontrolled excavations into the matrix. Two narrow trenches (units A1 and A2) were excavated to expose all four profiles of a 1.6x1.8 m^2 block, known as block A. This block was then divided into two units A-W and A-E and excavated following the stratigraphic lenses exposed and mapped in the wall profiles. During the 1976 field season a trench, designated as the A-C trench, was excavated to connect Areas A and C. This trench consisted of three 1.5x 1.5 m^2 units (AC1, AC2, AC3). Area A was the primary unit used to develop the analysis units (Stratigraphic zones) utilized in most of the Hinds Cave analyses to date (Shafer and Bryant 1977).

Area B was selected as the primary excavation unit for coprolite recovery. Located along the southwest wall of the rockshelter, archaeologists noticed numerous coprolites in both backdirt piles from previous looting activity as well as in situ in exposed profiles during the initial survey of the site (Figure 12). Following a similar procedure to that used in block A, the initial excavation units were narrow trenches designed to expose the stratigraphy of a larger excavation block. These trenches, designated as units B1-B6, were approximately a meter deep and exposed a well stratified deposit containing discrete lenses of coprolites. This block B consisted of a

1.5x1.5 m^2 unit with exposed profiles on three sides. In the 1976 season, this block was divided into two units, BN and BS (north and south respectively) during the field season due to the logistics of excavation. In addition, three more units, designated as B7-9, were excavated to expose the profile of block B before further excavation (Shafer and Bryant 1977).

The other excavation units were much smaller than areas A and B and were primarily focused on exposing more of the site's stratigraphy (Figure 12). Area C was a small excavation unit (1x1.5 m^2) placed near the center of the rockshelter. This unit was placed in a disturbed area of the site, where over a meter of fill had been removed by looters. The placement of this unit was based on the observation of in situ coprolite deposits in the floor of the looter's pit. In the 1976 field season, this unit was expanded to 2 m wide and several additional units were laid out and excavated. These include a addendum to C known as Unit CW to the west of unit C as well as 2 quadrants (CS1 and CS3) of a larger excavation block designated as C South. Finally a deep looter pit located along the east wall of CS3 was designated as unit ACC and excavated into a 2.7x1 m^2 unit to help evaluate the stratigraphy of the area. Area D was initially a test pit in the bottom of a looter's hole adjacent to Area A. This area consisted of two adjacent 1x1 m^2 units designated as D1 and D2. This area revealed that the cultural deposits in that area of the rockshelter extended much deeper than previously realized. This unit also uncovered several lenses of coprolites that date from the Early Archaic. Area E was a test pit measuring 1.25x1.5 m^2. This unit was excavated to explore the depth of cultural deposits near Area B. This unit also revealed that cultural deposits in this portion of the rockshelter were deeper than previously realized. This unit, and the subsequent B-E trench that linked the two areas, revealed several more latrine areas and associated coprolites (Shafer and Bryant 1977).

During the 1976 field season, two more units were opened in addition to continued excavation in areas A, B and C. The first of these, area F, was located near the north end of the rockshelter. This area was selected for excavation based on the presence of a fiber lens over 30 cm thick exposed by previous excavation by looters. Three small units [F1 (1x0.5 m^2), F2 (1x1 m^2), and F3 (1x1 m^2)] were placed in an L pattern near the rear shelter wall. This area yielded very few artifacts and consisted primarily of quids and cut leaf bases from the desert plant resources utilized by the human populations of the Lower Pecos Canyonlands. This fiber deposit consisted of distinctive lenses and indicates a pattern of re-use of this area of the site for plant processing and consumption over multiple occupations. This is further corroborated by the presence of a large burnt rock feature in the immediate vicinity. This final area, Area G, was placed in a small alcove near the southern end of the rockshelter. This area was evaluated for the extent of disturbance as well as to determine if the alcove was a specialized activity area within the larger rockshelter. Four small units (G1-G4) were laid out in a T shape in the alcove and excavated in arbitrary levels, since the stratigraphy of the area was not clear. Three of the units were 1x1 m^2 with the fourth slightly larger at 1x1.4 m^2. While a good sample of stone tools and faunal material, including an incomplete infant burial, was recovered in this alcove, the deposits were clearly of mixed age (Shafer and Bryant 1977).

Research on Hinds Cave Collections

While there is as yet no synthesis of the Hinds Cave excavation by Texas A&M University, more has been published about this excavation than any other in the Lower Pecos canyonlands. The initial series of published material includes the preliminary site reports (Bryant 1977a; Shafer and Bryant 1977; Shafer et al. 1975; Shafer and Speck 1974) as well as contemporaneous laboratory studies on textiles (Andrews and Adovasio 1980), faunal remains (Lord 1984), botanical components (Bryant 1977c; Dering 1979), organic residues on lithic tools (Shafer and Holloway 1979), radiocarbon dates (Valastro et al. 1979),and coprolites (Williams-Dean 1978). Publications based on the material recovered in this excavation have continued to the present day. Much of the research has focused on the abundant coprolites collected from this site, including studies of ancient DNA (Poinar et al. 2001; Reinhard et al. 2008), phytoliths (Reinhard and Danielson 2005), and faunal components (Reinhard et al. 2007; Sobolik 1996b), as well as continued examination of new samples (Edwards 1990; Stock 1983) and the re-examination of previous studies (Dean 2004, 2006; Riley 2008). These coprolite studies will be presented in more detail below.

Further work has been done on other aspects of the site, including a regional survey (Saunders 1986; Saunders 1992), climate change (Goodfriend and Ellis 2000), experimental studies of earth oven cooking (Dering 1999), radiocarbon dating of an infant burial (Steelman et al. 2004), more macrobotanical analyses (Sobolik 1991b; Woltz 1998), and further lithic residue analysis (Sobolik 1996a). No other site in the Lower Pecos canyonlands has a comparable amount of research, making Hinds Cave the most completely examined habitation site in the region. This intensive research focus on Hinds Cave has yielded more radiocarbon assays than any other site in the region (Table 6) (Dean 2004; Steelman et al. 2004; Valastro et al. 1979). The chronological relationship of Hinds Cave Analysis Units is presented in Tables 7 and 8. These tables also includes the diagnostic artifacts recovered in the Hinds Cave excavation as well as relevant radiocarbon dates associated with coprolite studies from the site.

Previous Coprolite Studies from Hinds Cave

Four previous studies have been conducted on coprolites recovered from Hinds Cave (Edwards 1990; Reinhard 1989; Stock 1983; Williams-Dean 1978). The coprolites analyzed in these studies span much of the Archaic occupation of the Lower Pecos (Turpin 1991b). Each of these studies has added to our knowledge of diet and nutritional health of the hunter-gatherer groups that populated the canyonlands. There appears to have been a remarkably stable human exploitation of the landscape over this period (Edwards 1990; Stock 1983; Williams-Dean 1978). Due to the lack of primary macrobotanical data available for individual specimens in Reinhard (1989), this study will not be included in this review.

Table 6. Radiocarbon Dates from Hinds Cave (41VV456). Calibrated with OxCal4.0 using IntCal04 Curve

Lab number	Area-Unit	Lens/Level	Analysis Unit	Context	AMS	δ13C Valu	Reported Assay BP	Calibrated Age Range BP (2σ)	Material Dated	Reference
CAMS 96373		upper deposits		Wooden stick	Y	-24.91	905 ± 35	740 - 914	Ash (Wood)	Steelman et al. 2004
CAMS 85492		upper deposits		Wooden stick	Y	-24.91	920 ± 35	745 - 923	Ash (Wood)	Steelman et al. 2005
CAMS 88193		upper deposits		Wooden stick	Y	-24.91	940 ± 40	765 - 932	Ash (Wood)	Steelman et al. 2006
CAMS 91407		upper deposits		Wooden stick	Y	-24.91	940 ± 35	778 - 930	Ash (Wood)	Steelman et al. 2007
CAMS 89606		upper deposits		Wooden stick	Y	-24.91	955 ± 30	795 - 928	Ash (Wood)	Steelman et al. 2008
CAMS 93683		upper deposits		Wooden stick	Y	-24.91	970 ± 35	792 - 952	Ash (Wood)	Steelman et al. 2009
Tx-5897		upper deposits		Wooden stick	N		1310 ± 97	987 - 1391	Wood	Steelman et al. 2010
Tx-2733	F-3	1 (Lev 3)		Burned Rock Midden	N		1820 ± 70	1566 - 1896	Charcoal	Valastro et al. 1979, Lord 1984
CAMS 85491		upper deposits		Bundle Burial	Y	-23.91	2095 ± 50	1930 - 2300	Mat	Steelman et al. 2004
CAMS 91410		upper deposits		Bundle Burial	Y	-14.65	2095 ± 40	1950 - 2292	Grass	Steelman et al. 2005
CAMS 88194		upper deposits		Bundle Burial	Y	-14.65	2125 ± 40	1992 - 2303	Grass	Steelman et al. 2006
CAMS 95671		upper deposits		Bundle Burial	Y	-25	2120 ± 40	1992 - 2302	Sotol	Steelman et al. 2007
CAMS 96371		upper deposits		Bundle Burial	Y	-14.65	2115 ± 35	1994 - 2297	Grass	Steelman et al. 2008
CAMS 96374		upper deposits		Bundle Burial	Y	-16.3	2120 ± 35	1994 - 2299	Twine	Steelman et al. 2009
CAMS 94532		upper deposits		Bundle Burial	Y	-25	2135 ± 40	1996 - 2305	Sotol	Steelman et al. 2010
CAMS 95670		upper deposits		Bundle Burial	Y	-25	2125 ± 35	1996 - 2300	Bone/Skin	Steelman et al. 2011
CAMS 96372		upper deposits		Bundle Burial	Y	-23.91	2140 ± 40	1999 - 2306	Mat	Steelman et al. 2012
CAMS 92188		upper deposits		Bundle Burial	Y	-23.91	2155 ± 40	2006 - 2310	Mat	Steelman et al. 2013
CAMS 93679		upper deposits		Bundle Burial	Y	-16.3	2155 ± 45	2005 - 2310	Twine	Steelman et al. 2014
Ua-15512	Block B	13		Latrine	Y	Unknown	2165 ± 60	2004 - 2328	Coprolite	Poinar et al. 2001
CAMS 93678		upper deposits		Bundle Burial	Y	-16.3	2170 ± 45	2044 - 2324	Twine	Steelman et al. 2004
CAMS 86525		upper deposits		Bundle Burial	Y	-14.65	2210 ± 45	2125 - 2337	Grass	Steelman et al. 2005
Tx-2746	Block B	3	2		N		2280 ± 60	2127 - 2455	Charcoal	Valastro et al. 1979, Lord 1984
Ua-15386	Block B	13		Latrine	Y	Unknown	2280 ± 90	2010 - 2696	Coprolite	Poinar et al. 2001
Ua-15511	Block B	13		Latrine	Y	Unknown	2370 ± 60	2210 - 2705	Coprolite	Poinar et al. 2001
Tx-5987		2		Bundle Burial	N		2710 ± 50	2746 - 2925	Sotol	Steelman et al. 2004
Tx-2748	Block B	7A	3		N		3680 ± 80	3731 - 4283	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2741	A-Ae	4	3	Fiber Lens	N		3780 ± 70	3980 - 4408	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2740	A-Ae	5	3	Fiber Lens	N		3840 ± 70	3997 - 4426	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2749	Block B	11	5		N		4410 ± 70	4853 - 5286	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2742	Aw	9B	5	Fiber Lens	N		4510 ± 70	4885 - 5440	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2750	Block B	3B	5	Latrine	N		4610 ± 70	5048 - 5578	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2747	Block B	11	5		N		4760 ± 70	5320 - 5605	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2743	A-Aw	7	5	Fiber Lens	N		4990 ± 70	5605 - 5895	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2458	Block B	13A	5d	Latrine	N		5765 ± 70	6409 - 6727	Coprolite	Williams-Dean 1978
Tx-2459	Block B	13A	5d	Latrine	N		5885 ± 80	6495 - 6896	Coprolite	Williams-Dean 1978
Beta 179749	Block B	13	5	Latrine	Y	-12.5	5940 ± 80	6563 - 6980	Coprolite	Dean 2004
Beta 180321	Block B	13	5		Y	-17.2	5920 ± 110	6468 - 7149	Coprolite	Dean 2004
Tx-2735	A-C	5C	6	Burned Rock Midden	N		6160 ± 80	6807 - 7256	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2732	A-C	8	6	Burned Rock Midden	N		6230 ± 90	6895 - 7411	Charcoal	Valastro et al. 1979, Lord 1984
Beta 179750	Block B	13	5	Latrine	Y	-13.1	6270 ± 90	6960 - 7417	Coprolite	Dean 2004
Tx-2744	A-A	5C	6	Burned Rock Midden	N		6540 ± 70	7320 - 7570	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2316	C	Lev 10	7		N		6750 ± 100	7436 - 7790	Charcoal	Lord 1984
Tx-2751	Block B South	10B	7	Latrine	N		6950 ± 90	7622 - 7950	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2315	B-E	Lev 4	7		N		7220 ± 60	7950 - 8170	Charcoal	Lord 1984
Tx-2738	C South-3	5	7		N		7470 ± 120	8020 - 8514	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2736	C	Lev 11	7		N		7490 ± 100	8045 - 8508	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2865	A-C Northwall	7	7	Prickly pear floor	N		7530 ± 120	8050 - 8582	Charred Wood	Valastro et al. 1979, Lord 1984
Tx-2867	A-C Northwall	7	7		N		7950 ± 110	8540 - 9122	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2737	D-1	Lev 7	7	Latrine	N		8180 ± 110	8778 - 9460	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2314	D-2	Lev 7	7		N		8280 ± 80	9032 - 9464	Charcoal	Lord 1984
Tx-2745	A-A	5K	6-7		N		8250 ± 80	9026 - 9432	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2734	G-1c	4	7		N		8490 ± 130	9127 - 9886	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2866	A-C Northwall		8		N		9120 ± 90	9964 - 10568	Charcoal	Valastro et al. 1979, Lord 1984
Tx-2739	A-C Northwall		7	Prickly pear floor	N		11550 ± 190	13088 - 13799	Prickley Pear	Valastro et al. 1979, Lord 1984

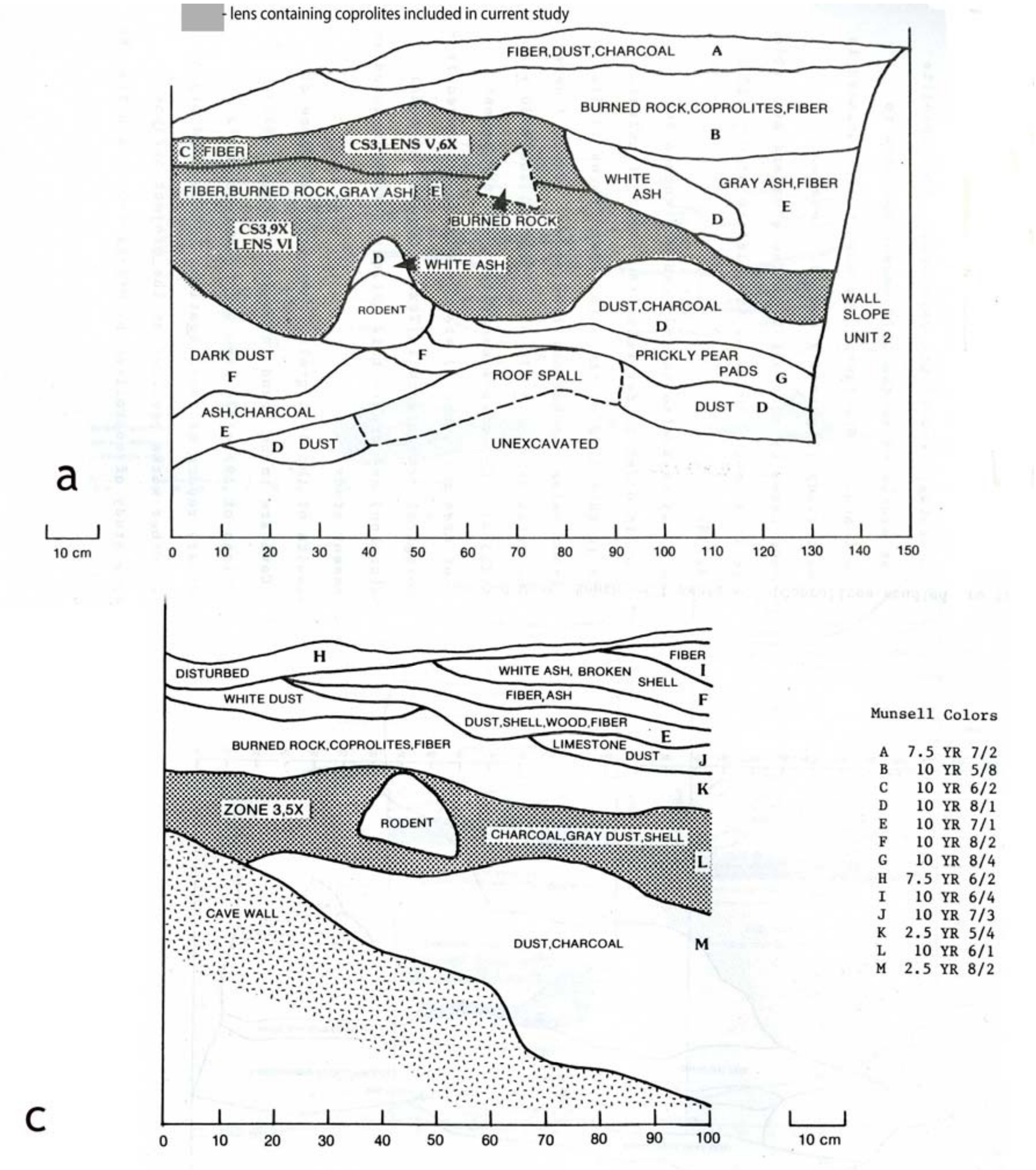
Table 7. The Hinds Cave Excavation and Chronology of Coprolite Studies Part 1

Radiocarbon Y.B.P.	Hinds Cave Analysis Units	Hinds Cave Projectile Points	Hinds Cave Block B levels	Hinds Cave Radiocarbon Dates associated with Coprolite Studies	Coprolite Studies from Hinds Cave	Other Coprolite Studies in the Lower Pecos
0	Disturbed					
500	1	Clifton, Perdiz, Livermore, Toyah	Lens I, 75 season (AU 1b)		Area B (1975), Unit B-4, lens I (n=32) Edwards 1990	
1000			Lens II, 75 season (AU 1b)		Area B (1975), Unit B-4, lens II (n=1) Edwards 1990	Baker Cave (41VV213), Unit N6/E9, stratum 2 (n=38) Sobolik 1988 and 1991 Stratigraphically associated with a radiocarbon date of 1100+-100 (B15634) (Brown, p.c.; Turpin 1991)
1500		Ensor, Frio, Paisano			Area B (1975), Unit B-1, Lens II, III (n=2) Reinhard 1988	
2000	2?		Lens III, IIIa (AU-2b)	B Block`(1975), Lens III - 2280+-60 (TX 2746)		Conejo Shelter (41VV162) Lens 3 through 17 (n=42) Bryant 1969 and 1974 Bracketed by dates on lens H - 1810+-70 (TX 1757) and lens 38 - 2690 +-80 (TX 1759) (Alexander 1974; Valastro et al. 1977)
2500	2+3	Marcos, Shumla, Montell, Castroville, Marshall	Lens IV-VI (AU 3b)			Parida Cave (41VV187), Test Pit 4, Levels 1-3 (n=11) Riskind 1970 Site dated by Diagnostic Projectile Points (Alexander 1970)
3000	3, 4, upper 5				Area B (1975), Unit B-6, lens V (n=19) Reinhard 1988 Area B (1975), Unit unknown, lens VII (n=4) Reinhard 1988	Frightful Cave, Upper Strata (n=16) Bryant 1974; Fry 1975 Radiocarbon dates (Taylor 1956)
3500		Val Verde, Langtry	Lens VIIA-C (AU 4b)	B Block (1975), lens VIIA - 3680+-80 (TX 2748)		
4000	5					
4500		Pandale, Nolan	Lens VIII-XII (AU 5c)	B Block(1975), Lens XI - 4410+-70 (TX 2749) B Block (1975), Lens XI - 4760+-70 (TX 2747)		Frightful Cave, Middle Strata (n=16) Bryant 1974; Fry 1975 Radiocarbon dates (Taylor 1956)

Table 8. The Hinds Cave Excavation and Chronology of Coprolite Studies Part 2

Radiocarbon Y.B.P.	Hinds Cave Analysis Units	Hinds Cave Projectile Points	Hinds Cave Block B levels	Hinds Cave Radiocarbon Dates associated with Coprolite Studies	Coprolite Studies from Hinds Cave	Other Coprolite Studies in the Lower Pecos
5000						
5500		Baker, Bandy, "early barbed"	Lens XIII A-C (AU 5d)			
500					Area B (1976), Unit B-9, lens I and II (n=7) Edwards 1990	
1000						
1500						Frightful Cave, Lower Strata (n=15) Bryant 1974; Fry 1975 Radiocarbon dates (Taylor 1956)
2000	7, 8		Lens I-XI (B South) and I-IX (B North), 76 season - AU 7	B South (1976) Lens 10B - 6950+-90(tx 2451)	Area B (1976), B-Block South, lens Xb (n=10) Current Study Area B (1976), B-Block North, lens VIII (n=10) Current Study Area B (1976), B-Block North, lens VIIIb (n=10) Current Study	
2500				Area C, Level 10 - 6750+-100 (TX-2316) Area C, Unit CS-3, Level 5 - 7470+-120 (TX-2738) Area C, Level 11 - 7490+-100 (TX-2736)	Area C, multiple unreported lenses from AU 7 (n=26) Stock 1983	
3000		Plainview, Golondrina, Angostura, early stemmed, lanceolate forms		Area D, Unit D1, Level 7 - 8180+-80 (TX-2737) Area D, Unit D2, Level 7 - 8280+-80 (TX-2714)	Area D, Unit D-2, level 7 (n=21) Stock 1983 Area D, Unit D-2, level 8 (n=7) Stock 1983 Area D, Unit D-2, level 13 (n=1) Stock 1983	
3500						
4000		Folsom, Plainview				

Stock (1983) focused upon the macrofossil constituents of 55 coprolites recovered from two areas within Hinds Cave. Twenty-nine coprolites from Area D, Unit D-2, levels 7 (n=21), 8(n=7) and 13(n=1) were analyzed (Table 6 and Figure 13a). These specimens were chosen since they represent the earliest dated coprolites recovered from any site in Texas (8778 B.P.-9460 B.P. and 9032 B.P.-9464 B.P. [Calibrated 95.4%]) (Tables 6-8) (Stock 1983; Valastro et al. 1979). This corresponds with the beginning of the long Viejo subperiod in Turpin's (2004) cultural chronology as well as the increasingly xeric Stockton Stage (Table 4) (Bryant 1966). Twenty-six coprolites were analyzed from several lenses in Area C, Analysis Unit 7 since it produced a large number of coprolites and was well dated to the Early Archaic (7436 B.P.-7790 B.P. 8020 B.P.-8514 B.P., 8045 B.P.-8508 B.P. Calibrated 95.4%) (Tables 6-8 and Figure 13b) (Stock 1983; Valastro et al. 1979). The primary goal of this research was a reconstruction of diet and its implications for adequate nutrition and health (Stock 1983). The coprolites analyzed in this study were deposited in an environment characterized by scrub grasslands with remnant woodlands and parklands (Bryant and Holloway 1985). As mentioned above, only the plant macrofossil data is available from this analysis.



Munsell Colors

A	7.5 YR 7/2
B	10 YR 5/8
C	10 YR 6/2
D	10 YR 8/1
E	10 YR 7/1
F	10 YR 8/2
G	10 YR 8/4
H	7.5 YR 6/2
I	10 YR 6/4
J	10 YR 7/3
K	2.5 YR 5/4
L	10 YR 6/1
M	2.5 YR 8/2

Figure 13. Profiles of Areas C and D, Hinds Cave (Stock 1983). A) Area C-South, Unit 3; B) Area C-C West, South Wall Profile; C) Area C-West, North Wall Profile; D) Unit D1, South Wall Profile; E) Unit D2, South Wall Profile

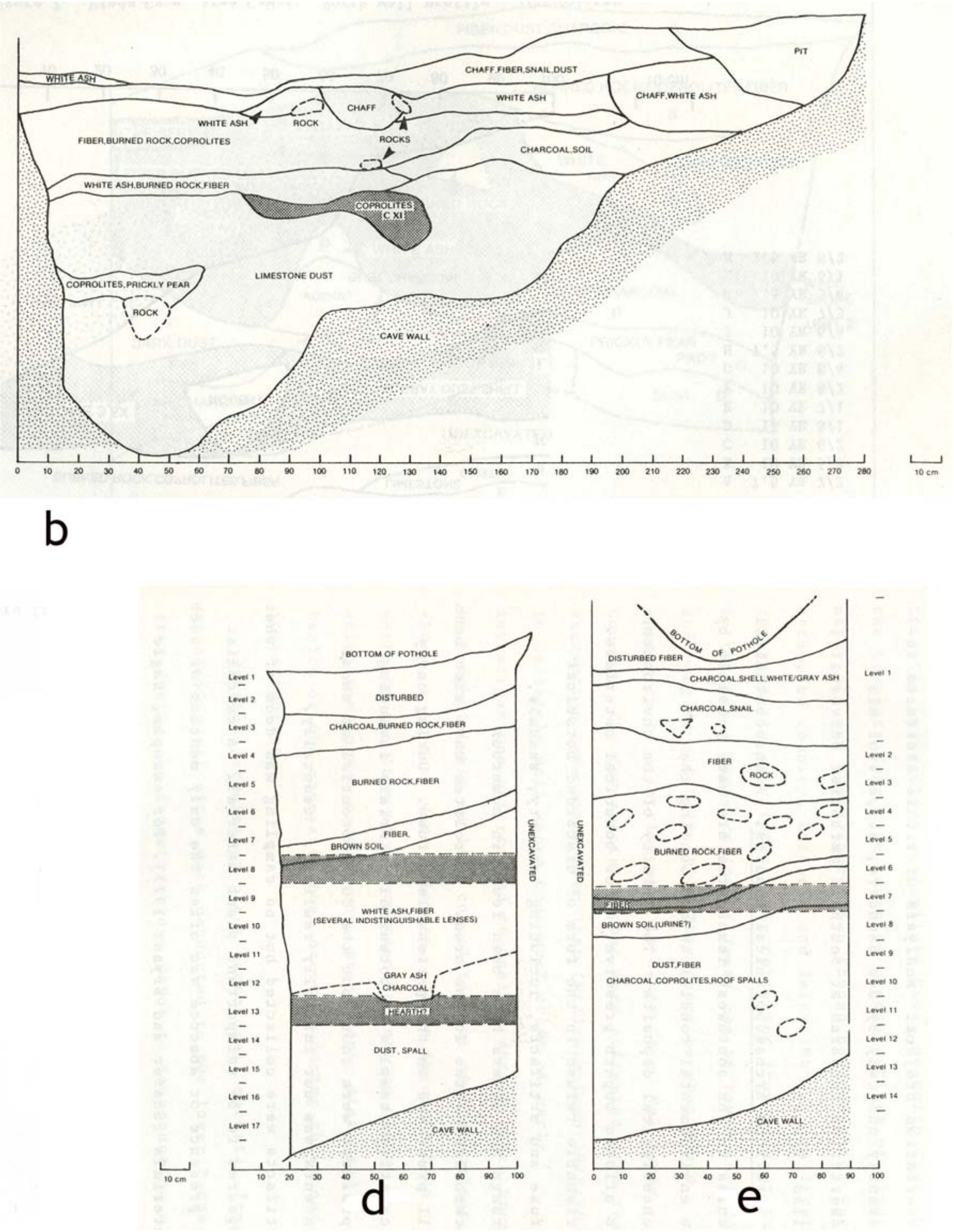


Figure 13. Continued

While Stock (1983) did report on phytoliths for these samples, the data was only presented in gross summary fashion for the two contexts, with no data provided for individual specimens.

Williams-Dean (1978) analyzed 100 coprolites from lens 13 (a latrine feature) in Area B (Figure 14 and Table 6). The matrix of Area B consisted of layers of coprolites separated by layers of ash, burnt rock, and fibrous organic debris (Shafer and Bryant 1977; Williams-Dean 1978). Lens 13 was chosen for analysis because it was the oldest and largest coprolite layer recovered during excavation of Area B during the 1975 excavation season (Williams-Dean 1978). Preliminary radiocarbon dates bracket the lens between 6409 B.P.-6727 B.P. and 6495 B.P.-6896 B.P (Calibrated 95.4%) (Tables 6-8) (Valastro et al. 1979) although more recent, refined dates have thrown this into question (Dean 2004; Poinar et al. 2001).

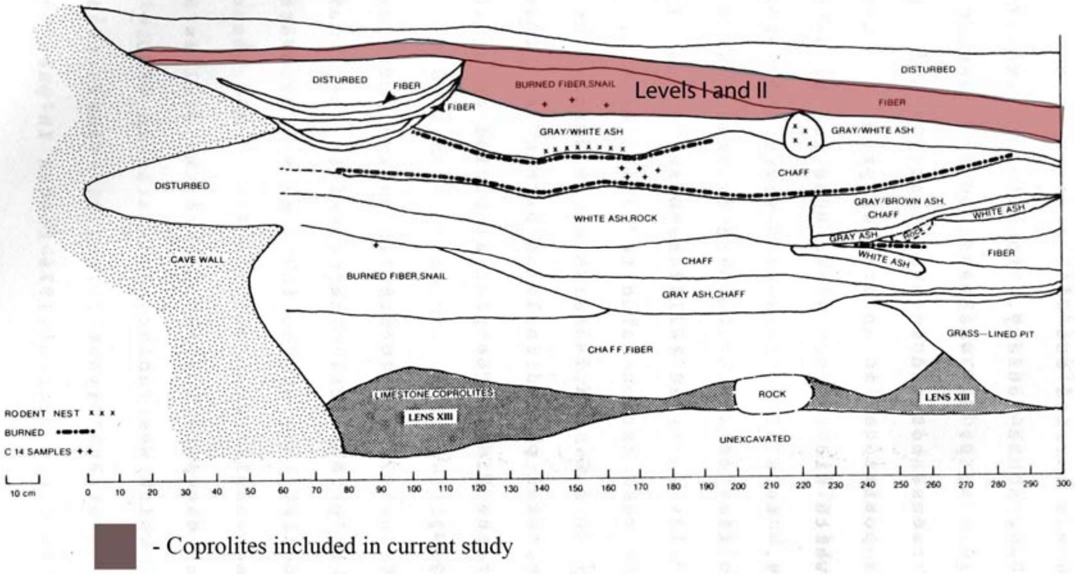


Figure 14. North Wall Profile of Area B, 1975 excavation (modified from Stock, 1983)

The two initial dates were reported by Lord (1984) as being from charcoal associated with the lens, but this has been contested by Dean, who distinctly recalls that these dates were derived directly from coprolites (Black 2005). Two different researchers have recently published six more radiocarbon dates derived from coprolites associated with lens 13 (Dean 2004; Poinar et al. 2001). These recent dates may indicate that the lens 13 latrine deposit was re-used in at least two occupations separated by thousands of years (Dean 2004). Conversely, this discrepancy in dates from a single context may be the result of mis-identification of specimen provenience (Black 2005). The three dates that are definitively from lens 13 were taken from small samples of coprolites analyzed by Williams-Dean (1978) in her dissertation. These three specimens yielded radiocarbon dates of 6563 B.P.-6980 B.P., 6468 B.P.-7149 B.P., and 6960 B.P.-7417 B.P. (Calibrated 95.4%) (Table 6) (Dean 2004). Two of these dates correspond nicely to the initial radiocarbon dates presented above, and the third is slightly older than the other dates from the deposit. It should be noted that lens 13, initially encountered during the 1975 excavation, was excavated with four different sub-lens designations (A-D) during the 1976 field season (Shafer et al. 1976) While this sublens provenience information was not given for the specimens in Williams-Dean (1978), the two coprolite fragments with the more recent dates presented in Dean (2004) are designated as coming from sublens 13A. The older date comes from a specimen with no sublens designation. The three coprolites analyzed for aDNA in Poinar et al. (2001) are given the provenience of block B, lens 13, but all three dates are significantly more recent than the dates presented above. These specimens yielded radiocarbon dates of 2004 B.P.-2328 B.P., 2010 B.P.-2695 B.P., and 2210 B.P.-2705 B.P. (Calibrated 95.4%) (Table 6) (Poinar et al. 2001). The huge discrepancy between these dates, as well as vagary possible with two decades between excavation and analysis, suggest that Black's (2005) assertion that the provenience for these specimens is incorrect is the most probable explanation. I suggest that the specimens used by Poinar et al. (2001) may be from Area B, Unit B-1, lens 3 since bags tagged as B-1-3 could easily be misconstrued as being from block B, lens 13. The dates associated with lens 3 in block B line up nicely with the dates from Poinar et al. (2001) (Table 6).

The primary objective of Williams-Dean's (1978) study was to determine the nature and adequacy of the diet of the prehistoric inhabitants of Hinds Cave. Previous researchers have suggested that human populations in the later Viejo subperiod would have focused increasingly on xeric associated plant communities as the environment continued to become drier and more xeric during the Stockton Stage (Bryant 1966d, 1977c; Bryant and Holloway 1985; Dering 1979; Johnson 1963; Lord 1984; Williams-Dean 1978). The data available from this analysis include faunal, macrobotanical and palynological data sets (Williams-Dean 1978), as well as stable isotope data available from the three specimens discussed in Dean (2004). For this current study, the macrobotanical, palynological and isotopic data will be presented and incorporated into the analysis of diet breadth, seasonality and habitat exploitation.

Edwards (1990) analyzed 40 coprolites from were supposedly from the upper two layers of the latrine Area B (Figure 14). While the author presents these coprolites as coming from Late Archaic contexts, the reality of the situation is much more complicated. The majority of these specimens do come from a Late Archaic context (Unit B4, Lens I (n=32) and II (n=1) (Edwards 1990). However, the remaining seven specimens in the study were recovered from unit B9, lenses I and II (Edwards 1990). This unit was excavated during the 1976 season and was one of the units used to expose the profile of Block B (Shafer et al. 1976). This unit was located much deeper in the excavation and has depths below datum (135-163 cm below datum in the southwest corner) that roughly correspond with lens 13 from the 1976 excavation (Shafer et al. 1976). While Edwards reports that the coprolites in this study date from 4050 to 2550 BP (Edwards 1990), this is assuredly not the case. Edwards (1990) did not report the radiocarbon data behind her dates, but the available radiocarbon data suggest that she is referring to radiocarbon samples TX-2746 (2127 B.P.-24550 B.P [Calibrated 95.4%]), TX-2748 (3731 B.P.-4283 B.P [Calibrated 95.4%]), and TX-2749 (4853 B.P.-5286 B.P [Calibrated 95.4%]) (Table 6) (Lord 1984; Valastro et al. 1979). All of these dates are from lenses below the strata sampled in unit B-4 in Edwards study and significantly above the specimens collected from unit B-9 (Valastro et al. 1979). The youngest date is from the lens directly below the two sampled by Edwards (1990) in Unit B-4, which indicates that the majority of specimens in this study were deposited during the Juno Stage in Bryant's (1966) climatic reconstruction and are associated with either the Flanders or Blue Hills subperiods in Turpin's (2004) cultural chronology. The Juno Stage is characterized by increasingly xeric conditions following the brief mesic interlude known as the Frio Interval (Bryant 1966d; Bryant and Holloway 1985(Bryant and Holloway 1985; Goodfriend and Ellis). Both the Flanders and Blue Hills subperiods exhibit an increased reliance on the desert succulent resources so common in this region (Turpin 2004). The remaining seven specimens are from approximately the same time period as the samples examined by Williams-Dean (1978). This study included both macrobotanical and palynological analyses of the coprolite specimens, although the palynological data is missing for one sample from the B-4 unit and four from the B-9 unit.

Reinhard included twenty-five coprolites from Hinds Cave in his dissertation (Reinhard 1989). These specimens were recovered from the trenches used to isolate block B in area B. Seventeen of these specimens were recovered from the trench designated as Unit B-6. The remaining eight specimens are from area B, but the unit designation is not clear. All of these specimens are from the Late Archaic.

Previous Reconstructions. All three studies suggested a warm season occupation of Hinds Cave (Edwards 1990; Stock 1983; Williams-Dean 1978). This conclusion is based upon pollen and macrobotanical data. These studies indicate a very broad-based foraging and hunting subsistence strategy (Edwards 1990; Stock 1983; Williams-Dean 1978). Despite the broad temporal scale covered by these three studies, there seems to be a consistent pattern of resource exploitation throughout the samples, indicating long term stability in the human exploitation of this environment (Edwards 1990). Throughout the studies, the majority of coprolites indicate a diet high in tunas (*Opuntia* sp. fruit), nopales, sotol, and agave supplemented by small animals and seasonally available plant resources (Stock 1983). While this may indicate cultural stability, Williams-Dean (1978) suggests that it is more accurately a reflection of the restricted availability of edible plants in the Lower Pecos.

Excavation Context of the Coprolite Specimens Analyzed in the Current Study

Thirty coprolites from three different contexts were examined in this analysis. These samples were taken from a set of three lenses excavated during the 1976 field season. These particular lenses were chosen for analysis for two reasons: first, these coprolites are the oldest specimens sampled from area B, which had high concentrations of coprolites throughout its matrix and has been interpreted as a re-used latrine feature throughout the Holocene (Shafer and Bryant 1977). This is based on the associated radiocarbon dates and stratigraphic context of the lenses. The dates associated with these specimens also fills in the temporal gap between Stock's (1983) specimens from Areas C and D and the study conducted by Williams-Dean (1978) on the largest lens in area B, lens 13; second, these smaller lenses could be the latrine residue of individual site occupations. Sampling from three contiguous lenses may tease out patterns of seasonal site occupation and harvesting impact on the local habitat that the previous studies have not uncovered. While two of the other studies did examine specimens from more than one excavation context (Edwards 1990; Stock 1983), the authors did not consider questions of changing subsistence between the different temporal contexts.

The first ten of the thirty coprolite specimens come from B-Block South, lens 10b (1976 excavation). This lens has an associated radiocarbon date on charcoal (7622 B.P.-7950 B.P. Calibrated 95.4%) (Table 6) that places it in the middle of both the xeric Stockton Stage of Bryant's (1966) climatic reconstruction as well as the Viejo subperiod of Turpin's (2004) cultural chronology (Valastro et al. 1979). The top of this lens ranged from 85-104 cm below datum and ended 102-118 cm below datum. This stratigraphic unit sloped significantly to the south-southeast. This lens consisted of a light tan compacted matrix, which is common throughout area B and is thought to be the result of repeated soaking of cave dust with urine (Shafer et al. 1976). This matrix of this lens contained abundant fiber, chaff, limestone, and unburnt bone. The western portion of the unit, which abuts the rear wall of the rockshelter, contained many coprolites and appeared to the excavators as a definite latrine with an estimated one hundred coprolites. More recent accessioning of this collection has placed the number of coprolites collected from this lens at 77 individually bagged specimens. The excavators indicate that the latrine feature may have had micro-layers, but they were not able to discern them while excavating. Subsequently, the feature was treated as a single lens (10b). Field notes from the excavation make it clear that coprolites were visible continuing into the next lens, but a distinct color change was encountered and the lens was closed. The underlying lens (11) also had coprolites along the rear wall of the rockshelter. Recent accessioning work of the Hinds Cave coprolite collection revealed that 44 coprolites were collected from this context. Excavation of unit B-Block South was terminated following lens 11, which ended at depths of 121-130 cm below datum (Shafer et al. 1976).

The second ten specimens come from B-Block North, lens 8 (1976 excavation). Fieldnotes from the excavation describe the context as a highly concentrated coprolite lens that does not extend across the entire unit, but is focused along the rear wall of the rockshelter. Beginning elevations range from 64-82 cm below datum. Ending elevations range from 78-91 cm below datum. Much like lens 10b in B-Block South, this stratigraphic unit slopes to the south-southeast. One hundred and ten coprolites were collected from this context. This lens was separated from the following stratigraphic unit by the remains of a badly degraded flooring composed of prickly pear nopales, most of which had feces adhering to them (Shafer et al. 1976).

The final ten specimens included in this study were recovered from B-Block North, lens 8b (1976 Excavation). This lens was separated from lens 8 by the previously mentioned floor of nopales. Beginning elevations range from 78-91 cm below datum. Final elevations for this lens were not recorded in the excavation field notes. This lens did not have the same density of coprolites as the superseding lens, but 36 coprolites from this context were collected during excavation. Lens 8b had an increased amount of cave dust compared to the preceding stratigraphic units and further excavation of the unit showed this to be the lowest coprolite deposit in the unit. The following lens (9) was composed primarily of limestone cave dust and spalls, with a small amount of charcoal noted as well. Two coprolites were collected from this context. Beginning elevations for this lens are not reported in the excavation field notes. Final elevations for this lens range from 96-118 cm below datum. Like the prior lenses from both B-Block North and B-Block South, the lens slopes significantly to the south-southeast. Excavation was discontinued, except for a small section of the unit floor along the north wall, which was excavated to bedrock, encountered between 110-138 cm below datum.

The close stratigraphic association of all three excavation contexts used in this study with the single radiocarbon date from the lower levels of excavation area B justify assigning all of the specimens from these lenses to the Stockton Stage of Bryant's (1966) climatic reconstruction and the Viejo subperiod of Turpin's (2004) cultural chronology. The date is from charcoal recovered from lens 10b of B-Block South. The beginning elevations from the northern portion of this unit (87-91 cm below datum) align with the recorded elevations (90-91 cm below datum) of the southern portion of the prickly pear floor that separates lens 8 and 8b in the adjacent unit (B-Block North) (Shafer et al. 1976). Thus, all three of the lenses considered here are in direct stratigraphic association with the radiocarbon date (Valastro et al. 1979). It is possible that lens 10b of B-Block

South and lens 8b of B-Block North are the same lens, but they have been considered as two different contexts for the purposes of this study.

The coprolite studies from Hinds Cave inform on the exploitation of the Lower Pecos canyonlands by hunter-gatherer populations across the Holocene. This robust dataset provides direct evidence of individual dietary choices as well as diet-breadth. The previous reconstructions referenced above all suggest that the human populations occupying the canyonlands were highly dependent on a limited suite of xeric resources for the bulk of their caloric intake. However, none of the prior studies approached the reconstruction of diet at the scale of individual coprolite specimens and, by extension, individual actors in the archaeological record. The current study rectifies that by considered each specimen as a discrete record of diet-breadth and seasonal exploitation of available resources. The following chapter reviews the development of several reference collections required to undertake this study as well as the general laboratory methods utilized in this analysis.

CHAPTER VII

MATERIALS AND METHODS

This chapter provides an overview of the components recovered from the thirty coprolite specimens included in this study and the methods used to accurately identify them. The first section reviews the development of reference collections for several of the major constituents recovered in many of the specimens. The development of these reference collections was a necessary step in fully evaluating the dietary components recovered as well as the ultimate goal of this study, assessing diet-breadth and seasonality of deposition. This is followed by a pilot study comparing sub-sampling methods previously used on coprolite specimens. Researchers have used very different sub-sampling methods in coprolite analyses. This pilot study compares the congruent botanical data of several small sub-samples from three specimens to assess the similarity between recovered constituents from each of the sub-samples. The following section reports on the laboratory procedures used to extract and isolate the various components of each specimen, as well as the methods used to properly identify the taxa represented in each component. A brief overview of the data sets available from the other coprolite studies in the Lower Pecos canyonlands and the methods of quantification utilized by these researchers follows. The chapter concludes with an explanation of the statistical methods employed to evaluate these data for diet-breadth and seasonality of deposition.

Reference Collections

Previous studies have identified the major plant staples of the human populations inhabiting the Lower Pecos canyonlands as lechuguilla caudex, sotol caudex, prickly pear nopales, prickly pear tunas and wild onion bulbs (Bousman and Quigg 2006; Brown 1991; Danielson and Reinhard 1998; Dering 1999; Huebner 1991; Riley 2008; Sobolik 1988b; Sobolik 1991a, 1996a). The differential use of these resources can be addressed with several co-varying lines of evidence within a single coprolite specimen. This congruent approach to evaluating the diet-breath of the meals represented in a coprolite requires the development of the necessary reference collections of microscopic components of these resources. To that end, I generated phytolith, fiber, and epidermal cell reference collections from botanical source material focused on assessing the importance of these resources in the meals reflected in the coprolites examined. In addition, a small reference collection of starch from potential or known food resources in the region was also developed. Each of these will be discussed in detail in the following section.

Fiber References. Fiber bundles and individual fiber cells, or ultimates, constitute the bulk of macrofossil material in many of the coprolites from the Lower Pecos canyonlands (Bryant 1969, 1974b; Edwards 1990; Fry 1975; Riskind 1970; Sobolik 1991a; Stock 1983; Williams-Dean 1978). Despite the dominance of this component, there have been few attempts to identify the botanical source of these structures. This is especially important for the current study, as most of the staple resources evaluated in the diet-breadth model have high fiber content. The botanical identification of the fiber ultimates would contribute greatly to an understanding of resource consumption and dietary combinations in the meals represented in the coprolite specimens. This is particularly true when fiber analysis is combined with epidermal cell identification, as different resources contain very different proportions of these two plant cell types. Epidermal cell counts would skew the importance of nopales and onion relative to lechuguilla and sotol. This is due to the anatomical composition of the consumed parts of these plant resources. The caudex of lechuguilla and sotol consists primarily of fiber and parenchyma. While there is some epidermal tissue associated with the leaf bases and inflorescence of these resources, much of the epidermal tissue of these plants is removed prior to cooking (Woltz 1998). The bulb of wild onions contains a great deal of epidermal tissue, as do the nopales of a prickly pear. Utilizing both lines of evidence allows for a better evaluation of the relative importance of each of these resources.

Fiber ultimates from samples of each of the staple resources were quantified using a microscope (Table 9). Individual cells were measured for length, cell wall thinkness, lumen thickness. Distinguishing characteristics derived from the fiber literature, such as cell ends and cross markings, were also noted. This reference data were compared to existing publications available on fiber analysis, generally, and several of these taxa specifically (Arruda and Melo-De-Pinna 2010; Bell and King 1944; Catling and Grayson 1998; Mayorga-Hernandez 2004; Mclaughlin and Schuck 1991; Olivotto 1996; Pando-Moreno 2008). While there is overlap in the dimensions recorded for lechuguilla and sotol, visual inspection under the microscope microscope clearly distinguishes between the two botanical sources. Sotol fibers are significantly more gracile in appearance, with thinner cell walls (Figures 15 and 16). Both prickly pear and onion fibers are extremely short in comparison to most species examined in the literature (Figures 17-19). In many ways, these cells appear more similar to schlerids than true fiber ultimates. Overall, the fiber ultimates from these four taxa are readily distinguishable from one another (Figures 15-19).

Table 9. Fiber Ultimate Measurements (based on 50 individual cells)

Species	**Mean Length (µm)**	**Mean Width (µm)**	**Mean Cell Wall Width (µm)**	**Mean Lumen Width (µm)**
Agave lechuguilla	620	26.5	11.3	3.8
Dasylirion wheeleri	1200	24.2	9.4	5.1
Opuntia sp.	220	21.7	3.3	17.5
Allium sp.	460	8	1.5	4.5

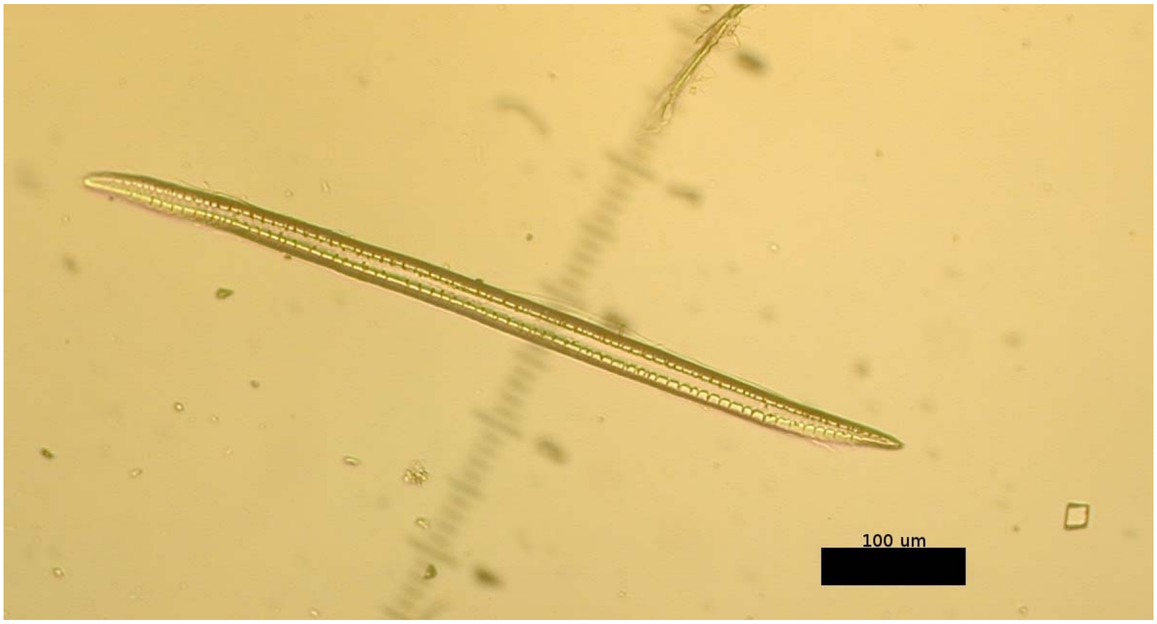


Figure 15. Fiber Ultimte from A*gave lechuguilla*

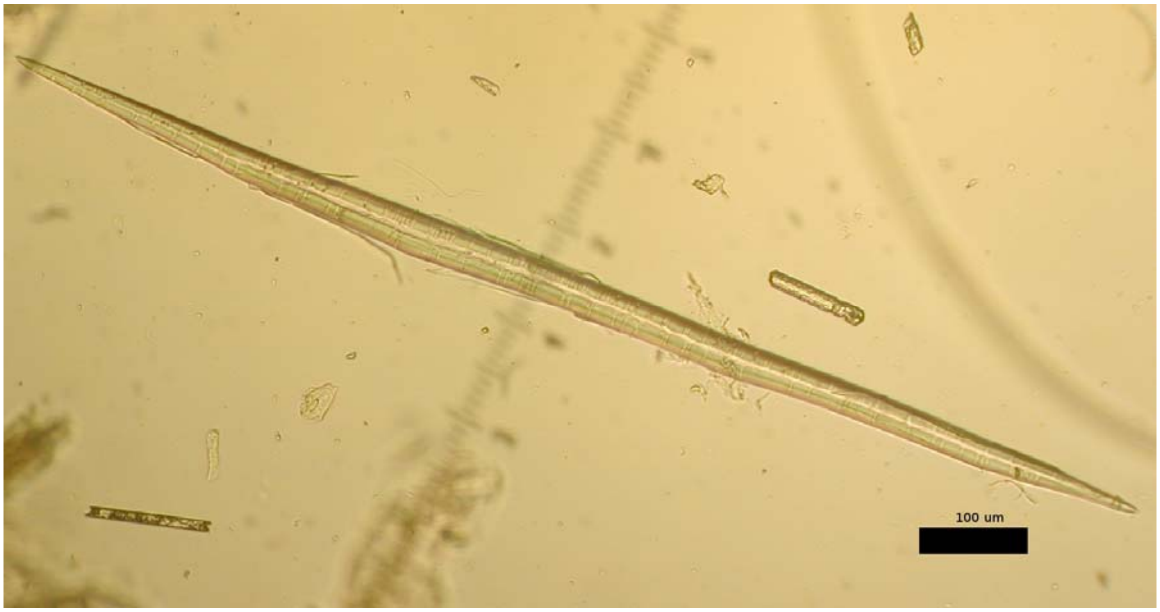


Figure 16. Fiber Ultimate from *Dasylirion wheeleri*

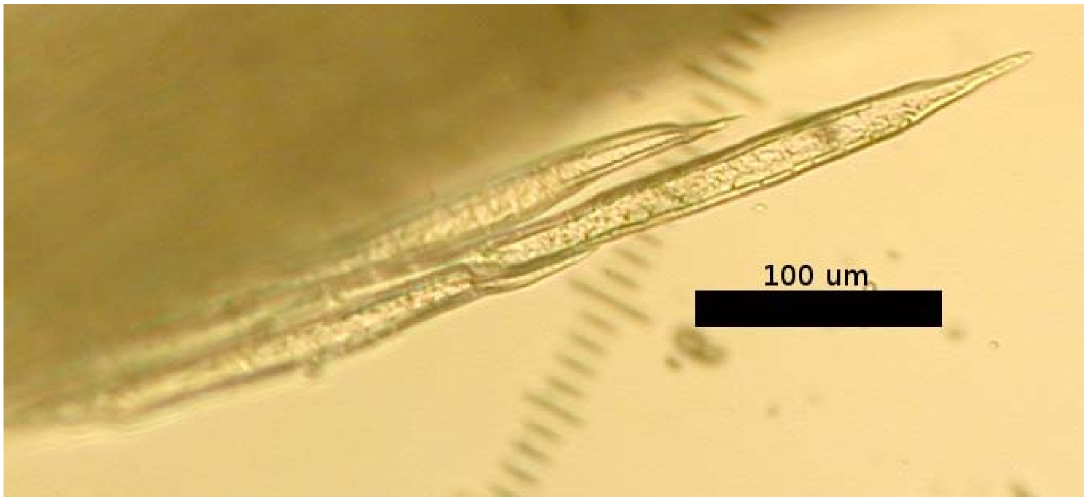


Figure 17. Fiber ultimates from *Opuntia* sp.

Figure 18. Vascular bundle from *Opuntia* sp.

Figure 19. Fiber Ultimate from *Allium* sp.

Epidermal Tissue. Besides fiber, epidermal tissue makes up the bulk of most coprolite samples examined from the Lower Pecos canyonlands (Bryant 1969, 1974b; Edwards 1990; Fry 1975; Riskind 1970; Sobolik 1991a; Stock 1983; Williams-Dean 1978). While this has been investigated in some of the prior studies (Sobolik 1991a; Williams-Dean 1978), the overall importance of these data have been neglected. Epidermal cell shape and arrangement were used as distinguishing characteristics to classify the abundant sheets of plant epidermis present in each sample. Multiple samples were taken from each component identified in the macrobotanical sorting stage of analysis. Identification was made with reference to the literature (Sobolik 1992; Stoddard 1965) as well as the development of epidermal reference collections for the major resources known for the Lower Pecos canyonlands (Figures 20-23). In addition to the four primary taxa in this study, epidermal references were made for several other taxa that may have been important seasonal resources, such as amaranth (*Amaranthus cruentus*) fruit, mesquite (*Prosopis glandulosa*) seedpods, panic grass (*Panicum obtusum*) seeds, crow poison (*Nothoscordum bivalve*) bulbs, giant rain lily (*Cooperia pedunculata*) bulbs, wild grape (*Vitis sp.*) fruits, and dog-tooth violet (*Erythronium mesochoreum*) bulbs. This epidermal reference material is not presented here for the sake of brevity.

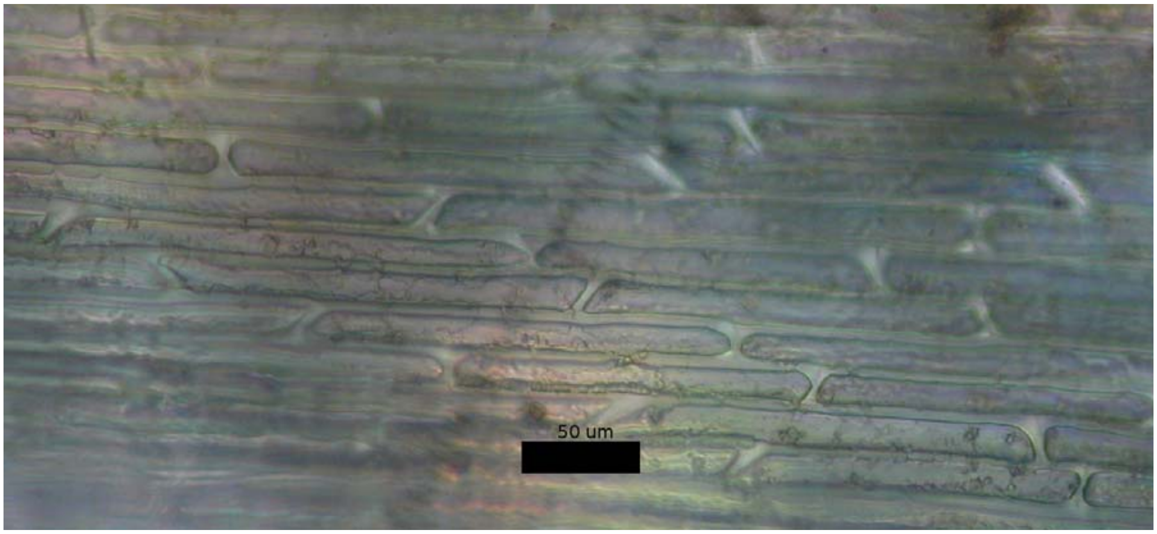


Figure 20. Epidermal cells from *Dasylirion wheeleri*

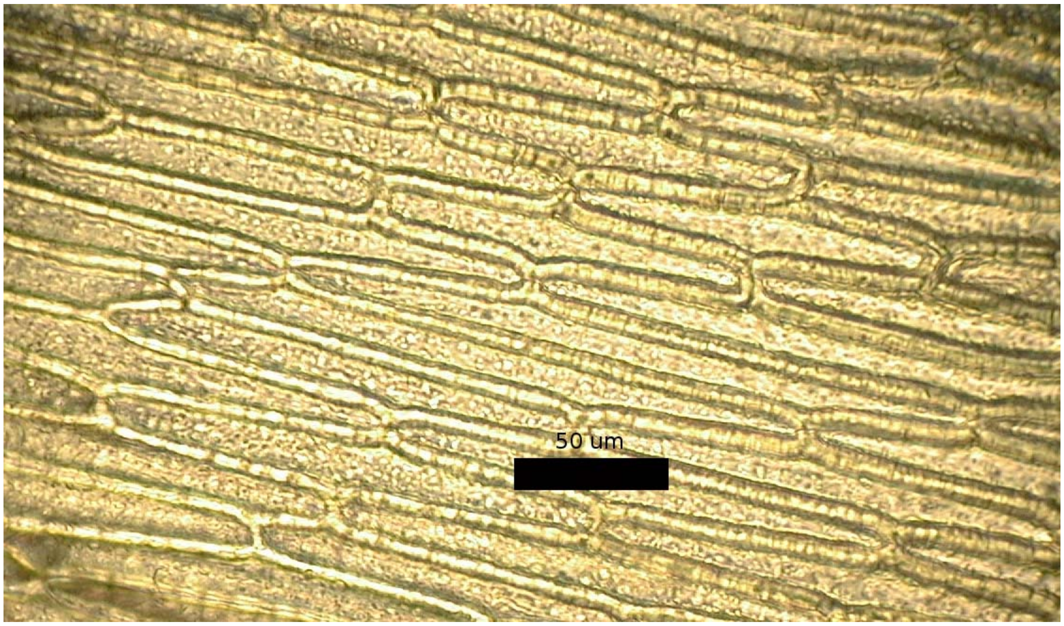


Figure 21. Epidermal cells from *Agave lechuguilla*

Figure 22. Epidermal Cells from *Opuntia* sp.

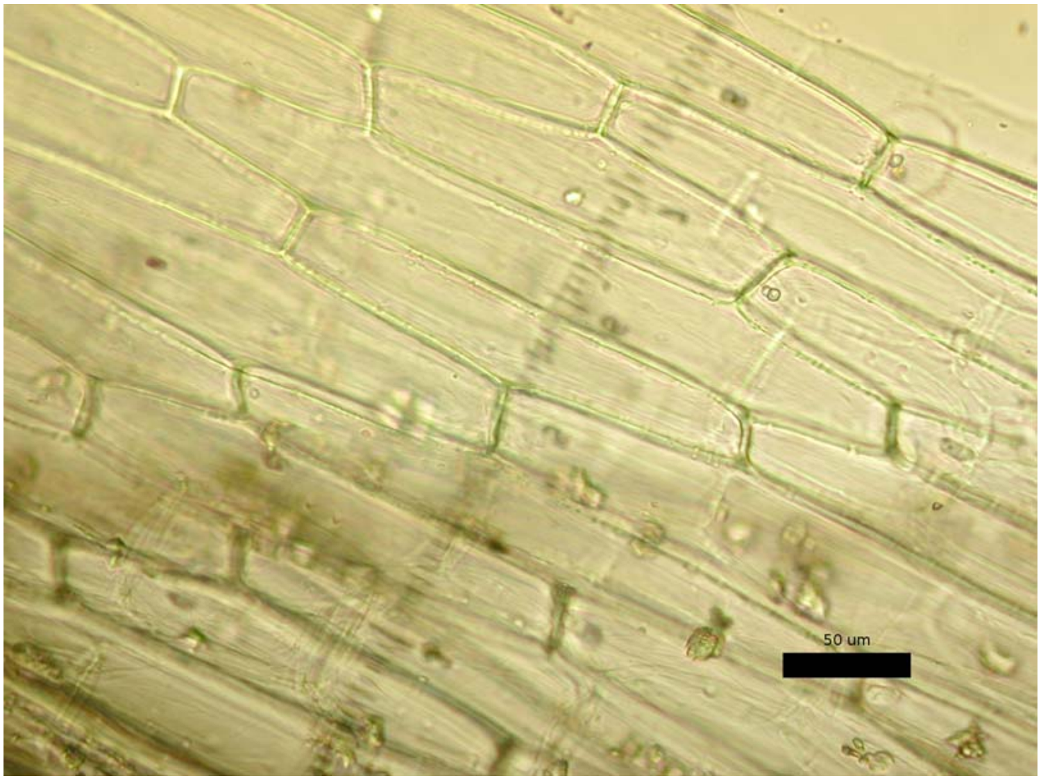


Figure 23. Epidermal cells from wild *Allium* sp.

Phytoliths. Phytoliths can make up as much as 40% of the volume of a coprolite sample (Danielson 1993; Stock 1983). While most studies focus on silica phytoliths, the major resources of the Lower Pecos canyonlands contain abundant crystals of calcium oxalate (Danielson 1993; Danielson and Reinhard 1998; Ginestra 2009; Jones and Bryant 1992; Monje 2002; Olivotto 1996; Reinhard and Danielson 2005). Phytolith evidence has also been recovered in dental calculus (Buchet 2001; Fox 1994; Hardy et al. 2009; Henry and Piperno 2008; Lalueza Fox et al. 1996; Middleton 1994; Philippe 2010), and may be a major cause of dental wear observed among skeletal populations in the region (Danielson 1993; Danielson and Reinhard 1998; Reinhard and Danielson 2005). These crystal morphotypes, while not specific enough to distinguish resources to specific taxa, provide a third line of evidence to evaluate use of the staple resources considered in this study, along with fiber and epidermal tissue.

Calcium oxalate crystals occur in three major types in botanical tissue from the region (Figures 24-27). It should be noted that other species not considered here also produce the same morphotypes of calcium oxalate crystals, though rarely in the abundance encountered in the three resources considered here. *Opuntia* sp. are characterized by the abundance of druse crystals throughout the vegetative structure of the plant (Figure 24). While there are distinct taxonomic differences in druse morphology observable under SEM (scanning electron microscopy) (Jones and Bryant 1992), this current study considers these as one class, regardless of size or shape of crystalline development.

Both lechuguilla and sotol produce two different but related morphotypes, raphide and styluses (Figures 25 and 26). Raphides occur both individually and in bundles throughout the vegetative structure of the plant. The stylus morphotype is also encountered throughout the vegetative tissue of both of these plant resources. Preliminary SEM studies of the phytolith component of lechuguilla and sotol have not produced any readily discernable unique characteristics to distinguish between the two taxa (Riley 2006). In the current study, both raphide and stylus morphotypes are considered to represent a joint class of lechuguilla and sotol. Wild onion resources did not yield any phytoliths in the creation of the reference collection for this study. Mesquite yielded a family specific phytolith morphotype (Danielson 1993) that was also encountered in a coprolite specimen (Figure 28). A minimum count of 200 phytoliths was made for each coprolite specimen. No attempt was made to calculate a concentration value for phytoliths, although this may be a useful tool for further study.

Figure 24. Druse phytoliths from Opuntia sp.

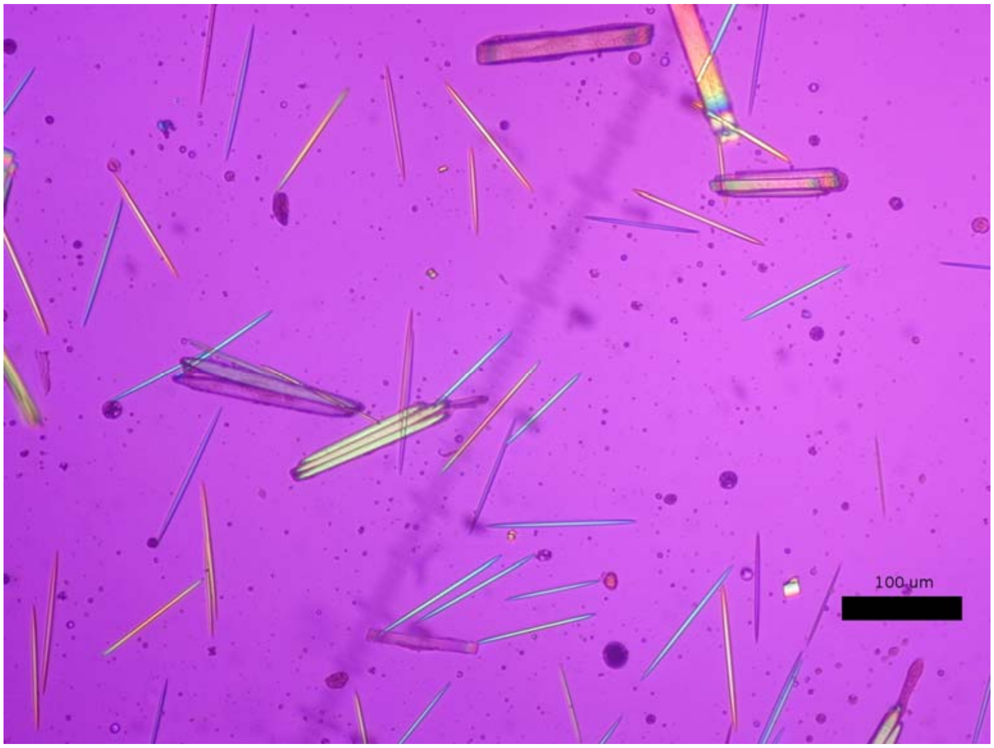


Figure 25. Raphide and Stylus Phytoliths from Agave lechuguilla leaf

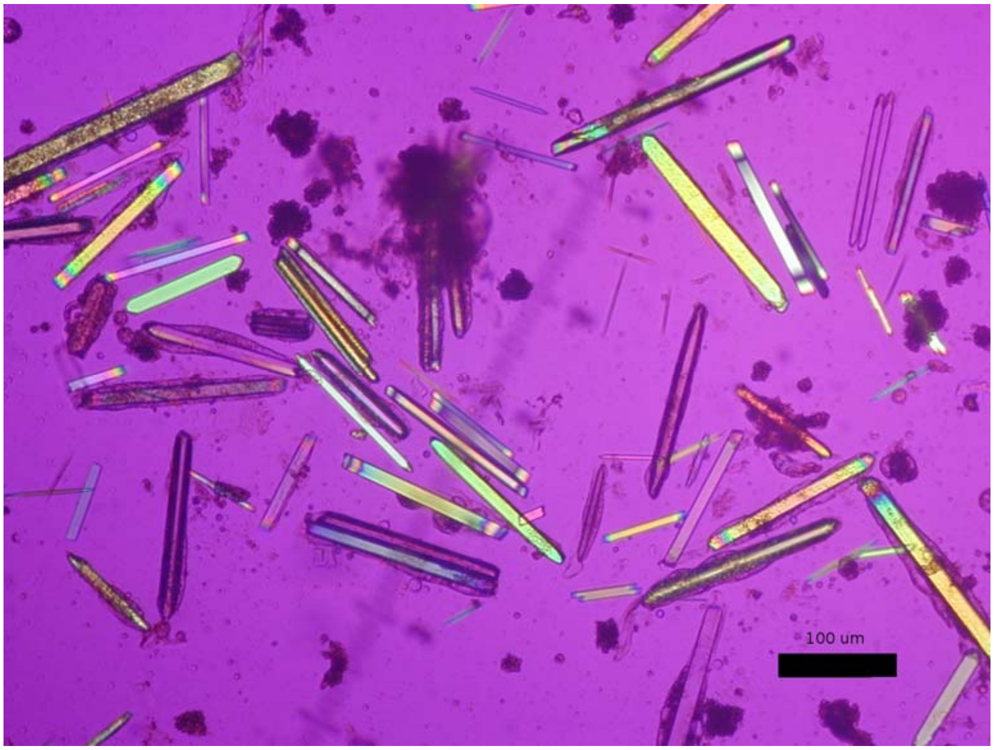


Figure 26. Stylus Phytoliths from Agave lechuguilla caudex

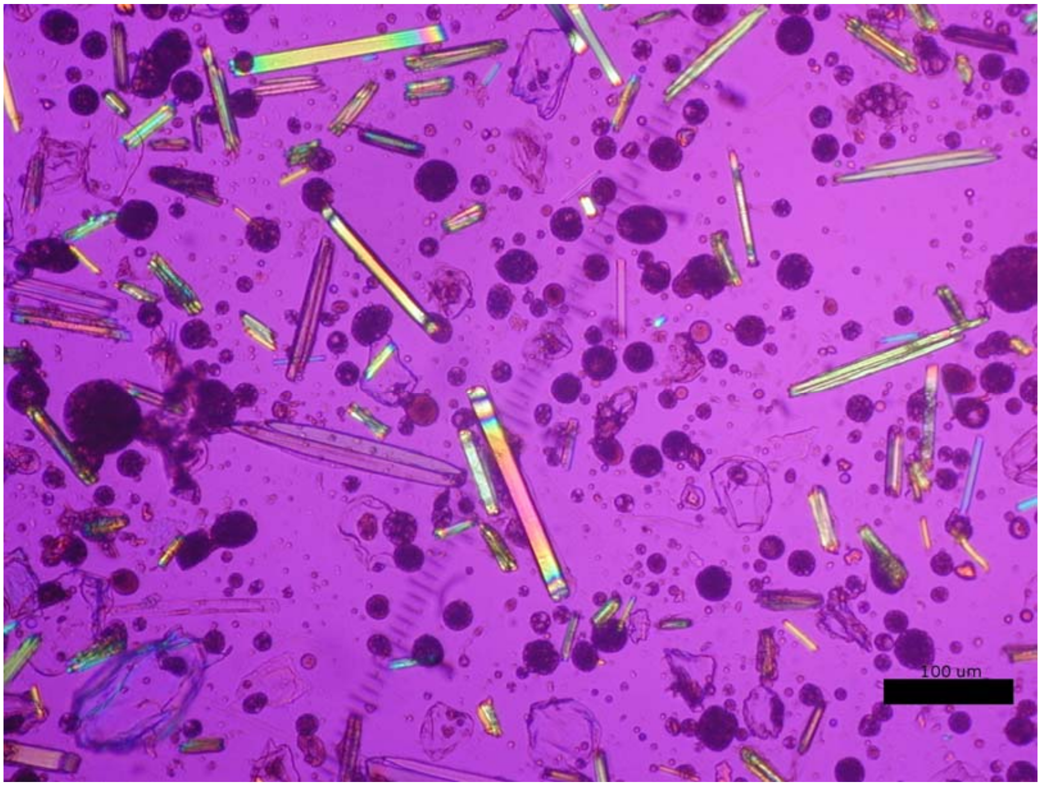


Figure 27. Stylus Phytoliths from Dasylirion wheeleri leaf base

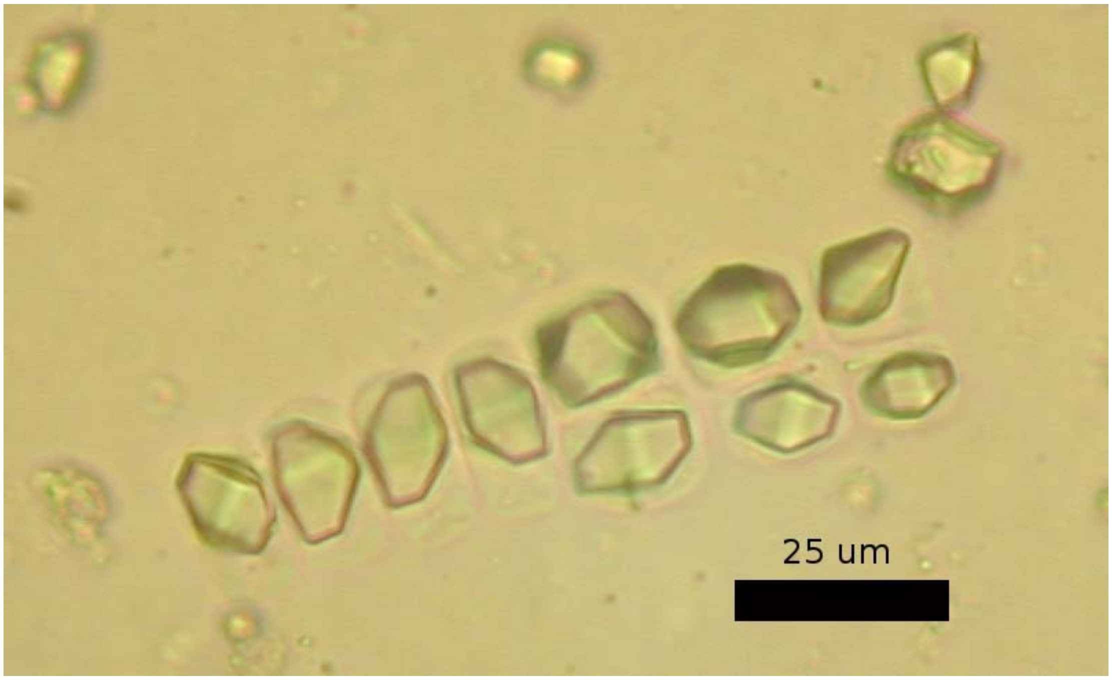


Figure 28. Phytoliths from Prosopis glandulosa seedpod

Starch Reference Collection. Archaeological starch research has seen little application to hunter-gatherer sites in North America (Messner 2008; Zarrillo and Kooyman 2006). This is partly due to the need for a reference collection of major potential food resources for each region. The development of this collection is hindered by the rare recovery of geophytes and small seeds from the archaeological record, as well as the imprecision of the observations available in the the ethnohistoric record (Thoms 2008b). These limitations are ameliorated in the Lower Pecos canyonlands by the recovery of many plant resources in the rockshelters across the region, as well as the extensive coprolite data available. This section presents an overview of the starch reference collection developed over the course of this research following a brief review of the microscopic methods useful in starch grain analysis.

Despite the long history of microbotanical analyses of coprolites in archaeology, very few of these studies have attempted to recover starch granules. Exceptions include work by Horrocks on coprolites (Horrocks 2004, Horrocks et al. 2004) and latrine fill (Horrocks and Best 2004) from New Zealand. Other researchers have noted the presence of starch in coprolite samples (Reinhard Personal Communication), but have not formally analyzed or published on this component of the microbotanical record. While starch is not used as a storage carbohydrate in the previously identified plant staples of the Lower Pecos canyonlands, this technique could yield valuable insight into the use of secondary plant resources or, possibly, unidentified staples.

The identification of starch granules recovered from archaeological contexts has become one of the more important components of recent paleoethnobotanical studies over the last decade (see Torrence and Barton (2006) for an recent overview). While this is a relatively new subfield in archaeology, starch microscopy has long had a place in food science (Flint 1994) and botany (Cortella and Pochettino 1994). Starch was first observed and identified microscopically in 1719 by Antonie van Leeuwenhoek (Thomas and Atwell 1999). Since then, many researchers have shown that starch granules can be microscopically associated with botanical source material based on distinguishing morphological characteristics, the most important being shape and size (Badenhuizen 1965; Cortella and Pochettino 1994; Czaja 1978; Evers 1979; Moss 1976; Reichert 1913). This section provides an overview of some of the techniques used in the light microscopy of starch. Many of the diagnostic features of starch used by paleoethnobotanists, such as differences in the lamellae and hilum location, have been observed and described under brightfield light. Transmitted brightfield light can be used to observe starch granules but it can be very difficult to observe the features necessary to distinguish individual differences between starch grains (Barton and Fullagar 2006). Additionally, because starch grains generally exhibit very low contrast in most mounting media, it can be very difficult to observe granules from an unknown specimen with other microscopic components. For these reasons, much of the initial microscopy used to identify the presence of starch in an archaeological sample relies on polarized light microscopy.

All undamaged starch grains have a high degree of molecular orientation (Evers 1979). This structured organization of the granule results in a characteristic birefringence pattern when starch is viewed in cross-polarized light (Thomas and Atwell

1999). This uniaxial birefringent pattern is known variously as an extinction cross or a maltese cross (Barton and Fullagar 2006; Weaver 2003). Birefringence is a complex optical property of many ordered compounds. Light entering the specimen is split into two components which are plane polarized perpendicular to each other. The refractive index of a birefringent specimen varies with the direction of passage, causing one of the components to be retarded relative to the other component. This optical path difference creates either constructive or destructive interference when the two component waves recombine after leaving the specimen. When the resultant recombined light passes through a second polarizing filter (the analyzer) set at a right angle to the original polarizing filter, any light that has not passed through a birefringent compound will be prevented from passing the analyzer. This microscopic method is very useful for the initial investigation of unknown samples since starch grains are readily visible and relatively distinct from other birefringent biological compounds (Canti 1997, 1998, 1999; Haslam 2006; Loy 2006). Many of the samples examined from the Lower Pecos in this study and prior work contain a great number of thickened rings of cellulose that appear to be derived from prickly pear vasculature (Figure 18).

While the extinction cross does provide some distinguishing features and is useful for the initial indication of starch ubiquity, many of the attributes used to differentiate between starch types are obscured in polarized light microscopy. This method may also not detect damaged or gelatinized starch grains, which lose birefringence as the molecular order of native starch is disrupted (Evers 1979). Starch grains with very high amylopectin content may also not exhibit birefringent optical properties (Evers 1979).

Under traditional food preparation methods, starch grain structure can be modified by mechanical damage from grinding and milling techniques or gelatinized through wet cooking methods (Babot 2003). Freezing, dehydration, roasting, and charring can also cause damage to starch granules that alters diagnostic features necessary for the identification of native starch granules (Babot 2003). Starch grains recovered in coprolites or latrines may also exhibit enzymatic damage from partial digestion (Autio 2001; Evers 1979). Mechanical damage can result in four different types of modification; 1) radial cracking associated with the hilum, 2) chipping and splitting along the margins of the granule, 3) abrasions and 4) a partial loss of granule structure resulting in a "ghost" granule (Williams 1968). Starch grains that have been damaged by milling or gelatinization will absorb any of the cholozal series of dyes, the most commonly used ones being Congo Red and Trypan Blue (Evers 1979; Flint 1994; Lamb 2005). Due to greater water absorption, damaged starch grains take up these dyes while native starches will appear unstained (Banks and Greenwood 1975). Baker and Hobson (1952) report a combined staining procedure using Safranin O and Niagra Blue 4B that could differentiate between the undamaged and damaged regions of the granule. This appears to be particularly useful with granules subjected to enzymic hydrolysis (Baker and Hobson 1952). Congo Red is preferred due to its ease of application and the reversibility of the method (Evers 1979). This is due to the relatively weak hydrogen bonds between the chromophore and the hydroxyl groups of the starch molecules (Evers 1979).

Recently, Torrence et al. (2004) have applied digital image analysis and multivariate statistics to discriminate between starch granules from 29 taxa in one area of Papau New Guinea. The authors suggest that this approach is based on the implicit assumption of morphological distinctiveness underlying previous starch granule keys. This method used digital images to capture 18 variables related to starch grain morphology. While the authors suggest that discriminant analysis were successful in determining taxonomic affiliation for granules, none of the success rates exceeded 75% and were as low as 47% (Torrence et al. 2004). This is probably unacceptable for archaeological specimens, which yield small amounts of starch and would not have the statistical power to minimize identification errors during interpretation.

A potential method for distinguishing between unknown starch granules could develop out of the field of geometric morphometrics. This intriguing method has been successfully used in wildlife zoology (Clabaut et al. 2007; Foster 2008a; Navia et al. 2006), botany (Niklas et al. 1999; Shipunov and Bateman 2005), and paleoanthropology (Bookstein 2008; Gomez-Robles et al. 2007), but has not been applied to the identification of archaeological starch. This method uses the distribution of tightly defined landmarks to develop quantifiable, rigorous descriptions of shape (Elewa 2004; Mclellan and Endler 1998; Zelditch et al. 2004).

The current study utilized cross-polarized light microscopy for the initial identification of starch granules in the coprolite specimens. Granules identified as starch were further examined under brightfield light to detect features important for botanical source identification. No attempt was made to selectively stain damaged starch granules using the methods described above, although this is obviously an important next step in a study of coprolites, as granules could be damaged by both processing and digestion. This was not explored further in the present study, due to the lack of evidence for major food resources that utilize starch as a storage carbohydrate and limited recovery of undamaged starch in the current study.

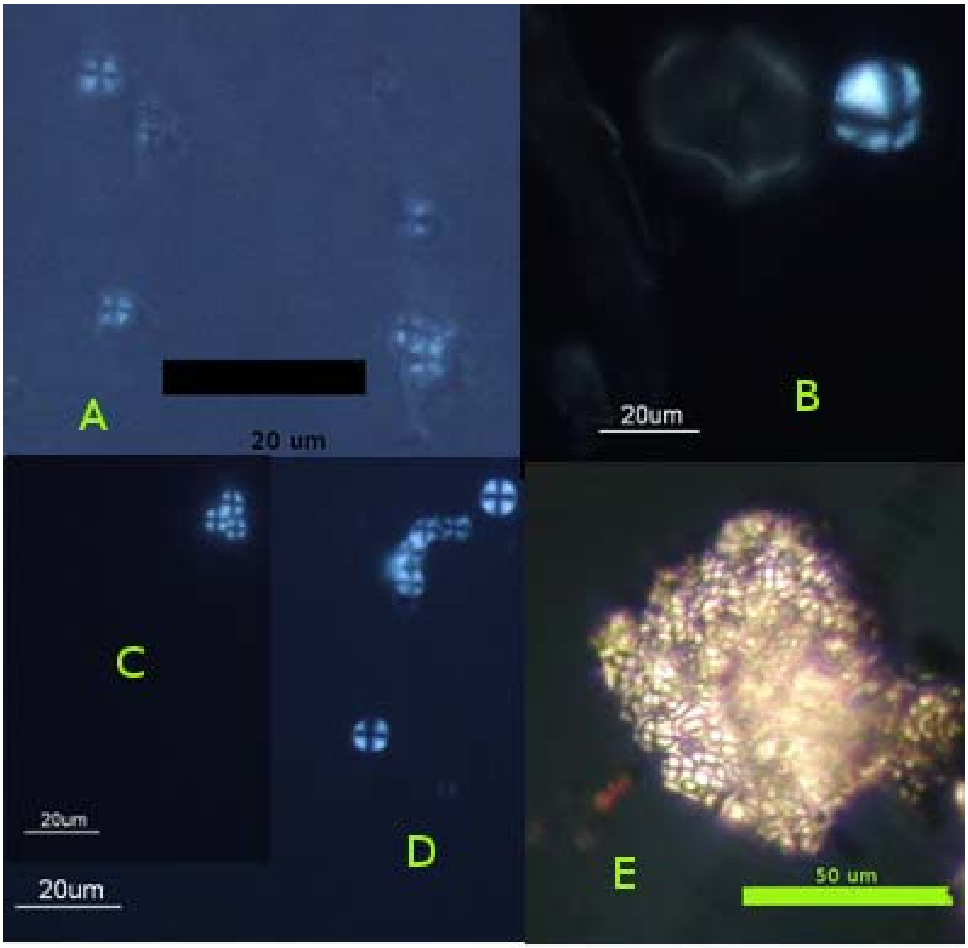


Figure 29. Cross-Polarized Light Micrographs of Starch Granules from Grass Seeds (A-Achnatherum hymenoides, B-Andropogon gerardii, C- Setaria lutescens, D- Panicum sonorum, E-Sporobolus asper)

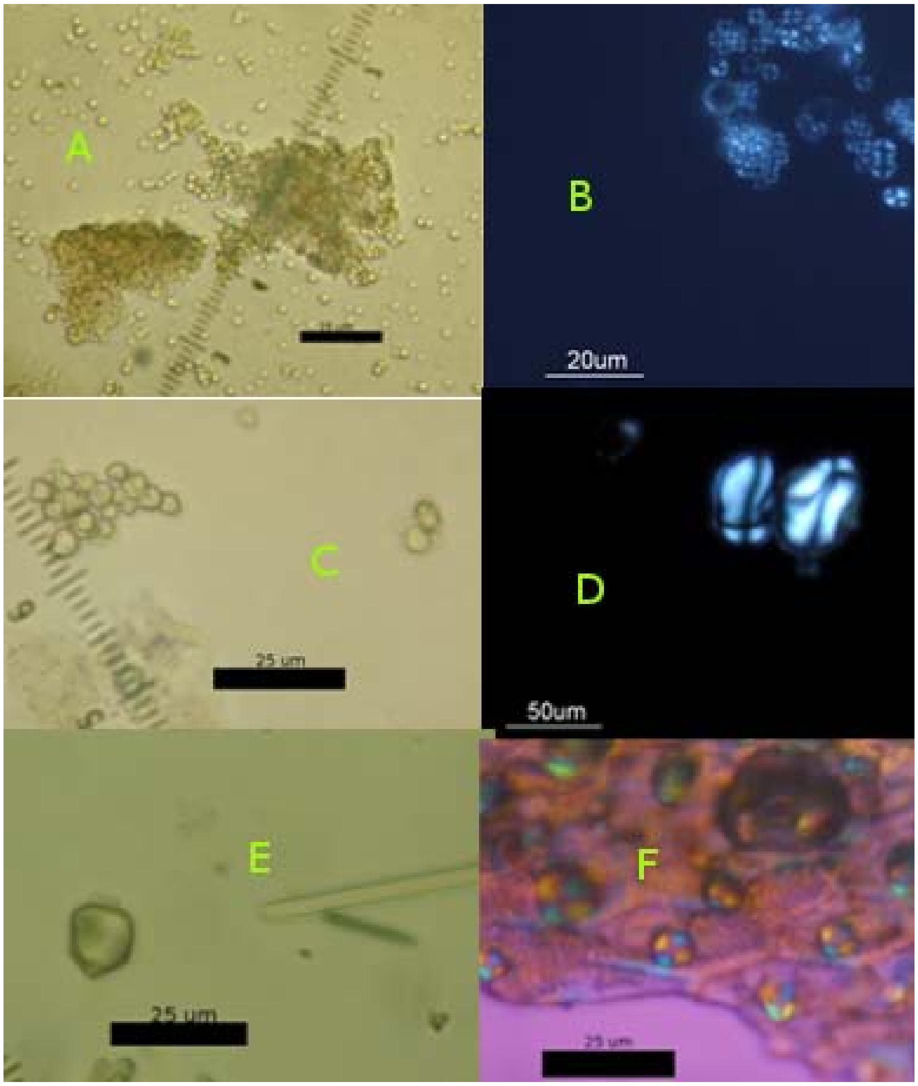


Figure 30. Micrographs of Starch from seeds and meristem (A- Brightfield Micrograph of Amaranthus sp., B- Cross-Polarized Light Micrograph of Carex Comosa, C- Brightfield Micrograph of Opuntia sp., D- Cross-Polarized Light Micrograph of Prosopis glandulosa, E- Brightfield Micrograph of Yucca bacata caudex, F- ¼ λ Retarded Cross-Polarized Light Micrograph of Yucca bacata leaf meristem)

The strength of starch analysis of coprolites from the Lower Pecos canyonlands is that it may reveal previously unknown plant food resources. It may also provide a line of evidence to re-evaluate the importance of known food resources, such as mesquite or acorns, that may leave little visible record in coprolite specimens. Figures 29-31 present micrographs of starch granules from some of the plant resources investigated in this study. Table 10 presents metric data for starch granules recovered from some of the known resources utilized in the region as well as some potential resources that have not been directly identified in the Lower Pecos canyonlands but are documented ethnographically in the broader region (Ebeling 1986; Havard 1895; Moerman 1998).

The staple plant resources of the Lower Pecos canyonlands were investigated for the occurrence of starch granules. Unfortunately, most of the major resources have little to no starch, using fructans as their primary storage carbohydrate (Darbyshire and Henry 1981; Lopez and Urias-Silvas 2007b; Mancilla-Margalli and Lopez 2006). The only starch noted during the microscopic examination of various component of these taxa were in the seeds of prickly pear tunas, which contain abundant small starch granules (Figure 30). *Yucca sp.* also has small starch granules throughout much of its vegetative structure (Figure 30). Interestingly, the caudex of this taxa contains very little starch, despite being the primary storage organ for the plant. The starch in yucca is primarily observed embedded in the meristematic tissue of the leaves of this genus (Figure 30).

Table 10. Measurements of Starch Granules from Modern Botanical References

Taxa	Part	Shape	Length (um)	Cross angle	Hilum	Fissures/ Striations	Lamellae	Vacuole/ Visible Hilum
Achnatherum hymenoides	seed	spherical	3.5-4.0	90	centric	Absent	Absent	Absent
Amaranthus sp.	small fruit	spherical	2.0-2.5	90	centric	Absent	Absent	Absent
Andropogon gerardii	seed	spherical	15.0-18.0	100	centric	Absent	Absent	Absent
Callirhoe involucrata	USO	spherical/oval	5.0-25.0	110	eccentric	Some	Present	Absent
Carex comosa	seed	spherical	3.0-5.0	90	centric	Absent	Absent	Absent
Claytonia virginica	USO	bell shaped	5.0-25.0	90	eccentric	Some	Present	Absent
Cooperia drummondi	USO	variable	15.0-50.0	110	eccentric	Present	Present	Present
Erythronium sp.	USO	bell shaped	45.0-55.0	130	eccentric	Absent	Present	Absent
Liatrus mucronata	USO	bell shaped	15.0-25.0	130	eccentric	Absent	Absent	Present
Nothoscordum bivalve	USO	lenticular/spherical	5.0-30.0	110	eccentric	Present	Present	Present
Opuntia sp.	seed	spherical	4.0-6.5	90	centric	Absent	Absent	Absent
Opuntia sp.	cladode	None	N/A	N/A	N/A	N/A	N/A	N/A
Opuntia sp.	tuna	None	N/A	N/A	N/A	N/A	N/A	N/A
Panicum sp.	seed	spherical	4.5-6.0	90	centric	Absent	Absent	Absent
Prosopis glandulosa	seedpod	variable	6.0-30.0	variable	eccentric	Absent	Some	Present
Quercus sp.	nut	ovoid	8.0-15.0	90-120	centric	Absent	Absent	Absent
Setaria lutescens	seed	spherical	6.0-8.0	90	centric	Absent	Absent	Absent
Smilax sp.	USO	bell shaped	7.0-12.0	90	centric	Absent	Absent	Present
Sporobolus sp.	seed	spherical	6.0-8.0	90	centric	Absent	Absent	Absent
Yucca bacata	Leaf	Spherical	13.0-19.0	90	centric	Absent	Absent	Present
Yucca bacata	Caudex	Spherical	10.0-15.0	90	centric	Absent	Absent	Present

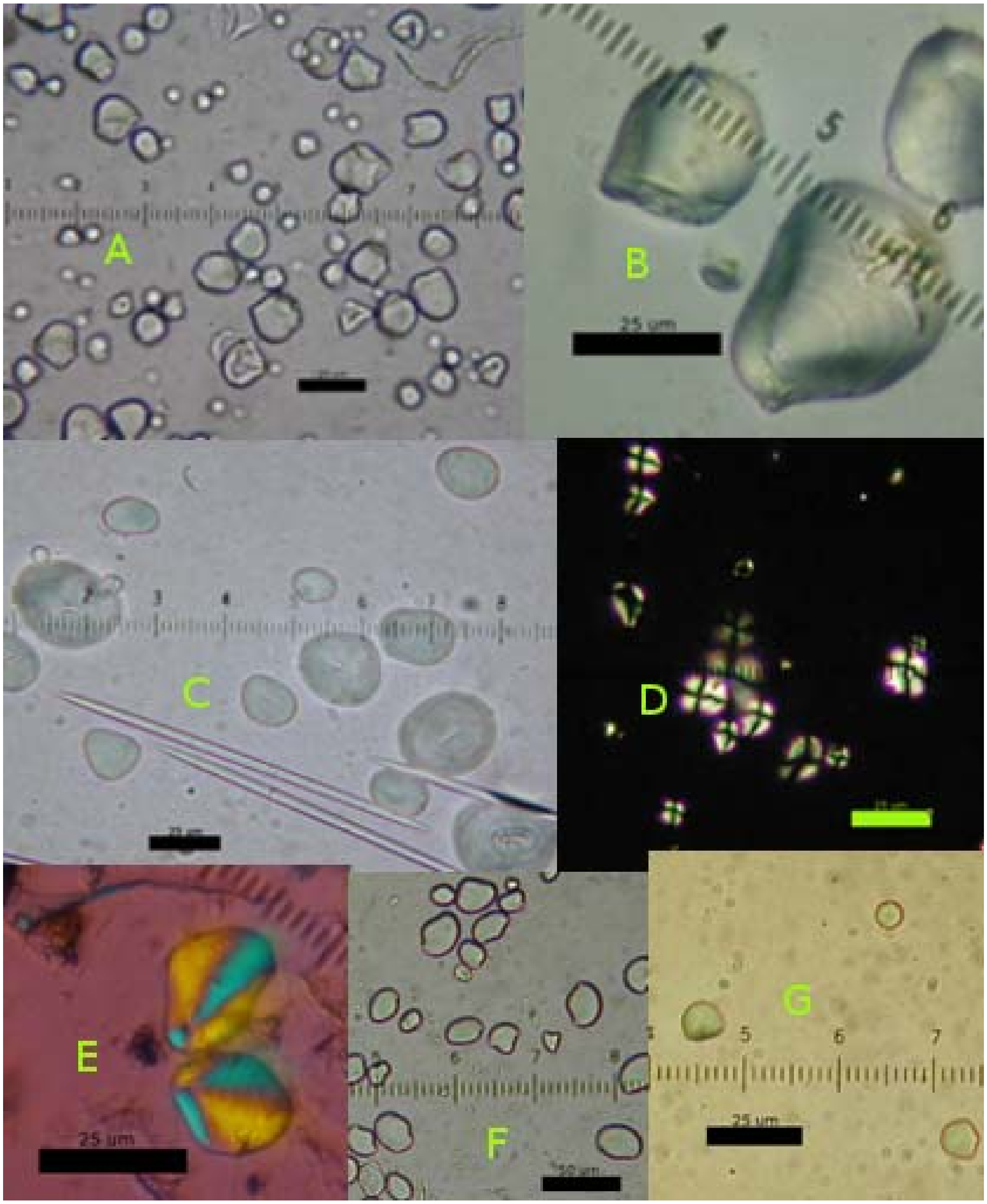


Figure 31. Micrographs of Starch Granules from Geophytes (A- Brightfield Micrograph of *Callirhoe involucrata*, B- Brightfield Micrograph of *Cooperia drummondi*, C- Brightfield Micrograph of *Claytonia virginica*, D- Cross-Polarized Light Micrograph of *Erythronium sp.*, E- ¼ λ Retarded Cross-Polarized Light Micrograph of *Liatrus mucronata*, F- Brightfield Micrograph of *Nothoscordum bivalve*, G- Brightfield Micrograph of *Smilax sp.*)

Sub-Sampling Coprolites

There is an unresolved debate among coprolite researchers on the proper amount of specimen to sub-sample (Callen and Cameron 1960; Dean 2006; Reinhard 1989; Reinhard and Bryant 1992; Sutton and Reinhard 1995). In the earliest modern studies of Callen and Cameron (1960), the normal procedure was to process the entire specimen for analysis. This approach was superseded by sub-sampling half of a coprolite along its axis of orientation, when observable, or the longest axis (Bryant 1969; Fry 1970; Heizer 1967; Riskind 1970; Williams-Dean 1978). This has continued to be the method employed by most researchers, as it leaves half of the specimen for future research while still providing an adequate representation of the overall specimen.

Some researchers have advocated sub-sampling on a much more discrete level, usually with very small, one to five gram sub-samples being removed from a specimen (Jones 1988; Reinhard 1989). This approach is useful in that the same specimen can be freshly sub-sampled for each type of analysis utilized in the study. However, there are concerns about the extrapolation of the material recovered in a single gram from a large specimen, some of which weigh well over 100 grams, to the dietary material distributed throughout the material as a whole (Dean 2006). Studies have demonstrated that pollen samples taken along the axis of colonic orientation of a coprolite are not similar and represent different mixtures of pollen types (Dean 2006). To date, there has been no attempt to systematically evaluate the different sub-sampling strategies utilized for coprolite research.

In developing this dissertation research, I have conducted a pilot study evaluating the relationship between different sub-samples of the same specimen. Three specimens from lens 10b had three sub-samples taken for examination (Table 11). Two samples (a,b) were from the specimen and a third (c) from the loose material bagged with the specimen. Each sub-sample was treated following standard methods outlined above and examined for macrofossil components, phytoliths, epidermal fragments, and starch content (Table 12). Overall, the sub-samples from each specimen give a generally similar image of dietary consumption. The staple resources consumed by each individual are apparent across all three sub-samples but none of the sub-samples represent the entire dietary menu contained in the specimen. This is corroborated by the pollen data presented in Dean (2006). This study suggests that sampling half of a specimen along its longest axis remains the best compromise between accurately assessing the diet reflected in a coprolite and preserving part of the unaltered specimen for future research methods.

Table 11. Measurements of Coprolite Specimens used in Sub-Sampling Study

Sample Designation	21-1a	21-1b	21-1c	21-2a	21-2b	21-2c	21-3a	21-3b	21-3c
Weight (g)	1.60	1.61	1.67	1.60	1.63	1.62	1.60	1.65	1.68
Total Weight (g)	63.80	63.80	63.80	72.00	72.00	72.00	33.02	33.02	33.02
Fragmentary Weight (g)	36.84	36.84	36.84	46.81	46.81	46.81	10.45	10.45	10.45

Table 12. Data from Sub-Sampling Study

Category	Sample Designation	21-1a	21-1b	21-1c	21-2a	21-2b	21-2c	21-3a	21-3b	21-3c
Macrobotanical	Allium sp. leaf	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volume (ml)	Fiber	2.59	0.90	3.57	0.57	3.69	1.02	0.00	0.00	0.00
	Opuntia sp. Vascular	0.29	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10
	Dasylirion sp. quids	0.00	2.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macrobotanical	Allium sp. bulb		2							
Counts	Dasylirion sp. leafbas	1								
	Opuntia sp. Spine							1		
	Opuntia sp. Glochid									1
	Opuntia sp. Seed			1			1			1
	Bone			5	2	1	1			
Epidermal Cell	Agave sp.		y				y		y	
and Starch Grain	Allium sp.	y	y	y	y	y	y		y	
Ubiquity	Dasylirion sp.	y	y							
	Opuntia sp.	y						y	y	y
	Starch	y		y			y			
Phytolith %	Raphide	62	57	57	59	67	69	69	62	64
	Druse	18	20	19	10	9	9	23	27	24
	Stylus	21	23	24	31	23	21	8	11	11
	Bilobate					0.37	0.36			

Laboratory Procedures and Analysis

Ten specimens were selected from the coprolite assemblages of the three lenses described in Chapter V. The overall goal was to select specimens that reflected the diversity of shape and size present in the total assemblage for each lens. The selected specimens were documented following recent recommendations for standardized coprolite analysis (Table 13) (Jouy-Avantin et al. 2003). Digital photographs were taken of each specimen, along with measurements and dry weight. Following this, each specimen was brushed to remove loose dust and obvious external adherents and sub-sampled. The dry weights of the resulting loose fraction as well as the sub-sampled portion of each specimen were recorded. The coprolites were divided along the longest axis. Many of these specimens were flattened patties, with no obvious axis of orientation. The specimens were cut with a razor, although frequently the specimen would crumble or break along internal points of weakness during this process. This method of sub-sampling leaves half of the specimen for future analyses while providing a representative sample of the overall dietary information in each specimen. Sub-sampling methods in coprolite studies are discussed further in the following section. Following Callen and Cameron (1960), the specimens were placed in a 0.5% Tri-sodium phosphate (w/v) solution for a minimum of 48 hours. Specimens were examined after 48 hours, gently stirred, and allowed to sit longer if rehydration was not complete. The solution was examined for color and odor. All specimens examined turned the solution an opaque brown to black, a reaction of the solution to the bile acids in the coprolites (Fry 1985; Sutton et al. 2010). Most of the specimens exhibited a slight scatological odor during re-hydration. This was not particularly pungent but it was noticeable. This is expected based on the dominance of plant derived components in all of the specimens (Fry 1985; Moore et al. 1984).

Each specimen was screened through a 350 µm geologic sieve and washed with a solution of 50% ethanol to break the surface tension of water and disperse trapped microfossils in the fiber matrix. This sieve size was chosen to ensure that all seeds would be recovered in the coarse fraction and larger phytoliths and pollen grains would pass into the fine fraction (Pearsall 2000). The coarse fraction on the sieve was rinsed with water and stored for analysis of the macrofossils considered in this study. The fine fraction collected under the sieve was allowed to settle for at least 6 hours before siphoning off the supernatant. The resulting material was collected and sub-sampled for phytolith, starch, and pollen analysis (Figure 32).

Table 13. Measurements of Coprolite Specimens

Sample ID	Excavation Unit	Lens	Maximum Length (mm)	Maximum Width (mm)	Maximum Thickness (mm)	Weight (g)	Weight of frags (g)	Munsell Color	Sample Weight (g)
14x-1	B Block - North	VIII	106	86	34	100.22	4.40	5y 7/2	49.06
14x-2	B Block - North	VIII	90	78	33	86.52	31.27	5y 8/3	64.78
14x-3	B Block - North	VIII	111	96	27	71.22	18.98	5y 7/2	44.31
14x-4	B Block - North	VIII	128	77	25	70.94	7.85	5y 7/2	38.33
14x-5	B Block - North	VIII	120	101	16	50.14	5.30	5y 8/3	24.06
14x-6	B Block - North	VIII	80	51	12	14.50	17.50	5y 8/1	12.48
14x-7	B Block - North	VIII	124	86	23	86.08	11.62	5y 7/2	40.49
14x-8	B Block - North	VIII	103	89	23	70.02	9.40	5y 7/2	38.12
14x-9	B Block - North	VIII	94	90	42	107.21	13.27	5y 7/2	55.35
14x-10	B Block - North	VIII	104	80	41	68.41	10.50	5y 7/2	35.45
15x-1	B Block - North	VIIIB	92	92	37	58.05	21.75	5y 7/2	26.52
15x-2	B Block - North	VIIIB	91	58	34	60.35	0.00	5yr 8/2	27.00
15x-3	B Block - North	VIIIB	107	95	44	77.40	0.00	5y 7/2	38.41
15x-4	B Block - North	VIIIB	81	55	29	40.38	0.00	5y 6/4	20.34
15x-5	B Block - North	VIIIB	104	71	32	68.35	5.35	5y 7/1	17.74
15x-6	B Block - North	VIIIB	80	65	19	36.54	0.00	5y 7/2	19.55
15x-7	B Block - North	VIIIB	104	91	51	68.32	0.00	5y 8/2	33.89
15x-8	B Block - North	VIIIB	88	74	25	77.63	0.00	5y 8/2	27.08
15x-9	B Block - North	VIIIB	111	80	30	83.98	0.00	5y 8/2	39.60
15x-10	B Block - North	VIIIB	104	68	27	67.30	0.00	5y 8/1	36.89
21x-1	B Block - South	Xb	84	78	32	63.80	36.84	5y 7/2	26.96
21x-2	B Block - South	Xb	71	37	33	72.00	46.81	5y 7/2	25.19
21x-3	B Block - South	Xb	NA	NA	NA	33.02	10.45	5y 7/2	22.57
21x-4	B Block - South	Xb	113	111	45	116.87	55.23	5y 7/2	63.05
21x-5	B Block - South	Xb	74	55	28	22.29	25.93	5y 7/2	10.49
21x-6	B Block - South	Xb	112	106	33	107.48	0.00	5y 7/2	63.28
21x-7	B Block - South	Xb	65	64	26	25.28	0.00	5y 7/2	14.44
21x-8	B Block - South	Xb	60	47	17	12.86	18.34	5y 7/2	5.45
21x-9	B Block - South	Xb	74	49	20	17.15	12.12	5y 7/2	10.95
21x-10	B Block - South	Xb	86	86	24	47.74	19.28	5y 7/2	26.74

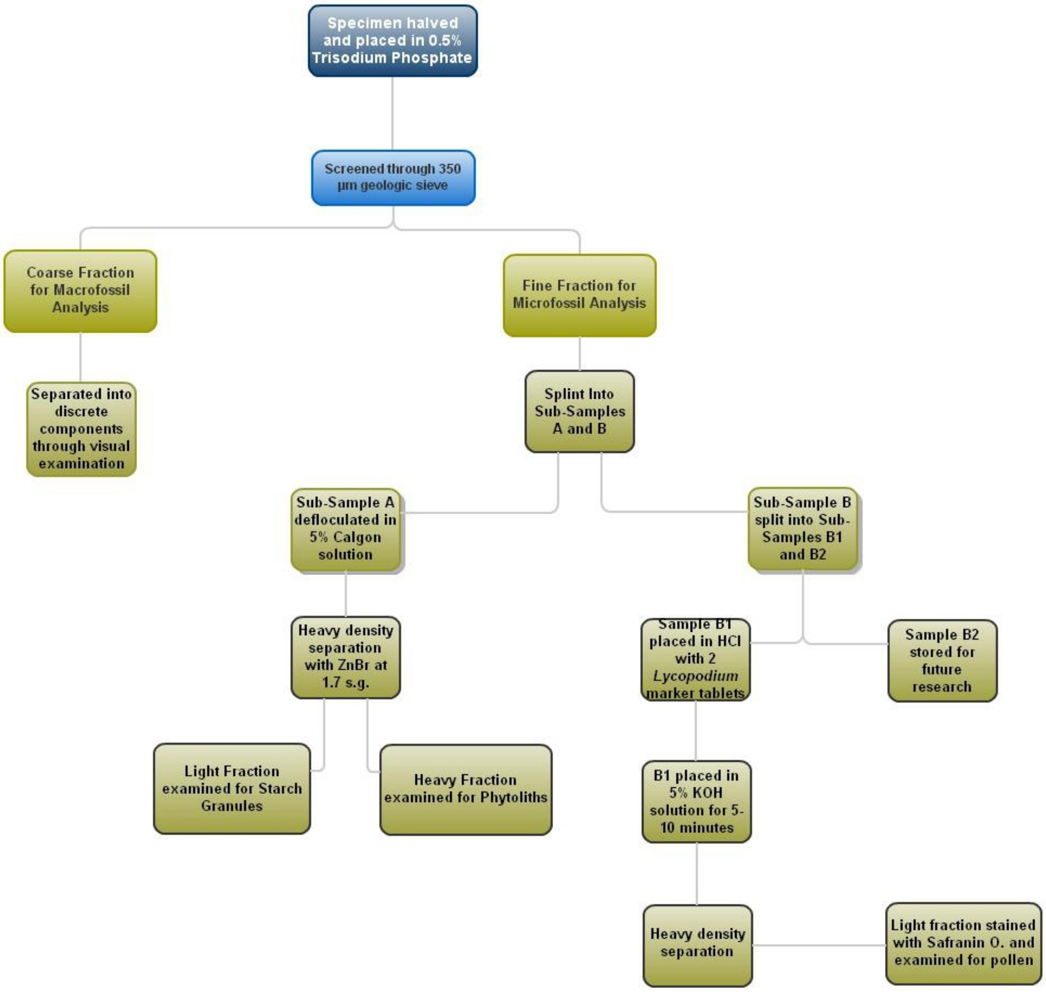


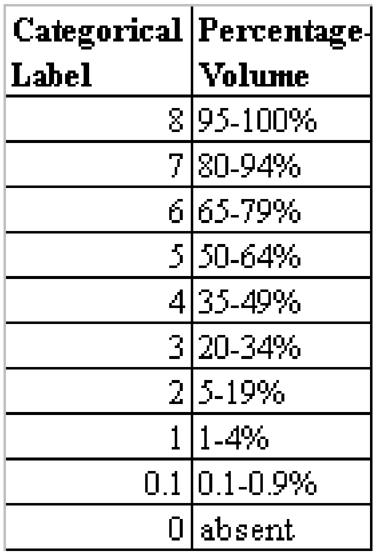
Figure 32. Flowchart of Coprolite Processing

Macrofossils. The material collected for macrofossil identification was not dried out following the rehydration technique. Repeated wetting and drying has deleterious effects on many cellular components (Gorham and Bryant 2001; Holloway 1981). The coarse fraction, suspended in a 5% ethanol solution, was transferred to a large, shallow tray and examined under an illuminated lab-bench magnifier, as well as a Wild Heerbruug dissecting microscope at 6-25x magnification when necessary. This initial examination separated the different components of each specimen for identification. Components, such as plant epidermal tissue and fiber bundles, that required high magnification for proper identification were mounted on slides in a 50/50 glycerol and water mounting medium, covered with a cover slip and sealed.

Identification of seeds was aided by the seed reference collection at Texas A&M University's Paleoethnobotany Laboratory and seed identification manuals (Knight 1978; Martin and Barkley 1973; Young and Young 1992). Bone and scales were cursorily examined but not identified. Epidermal and fiber cells were examined further using a Nikon Optiphot metallurgical microscope using the 4x (NA 0.1), 10x (NA 0.25), and 20x (NA 0.4) objectives. These components were identified with a reference collection developed for the study, described above, and referral to published sources (Bell and King 1944; Bock et al. 1988; Catling and Grayson 1998; Danielson 1993; Hather 1991; Mclaughlin and Schuck 1991; Olivotto 1996; Pando-Moreno 2008; Sobolik 1992; Stoddard 1965).

Quantification of the macrofossil components of each specimen was done through direct measurement of volume. This was converted to percentage-volume to conform with prior quantification methods used in coprolite studies in the Lower Pecos canyonlands (Bryant 1974b; Edwards 1990; Sobolik 1988b; Sobolik 1991a; Stock 1983; Williams-Dean 1978). This has been converted into an ordinal scale taken from Sobolik (1991a) to minimize inter-researcher error in estimation (Table 14).

Table 14. Ordinal Scale for Percent-Volume Measurements (based on Sobolik 1991)



Categorical Label	Percentage-Volume
8	95-100%
7	80-94%
6	65-79%
5	50-64%
4	35-49%
3	20-34%
2	5-19%
1	1-4%
0.1	0.1-0.9%
0	absent

Phytoliths, Pollen, and Starch. The fine fraction collected under the sieve was gently vortexed, split into two equal samples (A and B) by volume, and placed in 50ml nalgene testtubes (Figure 32). Subsample A from each specimen was processed for phytoliths and starch. This processing followed a modification of the procedure by Coil et al. (2003). The samples were placed in a solution of 5% Calgon (Sodium hexametaphosphate) overnight in order to deflocculate the sample and disperse any aggregated components. The samples were then centrifuged for 3 minutes at 2500 rpm and decanted until the supernatant was clear. The sample was then centrifuged for 10 minutes, decanted, and inverted to dry. A zinc bromide solution with a specific gravity of 1.7 was added to the sample, which was then gently stirred (Coil et al. 2003). Many archaelogical starch researchers use a heavy density solution with a specific gravity of 1.7 because all known starch are suspended at this density (Torrence and Barton 2006). Most of the samples in this study caused a slight reaction with the HCl used to suspend the zinc bromide, probably due to the presence of microscopic shell, bone, and limestone

($CaCO_3$) fragments in each sample. The sides of the tube were washed with 95% ethanol and water was added to the sample, being careful not to break the surface tension of the zinc bromide solution. The sample was then centrifuged at low speeds (under 1000 rpm) for 5 minutes, followed by high speed (2500 rpm) for another five minutes. The resultant band of material suspended at the interface of the zinc bromide and water was removed and place in a second test tube. This procedure was repeated until no visible accumulation of material occurred at the interface. The resulting heavy and light fractions were washed in water three to five times and stored in dram vials. The light fraction was microscopically examined for the presence of starch granules using the 40x (NA 0.65) objective of a Nikon Optiphot metallurgical microscope. The heavy fraction from this procedure was microscopically examined for phytoliths with the 20x (NA 0.4) and 40x (NA 0.65) objectives of a Nikon Optiphot metallurgical microscope. A minimum of 200 phytoliths per sample were counted. Additionally, the light fraction was scanned for unique phytolith shapes.

Sub-sample B was vortexed thoroughly and split in half by volume into sub-samples B1 and B2. Sub-sample B1 of each specimen was placed in a beaker with 2 *Lycopodium* tablets (18,583 +/- 764 spores/tablet) and HCl to cover. After the reaction was no longer discernable, more HCl was added to ensure complete dissolution. This was diluted with water and allowed to settle for a minimum of 3 hours. Most of the supernatant was siphoned off from the samples, which were transferred to 50 ml nalgene test tubes. These were centrifuged,decanted, and diluted with distilled water twice to ensure that all HCl had been washed out. The samples were then placed in a 5% KOH solution for 5-10 minutes, depending on the sample. Any remnant KOH was removed by centrifuging and decanting each sample three times. The sample was then centrifuged for 10 minutes, decanted, and inverted to dry. A zinc bromide solution with a specific gravity of 2.0 was added to the sample, which was then gently stirred. This relatively heavy specific gravity was chosen to ensure that all the pollen grains in the sample were captured in the light fraction. The sides of the tube were washed with 95% ethanol and water was added to the sample, being careful not to break the surface tension of the zinc bromide solution. The sample was then centrifuged at low speeds (under 1000 rpm) for 5 minutes, followed by high speed (2500 rpm) for another five minutes. The resultant band of material suspended at the interface of the zinc bromide and water was removed and place in a second test tube. This procedure was repeated until no visible accumulation of material occurred at the interface. The resulting heavy and light fractions were washed in water three to five times and stained with safranin O. The samples were then dehydrated with 95% ethanol, centrifuged and decanted into in dram vials with glycerol. The resulting sample was microscopically examined using the 20x (NA 0.46) and 40x (NA 0.70) objectives of an Olympus BH-2 compound microscope.

Initial identification of pollen grains (Kapp et al. 2007; Mcandrews 1966) were confirmed with the pollen reference collections in the Palynology Laboratory at Texas A&M University. Two hundred grain pollen counts were attempted for each sample, but were not achieved due to very low concentration values. Prior studies of pollen from coprolites had concentration values ranging from as high as seven million pollen grains/gram (Dean 1993; Kelso and Solomon 2006; Reinhard et al. 2006; Reinhard et al.

1991; Sobolik 1988a). These extremely high pollen concentration values require that a multitude of marker spores be added to ensure a relatively equitable abundance of pollen and marker spores during the counting process (Faegri and Iversen 1989; Moore et al. 1991). Anticipating this situation, I purposefully reduced the amount of material sampled for pollen analysis from each specimen. However, this novel method resulted in the opposite situation, where the marker spores were much more abundant than pollen grains. The overabundance of marker spores to pollen grains in many of these samples precludes any statistically valid attempt to characterize the pollen spectrum (Faegri and Iversen 1989; Moore et al. 1991). This is discussed in more detail in the results presented in the following chapter.

Data from Previous Coprolite Studies

All of the samples in three previous studies of Hinds Cave quantified macrofossils using a visual-estimation of percentage-volume (Edwards 1990; Stock 1983; Williams-Dean 1978). This was converted into the ordinal scale taken from Sobolik (1991a) to minimize inter-researcher error in estimation and assure comparatibility to the data from Sobolik (Table 14). The data from Conejo shelter is presented in a slightly different ordinal scale based on a visual-estimation of percentage-volume. The data from Frightful Cave is presented as percentage-weight and the Parida Cave studies presents the data only as ubiquity. Despite the differences in quantification used among the studies, all of them were included in the current analysis to generate the most robust coprolite record of paleodiet possible for the Lower Pecos canyonlands. All of the coprolite datasets included in this study are presented in appendices C and D.

Statistical Analysis

Each coprolite represents a combination of dietary items that can generally be considered to represent a meal (Fry, 1985) or perhaps several meals (Sutton and Reinhard, 1995), both relatively focused windows into an individual's dietary decisions. This provides a framework for analysis, but it also requires that each specimen be considered as a discrete unit in order to observe the relationship between dietary constituents recovered together. This is complicated by the large number of dietary items generally recovered in coprolite studies, which results in a cumbersome matrix with many empty cells. Patterning within this large data set is hard to explore without the use of statistics, which are limited, in turn, by the nature of coprolite quantification as well as comparability between studies (Jouy-Avantin et al. 2003).

This study uses cluster analysis as an exploratory statistical technique to look for patterning in the macrobotanical components of the coprolite studies from the Lower Pecos canyonlands. This technique allows each coprolite to be considered as an individual entity while expressing the similarity between each specimen as a distance measure. This allows research questions to be framed around the analysis of each coprolite rather than by a limited comparison of individual constituents between specimens. Other studies of coprolites have successfully used cluster analysis to explore questions of seasonality and menu (dietary combinations) (Sutton 1993, 1998; Sutton and Reinhard 1995). This technique is particularly useful for exploring data derived from coprolite analyses, because cluster analysis has no assumptions of normally distributed data. The macrobotanical data from the Lower Pecos coprolite studies were analyzed using a hierarchical cluster analysis, available in SPSS-PC 11.5 (Statistical Package for the Social Sciences). Hierarchical cluster analysis attempts to minimize within-group variance while maximizing between group variance. Individual specimens were clustered using Ward's method as the clustering technique and Squared Euclidean distance for the distance measure. The macrobotanical data from each coprolite study were analyzed individually for clustering. The data were not combined for a single analysis due to the lack of consistency between the categories used in the previous studies (Edwards 1990; Stock 1983; Williams-Dean 1978). Fiber, which forms the bulk of the volume for each specimen, was not considered for any of the prior studies due to lack of identification, but was incorporated into the statistical analysis of the current study. The number of clusters from each study was determined with reference to a scree plot of the agglomeration coefficients as well as the dendrogram produced in SPSS-PC. These clusters were then assessed with Canonical Discriminant Analysis in SPSS-PC 11.5, commonly used for a similar purpose in Instrumental Neutron Activation Analysis data sets (Baxter, 1994; Glascock, 1992; Johnson et al. 2007). This approach serves three purposes; (1) it evaluates the assigned group membership of each specimen; (2) it identifies the important variables in defining clusters; and (3) it provides a visual representation of cluster association. Overall, this statistical approach yields patterns of similar dietary exploitation between coprolites while maintaining the relationship between various components in individual specimens. These patterns of resource combination inform on diet-breadth as well as seasonality of deposition.

CHAPTER VIII

RESULTS

Studies of coprolites from the Lower Pecos Canyonlands have created a wide assortment of data, analyzing aDNA (Poinar et al. 2001), staple isotope (Dean 2004), phytolith (Danielson 1993), parasites (Reinhard 1989), macrofossil (Bryant 1974b; Edwards 1990; Fry 1975; Reinhard 1989; Riskind 1970; Sobolik 1991a; Stock 1983; Williams-Dean 1978) and pollen (Bryant 1974b, 1975; Edwards 1990; Riskind 1970; Sobolik 1991a; Williams-Dean 1978) components of individual specimens. The present analysis focuses primarily on the macrofossil, fiber, and phytolith components of the specimens under examination. This approach is necessary to address the diet-breadth model developed in the current study. The other components outlined in the preceding chapter are considered here, but are not directly related to the primary research focus of diet-breadth of the current study. The data from the study will also be used to assess questions of seasonality of site use through resource availability and micro-habitat exploitation.

Following the presentation of the primary data in this study, the cluster analysis and discriminant analysis results of the macrofossil data from the other Hinds Cave coprolite studies are presented in chronological order. The data from these studies are available in Appendix A. The results of these data are used to address some aspects of diet-breadth, but this is limited by the lack of phytolith, epidermal, and fiber cell identification in all of these studies. These three components constitute the major items recovered in most coprolites analyzed from the Lower Pecos canyonlands and are correlated indicators of staple resource exploitation.

A short review of the specialized aDNA and staple isotope data available for a small sub-set of specimens follows the presentation of the comparable data sets available for all four Hinds Cave studies. These techniques have not been applied to enough samples to yield any but the most tentative of conclusions. These data are primarily presented to corroborate the conclusions based on the other lines of evidence and suggest some future avenues of research for coprolite studies in the Lower Pecos canyonlands.

Four other coprolite studies are spread across and beyond the Lower Pecos canyonlands (Figure 2). These sites are used to assess spatial variation in diet across the canyonlands. Conejo Shelter and Parida Cave are located near the mouth of the Pecos River, in an environment very similar to the setting of Hinds Cave, just upstream on Still Canyon. Baker Cave is located east of the Devils River in a more mesic environment, currently characterized as the Balconian oak-cedar zone. Frightful Cave is located nearly 200 miles to the south of Hinds Cave, in the well-watered Cuatro Cienegas basin in the center of the modern state of Coahuila, Mexico. This site provides an external point of comparison in evaluating the Lower Pecos canyonlands as a distinct cultural area. The data sets from these studies are available in Appendix B.

Finally, the available skeletal stable carbon isotope data from the Lower Pecos canyonlands is presented. These data provide a long-term, gross view of individual dietary patterns that contrasts with the more refined and temporally limited data available from the coprolites. A dietary reconstruction relying on both coprolites and skeletal stable isotopes presents a much more robust and nuanced understanding of past human lifeways than either data set individually.

Data from the Current Study

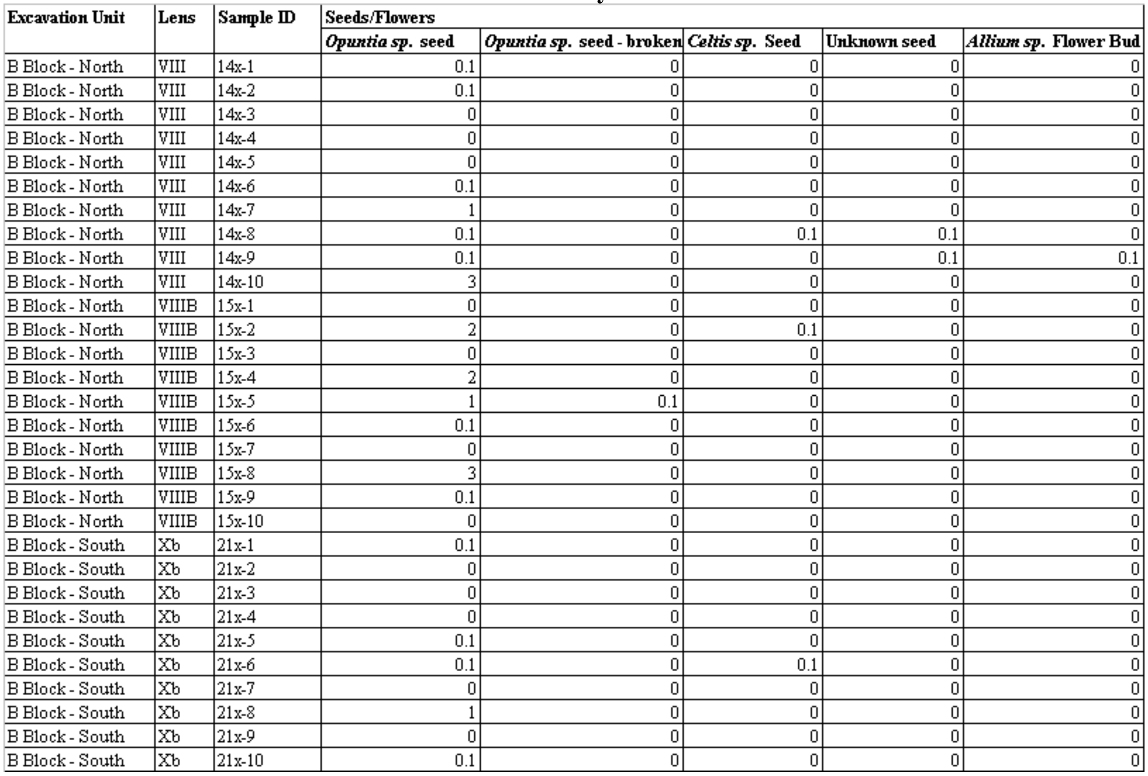
The categorized macrofossil data of the thirty specimens included in my current study are presented in Tables 15-17. These data include plant, animal, and inorganic components recovered from each specimen. These data are divided into three tables for ease of presentation. Fiber is the dominant component in almost every specimen (Table 15). Epidermal tissues of all four of the staple resources discussed throughout this research were identified and range in importance from trace to dominant component of individual specimens (Table 15). Epidermal tissues from a grass and at least one unidentified plant resource were also recovered. Seeds were not very common in the specimens examined here (Table 16). While prickly pear seeds were recovered in eighteen of the thirty specimens, they only occurred above trace levels in seven of the specimens (Table 16). The only other identified seed in the study was hackberry (*Celtis sp.*), which occurred in trace amounts in two specimens. The faunal and other animal remains recovered from these specimens were mostly left unidentified (Table 17). Bone occurred in twenty-three of the thirty specimens, primarily in trace amounts. Most of this bone came from small animals, such as fish, lizards, and rodents. This statement is based on the diminutive size of most of the recovered faunal material. Some of the faunal elements were readily identified and have been reported as such. Several specimens contain fish skeletal components and two specimens contain evidence of lagomorph (rabbit) consumption. Only one specimen contains evidence of larger game

(Table 17). The data presented in Tables 15-17 were analyzed using the cluster analysis methods described in the previous chapter.

Table 15. Fiber and Epidermal Cell Data from Current Study

Excavation Unit	**Lens**	**Sample ID**	**Fiber**	**Epidermal Tissue**						
			Fiber	***Agave sp.***	***Dasylirion sp.***	***Opuntia sp.***	***Allium sp.***	***Poaceae***	**Unknown**	**Unknown stem**
B Block - North	VIII	14x-1	5	3	3	0	0	0	0	0
B Block - North	VIII	14x-2	5	0	2	3	0	0	0	0
B Block - North	VIII	14x-3	6	2	2	0	2	0	1	0
B Block - North	VIII	14x-4	7	2	1	0	0.1	0	0	0
B Block - North	VIII	14x-5	7	0	1	2	0	0	0.1	0
B Block - North	VIII	14x-6	4	3	1	0	1	0.1	0	0
B Block - North	VIII	14x-7	4	4	0	2	0	0	0.1	0
B Block - North	VIII	14x-8	6	2	0	2	1	0	0	0
B Block - North	VIII	14x-9	6	2	1	1	0	0	0	0
B Block - North	VIII	14x-10	6	1	0	1	0	0	0	0
B Block - North	VIIIB	15x-1	5	3	2	0.1	0	0	0	0
B Block - North	VIIIB	15x-2	5	0	0	2	0	0	2	0
B Block - North	VIIIB	15x-3	7	0	2	1	0	0	0	0
B Block - North	VIIIB	15x-4	7	0	0.1	1	0	0	0	0
B Block - North	VIIIB	15x-5	4	0.1	2	5	0	0	0	0
B Block - North	VIIIB	15x-6	5	3	2	0.1	0	0	0	0
B Block - North	VIIIB	15x-7	6	3	1	0	0	0	0	0
B Block - North	VIIIB	15x-8	5	0	0.1	2	0	0	0	0
B Block - North	VIIIB	15x-9	4	2	2	3	0	0	0	0
B Block - North	VIIIB	15x-10	5	2	2	2	0	0	0	0
B Block - South	Xb	21x-1	5	3	0	0	2	0	0	0
B Block - South	Xb	21x-2	5	4	0	0.1	0	0	0	0
B Block - South	Xb	21x-3	8	0	1	0	0	0	0.1	0.1
B Block - South	Xb	21x-4	6	3	0	0	0	0	0	0
B Block - South	Xb	21x-5	6	0	0	0	0	0	0	0
B Block - South	Xb	21x-6	6	2	2	0.1	0	0	0	0
B Block - South	Xb	21x-7	8	0.1	0	0	0	0	0	0
B Block - South	Xb	21x-8	4	5	0	0	0	0	0	0
B Block - South	Xb	21x-9	8	0	0	0	0	0	0	0
B Block - South	Xb	21x-10	5	4	0.1	0	0	0	0	0

Table 16. Seed and Flower Data from Current Study



Excavation Unit	Lens	Sample ID	Seeds/Flowers				
			Opuntia sp. **seed**	***Opuntia sp.*** **seed - broken**	***Celtis sp.*** **Seed**	**Unknown seed**	***Allium sp.*** **Flower Bud**
B Block - North	VIII	14x-1	0.1	0	0	0	0
B Block - North	VIII	14x-2	0.1	0	0	0	0
B Block - North	VIII	14x-3	0	0	0	0	0
B Block - North	VIII	14x-4	0	0	0	0	0
B Block - North	VIII	14x-5	0	0	0	0	0
B Block - North	VIII	14x-6	0.1	0	0	0	0
B Block - North	VIII	14x-7	1	0	0	0	0
B Block - North	VIII	14x-8	0.1	0	0.1	0.1	0
B Block - North	VIII	14x-9	0.1	0	0	0.1	0.1
B Block - North	VIII	14x-10	3	0	0	0	0
B Block - North	VIIIB	15x-1	0	0	0	0	0
B Block - North	VIIIB	15x-2	2	0	0.1	0	0
B Block - North	VIIIB	15x-3	0	0	0	0	0
B Block - North	VIIIB	15x-4	2	0	0	0	0
B Block - North	VIIIB	15x-5	1	0.1	0	0	0
B Block - North	VIIIB	15x-6	0.1	0	0	0	0
B Block - North	VIIIB	15x-7	0	0	0	0	0
B Block - North	VIIIB	15x-8	3	0	0	0	0
B Block - North	VIIIB	15x-9	0.1	0	0	0	0
B Block - North	VIIIB	15x-10	0	0	0	0	0
B Block - South	Xb	21x-1	0.1	0	0	0	0
B Block - South	Xb	21x-2	0	0	0	0	0
B Block - South	Xb	21x-3	0	0	0	0	0
B Block - South	Xb	21x-4	0	0	0	0	0
B Block - South	Xb	21x-5	0.1	0	0	0	0
B Block - South	Xb	21x-6	0.1	0	0.1	0	0
B Block - South	Xb	21x-7	0	0	0	0	0
B Block - South	Xb	21x-8	1	0	0	0	0
B Block - South	Xb	21x-9	0	0	0	0	0
B Block - South	Xb	21x-10	0.1	0	0	0	0

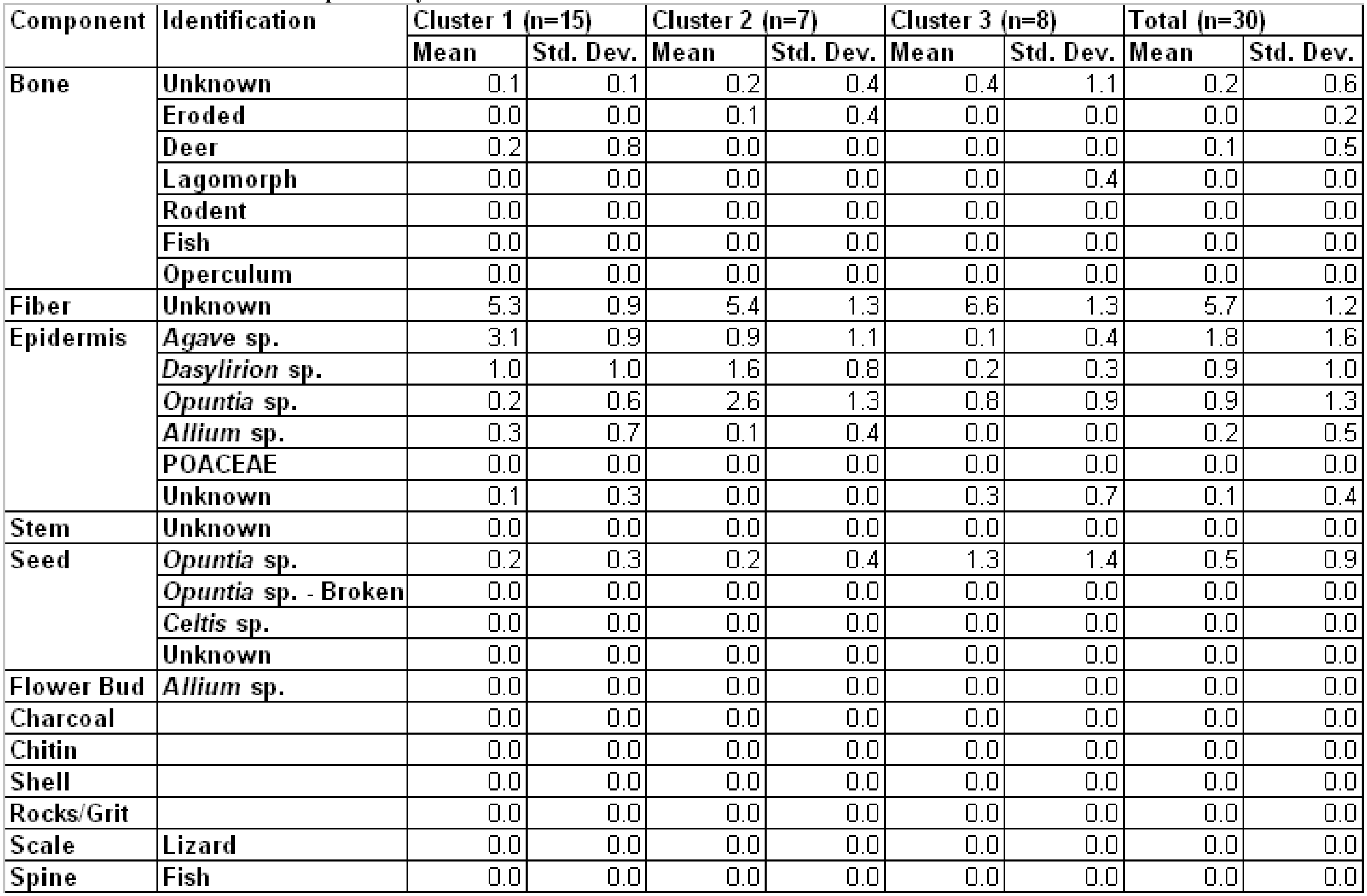
Table 17. Animal and Inorganic Data from the Current Study

Excavation Unit	Lens	Sample ID	Animal Components											Inorganic components		Total Volume
			Bone- Unknown	Eroded Bone	Bone- Deer	Bone - Lagomorph	Bone-Rodent	Bone- Fish	Operculum	Fish Spine	Lizard Scale	Chitin	Shell	Charcoal	Rocks/Grit	
B Block - North	VIII	14x-1	0.1	0	0	0	0	0	0	0	0.1	0	0	0.1	0	100
B Block - North	VIII	14x-2	0.1	1	0	0	0	0	0	0	0	0.1	0	0	0	100
B Block - North	VIII	14x-3	0	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - North	VIII	14x-4	0.1	0	0	0	0	0	0	0	0	0	0.1	0	0	100
B Block - North	VIII	14x-5	0.1	0	0	0	0	0	0	0	0	0	0	0	0.1	100
B Block - North	VIII	14x-6	0	0	3	0	0	0	0	0	0	0	0	0	0	100
B Block - North	VIII	14x-7	0	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - North	VIII	14x-8	0.1	0	0	0	0	0	0	0	0.1	0.1	0	0.1	0	100
B Block - North	VIII	14x-9	0.1	0	0	0	0	0	0.1	0	0	0	0	0	0	100
B Block - North	VIII	14x-10	0	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - North	VIIIB	15x-1	0.1	0	0	0	0	0	0	0	0	0.1	0	0.1	0	100
B Block - North	VIIIB	15x-2	0	0	0	0.1	0	0	0	0	0	0.1	0.1	0	0	100
B Block - North	VIIIB	15x-3	0	0	0	0	0.1	0	0	0	0.1	0	0	0	0	100
B Block - North	VIIIB	15x-4	0	0	0	0.1	0	0	0	0	0	0	0	0	0	100
B Block - North	VIIIB	15x-5	0.1	0	0	0	0	0	0	0	0	0	0	0	0.1	100
B Block - North	VIIIB	15x-6	0	0	0	0	0	0	0	0	0	0	0	0	0.1	100
B Block - North	VIIIB	15x-7	0.1	0	0	0	0	0	0	0	0	0	0	0.1	0	100
B Block - North	VIIIB	15x-8	0.1	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - North	VIIIB	15x-9	1	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - North	VIIIB	15x-10	0	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - South	Xb	21x-1	0.1	0	0	0	0	0	0	0	0	0	0	0.1	0	100
B Block - South	Xb	21x-2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - South	Xb	21x-3	0	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - South	Xb	21x-4	0.1	0	0	0	0	0	0	0	0	0	0	0.1	0	100
B Block - South	Xb	21x-5	3	0	0	0	0	0	0	0	0.1	0	0	0	0	100
B Block - South	Xb	21x-6	0	0	0	0	0	0.1	0	0.1	0.1	0	0	0	0	100
B Block - South	Xb	21x-7	0	0	0	0	0	0.1	0	0	0.1	0	0	0	0	100
B Block - South	Xb	21x-8	0	0	0	0	0	0.1	0	0	0	0	0	0	0	100
B Block - South	Xb	21x-9	0	0	0	0	0	0	0	0	0	0	0	0	0	100
B Block - South	Xb	21x-10	0.1	0	0	0	0	0	0	0	0	0.1	0	0	0	100

The thirty specimens from the current study were divided into three clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 33). The mean values of each component are presented by cluster in Table 18. All three clusters exhibit high levels of fiber. Cluster 1 (n=15) is characterized by high amounts of lechuguilla epidermal tissue and the presence of onion epidermal tissue. While sotol epidermal tissue is noted among specimens included in this cluster, it is at a relatively low level. There is very little recovery of prickly pear seeds or epidermal tissue in this cluster. Bone in this cluster is considerably below the overall mean for all specimens. However, the specimen with the deer bone is included in this cluster.

Cluster 2 (n=7) exhibits the highest levels of epidermal tissue from both sotol and prickly pear. Lechuguilla and onion epidermal tissue are both present at relatively low levels. Prickly pear seeds are present at levels well below the mean for all specimens and proportionally identical to cluster 1. The one specimen with broken prickly pear seeds is included in this cluster.

Table 18. Mean Values of All Components by Cluster



Component	Identification	Cluster 1 (n=15)		Cluster 2 (n=7)		Cluster 3 (n=8)		Total (n=30)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Bone	**Unknown**	0.1	0.1	0.2	0.4	0.4	1.1	0.2	0.6
	Eroded	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.2
	Deer	0.2	0.8	0.0	0.0	0.0	0.0	0.1	0.5
	Lagomorph	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
	Rodent	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Fish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Operculum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fiber	**Unknown**	5.3	0.9	5.4	1.3	6.6	1.3	5.7	1.2
Epidermis	***Agave* sp.**	3.1	0.9	0.9	1.1	0.1	0.4	1.8	1.6
	***Dasylirion* sp.**	1.0	1.0	1.6	0.8	0.2	0.3	0.9	1.0
	***Opuntia* sp.**	0.2	0.6	2.6	1.3	0.8	0.9	0.9	1.3
	***Allium* sp.**	0.3	0.7	0.1	0.4	0.0	0.0	0.2	0.5
	POACEAE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unknown	0.1	0.3	0.0	0.0	0.3	0.7	0.1	0.4
Stem	**Unknown**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seed	***Opuntia* sp.**	0.2	0.3	0.2	0.4	1.3	1.4	0.5	0.9
	***Opuntia* sp. - Broken**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	***Celtis* sp.**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flower Bud	***Allium* sp.**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Charcoal		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chitin		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shell		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rocks/Grit		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scale	**Lizard**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spine	**Fish**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

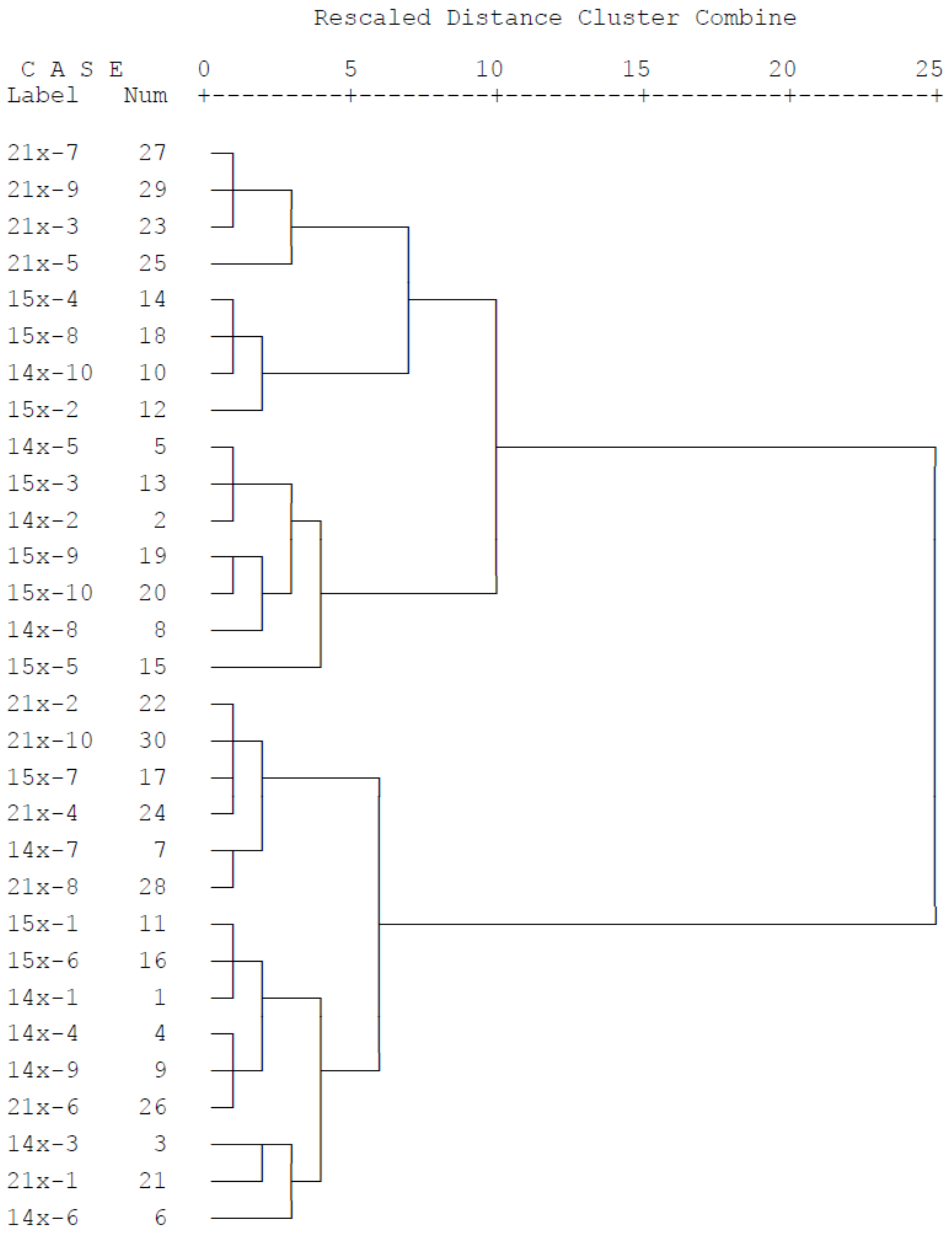


Figure 33. Dendogram of Data based on Ward's Method. All Components from the Current Study

Cluster 3 (n=8) is associated with high levels of prickly pear seeds and moderate amounts of prickly pear epidermal tissue. Unknown epidermal tissue is also highest in this cluster. Lechuguilla and sotol epidermal tissue are noted at values well below the mean for all specimens. Bone recovery is highest among this cluster, which also contains both specimens with evidence of lagomorph consumption. While both charcoal and grit are present at low levels across many specimens, it is interesting to note that none of the specimens grouped into cluster 3 contained either of these specimens. This may reflect the lack of cooking or processing for the meals reflected in the coprolites in this cluster.

Figure 34 provides a visual display of the clusters along the first two factors generated with canonical discriminant analysis (CDA_. Tables 19 and 20 show the standardized canonical function coefficients and the structure matrix respectively. The first function explains 72.1% of the variance among the samples and the second function explains the remaining 27.9%. Tables 19 and 20 indicate that the first function dominantly expresses differences among the prickly pear seed, sotol epidermal tissue, and faunal components of the coprolite specimens. The second function reflects differences in the amounts of lechuguilla and prickly pear epidermal tissue, among other variables. The faunal component of the specimens is a major driver of function 1. These data may obscure relationships between the botanical variables that are at the heart of this study. For this reason, the analysis was re-run with the faunal variables excluded.

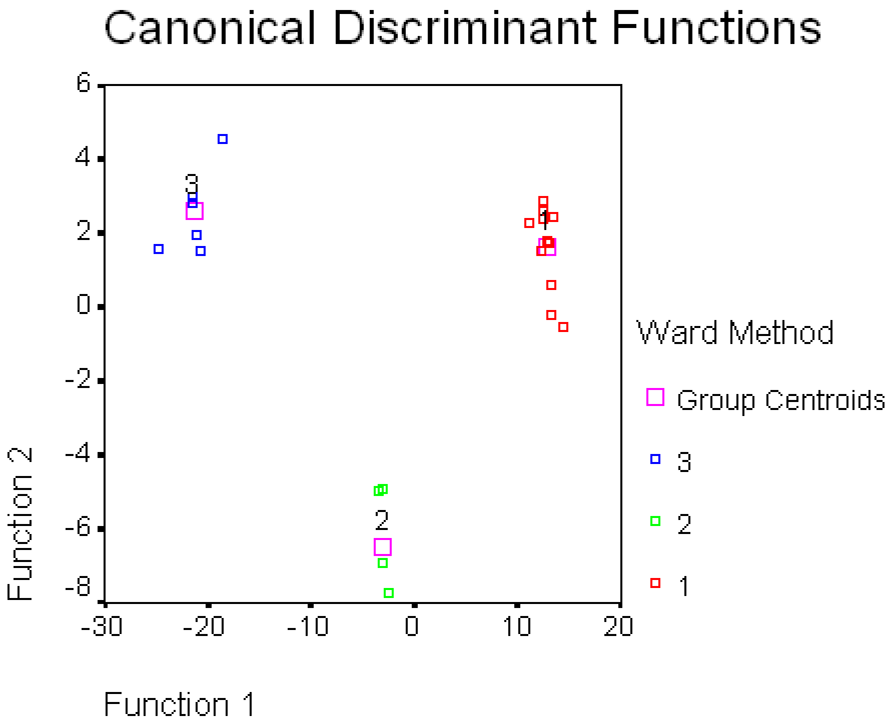
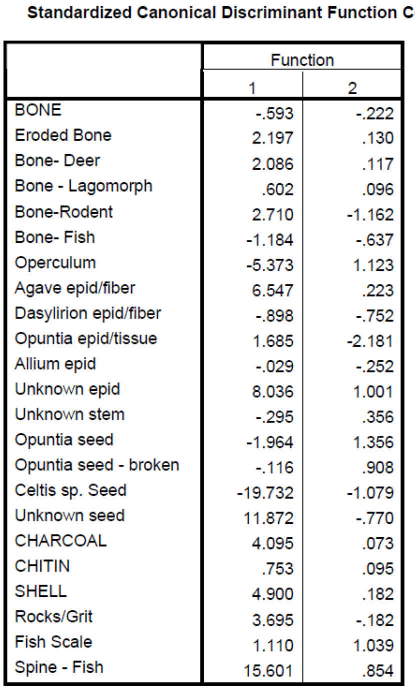


Figure 34. Placement of Clusters along Canonical Discriminant Functions 1 and 2. All Components from the Current Study

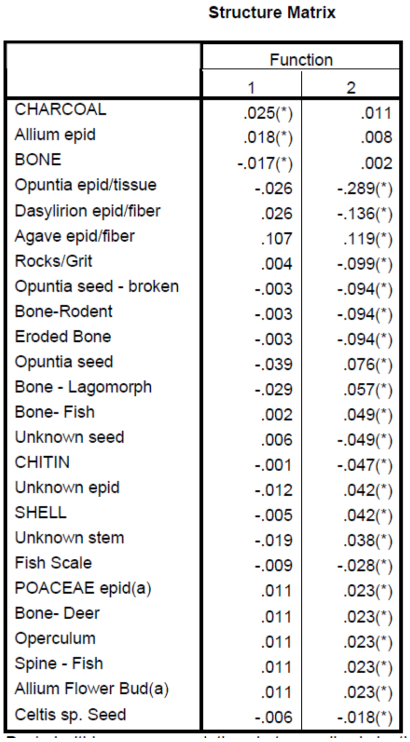
Table 19. Discriminant Function Coefficients of Cluster Analysis of all Components



Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
BONE	-.593	-.222
Eroded Bone	2.197	.130
Bone- Deer	2.086	.117
Bone - Lagomorph	.602	.096
Bone-Rodent	2.710	-1.162
Bone- Fish	-1.184	-.637
Operculum	-5.373	1.123
Agave epid/fiber	6.547	.223
Dasylirion epid/fiber	-.898	-.752
Opuntia epid/tissue	1.685	-2.181
Allium epid	-.029	-.252
Unknown epid	8.036	1.001
Unknown stem	-.295	.356
Opuntia seed	-1.964	1.356
Opuntia seed - broken	-.116	.908
Celtis sp. Seed	-19.732	-1.079
Unknown seed	11.872	-.770
CHARCOAL	4.095	.073
CHITIN	.753	.095
SHELL	4.900	.182
Rocks/Grit	3.695	-.182
Fish Scale	1.110	1.039
Spine - Fish	15.601	.854

Table 20. Structure Matrix of Cluster Analysis of all Components



Structure Matrix

	Function	
	1	2
CHARCOAL	.025(*)	.011
Allium epid	.018(*)	.008
BONE	-.017(*)	.002
Opuntia epid/tissue	-.026	-.289(*)
Dasylirion epid/fiber	.026	-.136(*)
Agave epid/fiber	.107	.119(*)
Rocks/Grit	.004	-.099(*)
Opuntia seed - broken	-.003	-.094(*)
Bone-Rodent	-.003	-.094(*)
Eroded Bone	-.003	-.094(*)
Opuntia seed	-.039	.076(*)
Bone - Lagomorph	-.029	.057(*)
Bone- Fish	.002	.049(*)
Unknown seed	.006	-.049(*)
CHITIN	-.001	-.047(*)
Unknown epid	-.012	.042(*)
SHELL	-.005	.042(*)
Unknown stem	-.019	.038(*)
Fish Scale	-.009	-.028(*)
POACEAE epid(a)	.011	.023(*)
Bone- Deer	.011	.023(*)
Operculum	.011	.023(*)
Spine - Fish	.011	.023(*)
Allium Flower Bud(a)	.011	.023(*)
Celtis sp. Seed	-.006	-.018(*)

The thirty specimens from the current study were again divided into three clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 35). The mean values of each component are presented by cluster in Table 21. Much like the prior analysis including the faunal component of the specimens, Cluster 1 (n=16) is characterized by high levels of lechuguilla epidermal tissue. The levels of sotol epidermal tissue are slightly higher than the mean across all specimens. All specimens from the study with onion epidermal tissue are included in this cluster. All other dietary components in this cluster are present at levels well below the mean across all specimens. All specimens containing charcoal are included in this cluster.

Cluster 2 (n=4) is again defined by significant levels of sotol and prickly pear epidermal tissue. Lechuguilla epidermal tissue is well below the mean for all specimens. Prickly pear seeds are present at a higher level than cluster 1, but well below the mean for all specimens. Cluster 3 (n=10) exhibits high levels of prickly pear seeds as the dominant dietary component other than fiber. Prickly pear epidermal tissue occurs at roughly the same level as the mean across all specimens in the study. Unknown epidermal tissue appears at twice the amount as the mean across all specimens. All other dietary components are present at levels below the mean for all specimens in the study.

Figure 36 provides a visual display of the clusters along the first two factors generated with CDA. Tables 22 and 23 show the standardized canonical function coefficients and the structure matrix respectively. The first function explains 78.8% of the variance among the samples and the second function explains the remaining 21.2%. Tables 22 and 23 indicate that the first function is positively correlated with lechuguilla epidermal tissue, onion epidermal tissue, and charcoal. It is negatively correlated with prickly pear seeds. The second function reflects differences in the amounts of sotol and prickly pear epidermal tissue, among other variables.

The results of this second analysis excluding the faunal components accord nicely with the first analysis, which incorporated the faunal data. Cluster 1 is characterized by lechuguilla, sotol and onion consumption, with other dietary components being relatively uncommon or in very trace amounts. Cluster 2 suggests a diet of sotol and nopales with small amounts of lechuguilla. Cluster 3 shows high levels of prickly pear seeds, reflecting the dominance of tunas in the consumption pattern reflected in these specimens.

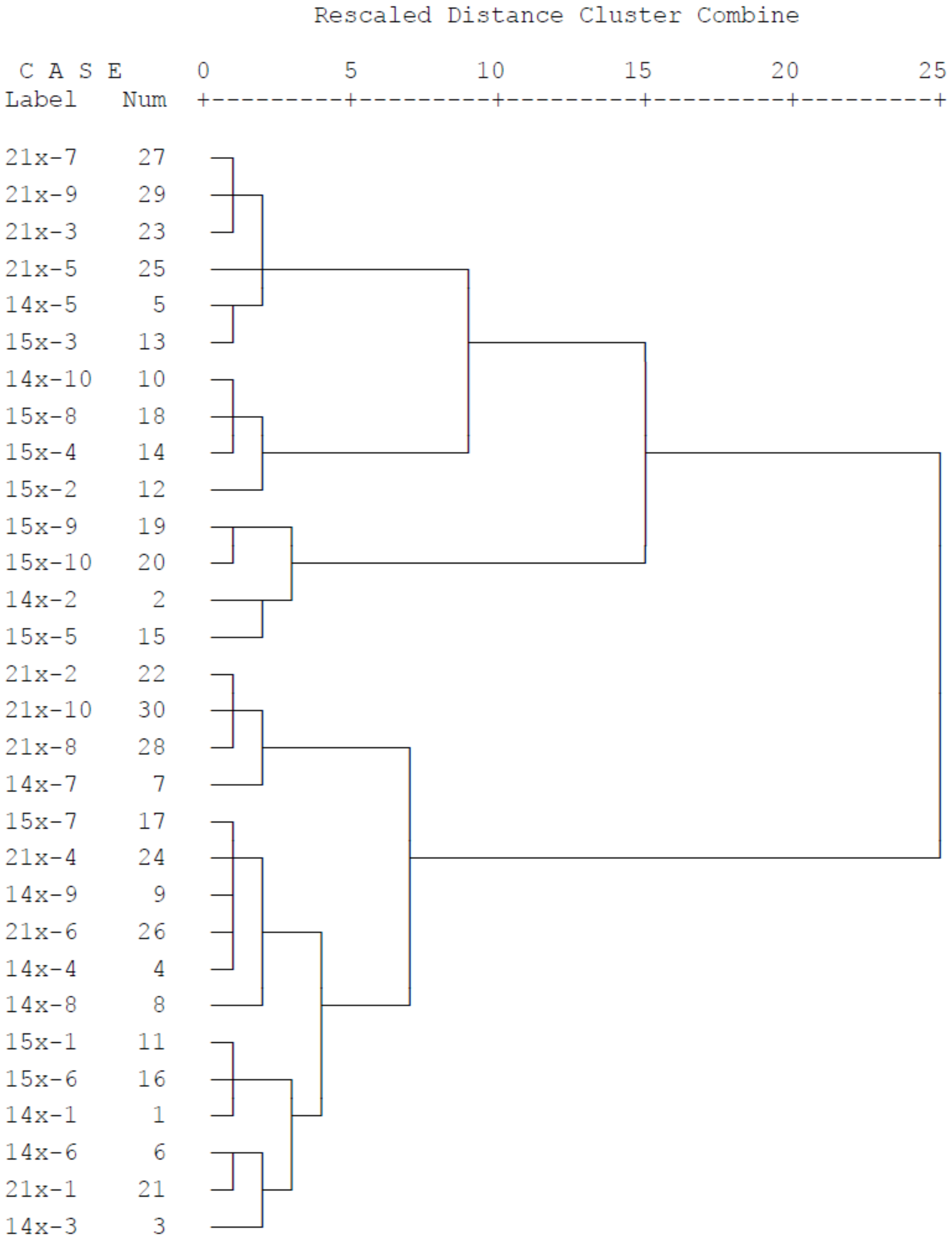


Figure 35. Dendogram of Data based on Ward's Method. Botanical Components from the Current Study

Table 21. Mean Values of Botanical Components by Cluster

Component	Identification	Cluster 1 (n=16)		Cluster 2 (n=4)		Cluster 3 (n=10)		Total (n=30)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Fiber	Unknown	5.3	0.9	4.5	0.6	6.7	1.2	5.7	1.2
Epidermis	*Agave* sp.	3.0	0.9	1.0	1.1	0.1	0.3	1.8	1.6
	Dasylirion sp.	0.9	1.0	2.0	0.0	0.4	0.7	0.9	1.0
	Opuntia sp.	0.3	0.7	3.3	1.3	0.9	0.9	0.9	1.3
	Allium sp.	0.4	0.7	0.0	0.0	0.0	0.0	0.2	0.5
	Poaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unknown	0.1	0.2	0.0	0.0	0.2	0.6	0.1	0.4
Stem	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seed	*Opuntia* sp.	0.2	0.3	0.3	0.5	1.0	1.3	0.5	0.9
	Opuntia sp.- Broken	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Celtis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flower Bud	*Allium* sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Charcoal		0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Chitin		0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Shell		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grit		0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Scale	Lizard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spine	Fish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bone	Deer	0.2	0.8	0.0	0.0	0.0	0.0	0.1	0.5

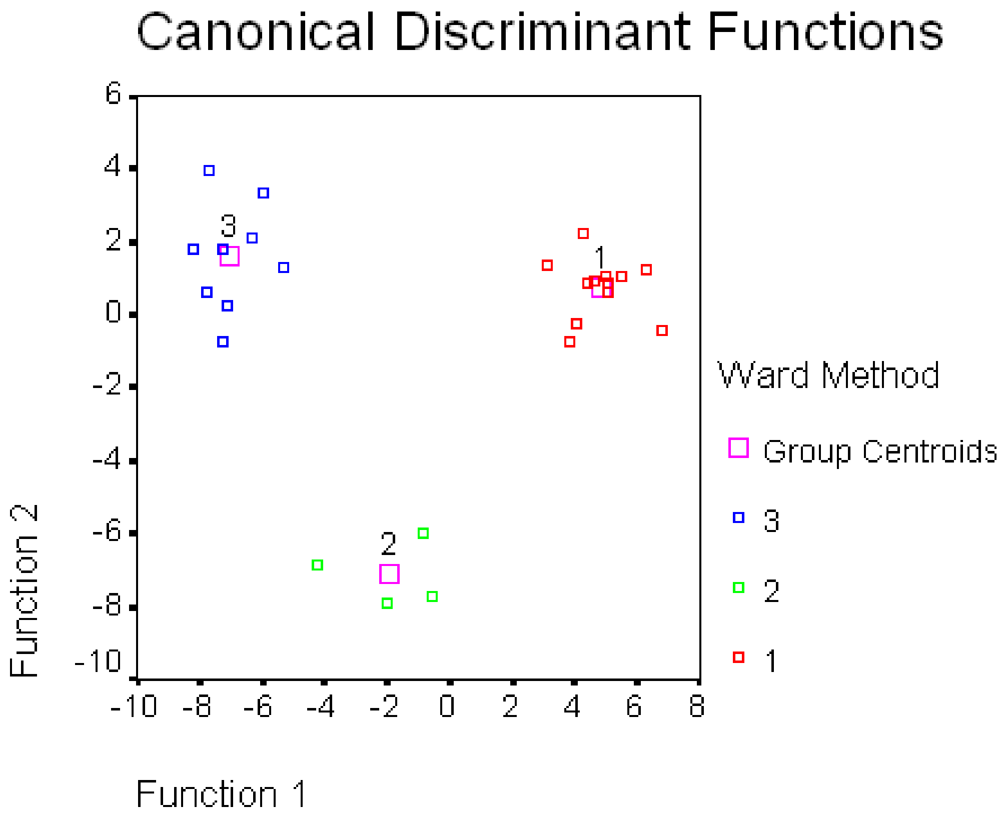
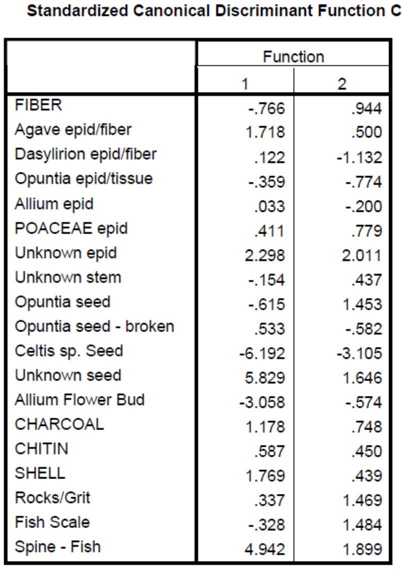


Figure 36. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Botanical Components from the Current Study

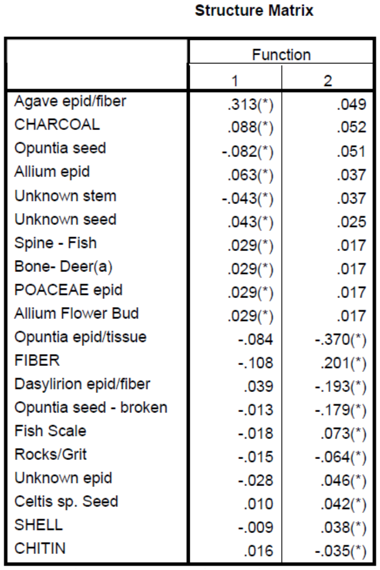
Table 22. Discriminant Function Coefficients of Cluster Analysis of Botanical Components



Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
FIBER	-.766	.944
Agave epid/fiber	1.718	.500
Dasylirion epid/fiber	.122	-1.132
Opuntia epid/tissue	-.359	-.774
Allium epid	.033	-.200
POACEAE epid	.411	.779
Unknown epid	2.298	2.011
Unknown stem	-.154	.437
Opuntia seed	-.615	1.453
Opuntia seed - broken	.533	-.582
Celtis sp. Seed	-6.192	-3.105
Unknown seed	5.829	1.646
Allium Flower Bud	-3.058	-.574
CHARCOAL	1.178	.748
CHITIN	.587	.450
SHELL	1.769	.439
Rocks/Grit	.337	1.469
Fish Scale	-.328	1.484
Spine - Fish	4.942	1.899

Table 23. Structure Matrix of Cluster Analysis of Botanical Components



Structure Matrix

	Function	
	1	2
Agave epid/fiber	.313(*)	.049
CHARCOAL	.088(*)	.052
Opuntia seed	-.082(*)	.051
Allium epid	.063(*)	.037
Unknown stem	-.043(*)	.037
Unknown seed	.043(*)	.025
Spine - Fish	.029(*)	.017
Bone- Deer(a)	.029(*)	.017
POACEAE epid	.029(*)	.017
Allium Flower Bud	.029(*)	.017
Opuntia epid/tissue	-.084	-.370(*)
FIBER	-.108	.201(*)
Dasylirion epid/fiber	.039	-.193(*)
Opuntia seed - broken	-.013	-.179(*)
Fish Scale	-.018	.073(*)
Rocks/Grit	-.015	-.064(*)
Unknown epid	-.028	.046(*)
Celtis sp. Seed	.010	.042(*)
SHELL	-.009	.038(*)
CHITIN	.016	-.035(*)

Comparing the Macrofossil Data with Phytoliths and Fiber Ultimates. In order to evaluate the diet-breath of the botanical resources recovered in these specimens, a combined cluster analysis of the epidermal tissue, fiber ultimates, and phytoliths was conducted. These multiple lines of congruent evidence all reflect the consumption of the four staple resources identified for the region. These interdependent data sets allow for a more rigorous examination of the importance of these different resources. Percentage data are used in this analysis to assure comparability among these data sets (Tables 24 and 25). Directly comparing the counts of fiber ultimates and phytoliths with the categorical scale used for the macrofossils would skew the analysis due to the large difference between the numerical values of these data sets.

The combined data set was evaluated with CDA against the three clusters generated using the macrofossil data without the faunal components (Figure 35). The mean values of each component are presented by cluster in Table 26. Cluster 1 (n=16) shows very high levels of lechuguilla epidermal tissue, lechuguilla fiber ultimates, and raphide-type phytoliths. Sotol epidermal tissue is also greater than the mean for all samples. All specimens with onion epidermal tissue and onion fiber ultimates are in this cluster. Prickly pear seeds are not abundant in specimens in this cluster.

Table 24. Percentage-Volume Data of Epidermal Tissue and Seeds from Staple Resources

Excavation Unit	Lens	Sample ID	Epidermal Tissue							Seeds	
			Agave sp.	*Dasylirion sp.*	*Opuntia sp.*	*Allium sp.*	*Poaceae*	Unknown	Unknown stem	*Opuntia sp.*	*Opuntia sp.* -broken
B Block - North	VIII	14x-1	29.0	26.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
B Block - North	VIII	14x-2	0.0	6.0	15.0	0.0	0.0	0.0	0.0	1.0	0.0
B Block - North	VIII	14x-3	8.0	22.0	0.0	5.0	0.0	1.0	0.0	0.0	0.0
B Block - North	VIII	14x-4	5.0	2.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
B Block - North	VIII	14x-5	0.0	0.2	2.0	0.0	0.0	0.2	0.0	0.0	0.0
B Block - North	VIII	14x-6	9.0	1.0	0.0	1.0	0.2	0.0	0.0	1.0	0.0
B Block - North	VIII	14x-7	56.0	0.0	25.0	0.0	0.0	1.0	0.0	1.0	0.0
B Block - North	VIII	14x-8	10.0	0.0	5.0	2.0	0.0	0.0	0.0	1.0	0.0
B Block - North	VIII	14x-9	12.0	3.0	3.0	0.0	0.0	0.0	0.0	1.0	0.0
B Block - North	VIII	14x-10	1.0	0.0	0.5	0.0	0.0	0.0	0.0	17.0	0.0
B Block - North	VIIIB	15x-1	22.0	12.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - North	VIIIB	15x-2	0.0	0.0	9.0	0.0	0.0	6.0	0.0	14.0	0.0
B Block - North	VIIIB	15x-3	0.0	5.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - North	VIIIB	15x-4	0.0	1.0	0.2	0.0	0.0	0.0	0.0	2.0	0.0
B Block - North	VIIIB	15x-5	1.0	9.0	41.0	0.0	0.0	0.0	0.0	0.5	0.2
B Block - North	VIIIB	15x-6	26.0	22.0	0.2	0.0	0.0	0.0	0.0	1.0	0.0
B Block - North	VIIIB	15x-7	28.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - North	VIIIB	15x-8	0.0	0.4	3.0	0.0	0.0	0.0	0.0	17.0	0.0
B Block - North	VIIIB	15x-9	10.0	9.0	30.0	0.0	0.0	0.0	0.0	0.4	0.0
B Block - North	VIIIB	15x-10	15.0	7.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - South	Xb	21x-1	26.0	0.0	0.0	17.0	0.0	0.0	0.0	1.0	0.0
B Block - South	Xb	21x-2	13.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - South	Xb	21x-3	0.0	2.0	0.0	0.0	0.0	0.3	1.0	0.0	0.0
B Block - South	Xb	21x-4	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - South	Xb	21x-5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
B Block - South	Xb	21x-6	15.0	12.0	0.4	0.0	0.0	0.0	0.0	1.0	0.0
B Block - South	Xb	21x-7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - South	Xb	21x-8	31.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
B Block - South	Xb	21x-9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B Block - South	Xb	21x-10	28.0	0.3	0.0	0.0	0.0	0.0	0.0	1.0	0.0

Table 25. Percentage Values of Fiber Ultimates and Phytoliths from Staple Resources

Excavation Unit	Lens	Sample ID	Fiber						Phytoliths			
			Agave sp.	*Dasylirion sp.*	*Opuntia sp.*	*Allium sp.*	Unknown	Total Count	Raphide	Druse	Stylus	Fabaceae
B Block - North	VIII	14x-1	50.0	38.9	7.4	0.0	3.7	54.0	21.6	22.0	56.4	0.0
B Block - North	VIII	14x-2	21.6	74.5	3.9	0.0	0.0	51.0	33.7	22.1	19.9	24.3
B Block - North	VIII	14x-3	41.4	39.7	0.0	15.5	3.4	58.0	32.4	32.4	35.2	0.0
B Block - North	VIII	14x-4	63.5	26.9	0.0	0.0	9.6	52.0	60.2	25.4	14.3	0.0
B Block - North	VIII	14x-5	0.0	80.4	13.7	0.0	5.9	51.0	49.6	28.2	22.2	0.0
B Block - North	VIII	14x-6	63.5	21.2	0.0	5.8	9.6	52.0	36.1	47.6	16.3	0.0
B Block - North	VIII	14x-7	66.1	8.9	16.1	0.0	8.9	56.0	55.7	22.3	22.0	0.0
B Block - North	VIII	14x-8	60.8	13.7	9.8	7.8	7.8	51.0	36.6	56.5	6.9	0.0
B Block - North	VIII	14x-9	67.3	25.0	7.7	0.0	0.0	52.0	36.4	57.7	5.9	0.0
B Block - North	VIII	14x-10	76.5	0.0	13.7	0.0	9.8	51.0	36.5	27.8	35.7	0.0
B Block - North	VIIIB	15x-1	64.7	35.3	0.0	0.0	0.0	51.0	82.7	0.8	16.5	0.0
B Block - North	VIIIB	15x-2	0.0	0.0	30.2	0.0	69.8	53.0	32.4	40.3	27.3	0.0
B Block - North	VIIIB	15x-3	0.0	79.2	15.1	0.0	5.7	53.0	6.6	66.5	26.9	0.0
B Block - North	VIIIB	15x-4	0.0	52.9	39.2	0.0	7.8	51.0	73.4	25.8	0.8	0.0
B Block - North	VIIIB	15x-5	20.0	50.0	26.0	0.0	4.0	50.0	14.8	64.6	20.6	0.0
B Block - North	VIIIB	15x-6	67.3	27.3	0.0	0.0	5.5	55.0	89.7	0.0	10.3	0.0
B Block - North	VIIIB	15x-7	62.7	21.6	0.0	0.0	15.7	51.0	57.8	16.6	25.6	0.0
B Block - North	VIIIB	15x-8	0.0	51.0	34.7	0.0	14.3	50.0	28.0	58.7	13.3	0.0
B Block - North	VIIIB	15x-9	50.0	36.0	14.0	0.0	0.0	50.0	13.9	78.5	7.6	0.0
B Block - North	VIIIB	15x-10	40.0	50.0	4.0	0.0	6.0	50.0	19.1	75.0	5.9	0.0
B Block - South	Xb	21x-1	49.1	0.0	0.0	17.0	34.0	53.0	70.4	7.6	22.0	0.0
B Block - South	Xb	21x-2	78.0	0.0	16.0	0.0	6.0	50.0	49.8	12.4	37.8	0.0
B Block - South	Xb	21x-3	0.0	69.4	0.0	0.0	30.6	51.0	80.1	4.7	15.2	0.0
B Block - South	Xb	21x-4	92.2	0.0	0.0	0.0	7.8	51.0	53.9	12.3	33.8	0.0
B Block - South	Xb	21x-5	29.6	24.1	0.0	0.0	46.3	54.0	37.1	31.5	31.5	0.0
B Block - South	Xb	21x-6	45.6	33.3	5.3	0.0	15.8	57.0	62.1	17.0	21.0	0.0
B Block - South	Xb	21x-7	70.4	0.0	5.6	0.0	24.1	54.0	76.1	8.0	16.0	0.0
B Block - South	Xb	21x-8	84.2	8.8	0.0	0.0	7.0	57.0	37.3	8.5	54.2	0.0
B Block - South	Xb	21x-9	50.0	18.0	0.0	0.0	32.0	50.0	72.3	4.6	23.1	0.0
B Block - South	Xb	21x-10	80.4	11.8	0.0	0.0	7.8	51.0	72.6	13.3	14.2	0.0

Cluster 2 (n=4) is dominated by prickly pear epidermal tissue, sotol fiber ultimates, and druse-type phytoliths. Sotol epidermal tissue and prickly pear fiber ultimate values are above the mean for all specimens combined. Prickly pear seeds are encounted only in trace amounts in the specimens in this cluster. Cluster 3 (n=10) is characterized by high levels of prickly pear seeds. Other components encountered in this cluster at above average values for all combined specimens include prickly pear fiber ultimates, sotol fiber ultimates, unknown epidermal tissue and unknown fiber ultimates. Interestingly, the cluster mean values for the three major types of phytoliths encountered in this study are nearly identical to the mean values for all combined specimens. It should be noted that the much smaller raphide-type phytolith is the dominant type encountered across all specimens.

Figure 37 provides a visual display of the clusters along the first two factors generated with CDA. Tables 27 and 28 show the standardized canonical function coefficients and the structure matrix respectively. The first function explains 51.3% of the variance among the samples and the second function explains the remaining 48.6%. Tables 27 and 28 indicate that the first function is driven primarily by differences in the botanical source of the epidermal tissue and fiber ultimates recovered in each specimen. The second function is negatively correlated with both prickly pear seeds and druse-type phytoliths and positively correlated with raphide-type phytoliths.

This analysis indicates that three distinctive menus or dietary combinations occur in the specimens under examination. The first cluster reflects a diet dominated by lechuguilla with onion bulbs and sotol as secondary resources. The second cluster indicates a dietary combination of prickly pear nopales with secondary consumption of sotol. The third cluster suggests a diet composed almost entirely of prickly pear tunas and an unidentified resource. While all three sets of data analyzed in this section help clarify the roles of these different resources, the most important indicators of dietary consumption were the macrofossils, specifically the epidermal tissue identifications. The microscopic fiber ultimates and phytoliths present a more muddled picture. Perhaps this is due to the mixing and trapping of microscopic components in the dietary tract observed by Williams-Dean (1978) in her actualistic study of pollen passage. Slower passage of microscopic components may result in a longer term record of diet than the meal or meals reflected in the macrofossils.

Table 26. Mean Values of Staple Resource Indicators by Cluster

Component	Identification	Cluster 1 (n=16)		Cluster 2 (n=4)		Cluster 3 (n=10)		Total	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Epidermis	Agave sp.	21.38	12.69	6.50	7.23	0.11	0.31	12.30	13.79
	Dasylirion sp.	6.39	9.30	7.75	1.50	0.86	1.59	4.73	7.33
	Opuntia sp.	2.23	6.23	25.25	12.66	1.67	2.80	5.11	10.18
	Allium sp.	1.63	4.30	0.00	0.00	0.00	0.00	0.87	3.20
	Poaceae	0.01	0.05	0.00	0.00	0.00	0.00	0.01	0.04
	Unknown	0.13	0.34	0.00	0.00	0.65	1.88	0.28	1.11
	Stem	0.00	0.00	0.00	0.00	0.10	0.32	0.03	0.18
Seed	Opuntia sp.	0.53	0.49	0.48	0.41	5.02	7.65	2.02	4.79
	Opuntia sp. - broken	0.00	0.00	0.05	0.10	0.00	0.00	0.01	0.04
Fiber	Agave sp.	64.79	14.06	32.89	14.58	22.65	31.71	46.49	29.03
	Dasylirion sp.	19.52	13.75	52.63	16.01	37.51	33.00	29.93	24.76
	Opuntia sp.	3.89	5.83	11.98	10.48	15.22	14.80	8.75	11.22
	Allium sp.	2.88	5.72	0.00	0.00	0.00	0.00	1.54	4.37
	Unknown	8.92	8.02	2.50	3.00	24.63	20.87	13.30	15.50
Phytolith	Raphide	53.45	19.28	20.38	9.16	49.20	25.05	47.62	22.75
	Druse	22.03	18.03	60.04	25.97	29.62	21.23	29.63	23.18
	Stylus	24.52	15.28	13.51	7.82	21.19	10.18	21.94	13.15
	Mesquite	0.00	0.00	6.07	12.14	0.00	0.00	0.81	4.43

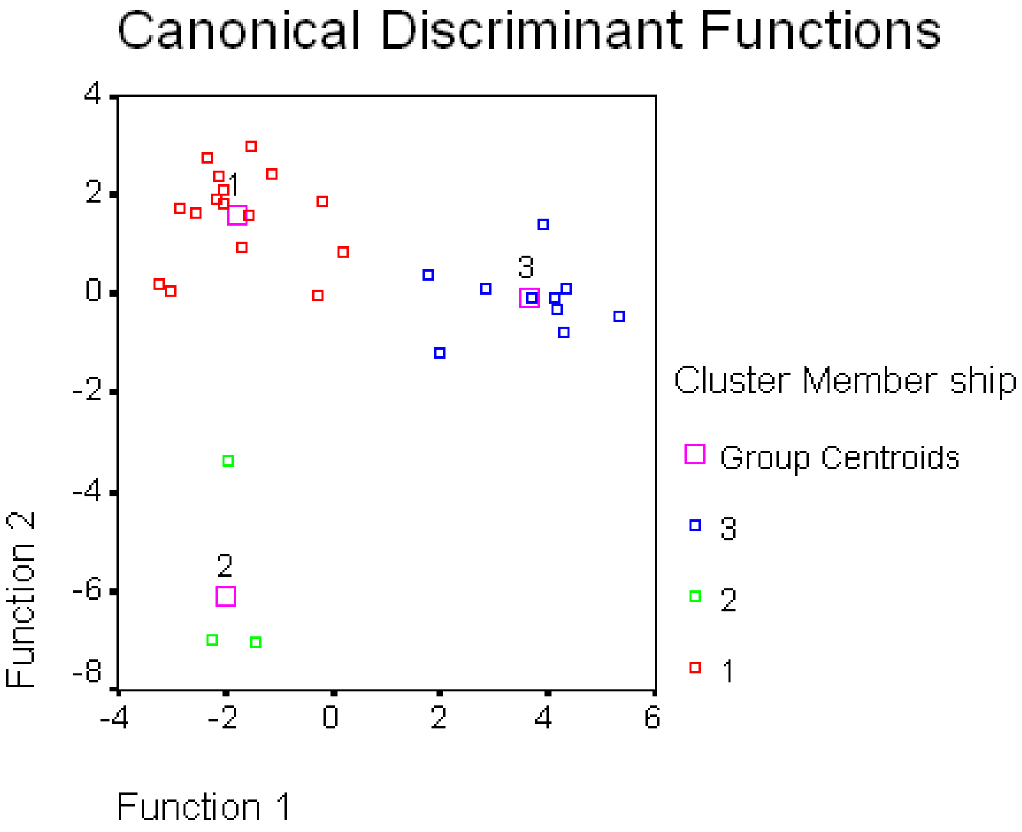


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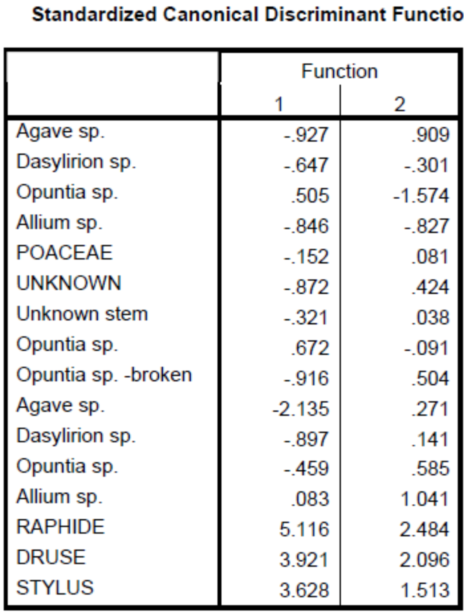
Figure 37. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Staple Resource Indicators from the Current Study

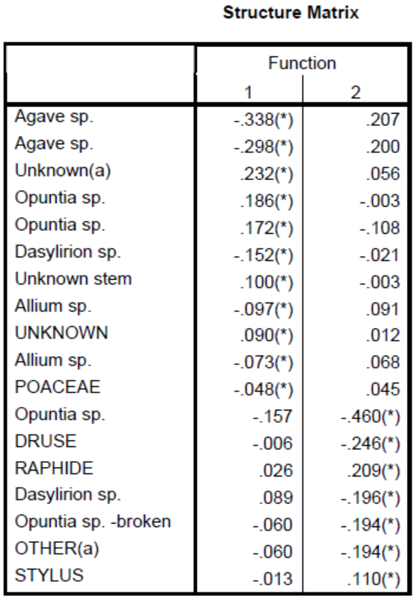
Table 27. Discriminant Function Coefficients of Cluster Analysis of Staple Resource Indicators



Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
Agave sp.	-.927	.909
Dasylirion sp.	-.647	-.301
Opuntia sp.	.505	-1.574
Allium sp.	-.846	-.827
POACEAE	-.152	.081
UNKNOWN	-.872	.424
Unknown stem	-.321	.038
Opuntia sp.	.672	-.091
Opuntia sp. -broken	-.916	.504
Agave sp.	-2.135	.271
Dasylirion sp.	-.897	.141
Opuntia sp.	-.459	.585
Allium sp.	.083	1.041
RAPHIDE	5.116	2.484
DRUSE	3.921	2.096
STYLUS	3.628	1.513

Table 28. Structure Matrix of Cluster Analysis of Staple Resource Indicators

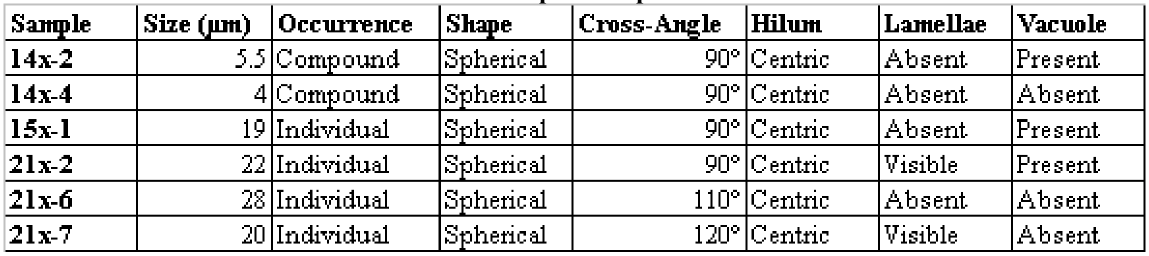


Structure Matrix

	Function	
	1	2
Agave sp.	-.338(*)	.207
Agave sp.	-.298(*)	.200
Unknown(a)	.232(*)	.056
Opuntia sp.	.186(*)	-.003
Opuntia sp.	.172(*)	-.108
Dasylirion sp.	-.152(*)	-.021
Unknown stem	.100(*)	-.003
Allium sp.	-.097(*)	.091
UNKNOWN	.090(*)	.012
Allium sp.	-.073(*)	.068
POACEAE	-.048(*)	.045
Opuntia sp.	-.157	-.460(*)
DRUSE	-.006	-.246(*)
RAPHIDE	.026	.209(*)
Dasylirion sp.	.089	-.196(*)
Opuntia sp. -broken	-.060	-.194(*)
OTHER(a)	-.060	-.194(*)
STYLUS	-.013	.110(*)

Starch. While all thirty coprolite specimens in this study were analyzed for starch, only six specimens yielded starch granules and none in great quantity (Table 29). None of the major staples of the Lower Pecos canyonlands use starch as a storage carbohydrate, so this was not unexpected. The starch granules recovered in this study were not identified to botanical source, due to the limited reference collection of known starchy resources in the region. Two of the coprolites contain aggregated, small, spherical starch granules similar to amyloplast cells observed in grass seed reference samples (Fig 16e). These starch granules have no damage or evidence of processing, which suggests that they may not represent intentionally ingested starch as a food resource. Instead, they may reflect the stomach contents of ingested small game, as Williams-Dean (1978) suggests for the grass seeds recovered in her study. The remaining four specimens contain larger, solitary starch granules that are likely derived from geophytes, although this remains tentative. This may indicate that there are secondary starchy resources incorporated into the regional subsistence strategy that have not been identified to date. Perhaps the most important result of this starch study is simply the recovery of starch from coprolite specimens. It is clear that some starch granules survive the digestive process in recognizable form. This suggests that starch research may prove a useful tool on coprolite specimens from other regions, where populations were more dependent on starchy resources as a component of their diet. The relatively abundant coprolites from the agricultural Southwest and the Great Basin region would be ideal collections to further explore this novel technique.

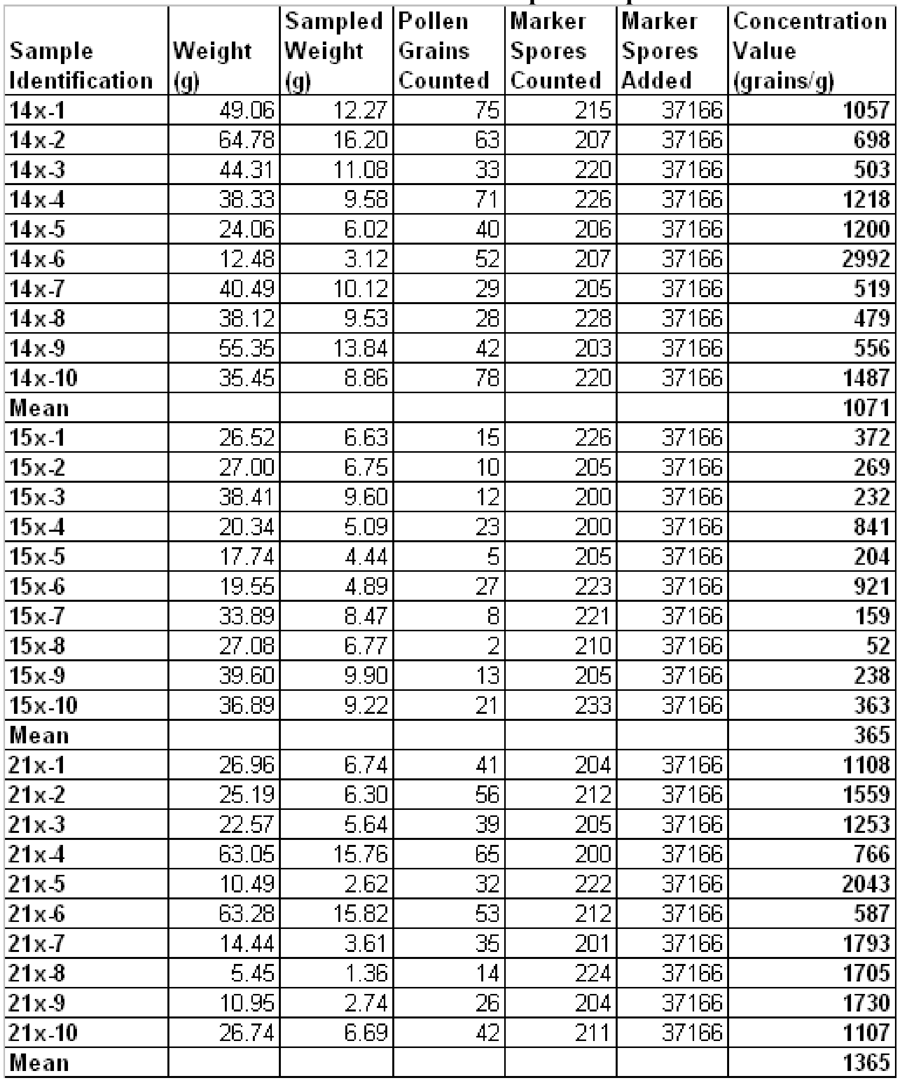
Table 29. Starch Granules Recovered from Coprolite Specimens



Sample	**Size (µm)**	**Occurrence**	**Shape**	**Cross-Angle**	**Hilum**	**Lamellae**	**Vacuole**
14x-2	5.5	Compound	Spherical	90°	Centric	Absent	Present
14x-4	4	Compound	Spherical	90°	Centric	Absent	Absent
15x-1	19	Individual	Spherical	90°	Centric	Absent	Present
21x-2	22	Individual	Spherical	90°	Centric	Visible	Present
21x-6	28	Individual	Spherical	110°	Centric	Absent	Absent
21x-7	20	Individual	Spherical	120°	Centric	Visible	Absent

Pollen. Upon initial examination of the processed pollen samples from these specimens, it was clear that the *Lycopodium* sp. marker spores were much more abundant than the fossil pollen grains in the samples. In every case, the over-abundance of the marker spores relative to the fossil pollen invalidated the statistical analysis of the samples (Moore et al. 1991). Despite the inherent inaccuracy, concentration values were calculated for each specimen (Table 30). Previous research has confirmed that pollen concentration values are very important for interpreting the pollen spectra of coprolite specimens, as they can distinguish between accumulated ambient pollen from air and water and purposefully ingested pollen representing dietary or medicinal consumption (Dean 1993; Kelso and Solomon 2006; Reinhard et al. 2006; Reinhard et al. 1991; Sobolik 1988a). The calculated concentration values of the thirty specimens in this study were markedly lower than expected based on prior pollen counts of coprolites from the Lower Pecos canyonlands (Edwards 1990; Sobolik 1991a). The concentration values from these specimens were well below the acceptable threshold for archaeological soil specimens, rendering any further analysis of these data untenable. While this could be due to the greater age of the current specimens than the coprolites examined for pollen in previous studies, or the damp conditions noted during the excavation of these specimens along the back wall of the rockshelter, it is more likely due to the processing method utilized in this study. Previous studies had added the marker spores during the initial rehydration step of the coprolite processing (Edwards 1990; Sobolik 1991a). In the current study, the marker spores were added much later in the processing (Figure 32) in order to minimize the number of tablets needed to generate statistically accurate results. The anticipated high levels of fossil pollen were not present in the thirty specimens, resulting in the over-abundance of marker spores and the limited applicability of the pollen data in the current study. While pollen may not directly inform on the issue of diet-breadth so central to this current study, it may nevertheless add more detail to our understanding of seasonality and, possibly, medical plant use. For these reasons, a second pollen study will be performed at a later date, using a fragment of each reserved half-specimen.

Table 30. Pollen Concentration Values for Coprolite Specimens



Sample Identification	Weight (g)	Sampled Weight (g)	Pollen Grains Counted	Marker Spores Counted	Marker Spores Added	Concentration Value (grains/g)
14x-1	49.06	12.27	75	215	37166	**1057**
14x-2	64.78	16.20	63	207	37166	**698**
14x-3	44.31	11.08	33	220	37166	**503**
14x-4	38.33	9.58	71	226	37166	**1218**
14x-5	24.06	6.02	40	206	37166	**1200**
14x-6	12.48	3.12	52	207	37166	**2992**
14x-7	40.49	10.12	29	205	37166	**519**
14x-8	38.12	9.53	28	228	37166	**479**
14x-9	55.35	13.84	42	203	37166	**556**
14x-10	35.45	8.86	78	220	37166	**1487**
Mean						**1071**
15x-1	26.52	6.63	15	226	37166	**372**
15x-2	27.00	6.75	10	205	37166	**269**
15x-3	38.41	9.60	12	200	37166	**232**
15x-4	20.34	5.09	23	200	37166	**841**
15x-5	17.74	4.44	5	205	37166	**204**
15x-6	19.55	4.89	27	223	37166	**921**
15x-7	33.89	8.47	8	221	37166	**159**
15x-8	27.08	6.77	2	210	37166	**52**
15x-9	39.60	9.90	13	205	37166	**238**
15x-10	36.89	9.22	21	233	37166	**363**
Mean						**365**
21x-1	26.96	6.74	41	204	37166	**1108**
21x-2	25.19	6.30	56	212	37166	**1559**
21x-3	22.57	5.64	39	205	37166	**1253**
21x-4	63.05	15.76	65	200	37166	**766**
21x-5	10.49	2.62	32	222	37166	**2043**
21x-6	63.28	15.82	53	212	37166	**587**
21x-7	14.44	3.61	35	201	37166	**1793**
21x-8	5.45	1.36	14	224	37166	**1705**
21x-9	10.95	2.74	26	204	37166	**1730**
21x-10	26.74	6.69	42	211	37166	**1107**
Mean						**1365**

Prior Studies from Hinds Cave

Stock. The macrobotanical data derived from fifty-five coprolite specimens by Stock (1983) were divided into three clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 38). Table 31 presents the average value of each constituent in each cluster. . Cluster 1 (n=33) contains most of the specimens from this study. There is a great diversity of dietary constituents recognized in these specimens, but none of them appear to be a dominant component of all the specimens. The most abundant component is unidentified epidermal tissue. Cluster 2 (n=10) shows very high levels of tuna seeds, both whole and broken. There is a high diversity of seasonally available nuts and fruits in these specimens as well. There is no evidence of prickly pear cactus epidermal cells, but a relatively high level of unidentified epidermal tissue. Cluster 3 (n=12) has a much higher value for prickly pear cactus (*Opuntia* sp.) epidermal cells. This suggests a greater dependence on nopales in the meals represented by these specimens. Onion (*Allium* sp.) bulbs are also prevelant in these specimens. There is relatively little evidence for seed and fruit consumption in these specimens.

Figure 39 provides a visual display of the clusters along the first two factors generated with CDA. Tables 32 and 33 show the standardized canonical function coefficients and the structure matrix respectively. Table 32 confirms that prickly pear cactus epidermal cells have a strong negative correlation for function 1 and a strong positive correlation for function 2. Prickly pear tuna seeds (both broken and whole) show a strong positive correlation with function 1. Interestingly, seeds from the Paniceae tribe of the Poaceae family, which do not appear to be an important driver of the clustering results, have a very strong negative correlation with function 1. This is reinforced by the structure matrix in Table 33.

The lack of epidermal identification in this study precludes any strong statement on consumption patterns. The third cluster reflects a diet focused on the exploitation of nopales and the second cluster, that of tunas, but the majority of the specimens in the study fall into the first cluster. The dominant component used to group these specimens is unidentified epidermal tissue. This epidermal tissue may be derived from sotol, lechuguilla, or an unknown resource. Further statements of diet-breadth for these specimens are therefore restricted to the clearly differentiated use of prickly pear resources indicated in clusters 2 and 3.

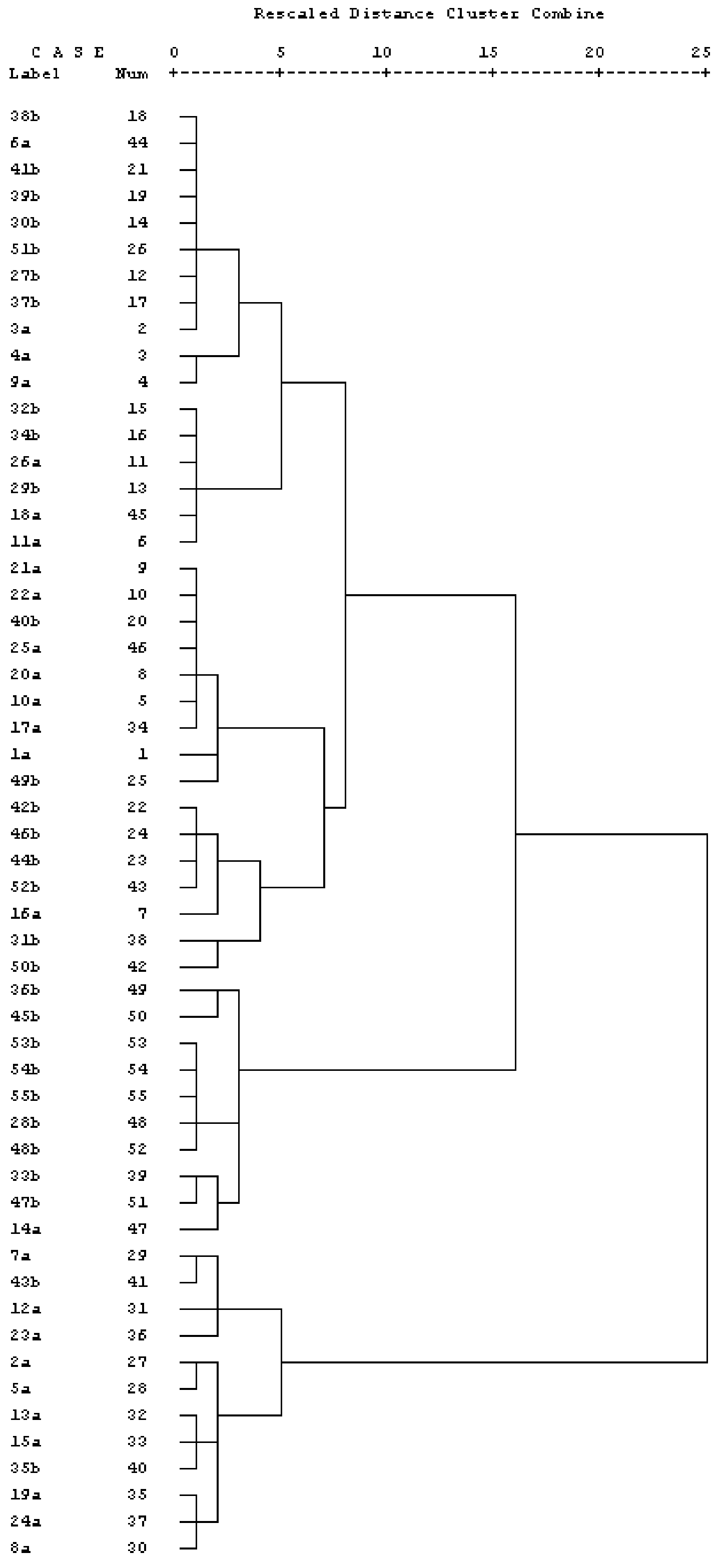


Figure 38. . Dendogram of Stock’s (1983) Data based on Ward's Method

Table 31. Mean Values of Stock's (1983) Data by Cluster

Component	Identification	Cluster 1 (n=33)		Cluster 2 (n=12)		Cluster 3 (n=10)		Total (n=55)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Seed	*Opuntia* sp. - Broken	0.2	0.4	2.8	0.9	0.2	0.6	0.8	1.2
	Opuntia sp.	0.1	0.2	1.0	0.7	0.0	0.0	0.3	0.5
Fiber	Unknown	6.4	1.7	5.3	1.1	6.4	1.1	6.2	1.5
Epidermis	*Opuntia* sp.	0.2	0.4	0.0	0.0	2.5	0.8	0.5	1.1
Flower Bud	Unknown	0.8	0.9	0.9	0.8	0.2	0.6	0.7	0.8
Bulb	*Allium* sp.	0.6	0.9	0.5	0.7	0.7	0.8	0.6	0.8
Glochids	*Opuntia* sp.	0.1	0.2	0.2	0.4	0.1	0.1	0.1	0.2
Nut Shell	*Juglans* sp.	0.1	0.3	0.2	0.4	0.0	0.0	0.1	0.3
Spine Base	*Opuntia* sp.	0.0	0.2	0.1	0.3	0.2	0.4	0.1	0.3
Seed	*Diospyros* sp.	0.1	0.3	0.3	0.4	0.0	0.0	0.1	0.3
	Opuntia leptocaulis	0.2	0.5	0.3	0.6	0.3	0.5	0.2	0.5
	Sporobolus sp.	0.0	0.2	0.1	0.3	0.0	0.0	0.1	0.2
	cf. *Coryphantha* sp.	0.1	0.2	0.1	0.3	0.0	0.0	0.1	0.2
	POACEAE	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Prosopis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Panicum sp.	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1
Bone	Unburnt	0.7	0.8	1.2	0.8	0.6	0.8	0.8	0.8
	Burnt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hair	Rodent	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.1
	Unknown	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Feather	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spines	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Skin	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scales	Unknown	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.2

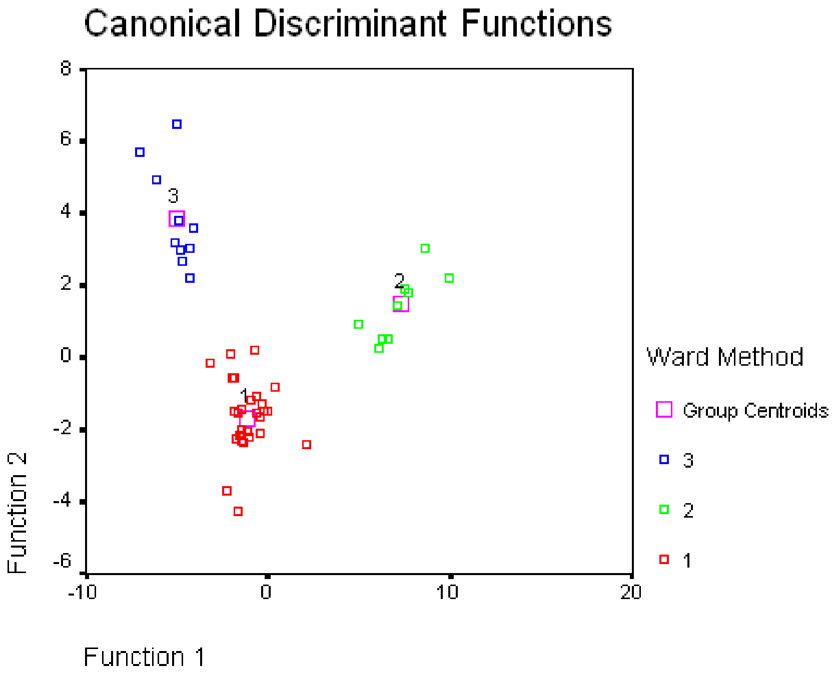
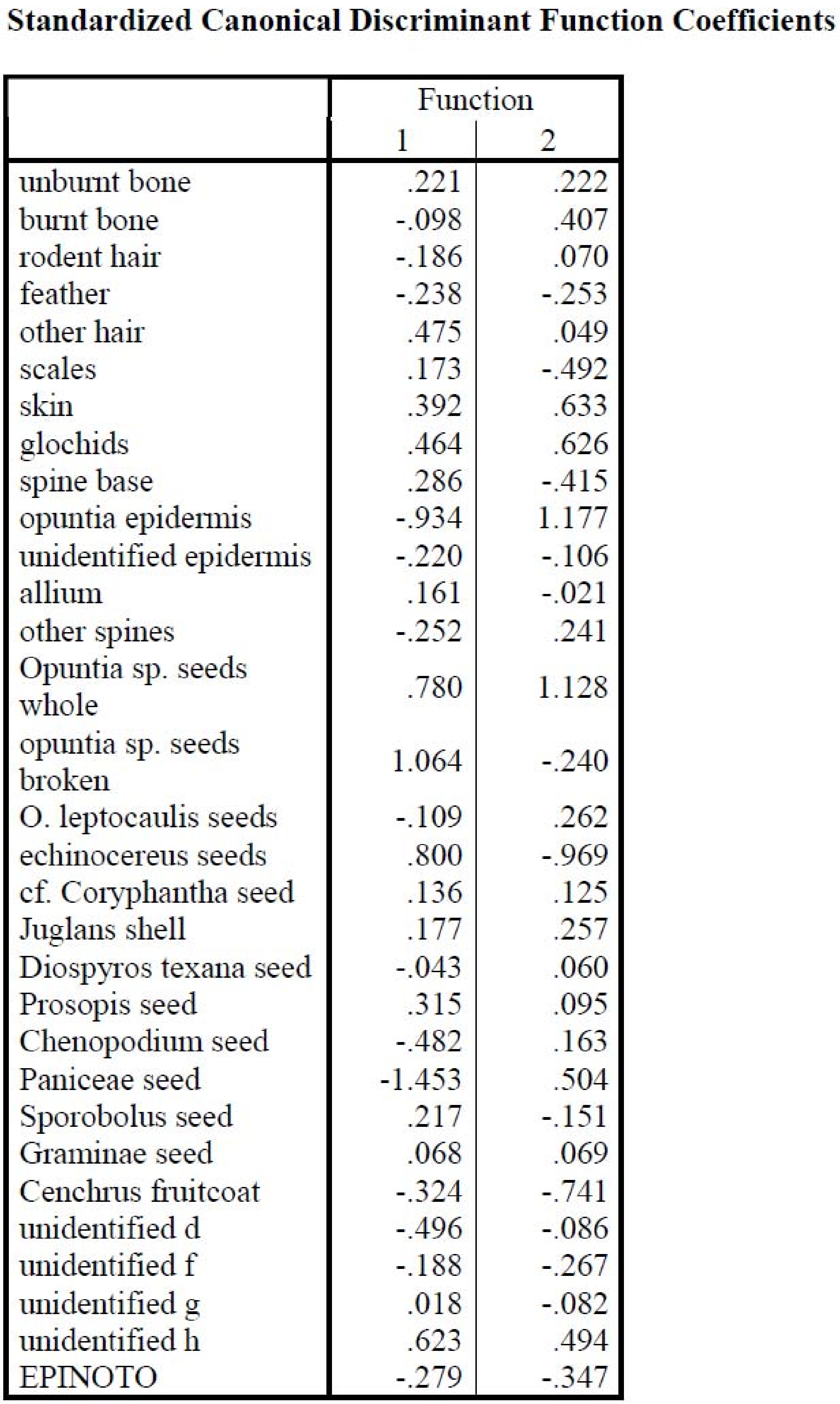


Figure 39. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Data from Stock (1983)

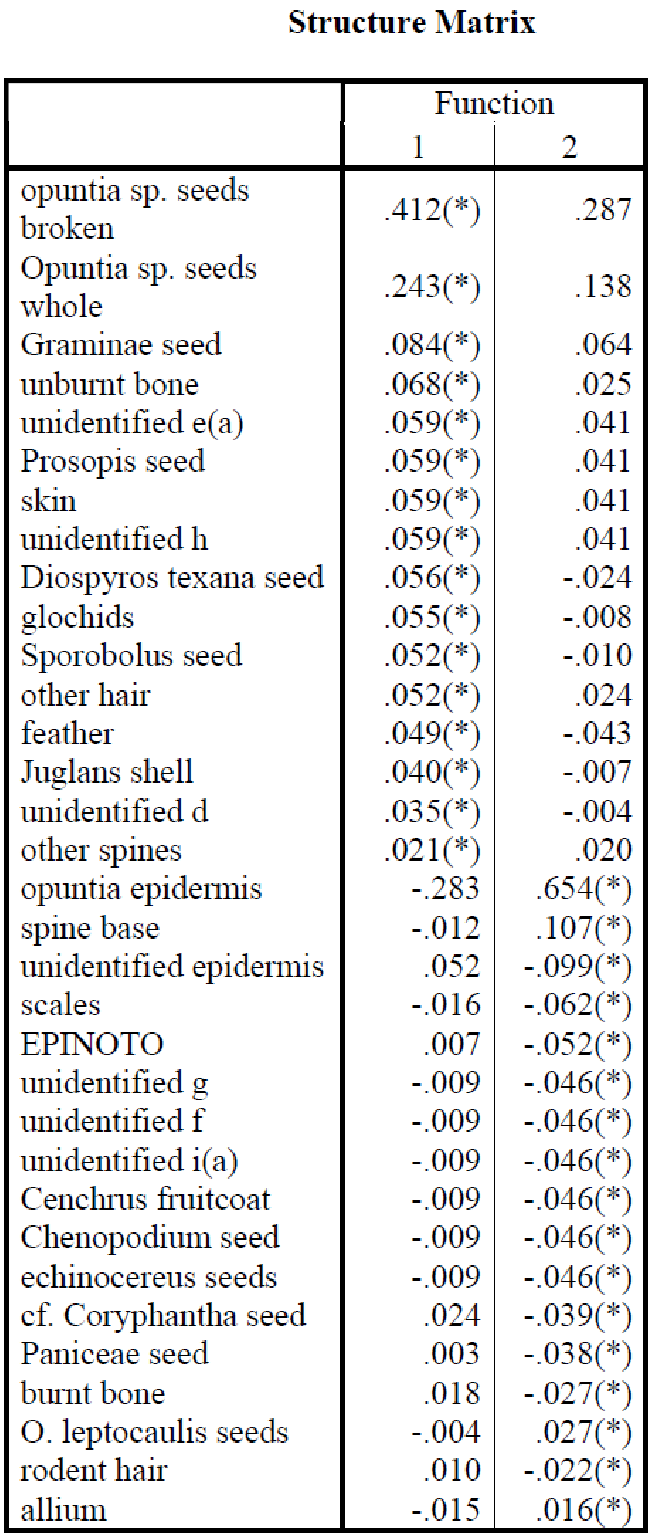
Table 32. Discriminant Function Coefficients of Cluster Analysis of Stock (1983)



Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
unburnt bone	.221	.222
burnt bone	-.098	.407
rodent hair	-.186	.070
feather	-.238	-.253
other hair	.475	.049
scales	.173	-.492
skin	.392	.633
glochids	.464	.626
spine base	.286	-.415
opuntia epidermis	-.934	1.177
unidentified epidermis	-.220	-.106
allium	.161	-.021
other spines	-.252	.241
Opuntia sp. seeds whole	.780	1.128
opuntia sp. seeds broken	1.064	-.240
O. leptocaulis seeds	-.109	.262
echinocereus seeds	.800	-.969
cf. Coryphantha seed	.136	.125
Juglans shell	.177	.257
Diospyros texana seed	-.043	.060
Prosopis seed	.315	.095
Chenopodium seed	-.482	.163
Paniceae seed	-1.453	.504
Sporobolus seed	.217	-.151
Graminae seed	.068	.069
Cenchrus fruitcoat	-.324	-.741
unidentified d	-.496	-.086
unidentified f	-.188	-.267
unidentified g	.018	-.082
unidentified h	.623	.494
EPINOTO	-.279	-.347

Table 33. Structure Matrix of Cluster Analysis of Stock (1983)



Structure Matrix

	Function	
	1	2
opuntia sp. seeds broken	.412(*)	.287
Opuntia sp. seeds whole	.243(*)	.138
Graminae seed	.084(*)	.064
unburnt bone	.068(*)	.025
unidentified e(a)	.059(*)	.041
Prosopis seed	.059(*)	.041
skin	.059(*)	.041
unidentified h	.059(*)	.041
Diospyros texana seed	.056(*)	-.024
glochids	.055(*)	-.008
Sporobolus seed	.052(*)	-.010
other hair	.052(*)	.024
feather	.049(*)	-.043
Juglans shell	.040(*)	-.007
unidentified d	.035(*)	-.004
other spines	.021(*)	.020
opuntia epidermis	-.283	.654(*)
spine base	-.012	.107(*)
unidentified epidermis	.052	-.099(*)
scales	-.016	-.062(*)
EPINOTO	.007	-.052(*)
unidentified g	-.009	-.046(*)
unidentified f	-.009	-.046(*)
unidentified i(a)	-.009	-.046(*)
Cenchrus fruitcoat	-.009	-.046(*)
Chenopodium seed	-.009	-.046(*)
echinocereus seeds	-.009	-.046(*)
cf. Coryphantha seed	.024	-.039(*)
Paniceae seed	.003	-.038(*)
burnt bone	.018	-.027(*)
O. leptocaulis seeds	-.004	.027(*)
rodent hair	.010	-.022(*)
allium	-.015	.016(*)

Williams-Dean. The specimens analyzed by Williams-Dean (1978) were divided into three clusters based upon a scree plot of the agglomeration coefficients of her macrobotanical data and visual inspection of the dendogram (Figure 40). Table 34 presents the average value of each constituent in each cluster. Cluster 1 (n=31) has a much higher average value for prickly pear cactus epidermal cells than the total assemblage. There is also a higher average value for onion bulb fragments. Cluster 2 (N=50) has a high diversity of constituents represented at low average levels. Walnut (*Juglans* sp.) and *Opuntia leptocaulis* seeds have higher averages than the total assemblage. Both bone fragments and lechuguilla epidermal cells are more abundant in this cluster than the total assemblage of coprolites. There is relatively little evidence of prickly pear tuna seeds or epidermal tissue other than lechuguilla in these samples. Cluster 3 (n=19) has a very high level of tuna seeds. Many of the tuna seeds in cluster 3 were broken or crushed, which may indicate processing for short-term storage, a practice observed in the ethnohistoric record (De Leon 1971; Foster 2008b; Krieger 2002; Thoms 2008b; Wade 2003). Alternatively, the increased fragmentation could reflect greater mastication than seen in the other coprolite specimens from this study or possibly a case of “second harvest” of undigested dietary components from fecal matter during times of famine (Heizer 1967). This practice, recorded in the ethnohistoric literature from Northern Mexico (Griffen 1969), seems unlikely, as it would suggest a pattern of repeated famine unsupported by the bioarchaeological data from the region (Hester et al. 1989; Mailloux 2003).

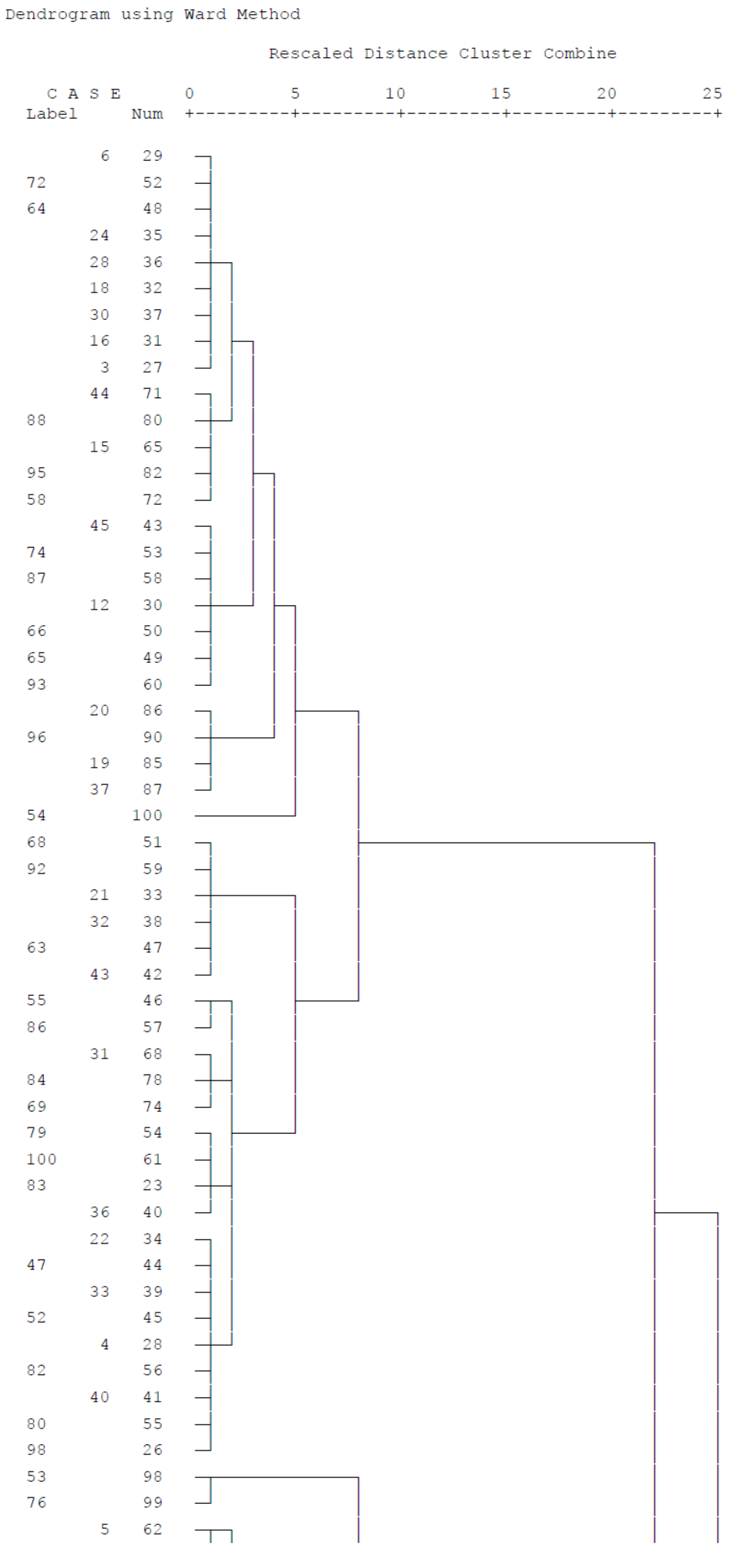


Figure 40. Dendogram of Williams-Dean’s (1978) Data based on Ward's Method

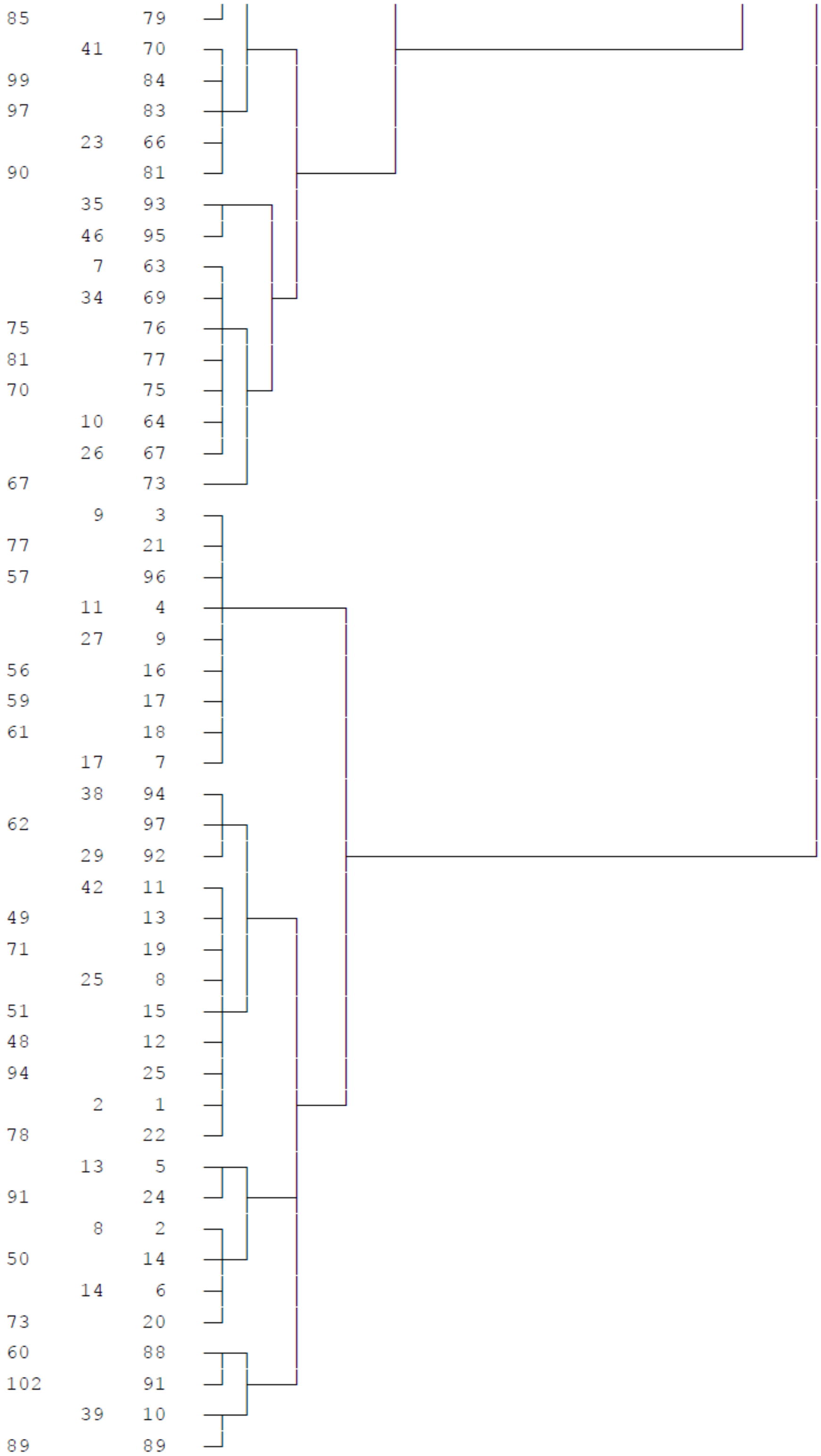


Figure 40. Continued

Figure 41 provides a visual display of the clusters along the first two factors generated with CDA. Tables 35 and 36 show the standardized canonical function coefficients and the structure matrix respectively. As seen in Table 35, function 1 has a positive correlation with tuna seeds (broken, big, and little), mesquite (*Prosopis* sp.) seeds, and sand bur (*Cenchrus* sp.) seeds, and a negative correlation with persimmon (*Diospyros* sp.) seeds, amaranth (*Amaranthus* sp.) seeds, grape (*Vitis* sp.) seeds, onion bulb fragments, and prickly pear cactus epidermal cells. Function 2 has a positive correlation with prickly pear cactus epidermal cells and sandbur seeds. This is reinforced by the structure matrix in table 36.

The first cluster (n=31) reflects a diet focused on nopales and onion bulbs. Other constituents such as persimmon (*Diospyros* sp.) and hackberry (*Celtis* sp.) were encountered in trace amounts in several of the specimens. The second cluster (n=50) has very low levels of identified plant resources. The largest deviation from the mean for all specimens is exhibited by lechuguilla epidermal tissue, though it still occurs at very low levels. Levels of walnut shell and cholla seed are also slightly elevated. Prickly pear seeds and epidermal tissue are present at extremely low levels in these specimens, suggesting that this cluster is defined by lack of prickly pear resources. It seems likely, based on the high fiber content and elevated lechuguilla epidermal tissue, that this cluster reflects a diet focused on roaster lechuguilla hearts supplemented by other resources. Cluster 3 (n=19) contains specimens with high levels of prickly pear seeds, indicating a diet focused on the consumption of tunas as the staple resource.

Table 34. Mean Values of Williams-Dean's (1978) Data by Cluster

Component	Identification	Cluster 1 (n=31)		Cluster 2 (n=50)		Cluster 3 (n=19)		Total (n=100)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Epidermis	*Opuntia* sp.	2.5	0.9	0.2	0.4	0.7	1.0	1.0	1.2
	Dasylirion sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Agave sp.	0.1	0.2	0.2	0.3	0.1	0.2	0.1	0.3
Fiber	Unknown	6.3	0.8	7.1	0.8	5.5	1.4	6.5	1.1
Seed	*Opuntia* sp. - broken	0.3	0.5	0.3	0.4	2.8	1.4	0.8	1.2
	Opuntia sp. - little	0.1	0.2	0.1	0.2	1.1	0.7	0.3	0.5
	Opuntia sp. - big	0.0	0.0	0.0	0.0	0.3	0.6	0.1	0.3
Bulb	*Allium* sp.	0.5	0.8	0.3	0.6	0.2	0.4	0.3	0.6
Nut Shell	*Juglans* sp.	0.0	0.0	0.3	0.7	0.1	0.3	0.2	0.6
Achene	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seed	*Diospyros* sp.	0.2	0.5	0.0	0.0	0.1	0.5	0.1	0.4
	Opuntia leptocaulis	0.3	0.7	0.4	0.8	0.2	0.5	0.3	0.7
	Sporobolus sp.	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
	Celtis sp.	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1
	Carex sp.	0.0	0.0	0.1	0.2	0.1	0.5	0.1	0.3
	Prosopis sp.	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	Cenchrus sp.	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.1
Bone	*Unknown*	0.9	1.0	1.6	1.2	1.4	1.0	1.3	1.1
Fur	*Unknown*	0.7	0.5	0.8	0.4	0.9	0.3	0.8	0.4

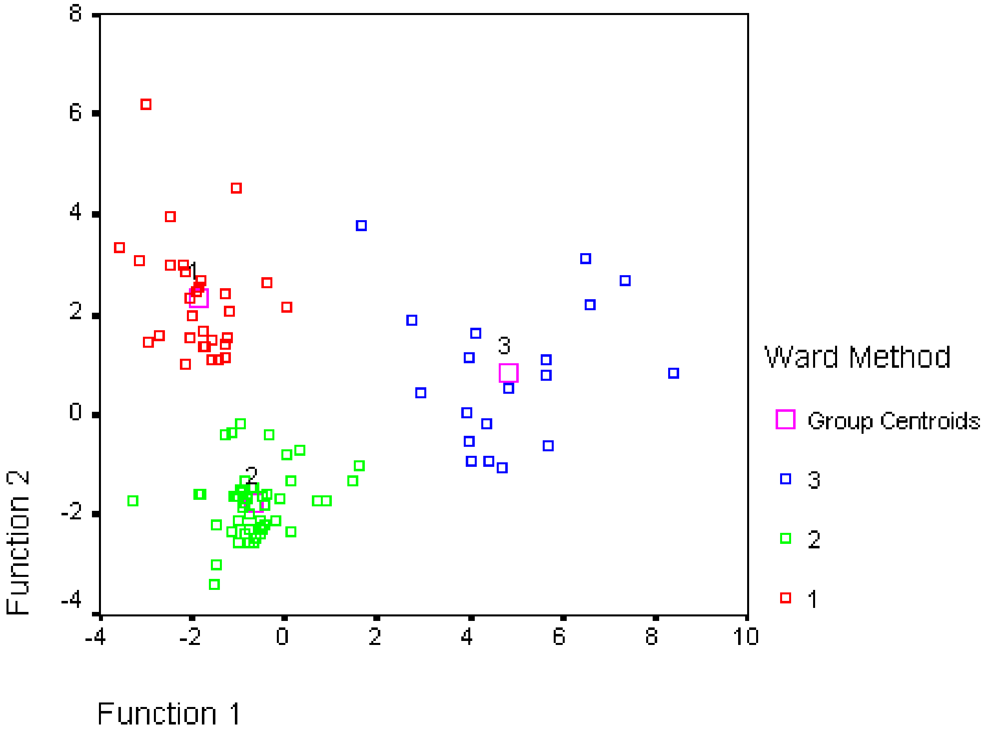
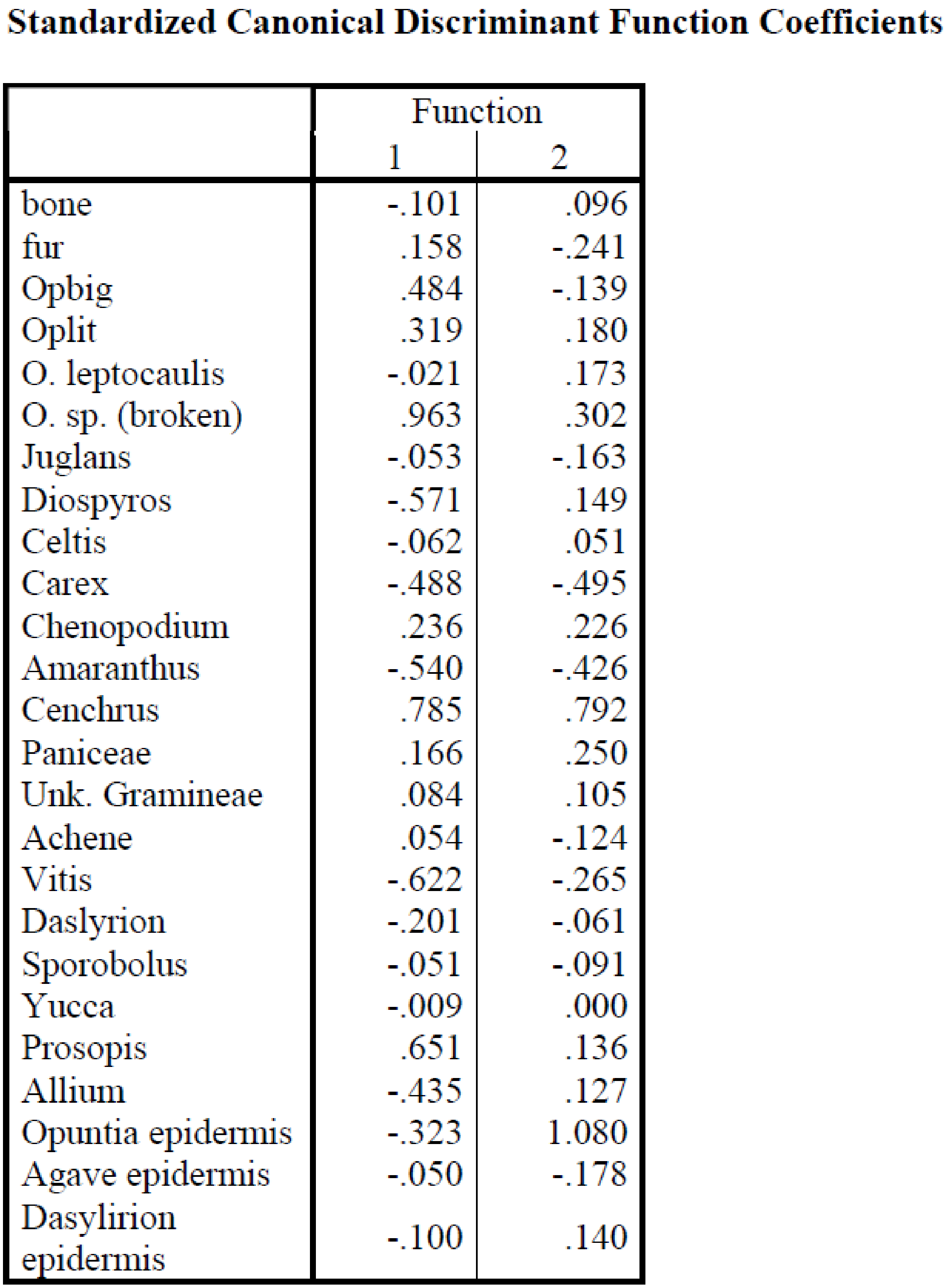


Figure 411. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Data from Williams-Dean (1978)

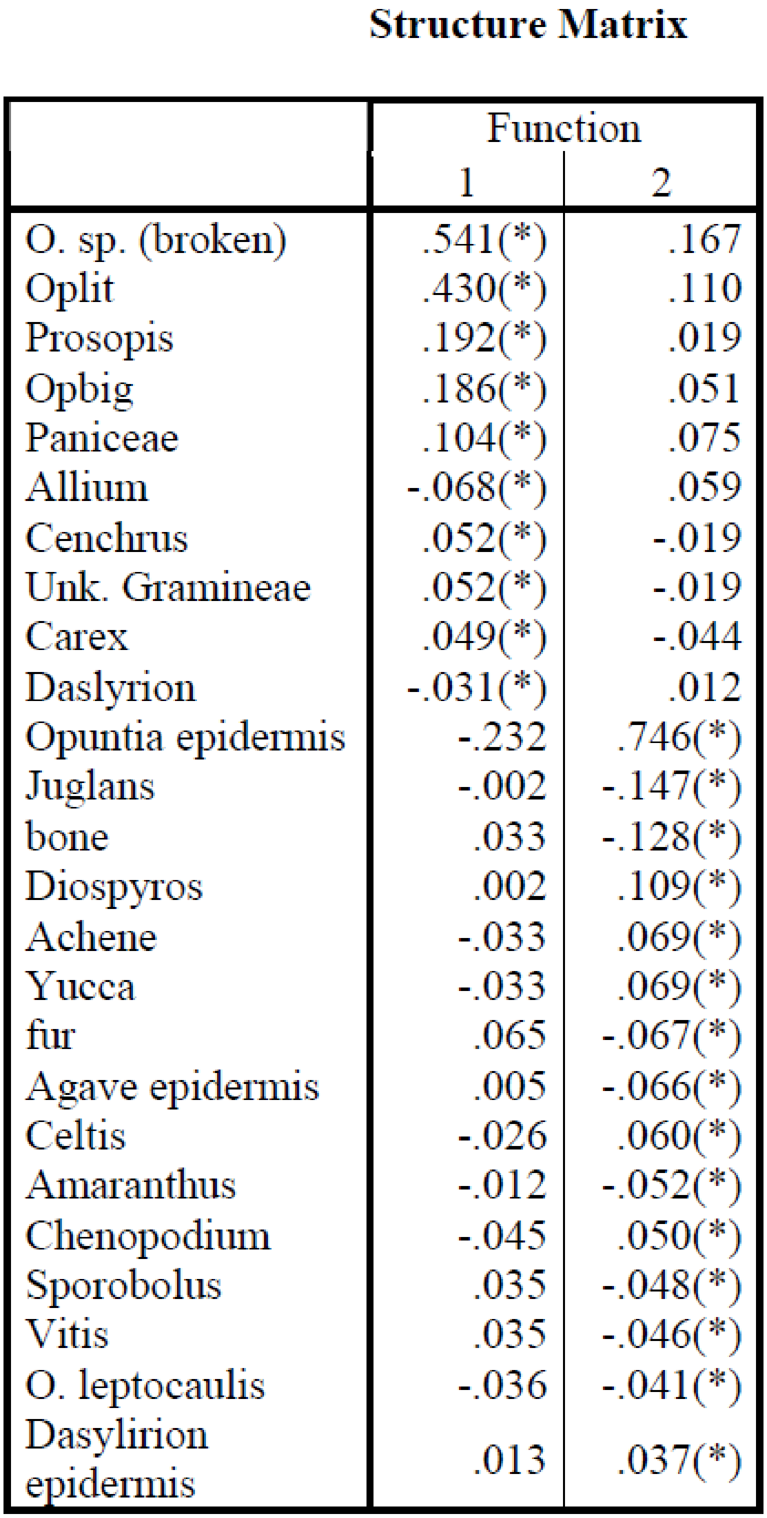
Table 35. Discriminant Function Coefficients of Cluster Analysis of Williams-Dean (1978)



Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
bone	-.101	.096
fur	.158	-.241
Opbig	.484	-.139
Oplit	.319	.180
O. leptocaulis	-.021	.173
O. sp. (broken)	.963	.302
Juglans	-.053	-.163
Diospyros	-.571	.149
Celtis	-.062	.051
Carex	-.488	-.495
Chenopodium	.236	.226
Amaranthus	-.540	-.426
Cenchrus	.785	.792
Paniceae	.166	.250
Unk. Gramineae	.084	.105
Achene	.054	-.124
Vitis	-.622	-.265
Daslyrion	-.201	-.061
Sporobolus	-.051	-.091
Yucca	-.009	.000
Prosopis	.651	.136
Allium	-.435	.127
Opuntia epidermis	-.323	1.080
Agave epidermis	-.050	-.178
Dasylirion epidermis	-.100	.140

Table 36. Structure Matrix of Cluster Analysis of Williams-Dean (1978)



Structure Matrix

	Function	
	1	2
O. sp. (broken)	.541(*)	.167
Oplit	.430(*)	.110
Prosopis	.192(*)	.019
Opbig	.186(*)	.051
Paniceae	.104(*)	.075
Allium	-.068(*)	.059
Cenchrus	.052(*)	-.019
Unk. Gramineae	.052(*)	-.019
Carex	.049(*)	-.044
Daslyrion	-.031(*)	.012
Opuntia epidermis	-.232	.746(*)
Juglans	-.002	-.147(*)
bone	.033	-.128(*)
Diospyros	.002	.109(*)
Achene	-.033	.069(*)
Yucca	-.033	.069(*)
fur	.065	-.067(*)
Agave epidermis	.005	-.066(*)
Celtis	-.026	.060(*)
Amaranthus	-.012	-.052(*)
Chenopodium	-.045	.050(*)
Sporobolus	.035	-.048(*)
Vitis	.035	-.046(*)
O. leptocaulis	-.036	-.041(*)
Dasylirion epidermis	.013	.037(*)

Edwards. The specimens from Edwards (1990) were divided into three clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 42). Table 37 presents the average value of each constituent in each cluster. Cluster 1 (n=24) has a much higher average value for burned bone than the total assemblage. No plant resources seem to be an important common constituent of the specimens in this cluster. There are low average values for both tuna seeds and unidentified epidermal tissue. The specimens in cluster 2 (N=7) are dominated by tuna seeds. While there are a number of other dietary constituents represented in these samples, they are present at relatively low levels other than tuna and persimmon seeds. Most of the coprolites that contained taxa unique to one specimen are included in this cluster. Cluster 3 (N=8) has high average levels of unidentified epidermal tissue, which includes prickly pear cactus in this study. This cluster also contains the only specimens with onion fragments in the assemblage. There are very low levels of tuna and persimmon seeds. There is no strong evidence of fruit or seed resources in these samples.

Figure 43 provides a visual display of the clusters along the first two factors generated with CDA. Tables 38 and 39 show the standardized canonical function coefficients and the structure matrix respectively. As seen in Table 38, function 1 has a positive correlation with tuna seeds, hair, and persimmon seeds, and a negative correlation with unidentified epidermal cells and unburnt bone. Function 2 has a positive correlation with unidentified epidermal cells, onion, and unidentified stems, as well as a negative correlation with unburnt bone. This is reinforced by the structure matrix in Table 39.

This study suffers from the same issues as that of Stock (1983). The lack of any epidermal identification in this study limits assessment of diet-breadth for these specimens. The only clear indicator of staple resource consumption in this study is the presence of prickly pear seeds in the second cluster. The data from this study are still valuable in assessing seasonality of defecation and micro-habitat exploitation. However, without identification of either fiber ultimates or epidermal tissue, the two major components in almost every specimen, any statements on diet-breadth of the specimens examined in this study are purely speculative.

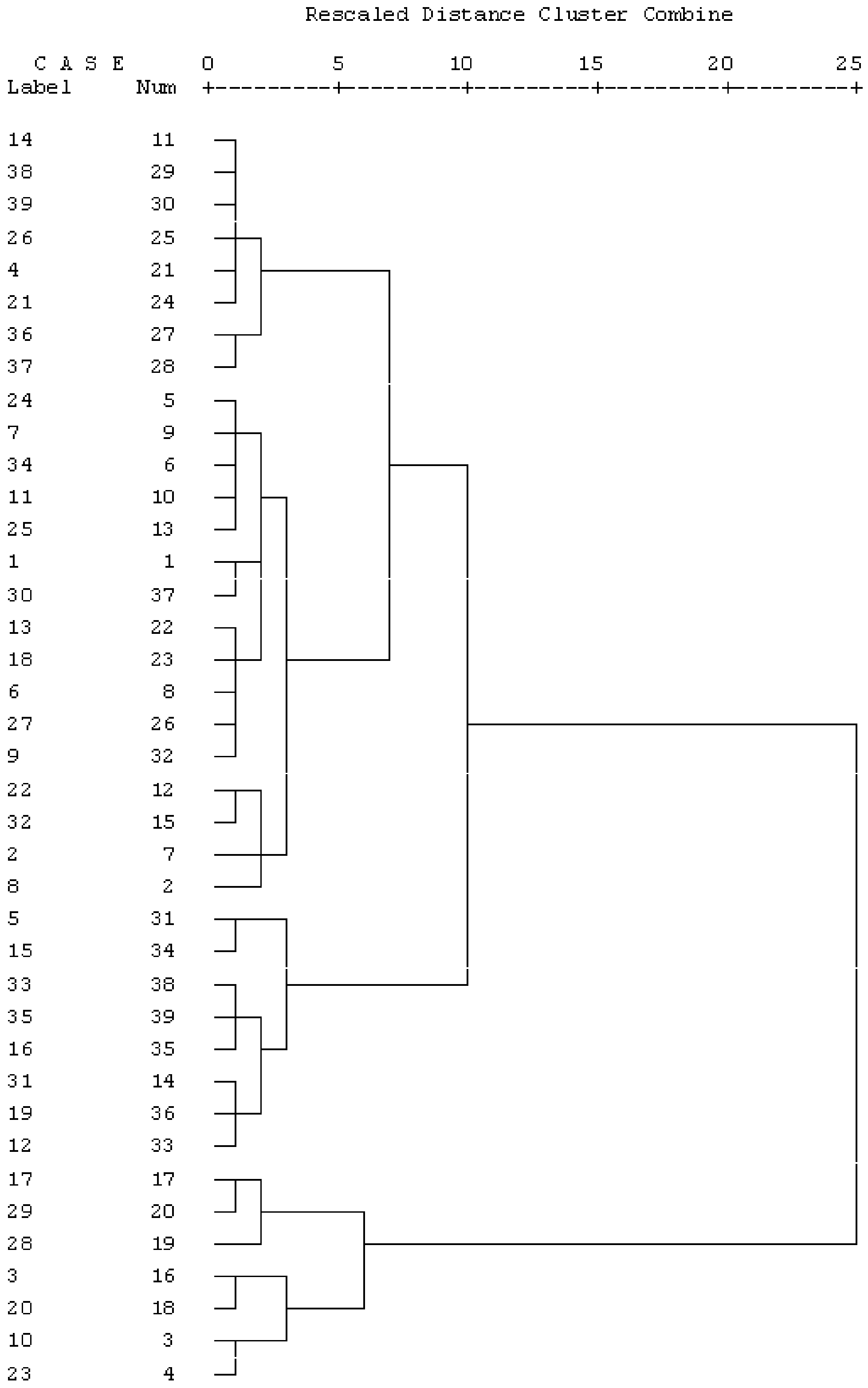


Figure 422. Dendogram of Edwards' (1990) Data based on Ward's Method

Table 37. Mean Values of Edwards' (1990) Data by Cluster

Component	Identification	Cluster 1 (n=24)		Cluster 2 (n=7)		Cluster 3 (n=8)		Total (n=39)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Seed	*Opuntia* sp.	1.0	1.0	4.7	1.5	0.3	0.5	1.5	1.8
Epidermis	Unknown	0.5	0.7	1.3	0.8	2.8	0.9	1.1	1.1
Bulb	*Allium* sp.	0.0	0.0	0.0	0.0	0.3	0.7	0.1	0.3
Stem	Unknown	0.0	0.0	0.0	0.0	0.3	0.7	0.1	0.3
Spines	Unknown	0.1	0.3	0.0	0.0	0.1	0.4	0.1	0.3
Fiber	Unknown	3.0	2.1	2.1	1.2	3.6	1.2	2.9	1.9
Seed	*Celtis* sp.	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.3
	Diospyros sp.	0.0	0.2	0.4	0.8	0.1	0.4	0.1	0.4
	Unknown	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.2
	Cassia sp.	0.2	0.5	0.1	0.4	0.0	0.0	0.1	0.4
	FABACEAE	0.1	0.3	0.1	0.4	0.0	0.0	0.1	0.3
	POACEAE	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2
	Polygonum sp.	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.2
	CYPERACEAE	0.0	0.0	0.3	0.8	0.0	0.0	0.1	0.3
	ASTERACEAE	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.2
Chitin	Insect	0.8	0.6	0.9	0.7	0.8	0.9	0.8	0.7
Bone	Unburnt	1.0	0.9	0.7	0.8	0.9	0.8	0.9	0.8
	Burnt	0.1	0.4	0.0	0.0	0.0	0.0	0.1	0.4
Feather	Unknown	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.2
Hair	Unknown	0.0	0.2	0.6	1.0	0.0	0.0	0.1	0.5

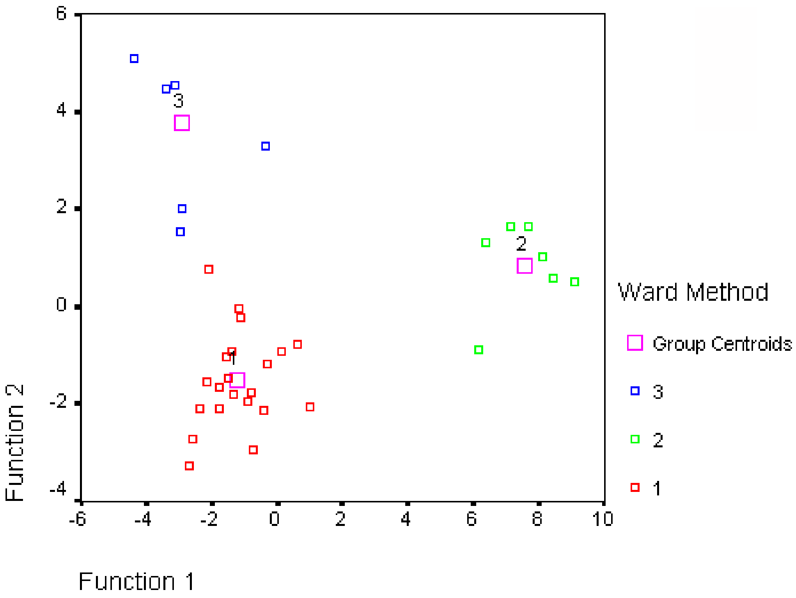
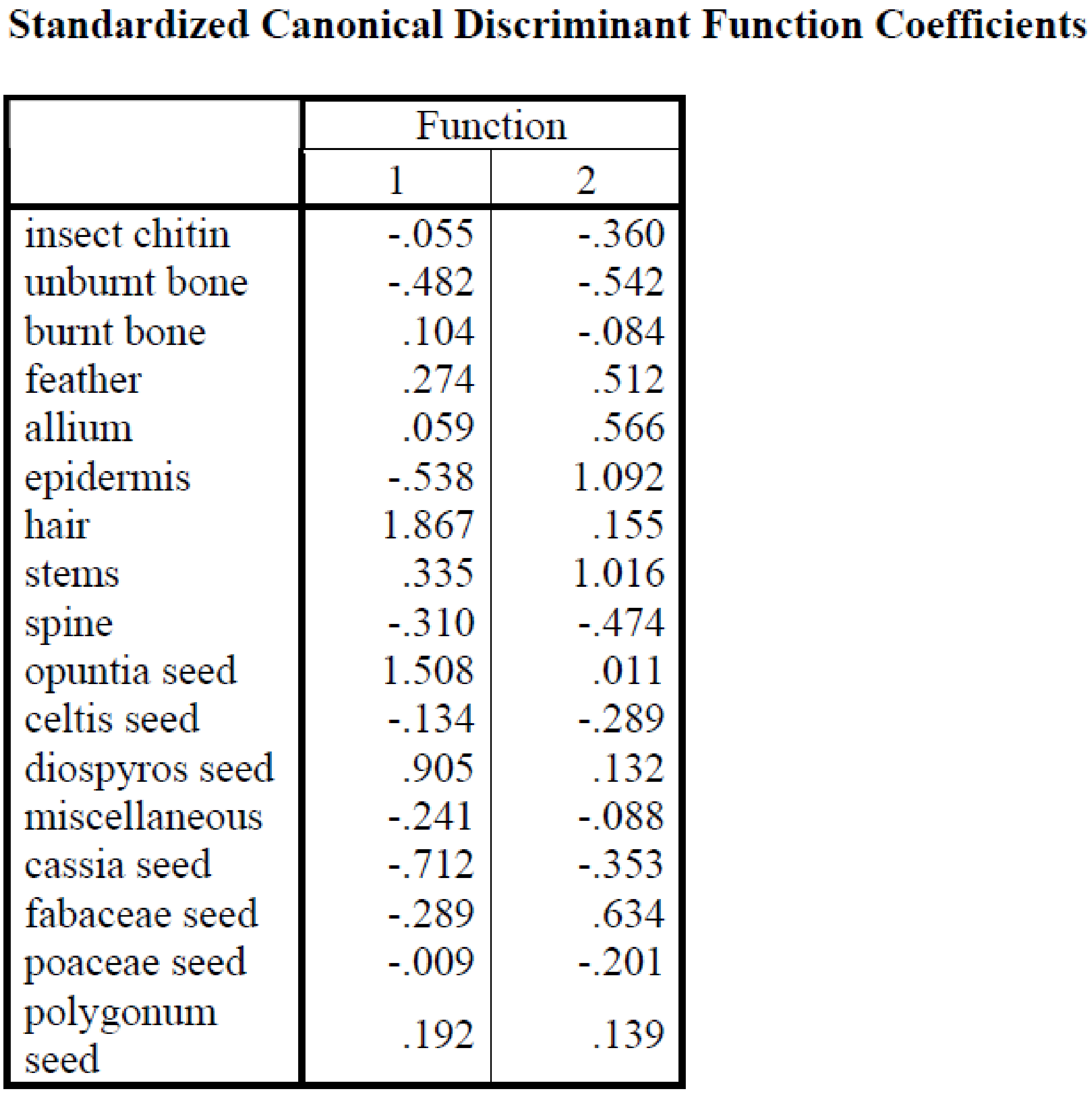


Figure 433. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Data from Edwards (1990)

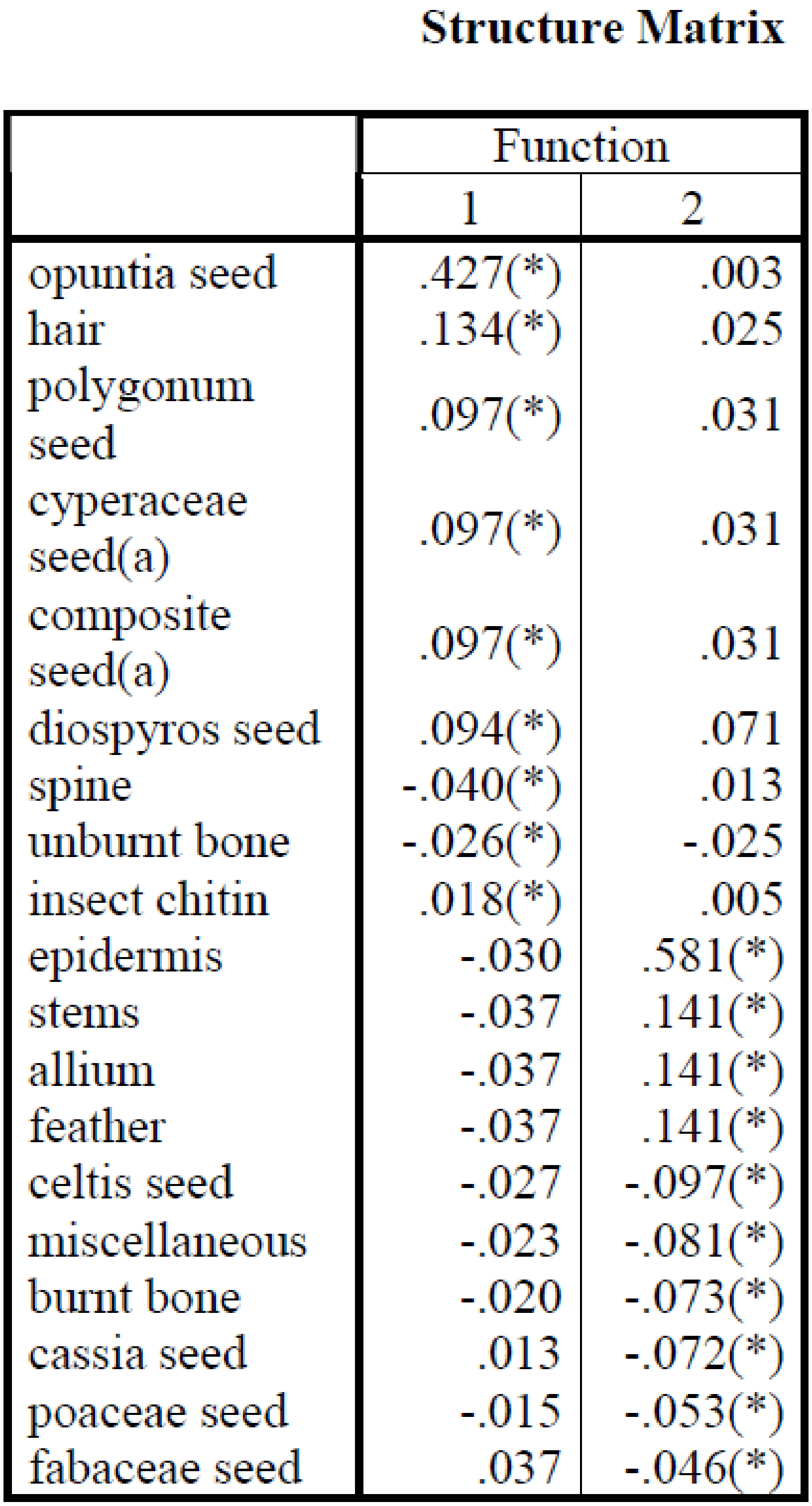
Table 38. Discriminant Function Coefficients of Cluster Analysis of Edwards (1990)



Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
insect chitin	-.055	-.360
unburnt bone	-.482	-.542
burnt bone	.104	-.084
feather	.274	.512
allium	.059	.566
epidermis	-.538	1.092
hair	1.867	.155
stems	.335	1.016
spine	-.310	-.474
opuntia seed	1.508	.011
celtis seed	-.134	-.289
diospyros seed	.905	.132
miscellaneous	-.241	-.088
cassia seed	-.712	-.353
fabaceae seed	-.289	.634
poaceae seed	-.009	-.201
polygonum seed	.192	.139

Table 39. Structure Matrix of Cluster Analysis of Edwards (1990)



Structure Matrix

	Function	
	1	2
opuntia seed	.427(*)	.003
hair	.134(*)	.025
polygonum seed	.097(*)	.031
cyperaceae seed(a)	.097(*)	.031
composite seed(a)	.097(*)	.031
diospyros seed	.094(*)	.071
spine	-.040(*)	.013
unburnt bone	-.026(*)	-.025
insect chitin	.018(*)	.005
epidermis	-.030	.581(*)
stems	-.037	.141(*)
allium	-.037	.141(*)
feather	-.037	.141(*)
celtis seed	-.027	-.097(*)
miscellaneous	-.023	-.081(*)
burnt bone	-.020	-.073(*)
cassia seed	.013	-.072(*)
poaceae seed	-.015	-.053(*)
fabaceae seed	.037	-.046(*)

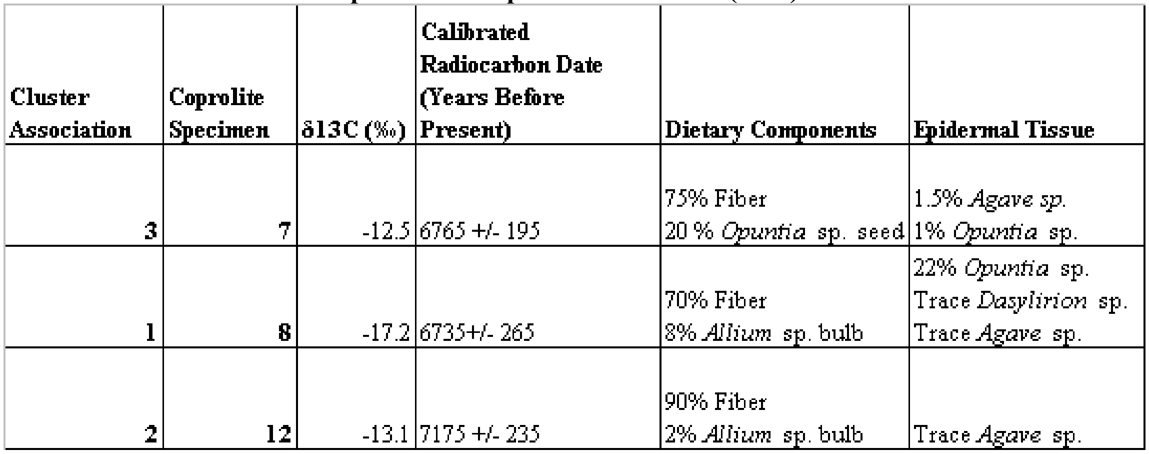
Staple Isotope Data. The macrofossil data from Williams-Dean (1978) are corroborated by stable carbon isotope values associated with recent radiocarbon dating of three of the coprolite specimens (Table 40) (Dean 2004). As outlined in Chapter VI, stable carbon isotope data from coprolites should reflect the photosynthetic pathways of the major botanical components in the diet (Codron et al. 2007a; Codron et al. 2007b; Deniro and Epstein 1978; Sponheimer et al. 2003b; Sternberg et al. 1984). While these data are available for too few specimens for any detailed analysis, it is interesting to note that there is some variation among the three samples. Coprolite specimen 7, with membership in cluster 3, exhibits very high levels of prickly pear seed, and relatively large amounts of lechuguilla epidermal tissue compared to other specimens in Williams-Dean's (1978) study. The reported $\delta^{13}C$ value of -12.5‰ supports the dietary dependence on plant resources exhibiting CAM photosynthetic pathways, such as prickly pear and lechuguilla (Sternberg et al. 1984). The dietary pattern represented in this cluster is that of staple dependence on prickly pear tunas.

Coprolite specimen 8, grouped in cluster 1, yielded very high levels of prickly pear epidermal tissue and onion bulbs. The reported $\delta^{13}C$ value of -17.2‰ suggests a mix of C3 and CAM/C4 resources. This is corroborated by the macrofossil data, which reflect a diet focused on both nopales (CAM) and onion (C3) resources. The third sample, coprolite specimen 12, a member of cluster 2, presents an interesting situation. There are not very high levels of any identified resource in this specimen. Onion bulbs and agave epidermal tissue are both reported, but the bulk of this specimen is composed of unidentified fiber. The reported $\delta^{13}C$ value of -13.1‰ suggests a diet dominated by

CAM/C4 resources with, possibly, a small amount of C3 resources also consumed. It seems likely that this specimen reflects a diet dominated by lechuguilla hearts, which would have an abundance of fiber and, potentially, little adhering epidermal tissue, depending on processing (Woltz 1998). Onion bulbs were also present in low quantities. Overall, this cluster exhibits a high diversity of constituents, but at very low levels. The high levels of fiber and proportionally greater levels of agave epidermal tissue suggest that this cluster reflects a diet focused on the exploitation of lechuguilla as the primary plant resource with different supplemental resources incorporated when available.

Staple carbon isotopes could prove a useful tool in corroborating the dietary patterns derived from the other lines of evidence considered in this study. While the gross patterning of plant resources based on photosynthetic pathway may not reveal individual taxa, it can inform on the general nature of the diet. This may be particularly useful for samples where the bulk of the specimen, generally fiber, has not been identified to a botanical source and other components only occur in very low levels, as is the case with the specimens in cluster 2. This approach also allows for a direct comparison between the staple carbon isotope data for skeletal populations in the region (Bousman and Quigg 2006; Huebner 1991) and the staple carbon isotope data derived from coprolites.

Table 40. Stable Carbon Isotope Data of Coprolites from Dean (2004)



Cluster Association	Coprolite Specimen	δ13C (‰)	Calibrated Radiocarbon Date (Years Before Present)	Dietary Components	Epidermal Tissue
3	7	-12.5	6765 +/- 195	75% Fiber 20 % *Opuntia* sp. seed	1.5% *Agave sp.* 1% *Opuntia* sp.
1	8	-17.2	6735+/- 265	70% Fiber 8% *Allium* sp. bulb	22% *Opuntia* sp. Trace *Dasylirion* sp. Trace *Agave* sp.
2	12	-13.1	7175 +/- 235	90% Fiber 2% *Allium* sp. bulb	Trace *Agave* sp.

aDNA Studies. Poinar et al. (2001) have published aDNA data from three coprolite specimens recovered in the Hinds Cave excavation (Table 41). While the context of these specimens is somewhat contentious, the data present an interesting view of the potential for combining aDNA studies with more commonly employed techniques in coprolite analysis. While Poinar et al. (2001) also report on the recovery of mtDNA from both humans and animals in these specimens, this review focuses solely on the chloroplast DNA reported from plant taxa for clarity and comparison with the other data sets from Hinds Cave coprolites. While there is some correlation between the molecular and macrofossil data of these specimens, the level of taxonomic identification for the aDNA data is at the family level, which limits inferences on families that contain more than one potential dietary component in the Lower Pecos canyonlands. Unfortunately, the macrofossil data from these specimens is presented as a simple ubiquity for each taxa, with no indication of what part of the plant was recovered. This limits comparison of these specimens with the data from the other studies of Hinds Cave coprolites.

The aDNA data could indicate a much more diverse diet than that reflected in the macrofossil data (Table 41). Five additional families not recovered in the macrofossils were present in the aDNA amplifications. However, it is possible that some of these identifications may be the result of DNA amplification of pollen or gut contents of small animals consumed in the diet, rather than direct dietary consumption (Reinhard et al. 2008). In addition, Reinhard et al. (2008) argue that some of the aDNA sequences identified by Poinar et al. (2001) are best explained as evidence of medicinal use of plant resources rather than dietary consumption. It is interesting to note that all three specimens contained macrofossil evidence of onions, lechuguilla and yucca, but had highly variable aDNA identifications, ranging from zero to ten out of a possible eleven cloned sequences. Clearly there is great potential for aDNA studies of coprolite specimens, both as a source of human mtDNA as well as aDNA from dietary and medicinal components in the coprolite. However, the limited handful of specimens with aDNA from Hinds Cave and the lack of understanding of the relationship of the aDNA results to dietary consumption preclude further interpretation.

Table 41. Chloroplastic aDNA data of Coprolites from Poinar et al. (2001)

Sample no.	Radiocarbon Years Before Present	ASTERACEAE		CACTACEAE		FOUQUIERIACEAE		FABACEAE		FAGACEAE		LILLIACEAE		RHAMNACEAE		ULMACEAE		SOLANACEAE	
		Molecular (max=11)	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**	**Molecular (max=11)**	**Macrofossil**
I	**2165 +/- 60 (Ua-15512)**	7			*Opuntia sp.*							10	*Allium* sp., *Agave* sp., *and Yucca* sp.			8			
II	**2370 +/- 60 (Ua-15511)**	3							*Prosopis sp.*	7		4	*Allium* sp., *Agave* sp., *and Yucca* sp.			12	*Celtis* sp.	6	
III	**2280 +/- 90 (Ua-15386)**	4			*Opuntia sp.*	1		7		1			*Allium* sp., *Agave* sp., and *Yucca* sp.	10		5			

Other Coprolite Studies from the Lower Pecos Canyonlands

Parida Cave. This small study of coprolites (n=11) from Parida Cave was primarily focused on the analysis of pollen grains in the specimens (Riskind 1970). The macrofossil data was recorded only as an ubiquity measure. Nonetheless, the data comprise the first published results of macrofossil data from coprolites in the Lower Pecos canyonlands. The lack of quantification limits interpretation, but some patterns of resource exploitation are evident in these data. The specimens were divided into three clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 44). Table 42 presents the average value of each constituent in each cluster. Cluster 1 (n=3) consists of all specimens in the study that contained agave fiber. Each specimen in this cluster also contained onion bulbs and unidentified grass seeds.

The specimens in cluster 2 (n=3) are differentiated from the other coprolites in the study by the presence of an unidentified stem. These specimens in this cluster also contain unidentified grass seeds. Cluster 3 (n=5) serves as a catchall for the remaining coprolites in the study. This is clear from the dendogram (Figure 44) as well. Most of the dietary components unique to this cluster only occur in one of the five specimens. Prickly pear vascular bundles occur in every specimen in this study. Prickly pear seeds occur in over half (6 of the 11) of the specimens, but do not play a role in defining the clusters.

Figure 45 provides a visual display of the clusters along the first two factors generated with CDA. Tables 43 and 44 show the standardized canonical function coefficients and the structure matrix respectively. Onion bulbs are the primary driver of the first function. The second function is positively correlated with the presence of sand and negatively correlated with mammal bone.

Overall, this study indicates that human populations occupying Parida Cave during the Late Archaic continued to depend on lechuguilla, onion, and prickly pear as important dietary resources. This study also documents grass seed as a possible dietary resource. Further statements on this collection are limited by both the small number of samples and the method of quantification utilized by Riskind (1970).

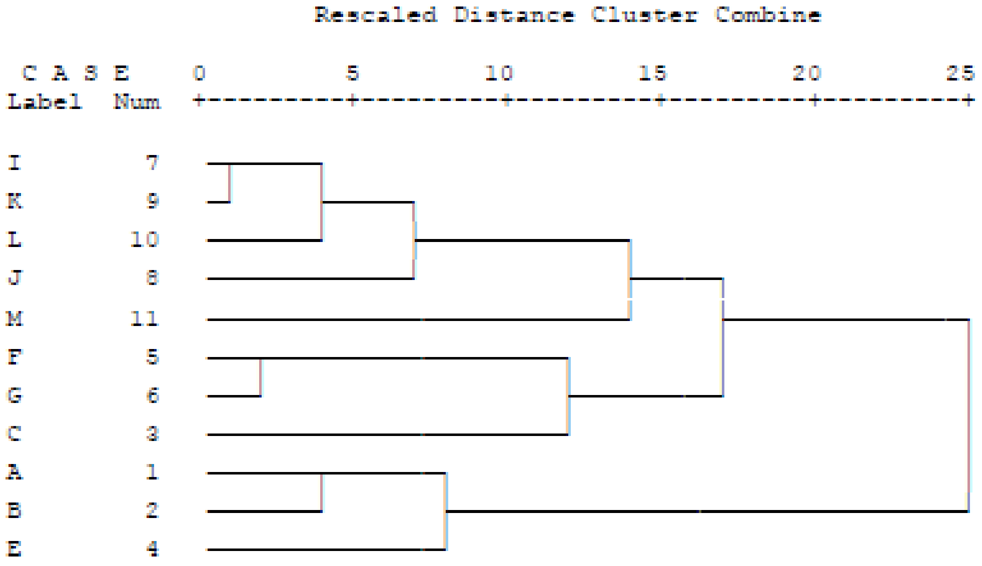


Figure 444. Dendogram of Riskind's (1970) Data based on Ward's Method

Table 42. Mean Values of Riskind's (1970) Data by Cluster

Component	Identification	Cluster 1 (n=3)		Cluster 2 (n=3)		Cluster 3 (n=5)		Total (n=11)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Seed	*Opuntia* sp.	0.7	0.6	0.3	0.6	0.6	0.5	0.5	0.5
Vascular Bundles	*Opuntia* sp.	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0
Spine	*Opuntia* sp.	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.3
Epidermis	*Opuntia* sp.	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.3
Fiber	*Agave* sp.	1.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
Charcoal	Unknown	0.0	0.0	0.7	0.6	0.6	0.5	0.5	0.5
Bulb	*Allium* sp.	1.0	0.0	0.3	0.6	0.0	0.0	0.4	0.5
Pebbles	N/A	0.7	0.6	0.3	0.6	0.2	0.4	0.4	0.5
Clay lumps	N/A	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.3
Seed coat	*Prosopis* sp.	0.3	0.6	0.0	0.0	0.2	0.4	0.2	0.4
Chitin	Insect	0.7	0.6	0.3	0.6	0.0	0.0	0.3	0.5
Seed	*POACEAE*	1.0	0.0	1.0	0.0	0.0	0.0	0.5	0.5
Flakes	Chert	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.3
Stem	Unknown	0.0	0.0	1.0	0.0	0.0	0.0	0.3	0.5
Sand	*N/A*	0.0	0.0	0.3	0.6	0.0	0.0	0.1	0.3
Hair	Unknown	0.3	0.6	0.0	0.0	0.0	0.0	0.1	0.3
Bone	Mammal	0.7	0.6	0.7	0.6	0.4	0.5	0.5	0.5

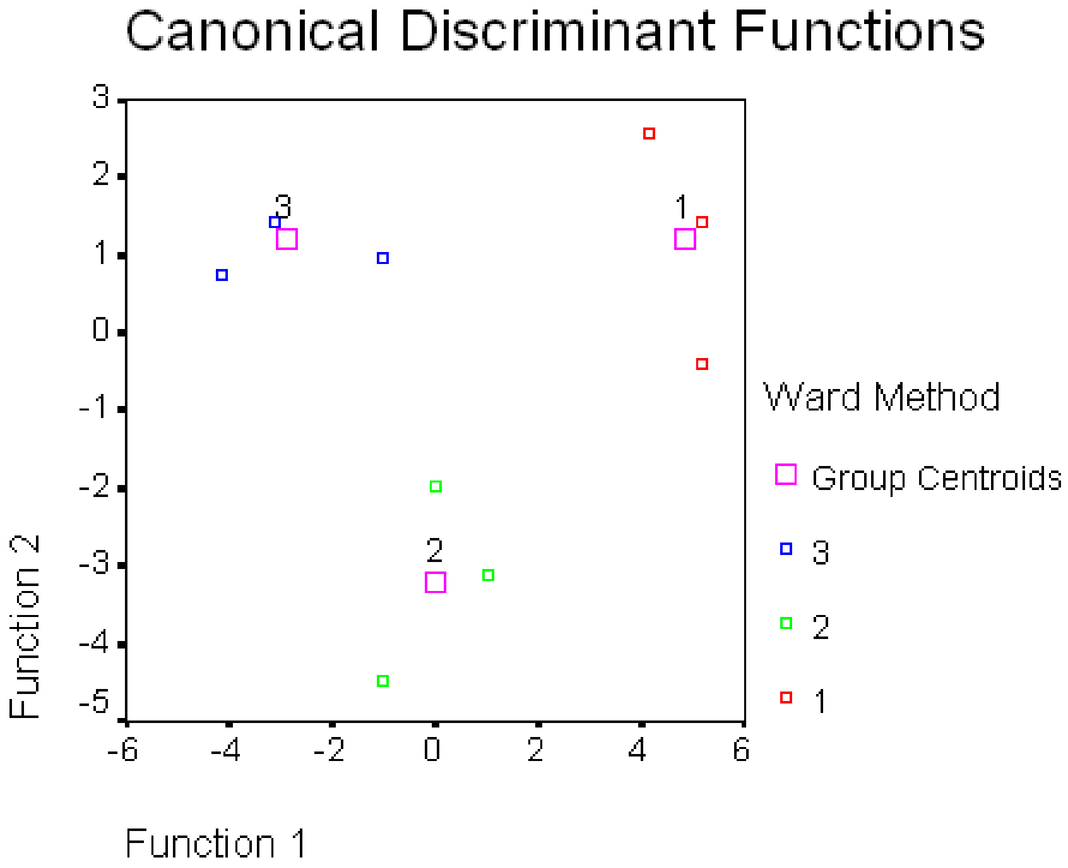
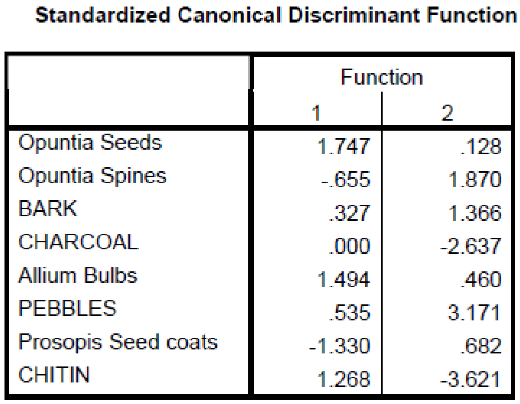


Figure 455. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Data from Riskind (1970)

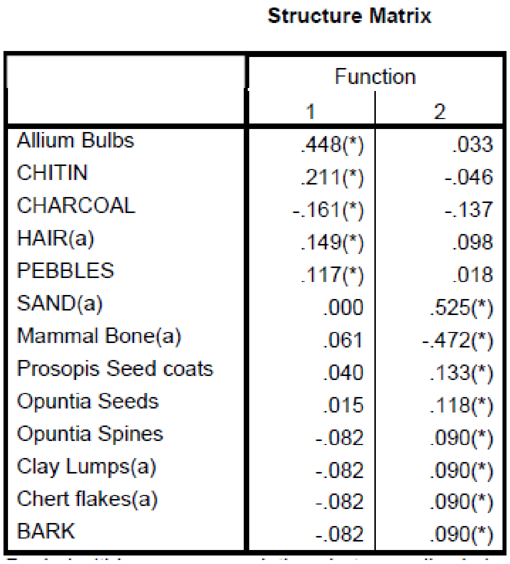
Table 43. Discriminant Function Coefficients of Cluster Analysis of Riskind (1970)



Standardized Canonical Discriminant Function Coefficients

	Function	
	1	2
Opuntia Seeds	1.747	.128
Opuntia Spines	-.655	1.870
BARK	.327	1.366
CHARCOAL	.000	-2.637
Allium Bulbs	1.494	.460
PEBBLES	.535	3.171
Prosopis Seed coats	-1.330	.682
CHITIN	1.268	-3.621

Table 44. Structure Matrix of Cluster Analysis of Riskind (1970)



Structure Matrix

	Function	
	1	2
Allium Bulbs	.448(*)	.033
CHITIN	.211(*)	-.046
CHARCOAL	-.161(*)	-.137
HAIR(a)	.149(*)	.098
PEBBLES	.117(*)	.018
SAND(a)	.000	.525(*)
Mammal Bone(a)	.061	-.472(*)
Prosopis Seed coats	.040	.133(*)
Opuntia Seeds	.015	.118(*)
Opuntia Spines	-.082	.090(*)
Clay Lumps(a)	-.082	.090(*)
Chert flakes(a)	-.082	.090(*)
BARK	-.082	.090(*)

Conejo Shelter. The data from Bryant (1974) were divided into four clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 46). The data from this study were presented using a slightly different ordinal scale of visual estimation of percentage-volume (Table 45).

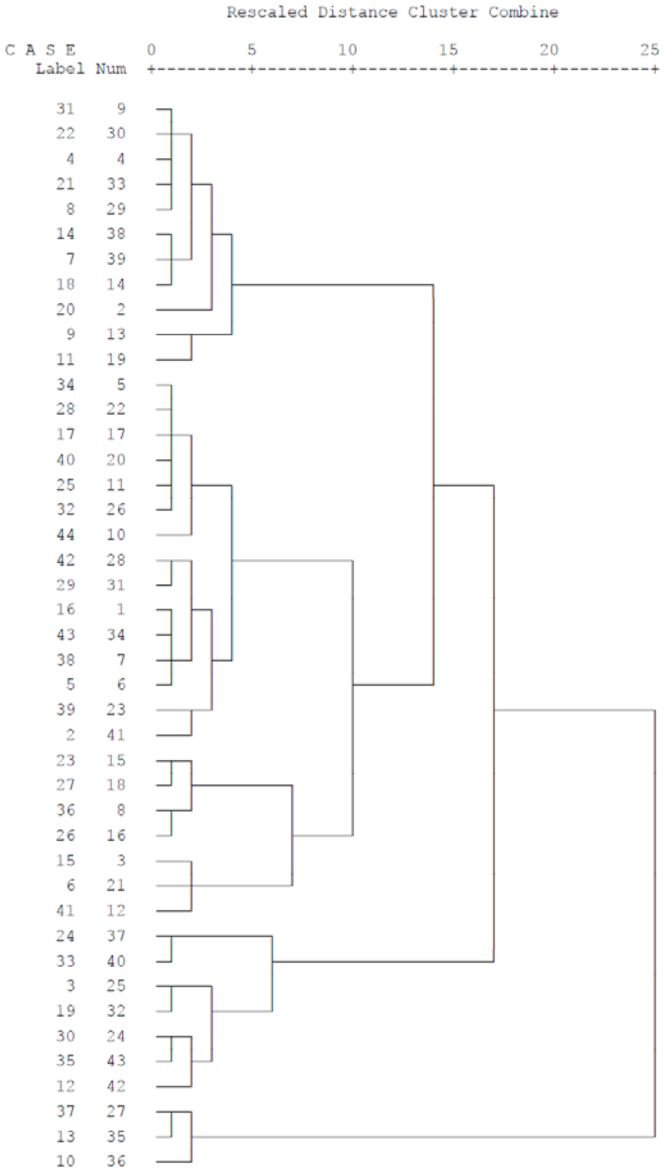
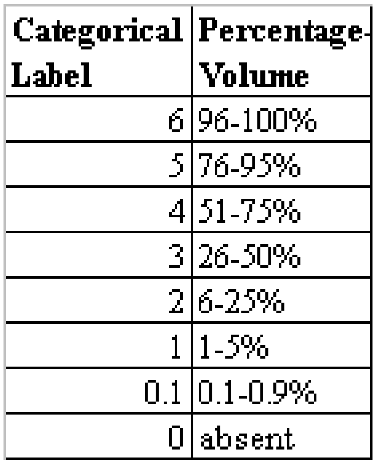


Figure 466. Dendogram of Bryant's (1974) Data based on Ward's Method

Table 46 presents the mean value of each constituent by cluster. Cluster 1 (n=22) is characterized by elevated levels of onion bulbs and prickly pear fiber. This cluster also contains a specimen with identified *Setaria* sp. seed. The specimens in this cluster exhibit low levels of prickly pear seeds and below average levels of agave/sotol/yucca fiber, treated here as a single category. Cluster 2 (n=11) contains specimens that exhibit

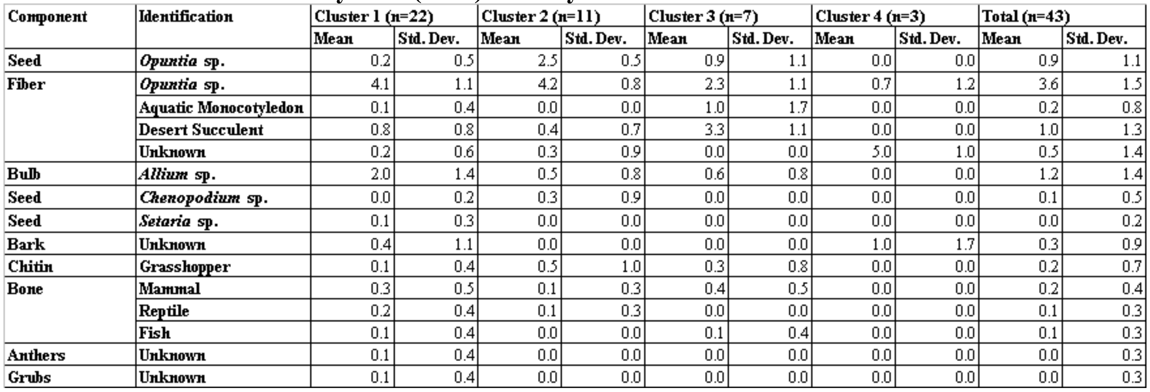
Table 45. Ordinal Scale for Percent-Volume Measurements of Bryant (1974)



Categorical Label	**Percentage-Volume**
6	96-100%
5	76-95%
4	51-75%
3	26-50%
2	6-25%
1	1-5%
0.1	0.1-0.9%
0	absent

high levels of prickly pear seeds and fiber. Some specimens in this cluster also contain *Chenopodium* sp. seeds. Cluster 3 (n=7) consists of coprolite specimens with large amounts of agave/sotol/yucca fiber. Aquatic monocot fibers are also a distinguishing characteristic of this cluster. There are below average values for prickly pear fiber and onion bulbs in this cluster. Specimens from Cluster 4 (n=3) contain only two resources. Prickly pear fiber occurs, but at the lowest levels seen in all the specimens from this study. The only other identified component in these specimens is an unidentified bark.

Table 46. Mean Values of Bryant's (1974) Data by Cluster



Component	**Identification**	**Cluster 1 (n=22)**		**Cluster 2 (n=11)**		**Cluster 3 (n=7)**		**Cluster 4 (n=3)**		**Total (n=43)**	
		Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Seed	***Opuntia* sp.**	0.2	0.5	2.5	0.5	0.9	1.1	0.0	0.0	0.9	1.1
Fiber	***Opuntia* sp.**	4.1	1.1	4.2	0.8	2.3	1.1	0.7	1.2	3.6	1.5
	Aquatic Monocotyledon	0.1	0.4	0.0	0.0	1.0	1.7	0.0	0.0	0.2	0.8
	Desert Succulent	0.8	0.8	0.4	0.7	3.3	1.1	0.0	0.0	1.0	1.3
	Unknown	0.2	0.6	0.3	0.9	0.0	0.0	5.0	1.0	0.5	1.4
Bulb	***Allium* sp.**	2.0	1.4	0.5	0.8	0.6	0.8	0.0	0.0	1.2	1.4
Seed	***Chenopodium* sp.**	0.0	0.2	0.3	0.9	0.0	0.0	0.0	0.0	0.1	0.5
Seed	***Setaria* sp.**	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Bark	**Unknown**	0.4	1.1	0.0	0.0	0.0	0.0	1.0	1.7	0.3	0.9
Chitin	**Grasshopper**	0.1	0.4	0.5	1.0	0.3	0.8	0.0	0.0	0.2	0.7
Bone	**Mammal**	0.3	0.5	0.1	0.3	0.4	0.5	0.0	0.0	0.2	0.4
	Reptile	0.2	0.4	0.1	0.3	0.0	0.0	0.0	0.0	0.1	0.3
	Fish	0.1	0.4	0.0	0.0	0.1	0.4	0.0	0.0	0.1	0.3
Anthers	**Unknown**	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Grubs	**Unknown**	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3

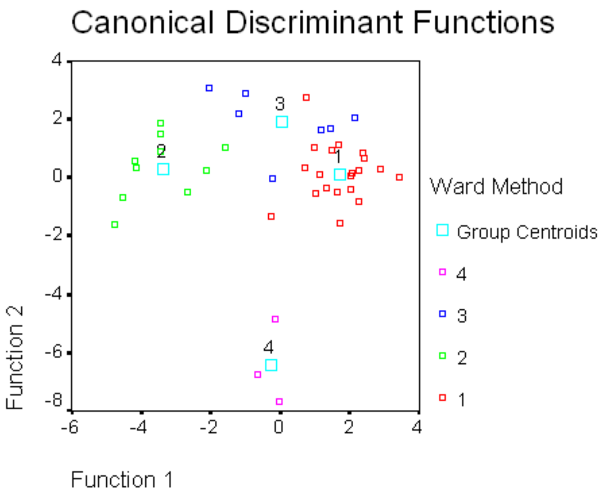


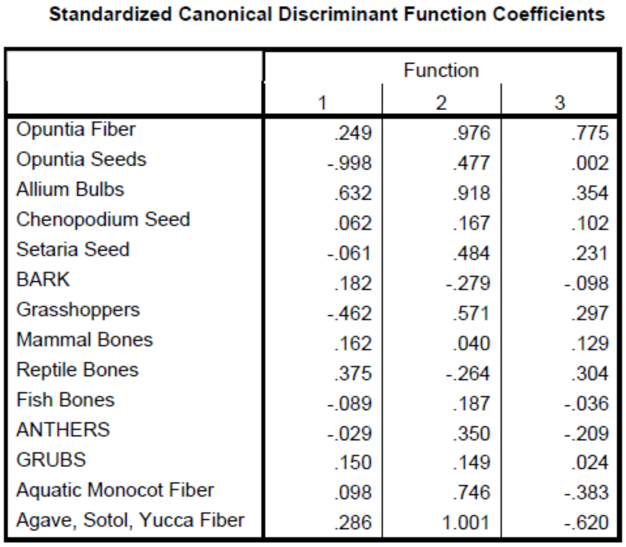
Figure 477. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Data from Bryant (1974)

Figure 47 provides a visual display of the clusters along the first two factors generated with CDA. Tables 47 and 48 show the standardized canonical function coefficients and the structure matrix respectively. Function 1 is negatively correlated with prickly pear seeds and positively correlated with onion bulbs. Function 2 is positively correlated with all three classes of fiber identified in this study and negatively correlated with the unidentified bark resource. Function 3 distinguishes between these fiber types, with prickly pear fiber positively correlated and agave/sotol/yucca fiber and aquatic monocot fiber negatively correlated.

Three of the four clusters from the Late Archaic coprolite analysis of this centrally located rockshelter can be directly correlated with the menus or dietary combinations noted in the Hinds Cave studies. The first cluster reflects a diet of nopales and onion bulbs. The second cluster indicates a diet dominated by tunas and supplemented by small amounts of other seasonal resources, such as *Chenopodium* sp.

seeds. The third cluster is characterized by the fibrous remains of desert succulents and an aquatic geophyte. These are resources that would require extensive cooking in earth-ovens to render the carbohydrates digestible. This study also indicates aspects of the regional diet that are not prevalent at Hinds Cave, specifically the use of small seeds as food resources.

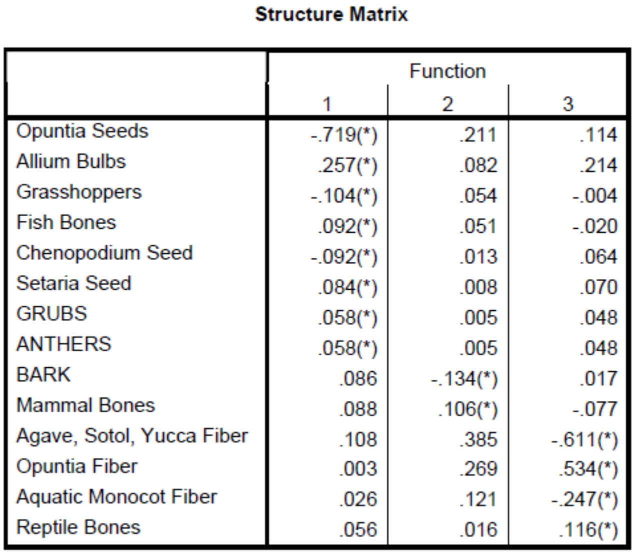
Table 47. Discriminant Function Coefficients of Cluster Analysis of Bryant (1974)



Standardized Canonical Discriminant Function Coefficients

	Function		
	1	2	3
Opuntia Fiber	.249	.976	.775
Opuntia Seeds	-.998	.477	.002
Allium Bulbs	.632	.918	.354
Chenopodium Seed	.062	.167	.102
Setaria Seed	-.061	.484	.231
BARK	.182	-.279	-.098
Grasshoppers	-.462	.571	.297
Mammal Bones	.162	.040	.129
Reptile Bones	.375	-.264	.304
Fish Bones	-.089	.187	-.036
ANTHERS	-.029	.350	-.209
GRUBS	.150	.149	.024
Aquatic Monocot Fiber	.098	.746	-.383
Agave, Sotol, Yucca Fiber	.286	1.001	-.620

Table 48. Structure Matrix of Cluster Analysis of Bryant (1974)

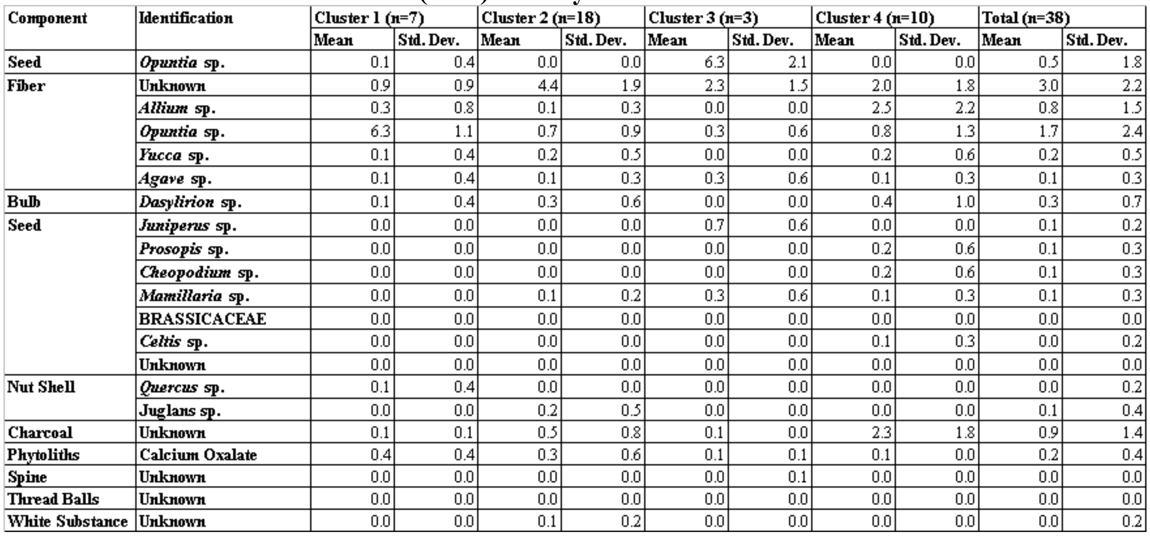


Structure Matrix

	Function		
	1	2	3
Opuntia Seeds	-.719(*)	.211	.114
Allium Bulbs	.257(*)	.082	.214
Grasshoppers	-.104(*)	.054	-.004
Fish Bones	.092(*)	.051	-.020
Chenopodium Seed	-.092(*)	.013	.064
Setaria Seed	.084(*)	.008	.070
GRUBS	.058(*)	.005	.048
ANTHERS	.058(*)	.005	.048
BARK	.086	-.134(*)	.017
Mammal Bones	.088	.106(*)	-.077
Agave, Sotol, Yucca Fiber	.108	.385	-.611(*)
Opuntia Fiber	.003	.269	.534(*)
Aquatic Monocot Fiber	.026	.121	-.247(*)
Reptile Bones	.056	.016	.116(*)

Baker Cave. The data from Sobolik (1991) were divided into four clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 48). Table 49 presents the average value of each constituent in each cluster. Cluster 1 (n=7) is dominated by prickly pear fiber (epidermal tissue). The only other resource that occurs at a level above the mean for all specimens combined is acorn shell. Cluster 2 (n=18) is defined primarily by high levels of epidermal tissue from an unknown resource and the presence of walnut shell. Cluster 3 (n=3) consists of coprolite specimens with large amounts of prickly pear seed. Specimens from Cluster 4 (n=10) exhibit elevated levels of onion epidermal tissue as well as high levels of charcoal. Sotol epidermal tissue is also elevated above the mean value for all specimens in the study.

Table 49. Mean Values of Sobolik's (1991) Data by Cluster



Component	Identification	Cluster 1 (n=7)		Cluster 2 (n=18)		Cluster 3 (n=3)		Cluster 4 (n=10)		Total (n=38)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Seed	*Opuntia* sp.	0.1	0.4	0.0	0.0	6.3	2.1	0.0	0.0	0.5	1.8
Fiber	Unknown	0.9	0.9	4.4	1.9	2.3	1.5	2.0	1.8	3.0	2.2
	Allium sp.	0.3	0.8	0.1	0.3	0.0	0.0	2.5	2.2	0.8	1.5
	Opuntia sp.	6.3	1.1	0.7	0.9	0.3	0.6	0.8	1.3	1.7	2.4
	Yucca sp.	0.1	0.4	0.2	0.5	0.0	0.0	0.2	0.6	0.2	0.5
	Agave sp.	0.1	0.4	0.1	0.3	0.3	0.6	0.1	0.3	0.1	0.3
Bulb	*Dasylirion* sp.	0.1	0.4	0.3	0.6	0.0	0.0	0.4	1.0	0.3	0.7
Seed	*Juniperus* sp.	0.0	0.0	0.0	0.0	0.7	0.6	0.0	0.0	0.1	0.2
	Prosopis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.1	0.3
	Cheopodium sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.1	0.3
	Mamillaria sp.	0.0	0.0	0.1	0.2	0.3	0.6	0.1	0.3	0.1	0.3
	BRASSICACEAE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Celtis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.2
	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nut Shell	*Quercus* sp.	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	Juglans sp.	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.0	0.1	0.4
Charcoal	Unknown	0.1	0.1	0.5	0.8	0.1	0.0	2.3	1.8	0.9	1.4
Phytoliths	Calcium Oxalate	0.4	0.4	0.3	0.6	0.1	0.1	0.1	0.0	0.2	0.4
Spine	Unknown	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Thread Balls	Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
White Substance	Unknown	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.2

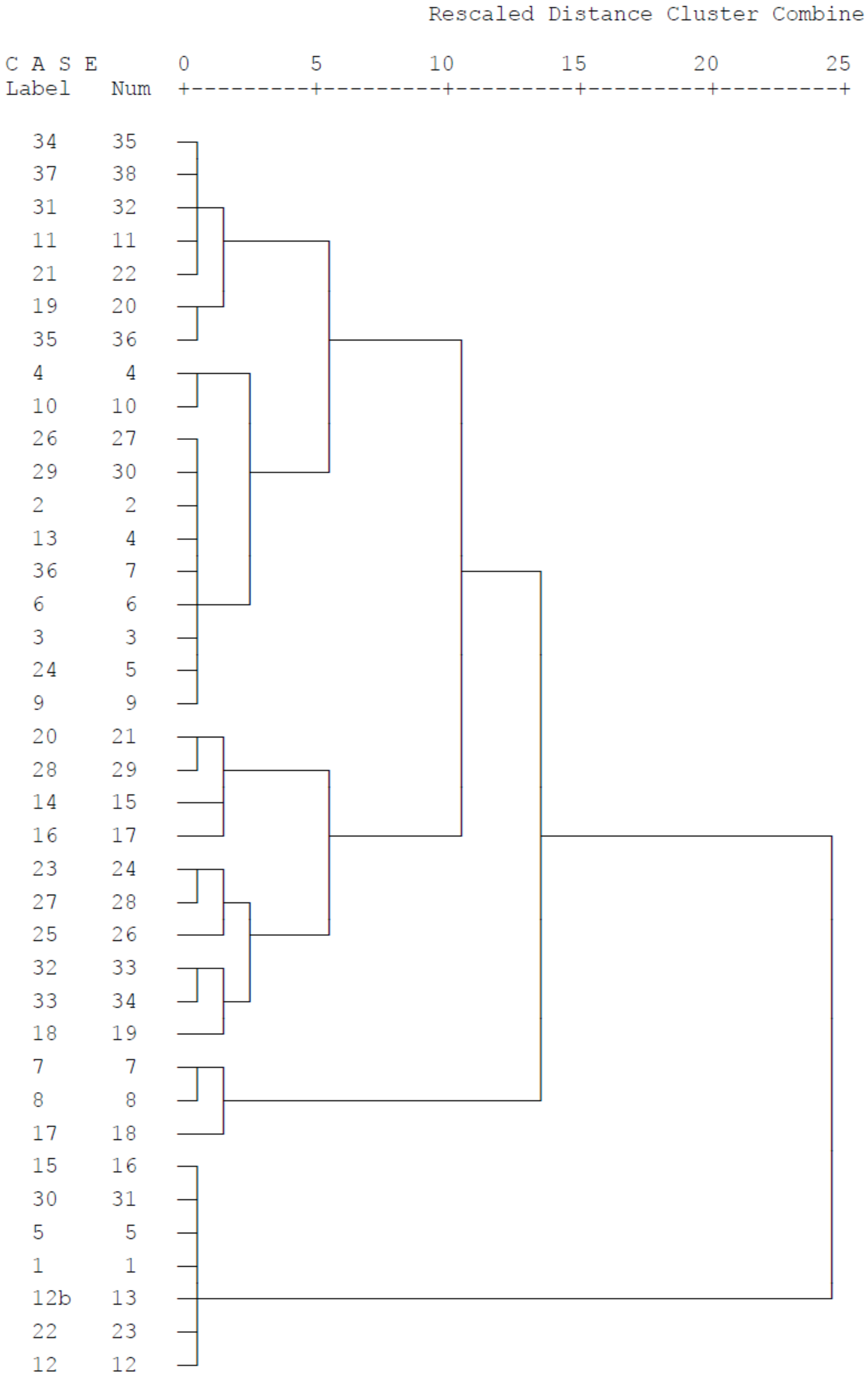


Figure 488. Dendogram of Sobolik's (1991) Data based on Ward's Method

Figure 49 provides a visual display of the clusters along the first two factors generated with CDA. Tables 50 and 51 show the standardized canonical function coefficients and the structure matrix respectively. Function 1 is negatively correlated with prickly pear seeds. Function 2 is positively correlated with charcoal and negatively correlated with prickly pear epidermal tissue. Function 3 further distinguishes between epidermal tissue, as prickly pear and onion epidermal tissue are positively correlated and the unknown fiber type is negatively correlated.

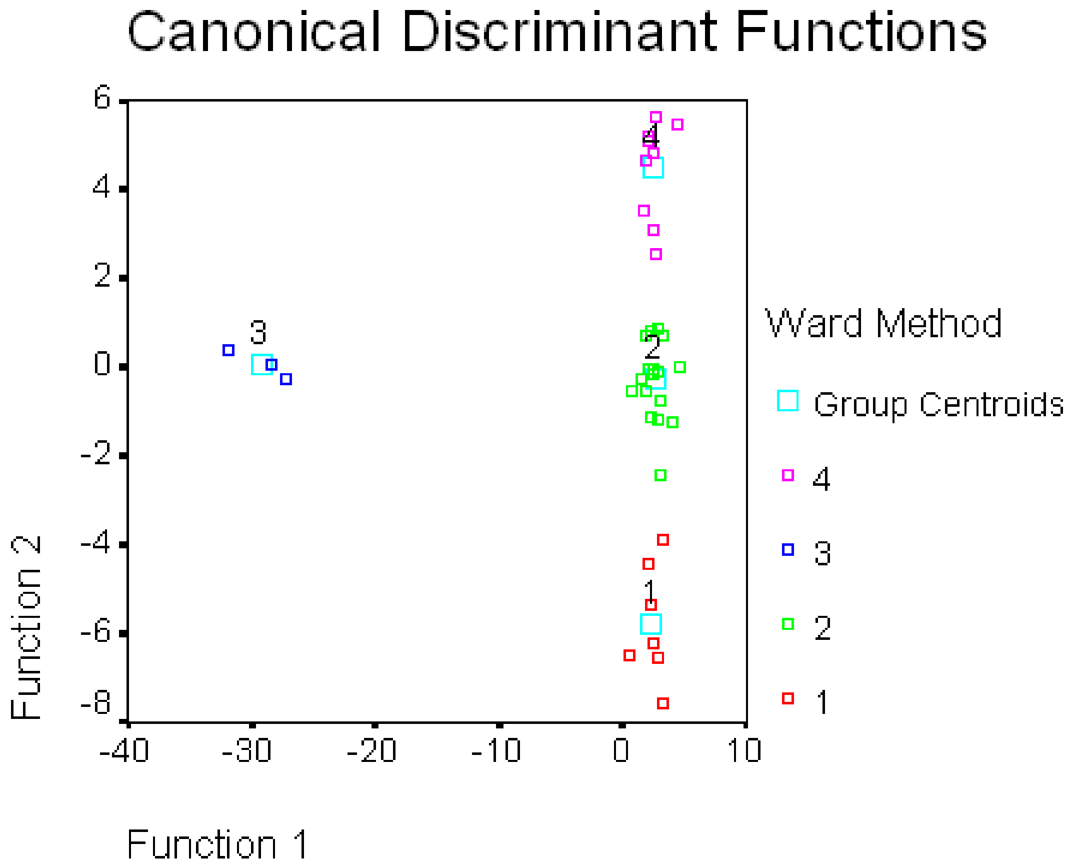
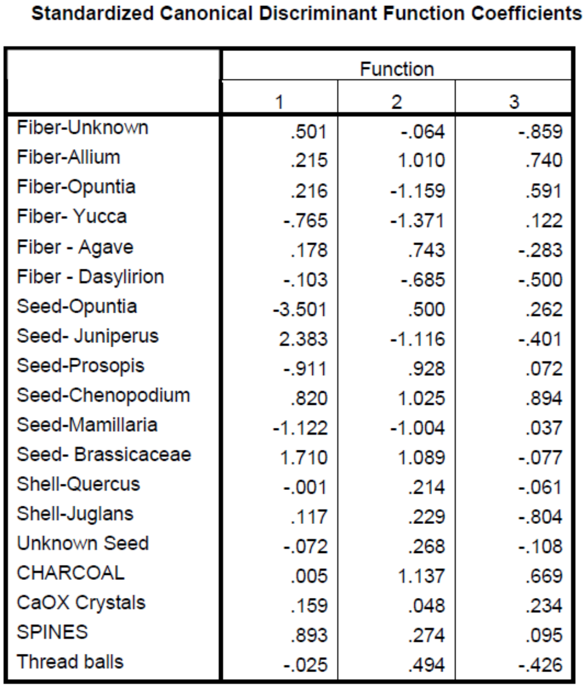


Figure 49. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Data from Sobolik (1991)

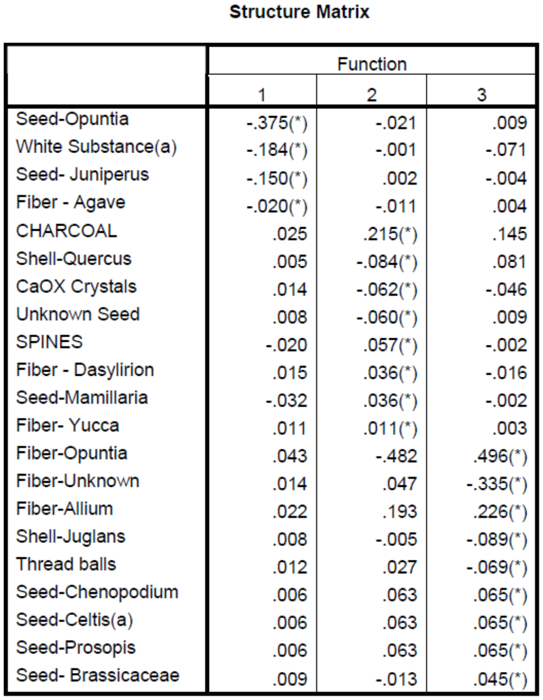
Table 50. Discriminant Function Coefficients of Cluster Analysis of Sobolik (1991)



Standardized Canonical Discriminant Function Coefficients

	Function		
	1	2	3
Fiber-Unknown	.501	-.064	-.859
Fiber-Allium	.215	1.010	.740
Fiber-Opuntia	.216	-1.159	.591
Fiber- Yucca	-.765	-1.371	.122
Fiber - Agave	.178	.743	-.283
Fiber - Dasylirion	-.103	-.685	-.500
Seed-Opuntia	-3.501	.500	.262
Seed- Juniperus	2.383	-1.116	-.401
Seed-Prosopis	-.911	.928	.072
Seed-Chenopodium	.820	1.025	.894
Seed-Mamillaria	-1.122	-1.004	.037
Seed- Brassicaceae	1.710	1.089	-.077
Shell-Quercus	-.001	.214	-.061
Shell-Juglans	.117	.229	-.804
Unknown Seed	-.072	.268	-.108
CHARCOAL	.005	1.137	.669
CaOX Crystals	.159	.048	.234
SPINES	.893	.274	.095
Thread balls	-.025	.494	-.426

Table 51. Structure Matrix of Cluster Analysis of Sobolik (1991)



Structure Matrix

	Function		
	1	2	3
Seed-Opuntia	-.375(*)	-.021	.009
White Substance(a)	-.184(*)	-.001	-.071
Seed- Juniperus	-.150(*)	.002	-.004
Fiber - Agave	-.020(*)	-.011	.004
CHARCOAL	.025	.215(*)	.145
Shell-Quercus	.005	-.084(*)	.081
CaOX Crystals	.014	-.062(*)	-.046
Unknown Seed	.008	-.060(*)	.009
SPINES	-.020	.057(*)	-.002
Fiber - Dasylirion	.015	.036(*)	-.016
Seed-Mamillaria	-.032	.036(*)	-.002
Fiber- Yucca	.011	.011(*)	.003
Fiber-Opuntia	.043	-.482	.496(*)
Fiber-Unknown	.014	.047	-.335(*)
Fiber-Allium	.022	.193	.226(*)
Shell-Juglans	.008	-.005	-.089(*)
Thread balls	.012	.027	-.069(*)
Seed-Chenopodium	.006	.063	.065(*)
Seed-Celtis(a)	.006	.063	.065(*)
Seed-Prosopis	.006	.063	.065(*)
Seed- Brassicaceae	.009	-.013	.045(*)

These coprolite specimens from Late Archaic populations along the eastern edge of the Lower Pecos canyonlands record some of the same dietary practices observed in the specimens recovered along the Pecos River drainage. However, there are some important differences for this site, located in the more mesic oak-cedar zone of the Balconian biotic province (Blair 1950). The first cluster exhibits a dependence on nopales as a staple resource, with lesser amounts of sotol and lechuguilla also observed. The dependence on just epidermal identification, rather than a combination of epidermal and fiber identification, may skew the interpretation of the diet due to differences in resource processing (Woltz 1998). The second cluster deviates from the dietary patterns observed in the more westerly sites, exhibiting a marked dependence on an unidentified resource represented by epidermal tissue and walnut shell. This resource combination suggests that the diet represented in this cluster is geared towards the available resources of the Edwards Plateau rather than the canyonlands per se. Its possible that the unidentified epidermal tissue is from a geophyte. This is corroborated by the relatively high level of charcoal in these samples, suggesting a baked resource. The third cluster, which only contains three specimens, contains specimens with high levels of prickly pear seeds, indicating a diet dependent on tunas as the primary resource. The fourth cluster reflects a diet high in baked onion, suggested by the high levels of onion epidermal tissue and charcoal. This cluster also exhibits higher than average levels of sotol epidermal tissue, suggesting that this was a complementary resource in these meals as well. Again, the differences in the amount of epidermal tissue expected from onions versus sotol limit quantifying the exact relationship between these two resources.

Overall, the human population occupying Baker Cave in the Late Archaic practiced a subsistence strategy similar in many ways to sites from the rest of the Lower Pecos canyonlands. This strategy also incorporated more mesic resources, such as walnut, that would not have been as available further to the west.

Frightful Cave. The data from the coprolites recovered from this site, located far to the south of the Lower Pecos canyonlands in the Quatro Cienegas basin in Coahuilla, were divided into four clusters based upon a scree plot of the agglomeration coefficients and the visual inspection of the dendogram (Figure 50). Table 52 presents the average value of each constituent in each cluster. Unlike the other sites, which were all quantified by visual estimation of percent-volume converted into an ordinal scale, the data from this site were quantified by percent-weight. The results of this cluster analysis are presented using the percent-weight data from the original study. Cluster 1 (n=11) exhibits a dominance of prickly pear seed. Cluster 2 (n=9) is primarily grouped based on higher levels of prickly pear epidermal tissue, onion seed pods, and an unknown fiber type. Very few prickly pear seeds were recovered in specimens in this cluster. Cluster 3 (n=5) is dominated by an unknown epidermal tissue type. Prickly pear seeds are nearly non-existent in these five specimens. Cluster 4 (n=7) is defined by a diversity of seed resources, including milkweed (*Asclepius* sp.), hackberry (*Celtis* sp.), cholla (*Opuntia imbricata*), indian rice grass (*Oryzopsis* sp.), texas pistachio (*Pistacia texana*), and mesquite (*Prosopis juliflora*). The specimens in this cluster also contain high levels of cactus epidermal tissue associated with the cholla seeds.

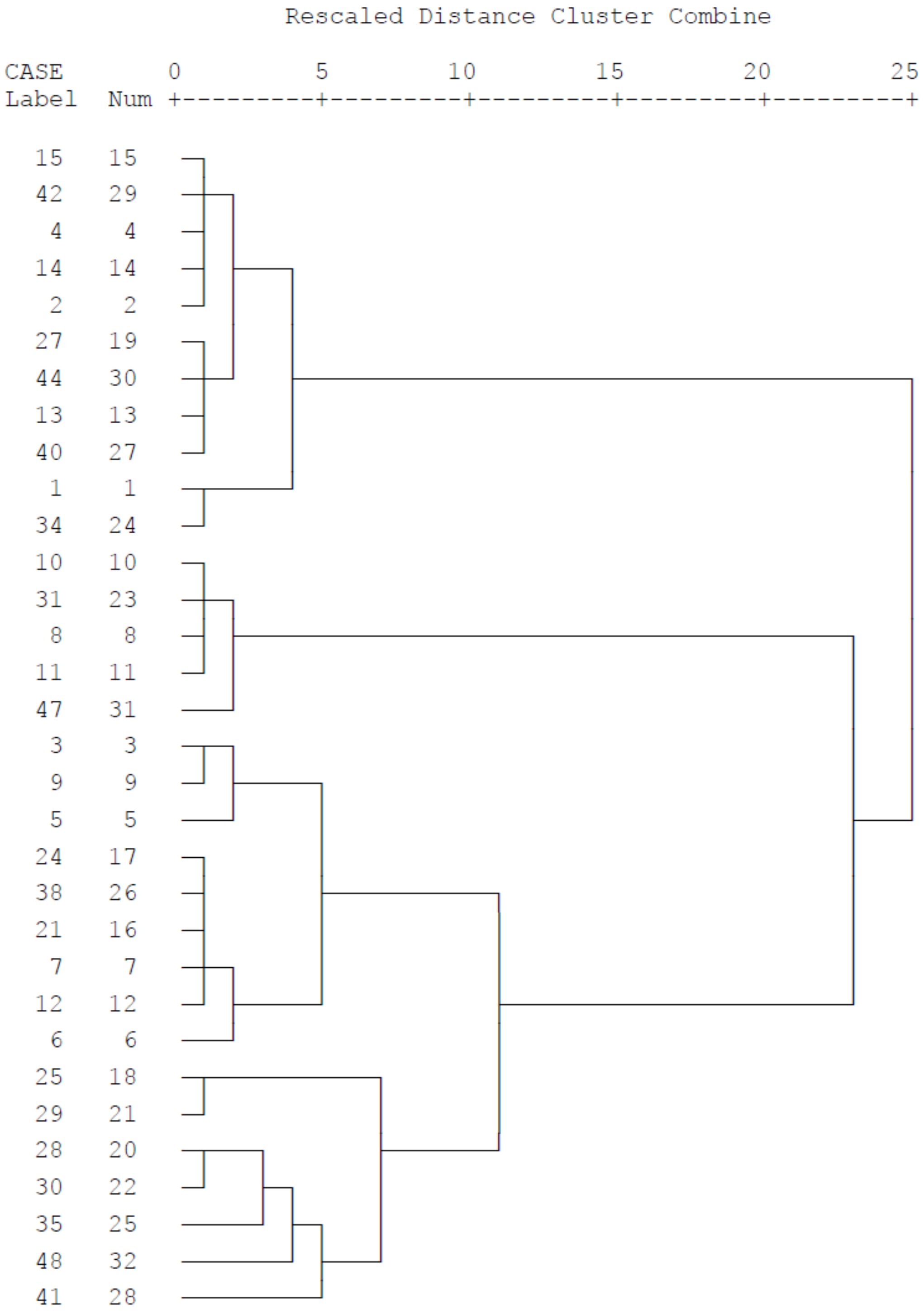


Figure 50. Dendogram of Fry's (1975) Data based on Ward's Method

Table 52. Mean Values of Fry's (1975) Data by Cluster

Component	Identification	Cluster 1 (n=11)		Cluster 2 (n=9)		Cluster 3 (n=5)		Cluster 4 (n=7)		Total (n=32)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Seed	*Opuntia lindheimeri*	56.4	13.4	4.5	8.2	0.1	0.1	14.7	17.6	23.9	27.0
Epidermis	CACTACEAE	4.7	5.7	12.6	13.1	4.2	5.2	20.2	14.8	10.2	11.9
	Unknown	19.4	8.3	17.9	17.5	78.8	13.8	3.1	5.1	24.7	27.0
Fiber	Unknown	1.7	2.4	45.5	20.1	6.3	4.7	5.8	4.9	15.6	21.9
Phytoliths	CACTACEAE	0.0	0.0	0.5	0.9	0.2	0.5	0.1	0.1	0.2	0.6
	Unknown	0.0	0.0	0.4	1.0	0.2	0.5	0.0	0.0	0.1	0.6
Seed Pod	*Allium* sp.	0.0	0.0	0.2	0.7	0.0	0.0	0.0	0.0	0.1	0.4
Seed	*Ancistrocactus* sp.	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
	Acacia sp.	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	Amaranthus sp.	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
	Asclepius sp.	0.0	0.0	0.0	0.0	0.0	0.0	5.8	15.4	1.3	7.2
	Bouteloua sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Celtis pallidus	0.2	0.4	0.4	1.1	0.0	0.0	3.5	7.9	0.9	3.8
	CHENOPODIACEAE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CACTACEAE	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.0	0.2
	Capsicum frutescens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
	Diospyros texana	7.9	14.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	8.8
	ASTERACEAE	0.8	2.7	0.0	0.0	0.0	0.0	0.1	0.2	0.3	1.6
	Helianthus sp.	0.4	1.3	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.8
	FABACEAE	0.8	2.7	0.4	1.0	0.0	0.0	0.1	0.3	0.4	1.7
	Opuntia imbricata	0.0	0.1	0.0	0.0	0.0	0.0	8.0	20.9	1.8	9.8
	Oryzopis sp.	0.0	0.0	0.0	0.0	0.0	0.0	3.1	8.0	0.7	3.7
	POACEAE	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.2
	Panicum sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pistacia texana	1.8	4.0	0.5	1.4	0.1	0.2	6.1	13.5	2.1	6.8
	Polygonum sp.	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.1	0.3
	Prosopis juliflora	0.4	1.0	1.1	3.4	0.0	0.0	15.6	26.8	3.9	13.5
	Rhus sp. seed	0.0	0.0	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.2
	Unknown	1.5	1.9	0.3	0.5	5.1	11.3	9.4	23.0	3.4	11.5
Spine	CACTACEAE	0.0	0.0	0.7	1.8	0.2	0.3	0.0	0.0	0.2	1.0
Stem	ROSACEAE	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1
	Unknown	1.2	3.6	1.5	2.3	0.6	0.6	0.5	0.6	1.0	2.4
Charcoal	Unknown	0.1	0.2	1.0	2.2	0.5	0.3	0.2	0.2	0.4	1.2
Resin	Unknown Plant	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Hair	Unknown	0.3	0.9	0.9	1.7	0.2	0.2	1.1	2.4	0.6	1.5
	Human	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feather	Unknown	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Bone	Unknown	0.4	1.2	6.5	8.2	0.8	1.5	1.3	3.1	2.4	5.2
	Rodent	0.0	0.0	1.2	3.6	0.0	0.0	0.0	0.0	0.3	1.9
	Lizard	0.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5
Shell	Egg	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.1
Scale	Reptile	0.0	0.0	2.6	7.7	0.0	0.0	0.0	0.0	0.7	4.1
Chitin	Unknown	1.1	2.2	1.2	2.1	1.9	2.7	0.4	0.5	1.1	2.0
	Grasshopper	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5
Grit	N/A	0.0	0.0	0.3	0.5	0.2	0.2	0.2	0.4	0.2	0.3

Figure 51 provides a visual display of the clusters along the first two factors generated with CDA. Tables 53 and 54 show the standardized canonical function coefficients and the structure matrix respectively. Function 1 is negatively correlated with unknown epidermal tissue, grit, and eggshell. Function 2 is positively correlated with unknown fiber and unknown epidermal tissue and negatively correlated with prickly pear seeds and charcoal. Function 3 is positively correlated with prickly pear seeds and cactus epidermal tissue and negatively correlated with charcoal.

This study from the Quatro Cienegas basin shares some similarities with the dietary patterns observed in specimens from the Lower Pecos, but is also markedly different in many aspects. The first cluster is comprised of specimens that exhibit a staple dependence on tunas, with limited amounts of other subsistence resources. The second cluster reflects a diet focused on nopales and an unknown fibrous resource that may be sotol or an agave species. The third cluster exhibits a dominance of an unknown epidermal tissue type. Again, this may be sotol or an agave species, since neither is identified in Fry's (1975) report, but this is purely speculative. The fourth cluster exhibts the most differences from the studies in the Lower Pecos canyonlands. This cluster is defined by a diverse diet of seasonally available fruit and small seed resources. Overall, this study indicates that at least some of the subsistence patterns observed in the Lower Pecos canyonlands extend across the greater Chihuahuan desert. However, there are several suites of resources such as the seasonally available small seeds that do not appear to be very important in the canyonlands. The possible explanations for this will be explored further in the following section.

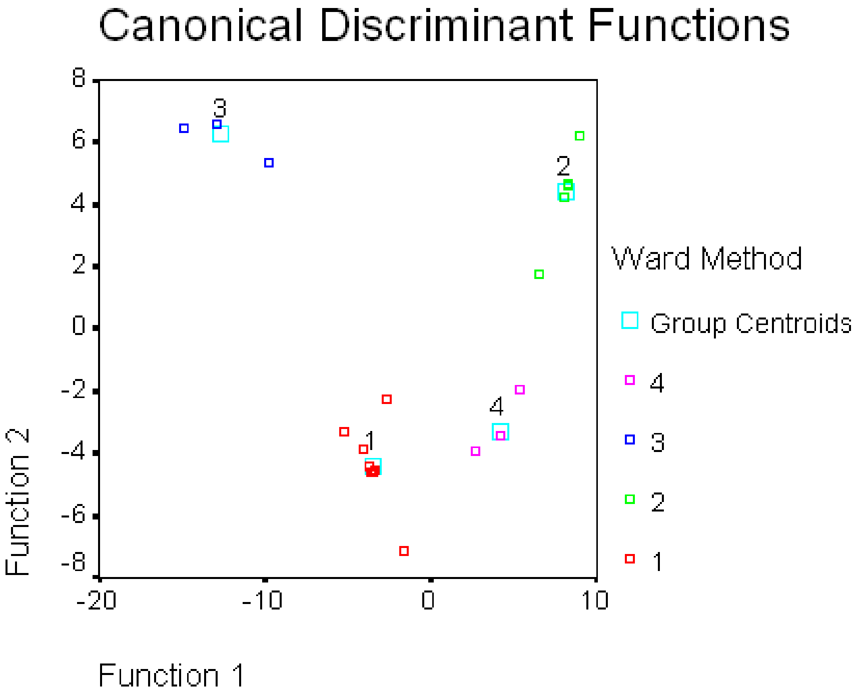
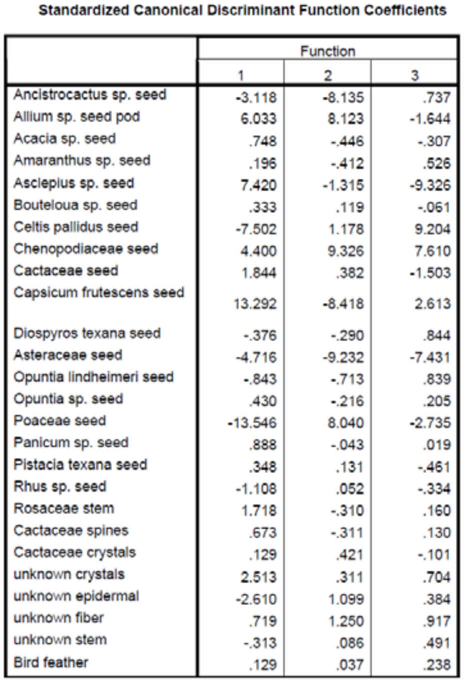


Figure 491. Placement of Clusters along Canonical Discriminant Functions 1 and 2. Data from Fry (1975)

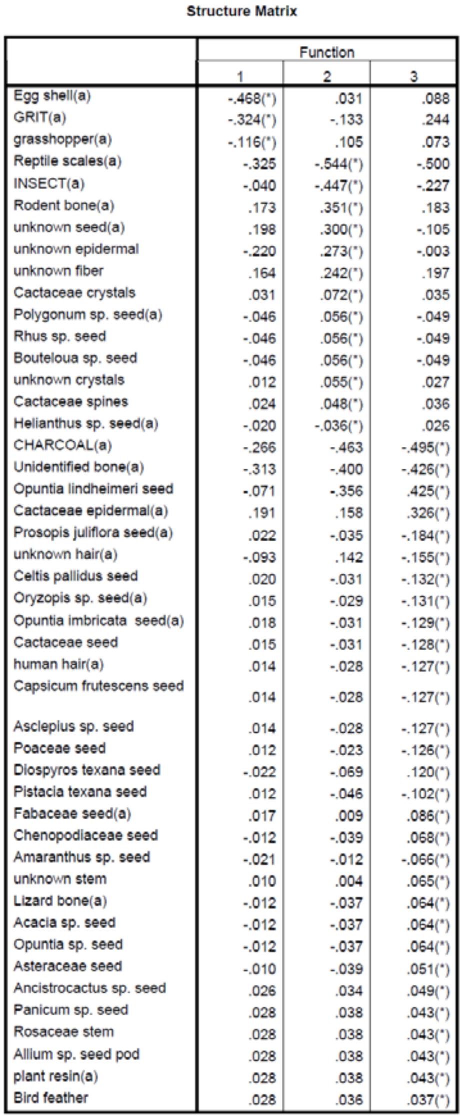
Table 53. Discriminant Function Coefficients of Cluster Analysis of Fry (1975)



Standardized Canonical Discriminant Function Coefficients

	Function		
	1	2	3
Ancistrocactus sp. seed	-3.118	-8.135	.737
Allium sp. seed pod	6.033	8.123	-1.644
Acacia sp. seed	.748	-.446	-.307
Amaranthus sp. seed	.196	-.412	.526
Asclepius sp. seed	7.420	-1.315	-9.326
Bouteloua sp. seed	.333	.119	-.061
Celtis pallidus seed	-7.502	1.178	9.204
Chenopodiaceae seed	4.400	9.326	7.610
Cactaceae seed	1.844	.382	-1.503
Capsicum frutescens seed	13.292	-8.418	2.613
Diospyros texana seed	-.376	-.290	.844
Asteraceae seed	-4.716	-9.232	-7.431
Opuntia lindheimeri seed	-.843	-.713	.839
Opuntia sp. seed	.430	-.216	.205
Poaceae seed	-13.546	8.040	-2.735
Panicum sp. seed	.888	-.043	.019
Pistacia texana seed	.348	.131	-.461
Rhus sp. seed	-1.108	.052	-.334
Rosaceae stem	1.718	-.310	.160
Cactaceae spines	.673	-.311	.130
Cactaceae crystals	.129	.421	-.101
unknown crystals	2.513	.311	.704
unknown epidermal	-2.610	1.099	.384
unknown fiber	.719	1.250	.917
unknown stem	-.313	.086	.491
Bird feather	.129	.037	.238

Table 54. Structure Matrix of Cluster Analysis of Fry (1975)



Structure Matrix

	Function		
	1	2	3
Egg shell(a)	-.468(*)	.031	.088
GRIT(a)	-.324(*)	-.133	.244
grasshopper(a)	-.116(*)	.105	.073
Reptile scales(a)	-.325	-.544(*)	-.500
INSECT(a)	-.040	-.447(*)	-.227
Rodent bone(a)	.173	.351(*)	.183
unknown seed(a)	.198	.300(*)	-.105
unknown epidermal	-.220	.273(*)	-.003
unknown fiber	.164	.242(*)	.197
Cactaceae crystals	.031	.072(*)	.035
Polygonum sp. seed(a)	-.046	.056(*)	-.049
Rhus sp. seed	-.046	.056(*)	-.049
Bouteloua sp. seed	-.046	.056(*)	-.049
unknown crystals	.012	.055(*)	.027
Cactaceae spines	.024	.048(*)	.036
Helianthus sp. seed(a)	-.020	-.036(*)	.026
CHARCOAL(a)	-.266	-.463	-.495(*)
Unidentified bone(a)	-.313	-.400	-.426(*)
Opuntia lindheimeri seed	-.071	-.356	.425(*)
Cactaceae epidermal(a)	.191	.158	.326(*)
Prosopis juliflora seed(a)	.022	-.035	-.184(*)
unknown hair(a)	-.093	.142	-.155(*)
Celtis pallidus seed	.020	-.031	-.132(*)
Oryzopis sp. seed(a)	.015	-.029	-.131(*)
Opuntia imbricata seed(a)	.018	-.031	-.129(*)
Cactaceae seed	.015	-.031	-.128(*)
human hair(a)	.014	-.028	-.127(*)
Capsicum frutescens seed	.014	-.028	-.127(*)
Asclepius sp. seed	.014	-.028	-.127(*)
Poaceae seed	.012	-.023	-.126(*)
Diospyros texana seed	-.022	-.069	.120(*)
Pistacia texana seed	.012	-.046	-.102(*)
Fabaceae seed(a)	.017	.009	.086(*)
Chenopodiaceae seed	-.012	-.039	.068(*)
Amaranthus sp. seed	-.021	-.012	-.066(*)
unknown stem	.010	.004	.065(*)
Lizard bone(a)	-.012	-.037	.064(*)
Acacia sp. seed	-.012	-.037	.064(*)
Opuntia sp. seed	-.012	-.037	.064(*)
Asteraceae seed	-.010	-.039	.051(*)
Ancistrocactus sp. seed	.026	.034	.049(*)
Panicum sp. seed	.028	.038	.043(*)
Rosaceae stem	.028	.038	.043(*)
Allium sp. seed pod	.028	.038	.043(*)
plant resin(a)	.028	.038	.043(*)
Bird feather	.028	.036	.037(*)

Skeletal Stable Carbon Isotopes from the Lower Pecos Canyonlands

A total of 31 human burials from the Lower Pecos canyonlands and surrounding region have staple carbon isotope data from bone collagen samples (Table 55) (Bement 1994; Bousman and Quigg 2006; Huebner 1991; Skinner 1978). These data present some long term dietary signals that complement the dietary reconstruction based on the coprolite evidence available from the canyonlands. These data are not directly comparable, as the δ^{13}C values are a composite record of long-term diet, influenced by the δ^{13}C values of both plant and animal resources. This can be clarified with reference to the δ^{15}N values from the same specimens, but this is not available for all of the specimens presented here. This limits dietary inference, since differences can be due to changes in both the source and abundance of animal food resources in addition to plant foodstuffs.

Table 55. Stable Carbon Isotope Data from Regional Skeletal Data

Component	Site	Sample	Sex	δ13C (‰) - Collagen	δ13C (‰) - Apatite	δ15N (‰) - Collagen
Early Archaic	Bering Sinkhole	CCNR-38043		-15.2	-6.9	9
Early Archaic	Bering Sinkhole	CCNR-38044		-15.2	-8.5	7.4
Early Archaic	Bering Sinkhole	CCNR-38046	F	-14.9	-7.3	9.6
Early Archaic	Bering Sinkhole	CCNR-38045		-14.3	-7.3	8.5
Early Archaic	Bering Sinkhole	CCNR-38047	M	-13.7	-5.9	8.8
Early Archaic	Seminole Sink	1527.9		-22.1		
Early Archaic	Seminole Sink	517		-18.4		
Early Archaic	Seminole Sink	798.1		-18.1		
Early Archaic	Seminole Sink	1755		-15.5		
Early Archaic	Seminole Sink	70		-13.7		
Early Archaic	Seminole Sink	541		-13.2		
Early Archaic	Seminole Sink	171		-12		
Early Archaic	Seminole Sink	1450		-11.4		
Middle Archaic	Bering Sinkhole	CCNR-38042	F	-16.6	-9.1	8.3
Middle Archaic	Bering Sinkhole	CCNR-38039		-16.2	-9.8	6.9
Middle Archaic	Bering Sinkhole	CCNR-38040	M	-16	-9.1	7.3
Middle Archaic	Bering Sinkhole	CCNR-38041	M	-15.2	-7.2	7.5
Late Archaic	Bering Sinkhole	CCNR-38034	F	-17.5	-9.9	8.2
Late Archaic	Bering Sinkhole	CCNR-68032	F	-16.7	-10.6	8.1
Late Archaic	Bering Sinkhole	CCNR-38033		-16.5	-9.3	9.7
Late Archaic	Bering Sinkhole	CCNR-38037	M	-16.5	-9.9	7.7
Late Archaic	Bering Sinkhole	CCNR-38036		-16.1	-8.8	7.1
Late Archaic	Bering Sinkhole	CCNR-38035	M	-15.9	-8	7.5
Late Archaic	Bering Sinkhole	CCNR-38038		-15.8	-10.1	7.8
Late Archaic	Conejo Shelter	4	M	-14.6	-7.7	16.6
Late Archaic	Conejo Shelter	2	F	-13.9	-7.3	12.6
Late Archaic	Conejo Shelter	1	M	-12.6	-8.6	10.2
Late Archaic	Conejo Shelter	3	M	-12.6	-7.6	10.5
Late Archaic	ELCOR Cave	1	M	-13	-6.6	
Late Archaic	ELCOR Cave	5	M	-12.3	-7.6	
Late Archaic	Skyline Shelter	1	F	-15.7	-7.8	5.3

The most complete temporal record of burials comes from Bering Sinkhole, a vertical shaft sinkhole located to the east of the canyonlands securely in the Oak-Cedar zone of the Balconian Biotic Province (Blair 1950). A total of sixteen separate burials from across the Archaic were recovered from this site (Table 55). The remaining fifteen specimens come from rockshelter or vertical shaft sinkholes from the sotol-lechuguilla zone of the Chihuahuan Biotic Province. Three of these sites are from the Lower Pecos canyonlands. Eight Early Archaic specimens were recovered from the Seminole Sink burial site. The other specimens all date from the Late Archaic contexts (Table 55). The results will be presented in chronological order.

The Early Archaic samples (n=8) from Seminole Sink exhibit δ^{13}C values that range between a diet dominated by CAM/C4 plant resources and a diet focused primarily on C3 resources. This set of samples exhibits the largest range δ^{13}C (-11.4 ‰ to -18.4‰, mean -14.6‰) observed for any of the contexts presented here and suggest that the burials at the site include at least two populations with differing subsistence strategies incorporating both CAM/C4 and C3 resources in different amounts (Bousman and Quigg 2006). The Early Archaic data (n=5) from the more mesic Bering Sinkhole have a similar mean δ^{13}C value (-14.7‰) to the samples from Seminole, but are much less variable (-13.7‰ to -15.2‰), clustering tightly around a value indicating a diet mixed equally between resources utilizing C3 and CAM/C4 photosynthesis.

There are no Middle Archaic data from the Lower Pecos canyonlands or elsewhere in the surrounding Chihuahuan Desert. The Middle Archaic data (n=4) from the Bering Sinkhole site have a mean δ^{13}C value of -16.0‰ with a range from -15.2‰ to

-16.6‰. These data indicate that the human population utilizing this vertical shaft for interment during the Middle Archaic incorporated more C3 resources into their subsistence strategy than the prior Early Archaic populations. Overall, the diet was mixed, incorporating both C4/CAM and C3 plant resources in some abundance. This may indicate a long-term mobility pattern that incorporated a larger region than the Lower Pecos canyonlands and extended into the Edwards Plateau or other regions with a greater abundance of plant resources exhibiting C3 photosynthesis. It is unclear if this pattern holds for the Lower Pecos canyonlands, but it seems unlikely based on the data available from the Early and Late Archaic.

The Late Archaic samples (n=7) from the Chihuahuan Desert Biotic Province have a mean $\delta^{13}C$ value of -13.5‰ and range from -12.3‰ to -15.7‰. These data suggest a population with a well-mixed diet with a primary focus on CAM/C4 plant resources. The Late Archaic data (n=7) from the Bering Sinkhole site exhibit the most depleted $\delta^{13}C$ values of any context presented in this current review (mean -16.6‰, range -15.8‰ to -17.5‰) These two sets of Late Archaic data indicate that the hunter-gatherers in the Lower Pecos canyonlands were more dependent on CAM/C4 resources than those groups located further to the east in the Edwards Plateau.

While these data present an image of dietary consumption that is not fully consistent with the patterns recorded in the coprolite data, the overall importance of CAM plant resources among the Archaic human populations in the canyonlands is corroborated. There, skeletal isotope date suggest more dietary variation among Early Archaic populations in the canyonlands than is recorded in the available coprolite data.

The range of $\delta^{13}C$ values from Seminole Sink are inconsistent with the distribution expected by a population with a homogenous diet (Bousman and Quigg 2006). Both of these populations exhibit some dependence on CAM/C4 plant resources. The overall picture of diet across the Archaic from the two groups of data suggest that populations on the Edwards Plateau increasingly relied on C3 plant resources in their diet, while the Lower Pecos hunter-gatherer populations were principally dependent on CAM/C4 plant resources. This corroborates the more precise, but temporally limited, data available from coprolites, which suggest at least seasonal dependence on CAM resources such as prickly pear tunas and lechuguilla hearts. C3 plants were also a part of the dietary pattern, demonstrated by both the common occurrence of sotol and onion in many of the specimens as well as the more mesic resources recovered in the Late Archaic coprolite study from Baker Cave (Sobolik 1991a). Overall, the long-term dietary trends recorded in the skeletal $\delta^{13}C$ values from the Lower Pecos canyonlands accord well with the coprolite data. These populations consumed a wide-variety of plant and animal resources, but were dependent on xeric CAM plant resources for the bulk of their caloric needs.

All of the available dietary data from the Lower Pecos canyonlands show a similar dependence on desert succulent resources throughout the Archaic. Diet-breadth is highly variable across the seasons, as should be expected among forager populations. A cool season dependence on baked resources such as lechuguilla and sotol extends back to the earliest coprolite records available in the canyonlands. The following chapter evaluates the coprolite specimens with reference to diet-breadth and seasonality.

CHAPTER IX

SUMMARY

The data from the current study expands prior dietary reconstructions for the Lower Pecos canyonlands. This discussion focuses on seasonality and diet-breadth interpretations of the clusters generated in the previous chapter. Overall, the data generated and synthesized herein suggest that a diet-breadth model using caloric return as the currency does not fully explain the seasonal dependence on low-ranked resources such as nopales and onion bulbs. The coprolite data, ranging in time from the Early Archaic to the Late Archaic, corroborate the strong dependence on the seasonal staples of lechuguilla, nopales, and tunas observed in the ethnohistoric literature. The temporal endurance of this subsistence strategy suggests that there may be some components of this dietary pattern which could inform on many of the diet-related health issues observed among modern Native-American and other populations (Johnston 2007; Nabhan 2002; Olson 1999; Richards and Patterson 2006; Taylor 2005; Teufel 1996; Watts et al. 2007; Wiedman 2005). This is discussed below, followed by a brief summary of research directions that may strengthen future coprolite studies.

Diet and Seasonality in the Lower Pecos Canyonlands

The data from the coprolite studies presented above is used to assess the diet-breadth model developed in this current study. As mentioned before, the limited identification of both the fiber and epidermal tissue components for most of these specimens does preclude a full identification and interpretation of the staple resources consumed in the meals represented in the coprolite. This section initially presents the diet-breadth interpretation of the thirty specimens included in the current study followed by some additional interpretation of the available data from the other studies (Bryant 1974b; Edwards 1990; Fry 1975; Riskind 1970; Sobolik 1991a; Stock 1983; Williams-Dean 1978).

The three clusters of specimens from the current study correlate nicely with dietary predictions based on the ethnohistoric record (Table 56) (De Leon 1971; Krieger 2002; Thoms 2008b). The first cluster (n=16) indicates a diet focused on the desert succulent resources of lechuguilla and sotol, with smaller amounts of onion bulbs also consumed. These specimens fit the expectations of a winter/early spring diet focused on the highest caloric return resources available in the canyonlands during that season. The inclusion of calorically limited onions may indicate that diet breadth for these spring and winter meals is fairly broad. However, there is little indication of small animal resources in these specimens compared with the other clusters. This cluster also includes the only direct evidence of large animal consumption from the current study. Overall, this cluster represents meals with a mixed diet-breadth, incorporating both low and high ranked resources available in the cold season.

Table 56. Diet-Breadth and Seasonal Interpretations of Coprolite Clusters from Hinds Cave Data

Cluster	Site	Chronological Period	Number of Specimens (n)	Major Dietary Components	Season of Deposition	Micro-habitat	Diet-Breadth
Riley 1	Hinds Cave	Early Archaic	16	*Agave sp.* caudex, *Dasylirion sp.* caudex, *Allium sp.* bulbs	Winter/Spring	Cliff/Canyon	Incorporates Low-ranked resource
Riley 2	Hinds Cave	Early Archaic	4	*Opuntia sp.* cladodes and *Daylirion sp.* caudex	Winter/Spring	Cliff/Canyon, Vega/Terrace or Upland (flats)	Incorporates Low-ranked resource
Riley 3	Hinds Cave	Early Archaic	10	*Opuntia sp.* tunas	Summer	Vega/Terrace or Upland (flats)	High-ranked resources only
Stock 1	Hinds Cave	Early Archiac	33	Unidentified epidermal tissue - may be *Agave sp* ., *Dasylirion sp* . or other	Fall/Winter	Cliff/Canyon, Vega/Terrace	Unknown
Stock 2	Hinds Cave	Early Archaic	10	*Opuntia sp.* tunas	Late Summer/Fall	Vega/Terrace	High-ranked resources only
Stock 3	Hinds Cave	Early Archaic	12	*Opuntia sp.* cladodes and *Allium sp.* bulbs	Spring	Vega/Terrace or Upland (flats)	Incorporates Low-ranked resource
Williams-Dean 1	Hinds Cave	Early Archaic	31	*Opuntia sp.* cladodes and *Allium sp.* bulbs	Spring	Vega/Terrace or Upland (flats)	Incorporates Low-ranked resource
Williams-Dean 2	Hinds Cave	Early Archaic	50	Bone fragments, *Agave sp.* caudex, *Juglans sp.* nuts, and *Opuntia leptocaulis* fruits	Fall/Winter	Cliff/Canyon, Vega/Terrace	High-ranked resources only
Williams-Dean 3	Hinds Cave	Early Archaic	19	*Opuntia sp.* tunas	Summer	Vega/Terrace or Upland (flats)	High-ranked resources only
Edwards 1	Hinds Cave	Early and Late Archaic	24	Burnt Bone	Fall/Winter	Upland (flats)	Unknown
Edwards 2	Hinds Cave	Early and Late Archaic	7	*Opuntia sp.* tunas and *Diospyros sp.* fruit	Summer	Vega/Terrace	High-ranked resources only
Edwards 3	Hinds Cave	Early and Late Archaic	8	*Allium sp.* bulbs and unidentified epidermal tissue - may be *Agave sp., Dasylirion sp., Opuntia sp.* or other	Spring	Cliff/Canyon,Vega/Terrace	Incorporates Low-ranked resource

The second cluster (n=4) from the current study represents the digested residue of meals composed almost entirely of nopales and sotol hearts, with the nopales making up the bulk of the plant-based diet. These specimens represent a seasonal dietary strategy focused on low-ranked nopales somewhat supplemented by the relatively high-ranked sotol hearts. This cluster accords nicely with the seasonal expectations of a spring diet from the ethnohistorical record (De Leon 1971; Krieger 2002). The third cluster (n=10) consists of coprolite specimens that reflect a diet dominated by prickly pear tunas. Other than less predictable and abundant mast resources such walnuts, tunas are the highest ranked resource in the diet-breadth model. Both the ethnohistoric record and the model predict that hunter-gatherer populations in the canyonlands would depend on these resources as a major staple during the summer. This is exactly what is seen in this cluster, which contains very little evidence of other plant resources. The diet reflected in these specimens is focused on highly-ranked tunas to the exclusion of other plant resources. Prickly pear cactus was an invaluable food resource across the Archaic. The tunas and seeds were a mid-summer staple and the nopales provided a reliable resource in times of seasonal scarcity.

Prickly pear cactus seeds and epidermal tissue were also important clustering variables in the other coprolite assemblages from Hinds Cave considered in this present study. Most specimens with high levels of tuna seeds [Stock Cluster 2 (n=10), Williams Dean Cluster 3 (n=19), and Edwards Cluster 2 (n=7)] have relatively low levels of other constituents, which reinforces the ethnohistoric record of the seasonal dominance of cactus tuna as a mid-summer resource (De Leon 1971; Krieger 2002; Taylor 1972; Wade 2003). This also supports the diet-breadth model, which predicts that hunter-gatherer populations in the Lower Pecos canyonlands would restrict their diet-breadth to just tunas when they were available for harvest.

The clusters with high levels of prickly pear cactus epidermal tissue [Stock Cluster 3 (n=12), Williams Dean Cluster 1 (n=31), and Edwards Cluster 3 (n=8)] also have a low diversity of other constituents. Each of these clusters also has higher levels of onion bulb fragments than the other clusters. This supports the view of Edwards

(1990) that cold season coprolites will contain a low diversity of dietary constituents and a heavy dependence on a handful of seasonally available staples such as nopales or onions (Table 56).

The remaining clusters [Stock Cluster 1 (n=33), Williams Dean Cluster 2 (n=50), and Edwards Cluster 1 (n=24)] are more difficult to evaluate, due to the limited identification of primary dietary components noted above. Cluster membership seems to be due to the absence of high levels of prickly pear cactus seeds and epidermal tissue. The specimens in these three clusters (which account for the majority of specimens in each study) reflect a high diversity and low abundance of dietary resources. I maintain that this is due to the lack of detailed identification of the major dietary constituents of fiber and epidermal tissue. It seems likely that some of these specimens reflect a dietary dependence on lechugulla and sotol hearts, while others may indicate a broad-based diet on seasonally available fruit and seed resources, similar to the clustering exhibited by the specimens from Baker, Frightful, and Parida Caves (Table 57).

Table 57. Diet-Breadth and Seasonal Interpretations of Coprolite Clusters from Other Sites

Cluster	Site	Chronological Period	Number of Specimens (n)	Major Dietary Components	Season of Deposition	Micro-habitat	Diet-Breadth
Riskind 1	Parida Cave	Late Archaic	3	*Agave sp.* caudex, *Allium sp.* bulbs and *Poaceae* seeds	Spring	Cliff/Canyon,Vega/Terrace	Incorporates Low-ranked resource
Riskind 2	Parida Cave	Late Archaic	3	Unidentified Stem and *Poaceae* seeds	Spring/Fall	Vega/Terrace or Upland (flats)	Unknown
Riskind 3	Parida Cave	Late Archaic	5	Diversity of Seed Resources	Summer	Vega/Terrace or Upland (flats)	Unknown
Bryant 1	Conejo Shelter	Late Archaic	22	*Allium sp* . bulbs and *Opuntia sp.* cladodes	Spring	Vega/Terrace or Upland (flats)	Incorporates Low-ranked resource
Bryant 2	Conejo Shelter	Late Archaic	11	*Opuntia sp. tunas*	Summer	Vega/Terrace or Upland (flats)	High-ranked resources only
Bryant 3	Conejo Shelter	Late Archaic	7	*Agave sp./Dasylirion sp./Yucca sp* . caudex	Fall/Winter	Cliff/Canyon	High-ranked resources only
Bryant 4	Conejo Shelter	Late Archaic	3	Unidentified bark	Fall/Winter	Unknown	Unknown
Sobolik 1	Baker Cave	Late Archaic	7	*Opuntia sp.* cladodes and *Quercus sp.* acorns	Fall/Winter	Vega/Terrace	Incorporates Low-ranked resource
Sobolik 2	Baker Cave	Late Archaic	18	Unknown epidermal tissue and *Juglans sp.* nuts	Fall/Winter	Vega/Terrace	High-ranked resources only
Sobolik 3	Baker Cave	Late Archaic	3	*Opuntia sp.* tunas	Summer	Vega/Terrace or Upland (flats)	High-ranked resources only
Sobolik 4	Baker Cave	Late Archaic	10	*Allium sp.* bulbs and *Dasylirion sp.* caudex	Spring	Cliff/Canyon	Incorporates Low-ranked resource
Fry 1	Frightful Cave	Middle and Late Archaic	11	*Opuntia sp.* tunas	Summer	N/A	High-ranked resources only
Fry 2	Frightful Cave	Middle and Late Archaic	9	*Opuntia sp.* cladodes and *Allium sp.* seed pods	Spring	N/A	Incorporates Low-ranked resource
Fry 3	Frightful Cave	Middle and Late Archaic	5	Unknown epidermal tissue	N/A	N/A	Unknown
Fry 4	Frightful Cave	Middle and Late Archaic	7	Diversity of Seed Resources	Summer/Fall	N/A	Unknown

Coprolite studies from the other sites discussed here exhibit some interesting parallels as well as differences in the revealed dietary patterns. Three of the sites (Conejo Shelter, Baker Cave and Frightful Cave) contain clusters of specimens that exhibit a dependence on tunas [Bryant 2 (n=11), Sobolik 3 (n=3), and Fry 1 (n=11)] (Table 57). This demonstrates that tunas were a preferred resource across their distribution, when available. The same three sites, distributed across the ecotonal boundaries in the Lower Pecos as well as far to the south, also contain coprolites which reflect a diet focused on nopales and supplemented with other resources such as onion bulbs or acorns [Bryant 1 (n=22), Sobolik 1 (n=7), and Fry 2 (n=9)] (Table 57). Interestingly, all three sites in the Lower Pecos canyonlands (Parida Cave, Conejo Shelter, and Baker Cave) contain coprolites focused on the caudices of desert succulents [Riskind 1 (n=3), Bryant 3 (n=7), and Sobolik 4 (n=10)], while the study from Frightful Cave, located much further to the south, does not. The analyses reviewed above all record a similar record of subsistence as the studies from Hinds Cave. This dietary pattern includes a monolithic dependence on tunas during the summer, intensive exploitation of lechuguilla and sotol hearts during the cool season, and a focus on nopales in the spring or during other times of resource scarcity.

The remaining clusters reflect some additional details of the subsistence patterns of hunter-gatherers in the canyonlands that have not been recorded for Hinds Cave. Three coprolite clusters [Riskind 2 (n=3), Riskind 3 (n=5) and Fry 4 (n=7)] exhibit a diverse and varied dependence on seed resources. This dietary pattern may reflect a seasonal pattern of exploitation of these resources in the late summer/early fall. An alternative explanation for some of these resources, which generally exhibit very little evidence of grinding or crushing had been proposed by Williams-Dean (1978), who argues that the small grass seeds noted in some of the specimens in her study may not be dietary items, but rather the gut contents of consumed rodents and other small game.

The remaining three clusters [Bryant 4 (n=3), Sobolik 2 (n=18), and Fry 3 (n=5)] are primarily defined by the presence of unknown resources. This indicates that there continue to be unidentified elements in the subsistence strategy practiced by the hunter-gatherer populations occupying the Lower Pecos canyonlands during the Holocene. Possible resources that remain to be explored include geophytes other than onionsand aquatic resources.

Overall, the combined coprolite data presented here provide a robust set of data to explore the subsistence strategies employed by the Holocene hunter-gatherer populations in the Lower Pecos Canyonlands. There are a total of 224 coprolite specimens from Hinds Cave, ranging from the Early Archaic to the Late Archaic, and another 124 coprolite specimens from the other sites. While differing levels of identification and expertise limit direct comparison between these data sets, there are general observations that reinforce the more detailed analysis presented above. Of the 224 specimens analyzed by various researchers from Hinds Cave, sixty-six (29.5%) contain the digested residue of a meal including baked sotol or lechuguilla caudex (Table 58). Another forty-seven (20.3%) contain evidence of nopale consumption. Forty-three of these specimens also contain onion bulbs, suggesting that these two resources were frequently consumed together as a meal. Forty-six (19.8%) of the specimens from Hinds Cave are the residue of meals focused on tunas as a staple resource. The remaining sixty-five specimens (29.0%) from Hinds Cave are not classifiable due to a lack of identification of the primary components recovered from the specimens. It seems likely that many of these remaining specimens reflect the consumption of either desert succulent resources or nopales, but the lack of epidermal and fiber identification from these studies (Edwards 1990; Stock 1983) precludes any secure statement of dietary reconstruction.

The comparative data from the other sites considered here exhibit a similar pattern of dietary dependence (Table 58). Overall, the data indicate that the plant resource components of many of the meals represented by these coprolite specimens were dominated by one or two staple plant resources. While this is frequently supplemented with trace amounts of secondary resources such as hackberry fruits and other small fruits and seeds, the data indicate a stable exploitation of the four major resources considered in this study that spans the Holocene. This fits well with the ethnohistoric observations of Cabeza de Vaca and De Leon the elder, both of whom indicate that the seasonal diet of the native groups observed was almost monolithic in composition (De Leon 1971; Krieger 2002; Thoms 2008b). While this may be partly due to the outsider perspective and clear disdain accorded native lifeways by de Leon (1971), the coprolite data corroborates the overall pattern of heavy dependence on a few staple resources across the annual cycle.

Table 58. Dominant Dietary Resources in Coprolite Specimens

	Hinds Cave		Other Sites		Total	
Dominant Resource	Number of Specimens (n)	Percentage	Number of Specimens (n)	Percentage	Number of Specimens (n)	Percentage
Nopales	47	21.0	38	30.6	85	24.4
Tunas	46	20.5	25	20.2	71	20.4
Caudex	66	29.5	20	16.1	86	24.7
Unknown	65	29.0	26	21.0	91	26.1
Small Seeds		0.0	15	12.1	15	4.3
Total	224	100.0	124	100.0	348	100.0

Both the ethnohistoric record and the coprolite data demonstrate that nopales and onions are much more important resources than would be predicted with the diet-breadth model. This suggests that the human populations in the canyonlands depended on these low-ranked resources on at least a seasonal basis. This may reflect a seasonal scarcity of food resources, since the clusters exhibiting high amounts of prickly pear cactus epidermal tissue indicate a late winter/early spring occupation of the site and generally have little evidence of combined meals with higher-ranked resources. Alternatively, a diet-breadth model based on a currency of gross caloric return may not fully explain the dietary choices made by human populations occupying the Lower Pecos canyonlands. It is possible that onion bulbs and nopales were incorporated into the diet for reasons other than gross caloric intake. Nopales have been an important food resource across the Holocene among the human populations occupying the Lower Pecos canyonlands.

As previous studies (Bryant 1974b; Dering 1979; Edwards 1990; Sobolik 1991a; Stock 1983; Williams-Dean 1978) have concluded, the human exploitation of the Lower Pecos environment appears to have followed a similar pattern across much of the Holocene. In the studies presented here, which span most of the Archaic, prickly pear cactus was an important seasonal resource, both during the summer when tunas were available and during the cool season, when the abundant nopales of these cacti would have been a low calorie but bulky food source. This study also indicates that Hinds Cave has been used as a habitation across the seasons during the Archaic. This researcher suggests that the mobility of populations in the Lower Pecos was more random and opportunistic than predicted in the model developed by Shafer (1986), responding to both long term and seasonal fluctuation in resource availability.

The availability of resources from multiple microhabitats near the riverine settings throughout most of this arid region may have an important role in reducing large-scale mobility. Human populations utilizing a broad-spectrum subsistence strategy could reduce their mobility costs while maintaining access to many important seasonal resources and, perhaps the most important staple of all, water (Taylor 1964). Most of the clusters contained plant resources from both the local Cliff/Canyon microhabitat around Hinds Cave as well as from the Vega/Terrace microhabitat located in the canyon bottoms (Table 56). This supports the tethered nomadism model of Taylor (1964) and suggests that much of the plant-based economy of human populations in the Lower Pecos was focused along the incised river systems of the region with limited use of the uplands for logistically-oriented hunting forays (Lord 1984; Saunders 1986).

The data presented in this study show that the human populations living along the northern fringe of the Chihuahuan Desert were dependent on fructan-based plant resources for the majority of their carbohydrate intake. The temporal depth and spatial breadth of this strategy across most of arid North America has some important dietary implications for modern populations exhibiting genetic continuation with the pre-

Columbian inhabitants of the region. Many populations living near the Mexican-United States border, especially Native Americans and Mexicans with indigenous heritage, have extremely high levels of diet-induced health issues, such as obesity and diabetes (Archer et al. 2002; Fogg 2010; Wiedman 2005). This is due, at least partly, to a major change in the carbohydrate composition of the diet of these populations over the last half-millennium of cultural change (Johnston 2007; Richards and Patterson 2006; Taylor 2005, 2006; Teufel 1996). Soluble dietary fibers generally, and specifically fructans, have been shown to have a positive, ameliorating effect on lipid and glucose metabolism (Beylot 2005; Daubioul et al. 2002; Daubioul 2005; Delzenne and Daubioul 2000; Roberfroid 1999; Williams and Jackson 2002). Studies have shown that the fructan components of both *Agave* sp. and *Dasylirion* sp. have similar effects on metabolic function as the commercially available fructans derived from chicory root (*Cichorium intybus* (LINN.)) (Ur et al. 2008). These data suggest that attempts to address the high prevalence of obesity and diabetes among indigenous populations in the Chihuahuan Desert with diet should focus on the promotion of neglected, tradititional food resources, both as whole foods as well as sources of fructans for the food industry (Huazano-Garcia 2009; Lopez and Urias-Silvas 2007b). In addition to the metabolic regulation benefits mentioned above, fructans have a positive impact on colon cancer (Langlands et al. 2004; Leach 2007; Pool-Zobel and Sauer 2007; Taper and Roberfroid 2002) and general colonic health (Heizer et al. 2009) as a prebiotic soluble fiber. The incredible temporal depth of fructan consumption by human populations in the Chihuahuan desert has already been noted by some researchers (Leach 2007; Leach and Sobolik 2010) and, it is hoped, may inform on the community health strategies applied in the borderlands today.

Future Research Directions

This study demonstrates the importance of exploring each of the congruent lines of evidence for dietary consumption available in a coprolite specimen. However, there are several limitations of the current study that could be resolved with future research. While coprolites are direct indicators of diet, the limited understanding of the quantifiable relationship between the consumed food resources and the undigested residue in the coprolite prevent a direct reconstruction of the diet and, more specifically, nutrition represented by a specimen. One method to address this limitation is the attempt to directly quantify the indigestible components of the major plant resources such as fiber and phytoliths, both in the coprolites as well as the plant resources directly. To this end, a concentration value calculated by adding a known quantity of marker spores to a known weight of each coprolite and plant reference could provide a method for directly quantifying the abundance of these resources in the diet. This method, derived from palynology, provides a direct measure of the amount of a resource represented in the specimen. It also negates the issues of differential digestion by only comparing the indigestible components of previously identified plant resources. A further analysis of this would require the development of several actualistic studies of diet and the resultant feces, similar to the work done on the passage of pollen through the human digestive system by Williams-Dean (1978). This would provide a direct analogy for reconstructing diet from undigested and indigestible fecal residues. In addition, this approach would generate a better understanding of the differential rate of passage for various components such as fiber ultimates and phytoliths.

This focus on congruent lines of evidence related to staple resource exploitation could also be strengthened through the increased application of staple carbon isotope and aDNA methods to the abundant coprolite record of the Lower Pecos canyonlands. Both of these techniques have strengths that complement the microscopic data sets as well as weakness that are offset by those same congruent data sets. Staple carbon isotopes provide a broad indication of dietary consumption based on differences in the photosynthetic pathways of resources. While this reveals a very gross generalization of diet, it is directly quantifiable and can be used to strengthen the more refined, but less quantifiable, data derived from traditional paleoethnobotanical studies of coprolites. aDNA analysis focused on chloroplast DNA from plant resources suffers from a limited understanding of the sources of DNA recovered in coprolites (Reinhard et al. 2008), but could provide an additional source of dietary information and help identify some of the unknown components observed with microscopy. Additionally, mtDNA analysis could clarify the role of larger animal resources in the diet, which are underrepresented among the faunal elements recovered from coprolite specimens (Reinhard et al. 2007; Sobolik 1993). Overall, the importance and reliability of these novel methods in coprolite analysis cannot be assessed until they have been applied to more specimens with paleoethnobotanical and faunal results.

Direct radiocarbon dating of individual coprolites may provide a new method to evaluate intensity of occupation at sites such as Hinds Cave. Rather than rely on stratigraphy and associated radiocarbon dates, each specimen could be assigned a date of deposition. This would help clarify the depositional nature of the discrete lenses observed during excavation. Further, specimens from unknown or unsecure contexts, such as looters back dirt, could be assigned a temporal provenience. This would be of great benefit at sites across the Lower Pecos canyonlands, where the upper deposits are frequently impacted by looting, grazing and other modern anthropogenic activities, forcing previous researchers to ignore the coprolite component of the Late Prehistoric and Historic periods that may be present at these sites.

While the starch analysis of specimens in the current study did not add to our understanding of diet in the Lower Pecos canyonlands, it did demonstrate that starch can be recovered from coprolite specimens, despite its digestibility in the human gut. The primary limiting factor of this study was the limited use of starchy resources in meals represented in the coprolite specimens. The overall dietary reconstruction suggests that the technique will not be very useful for specimens from the canyonlands. While there are a handful of specimens that indicate the consumption of small seed resources, the overall dietary pattern as well as lack of groundstone metates in the archaeological record suggest that small, starch-rich seeds were rarely consumed and were never a staple resource. This technique may be applied better to coprolite specimens from regions with known dependence on small seeds, such as the Great Basin (Fry 1970; Rhode 2003; Rhode et al. 2006), or domesticates, such as the Puebloan Southwest (Clary 1986; Fry and Hall 1975; Minnis 1989; Reinhard 1989; Sutton and Reinhard 1995), with better and more informative results.

Conclusion

Evaluating coprolites as the direct record of individual dietary choices over a short temporal window provides an excellent framework to assess the diet-breadth, seasonality of deposition and menus observed in past human subsistence patterns. The combined coprolite data available for the Lower Pecos canyonlands record a long term dietary pattern of seasonal dependence on a handful of staple resources, throughout the Archaic. There are three major seasonal menus reflected in the coprolite data. The first menu consists of nopales, and was principally, although not exclusively, consumed in the late spring. This menu is primarily consumed when other resources were not readily available and may be considered a dependable but undesirable meal. The second menu consists of pit-baked lechuguilla and sotol, common throughout the cool season. This menu entails high processing costs, but would provide a reliable caloric return. The third menu exhibits a monolithic reliance on tunas during the summer. The ease of harvest and consumption is reflected in the seasonal dominance of this resource, which was assuredly a highly desirable meal. These patterns of dietary consumption, which extend back eight thousand years, are corroborated by the written accounts of early European observers in the broader region. This long temporal depth is a reflection of how successful this subsistence pattern was at extracting a living foraging in a marginal, arid environment.

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APPENDIX A

COPROLITE DATA FROM PRIOR HINDS CAVE STUDIES

Macrofossil Data of Coprolite Specimens from Edwards (1990) – Part 1

sample	screen	dirt	rocks	chitin	charcoal	bone	Bone - burned	feather
1	3	2	0	1	0.1	2	0	0
2	2	2	0	0.1	0	2	0	0
3	3	2	0	1	0.1	1	0	0
4	3	6	0	1	0	0	0	0
5	4	2	0	2	0	2	0	1
6	3	1	0	0	1	1	0	0
7	2	2	0	0	0.1	1	0	0
8	3	2	0	1	0	3	0	0
9	3	2	0	1	1	1	0	0
10	2	2	0	2	1	2	0	0
11	2	1	0	1	0	1	0	0
12	4	2	0	1	1	1	0	0
13	5	2	1	1	1	1	0	0
14	3	1	0.1	0	0.1	0	0	0
15	3	2	0	2	1	2	0	0
16	4	2	0	0	0	1	0	0
17	3	2	0.1	0	2	0	0	0
18	5	3	1	1	1	1	0	0
19	5	2	0	1	0.1	0	0	0
20	3	1	1	1	1	1	0	0
21	7	1	1	1	0	0	0	0
22	2	2	0	2	0	2	0	0
23	2	2	0	1	1	1	0	0
24	3	2	0	1	0	2	0	0
25	2	1	0	1	0	0	0	0
26	6	2	1	0	1	0	0	0
27	5	3	0	1	0.1	1	0	0
28	2	1	0	1	0	0	0	0
29	2	0	0	0.1	0	0	0	0
30	3	2	0	2	0	2	0	0
31	2	1	0	0	0	0.1	0	0
32	4	1	0	1	0	2	0	0
33	3	2	0	0	0	0	0	0
34	3	3	0	1	0	1	0	0
35	2	1	0	0	1	1	0	0
36	7	2	0	0	0	0	1	0
37	7	0	0	1	0	0	2	0
38	8	0	0	0	0	0	0	0
39	7	1	1	0	1	0.1	0	0

Macrofossil Data of Coprolite Specimens from Edwards (1990) – Part 2

sample	fiber	allium	epidermis	hair	flake	shell	quid	stems	spine	opuntia sd.	celtis sd.
1	4	0	1	0	0	0	0	0	0	2	0
2	5	0	1	1	0	0	0	0	0	0	0
3	2	0	2	0	0	0	0	0	0	4	0
4	1	0	0	0	0	0	0	0	0	0	0
5	2	0	3	0	0	0	0	0	0	0	0
6	5	0	1	0	0	2	0	0	0	1	0
7	5	0	1	0	0	1	0	0	1	2	0
8	3	0	0	0	1	0	0	0	0	2	1
9	4	0	2	0	0	0	0	0	0.1	1	0
10	4	0	2	2	0	0	0	0	0	3	0
11	7	0	0	0	0	0	0	0	0	2	0
12	3	2	2	0	0	1	0	0	0	0	0
13	3	0	1	0	0	1	0	0	0	1	1
14	4	0	0	0	0	0	3	0	0	0	0
15	3	0	2	0	0	1	0	2	1	0	0
16	4	0	3	0	0	0	0	0	0	1	0
17	2	0	0	0	0	0	0	0	0	5	0
18	0	0	1	0	0	0.1	0	0	0	1	1
19	3	0	2	0	0	0.1	0	0	0	0	0
20	2	0	2	0	0	0	0	0	0	5	0
21	2	0	0	0	1	1	0	0	0	0	0
22	6	0	0	0	0	0	0	0	0	0	0
23	4	0	1	2	0	0	0	0	0	3	0
24	4	0	0	0	0	0	0	0	1	2	0
25	5	0	1	0	0	0	0	0	0	3	0
26	1	0	0	0	0.1	1	0	0	0	1	0
27	2	0	1	0	0	2	0	0	0	1	0
28	0	0	1	0	0	0	0	0	0	6	0
29	1	0	1	0	0	0	0	0	0	7	0
30	3	0	2	0	0	0	0	0	0	2	0
31	6	0	2	0	0	0	0	0	0	0	0
32	4	0	0	0	0	1	0	0	0	0	0
33	4	0	4	0	0	0	0	0	0	0	0
34	3	0	0	0	0	0	0	0	0	2	0
35	4	0	4	0	0	0	0	0	0	1	0
36	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	1	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Edwards (1990) – Part 3

sample	diospyros	misc	cassia	fabaceae	poaceae	polygonum	cyperaceae	asteraceae
1	0	0	0	0	0	0	0	0
2	0	0	2	0	0	0	0	0
3	2	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	1	1	0	1	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	1	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	1	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	1	1	0	0	0	0
24	0	0	0	1	0	0	0	0
25	0	0	1	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	1	0	0	0
28	0	0	0	0	0	1	2	1
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	1	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0.1	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 1

sample	bone	bone burned	hair rodent	feather	hair	fur	scale	skin
1a	0.1	0	0.1	0.1	0.1	0	0	0
3a	0.1	0.1	0.1	0	0	0	0	0
4a	0.1	0.1	0.1	0	0	0	0	0
9a	1	0	0.1	0	0	0	0	0
10a	0.1	0	0.1	0	0.1	0	0	0
11a	2	0	0	0.1	0	0	0	0
16a	0.1	0.1	0	0	0	0	0	0
20a	0.1	0	0.1	0	0.1	0	0	0
21a	0.1	0	0.1	0	0	0	0	0
22a	0.1	0	0.1	0	0	0	0	0
26a	2	0	0	0	0	0	0	0
27b	0.1	0	0.1	0	0	0	1	0
29b	2	0	0	0	0	0	0	0
30b	0	0	0	0	0	0	0	0
32b	2	0	0	0	0	0	0	0
34b	2	0	0.1	0	0	0	0	0
37b	0.1	0	0	0	0.1	0	0	0
38b	0	0	0	0	0	0	0	0
39b	0.1	0	0	0.1	0	0	0	0
40b	1	0.1	0	0	0	0	0	0
41b	0.1	0	0	0	0	0	0	0
42b	0.1	0.1	0	0	0	0	0	0
44b	0.1	0.1	0	0	0.1	0	0	0
46b	0	0.1	0	0.1	0	0	0	0
49b	0.1	0	0.1	0	0.1	0	0	0
51b	0	0	0	0	0.1	0	0.1	0
2a	1	0	0.1	0	0	0	0	0.1
5a	1	0	0.1	0	0.1	0	0	0
7a	0.1	0	0.1	0.1	0.1	0	0	0
8a	2	0.1	0	0.1	0.1	0	0	0
12a	1	0	0.1	0	0	0	0	0
13a	2	0.1	0	0.1	0.1	0	0	0
15a	2	0	0.1	0	0.1	0	0	0
17a	0.1	0.1	0	0	0.1	0	0	0
19a	1	0	0.1	0	0	0	0	0
23a	0.1	0	0.1	0	0.1	0	0	0
24a	2	0	0.1	0	0	0	0	0
31b	2	0	0.1	0	0.1	0	1	0
33b	2	0	0.1	0	0	0	0	0
35b	2	0.1	0.1	0	0.1	0	0	0
43b	0.1	0.1	0	0	0	0	0	0
50b	2	0.1	0.1	0	0	0	0	0
52b	1	0	0	0	0.1	0	0	0
6a	0	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 2

sample	fiber	glochids	spine	opuntia epidermis	mixed epidermis	allium	tissue	spine other
1a	6	0.1	0	0	2	0.1	0	0
3a	7	0.1	0	0	1	0	0	0
4a	6	1	1	0	0	0	0	0
9a	6	0.1	0	0	0	1	0	0
10a	6	0.1	0	0	2	1	0	0
11a	7	0.1	0	0	1	1	0	0
16a	7	1	0.1	1	0	1	0	0
20a	8	0.1	0	0	2	0	0	0
21a	7	0.1	0	0	2	1	0	0
22a	7	0.1	0	0	2	0.1	0	0
26a	7	0.1	0	0	0	0	0	0
27b	7	0	0	0	1	0	0	0.1
29b	7	0	0	0	0	0	0	0
30b	8	0	0.1	1	0	0.1	0	0
32b	7	0	0	0	0	0	0	0.1
34b	7	0.1	0.1	0	0.1	0	0	0
37b	8	0.1	0	0	1	0	0	0
38b	8	0	0	0	0	0	0	0
39b	8	0	0	0	0	0	0	0
40b	7	0	0	0	2	0	0	0
41b	8	0	0.1	0	0	0	0	0
42b	7	0.1	0	0	1	2	0	0.1
44b	7	0.1	0	0	1	1	0	0
46b	7	0.1	0.1	0	0	2	0	0
49b	7	0	0	0	2	0.1	0	0
51b	8	0.1	0	1	0	0	0	0
2a	6	0.1	0	0	1	1	0	0
5a	6	1	0	0	1	2	0	0
7a	4	0.1	0.1	0	1	0.1	0	0.1
8a	6	0.1	0	0	2	1	0	0
12a	4	0.1	0	0	0	0	0	0
13a	6	0	0	0	0.1	0.1	0	0
15a	6	0.1	0.1	0	0	0	0	0
17a	5	0.1	0	0	2	1	0	0
19a	7	1	0	0	1	0	0	0
23a	4	0.1	0	0	2	1	0	0
24a	5	0.1	0	0	1	0	0	0
31b	5	0.1	0	2	0	3	0	0
33b	6	0	0	2	0	2	0	0
35b	6	0.1	1	0	0	1	0	0.1
43b	4	0	0.1	0	2	0.1	0	0
50b	5	0.1	0	0	2	3	0	0
52b	6	0.1	0	0	1	2	0	0
6a	0	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 3

sample	**opuntia seed**	**opuntia seed broken**	**opuntia leptocaulis**	**echinocerus**	**coryphanthus**	**juglans**	**dasylirion seed**
1a	0	0	0	0	0.1	2	0
3a	0	1	0.1	0	0	0	0
4a	0	0.1	1	0	0	0	0
9a	0	0.1	0	0	0.1	0	0
10a	0	0	0	0	1	0	0
11a	0.1	0.1	0	0	0	0	0
16a	0	1	0	0	1	0	0
20a	0	1	0	0	0	0	0
21a	0	0.1	0	0	0.1	0	0
22a	0	0	0	0	0.1	0	0
26a	0	0.1	0	0	0	0	0
27b	0	0	0	0	0	0	0
29b	0.1	0	0	0	0	0	0
30b	0	0	0	0	0	0	0
32b	0	0	1	0	0	0	0
34b	0	0	1	0	0	0	0
37b	0	0	0	0	0	0	0
38b	0	0	0	0	0	0	0
39b	1	0.1	0.1	0	0	0	0
40b	0	0	0	0	0	0	0
41b	0	0	1	0	0	0	0
42b	0	0	0	0	0.1	0	0
44b	0	1	0.1	0	0.1	0	0
46b	0	0	0	0	0	0	0
49b	0	0	2	0	0	0	0
51b	0	0	0	0	0	0	0
2a	0.1	3	0	0	0	0	0
5a	0	2	0	0	0	1	0
7a	2	4	0	0	0	0	0
8a	1	2	0	0	0	0	0
12a	1	4	1	0	0.1	1	0
13a	0.1	2	0	0	0	0	0
15a	1	2	0	0	0.1	0	0
17a	1	1	0.1	0.1	0	0.1	0
19a	1	2	0	0	0	0	0
23a	1	3	2	0	0	0	0
24a	2	3	0	0	0	0	0
31b	0.1	1	1	0	0	0	0
33b	0	0	0	0	0	0	0
35b	1	2	0	0	1	0	0
43b	2	4	0	0	0	0	0
50b	0	0.1	0	0	0	0	0
52b	0	1	0	0	0	0	0
6a	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 4

sample	yucca seed	diospyros	celtis	prosopis	carex	chenopod	paniceae	sporobolus
1a	0	0	0	0	0	0	0	0
3a	0	1	0	0	0	0	0	0
4a	0	1	0	0	0	0	0	0
9a	0	1	0	0	0	0	0	0.1
10a	0	1	0	0	0	0	0	0
11a	0	0	0	0	0	0	0	0
16a	0	0	0	0	0	0	0	0
20a	0	0	0	0	0	0.1	0	1
21a	0	0	0	0	0	0	0	0
22a	0	0	0	0	0	0	0	0
26a	0	0	0	0	0	0	0	0
27b	0	0	0	0	0	0	0	0
29b	0	0	0	0	0	0	0	0
30b	0	0	0	0	0	0	0	0
32b	0	0	0	0	0	0	0	0
34b	0	0	0	0	0	0	0	0
37b	0	0	0	0	0	0	0	0
38b	0	0	0	0	0	0	0	0
39b	0	0	0	0	0	0	0	0
40b	0	0	0	0	0	0	0	0
41b	0	0	0	0	0	0	0	0
42b	0	0	0	0	0	0	0	0
44b	0	0	0	0	0	0	0	0
46b	0	0	0	0	0	0	0	0
49b	0	0	0	0	0	0	0	0
51b	0	0	0	0	0	0	0	0
2a	0	0	0	0	0	0	0	0.1
5a	0	0	0	0	0	0	0	0.1
7a	0	0	0	0	0	0	0	0.1
8a	0	1	0	0	0	0	0	0
12a	0	1	0	0.1	0	0	0.1	0.1
13a	0	1	0	0	0	0	0	0
15a	0	0	0	0	0	0	0	0.1
17a	0	0	0	0	0	0	1	0.1
19a	0	0	0	0	0	0	0	1
23a	0	0	0	0	0	0	0	0
24a	0	0	0	0	0	0	0	0
31b	0	0.1	0	0	0	0	0	0.1
33b	0	0	0	0	0	0	0	0
35b	0	0	0	0	0	0	0	0
43b	0	0.1	0	0	0	0	0.1	0
50b	0	0.1	0	0	0	0	0	0.1
52b	0	0	0	0	0	0	0	0.1
6a	0	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 5

sample	poaceae	cenchrus	vitis	achene	solanaceae	monocot	unidentified d	unidentified e
1a	0	0	0	0	0	0	0	0
3a	0	0	0	0	0	0	0	0
4a	0	0	0	0	0	0	0	0
9a	0	0	0	0	0	0	0	0
10a	0	0	0	0	0	0	0	0
11a	0	0	0	0	0	0	0	0
16a	0	1	0	0	0	0	0	0
20a	0.1	0	0	0	0	0	0	0
21a	0	0	0	0	0	0	0	0
22a	0	0	0	0	0	0	0	0
26a	0	0	0	0	0	0	0	0
27b	0	0	0	0	0	0	0	0
29b	0	0	0	0	0	0	0	0
30b	0	0	0	0	0	0	0	0
32b	0	0	0	0	0	0	0	0
34b	0	0	0	0	0	0	0	0
37b	0	0	0	0	0	0	0	0
38b	0	0	0	0	0	0	0	0
39b	0	0	0	0	0	0	0	0
40b	0	0	0	0	0	0	0	0
41b	0	0	0	0	0	0	0	0
42b	0	0	0	0	0	0	0	0
44b	0	0	0	0	0	0	0.1	0
46b	0	0	0	0	0	0	0	0
49b	0	0	0	0	0	0	0	0
51b	0	0	0	0	0	0	0	0
2a	0	0	0	0	0	0	0	0
5a	0	0	0	0	0	0	0	0
7a	0.1	0	0	0	0	0	0	0
8a	0.1	0	0	0	0	0	0	0
12a	0.1	0	0	0	0	0	0.1	0.1
13a	0	0	0	0	0	0	0	0
15a	0	0	0	0	0	0	0	0
17a	0.1	0	0	0	0	0	0	0
19a	0.1	0	0	0	0	0	0	0
23a	0	0	0	0	0	0	0	0
24a	0	0	0	0	0	0	0	0
31b	0.1	0	0	0	0	0	0	0
33b	0.1	0	0	0	0	0	0	0
35b	0.1	0	0	0	0	0	0	0
43b	0	0	0	0	0	0	0	0
50b	0	0	0	0	0	0	0	0
52b	0	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 6

sample	unidentified f	unidentified g	unidentified h	unidentified i	Brassicaceae	epidermis noto	anobidae
1a	0	0	0	0	0	0	0.1
3a	0	0	0	0	0	0	0
4a	0	0	0	0	0	1	0
9a	0	0	0	0	0	2	0
10a	0	0	0	0	0	0	0
11a	0	0	0	0	0	0	0
16a	0	0	0	0	0	0	0
20a	0	0	0	0	0	0	0
21a	0	0	0	0	0	0	0.1
22a	0	0	0	0	0	0	0
26a	0	0	0	0	0	0	0
27b	0	0	0	0	0	0	0
29b	0	0	0	0	0	0	0
30b	0	0	0	0	0	0	0
32b	0	0	0	0	0	0	0
34b	0	0	0	0	0	0	0
37b	0	0	0	0	0	0	0
38b	0	0	0	0	0	0	0
39b	0.1	0	0	0.1	0	0	0
40b	0	0	0	0	0	0	0
41b	0	0	0	0	0	0	0
42b	0	0	0	0	0	0	0
44b	0	0	0	0	0	0	0
46b	0	0	0	0	0	0	0
49b	0	0	0	0	0	0	0
51b	0	0	0	0	0	0	0
2a	0	0	0	0	0	0	0
5a	0	0	0	0	0	0	0
7a	0	0	0	0	0	0	0
8a	0	0	0	0	0	0	0
12a	0	0	0	0	0	0	0
13a	0	0	0.1	0	0	0	0
15a	0	0	0	0	0	0	0
17a	0	0	0	0	0	0	0
19a	0	0	0	0	0	0	0
23a	0	0	0	0	0	0	0
24a	0	0	0	0	0	0	0
31b	0	0	0	0	0	1	0
33b	0	0	0	0	0	0.1	0
35b	0	0	0	0	0	0	0
43b	0	0	0	0	0	1	0
50b	0	0	0	0	0	0	0
52b	0	0	0	0	0	0	0
6a	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 7

sample	crystals	bark	charcoal	leaf dicot	resin	snail	mussel
1a	1	0	1	0	0	0	0
3a	0	0	1	0	0	0	0
4a	0	0	1	0	0	0	0
9a	0	0	1	0	0	0	0
10a	1	1	1	0	0	2	0
11a	1	0	1	0	0	0	0
16a	0	0	1	0	0	0	0
20a	0	0	1	0	0	0	0.1
21a	0	0	1	0	0	0	0
22a	0	0	1	0	0	0	0
26a	0	0	0.1	0.1	0.1	0	0
27b	0	0	1	0	0	0	0
29b	0	0	0.1	0	0	0	0
30b	1	0	0.1	0	0	0	0
32b	0.1	0	0.1	0	0	0	0
34b	0	0	0.1	0	0	0	0
37b	0.1	0	0.1	0	0.1	0	0
38b	0.1	0	1	0	0	0	0
39b	0	0	0.1	0.1	0	0	0
40b	0	0	1	0	0.1	0	0
41b	1	0	1	0	0	0	0
42b	0	0	0.1	0	0.1	0	0
44b	0	0	1	0	0	0	0
46b	0	0	0.1	0	0	0	0
49b	0	0	0.1	0.1	0	0	0
51b	0	0	0.1	0	0	0	0
2a	0	0	1	0	0	0	0
5a	0	0	1	0	0	0	0
7a	0	0	1	0	0	0	0
8a	0	0	1	0	0.1	0	0
12a	0	0	1	0	0	0	0
13a	0	0	1	0	0	0	0
15a	0	0	0.1	0	0	0	0
17a	0	0	2	0	0	0	0
19a	0	0	1	0	0	0	0
23a	0	0	1	0	0	0	0
24a	0	0	1	0	0	0	0
31b	0	0	1	0	0	0	0
33b	0	0	0.1	0	0	0	0
35b	0	0	1	0	0	0	0
43b	0	0	0.1	0	0	0	0
50b	0	0	0.1	0	0	0	0
52b	1	0	0.1	0	0	0	0
6a	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 8

sample	parasite	helminth	diptera	ptinidae	insect	inorganic	flakes
1a	0	0	0	0	0	0.1	0
3a	0	0	0	0.1	0	0.1	0
4a	1	0	0	0.1	0	0.1	0
9a	0	0	0	0	0	0.1	0
10a	0	0	0	0.1	0	0.1	0
11a	0	0	0	0.1	0	0.1	0
16a	0	0	0	1	0	0.1	0
20a	0	0	0	1	0	0.1	0.1
21a	0	0	0	0	0	1	0
22a	0	0	0	0.1	0	0.1	0
26a	0	0	0	0	0	0.1	0
27b	0	0	0	0	0	1	0
29b	0	0	0	0	0	0.1	0
30b	0	0	0	0	0	0.1	0
32b	0	0	0	0	0	0.1	0
34b	0	0	0	0	0	0.1	0
37b	0	0	0	0.1	0	0.1	0
38b	0	0	0	0	0	0.1	0
39b	0	0	0	0	0.1	0.1	0
40b	0	0	0	0	0	1	0
41b	0	0	0	0.1	0	1	0
42b	0	0	0	0.1	0	0.1	0
44b	0	0	0	0	0	0.1	0
46b	0	0	0	0	0	0.1	0
49b	0	0	0	0	0.1	0.1	0
51b	0	0	0	0	0	0.1	0
2a	0	0	0	0.1	0	0.1	0
5a	1	0	0	0	0	0.1	0.1
7a	0	0	0	0.1	0	0.1	0
8a	0	0	0	0.1	0	1	0.1
12a	0	0	0	0	0.1	0.1	0
13a	0	0	0	0.1	0	0.1	0.1
15a	0	0	0	0.1	0.1	0.1	0
17a	0	0	0	0	0.1	2	1
19a	0	0	0	0	0	1	0
23a	0	0	0	0	0.1	1	0
24a	0	0	0	0.1	0	1	0
31b	0	0	0	0.1	0	0.1	0
33b	0	0	0	0	0	2	0.1
35b	0	0	0	0.1	0	0.1	0
43b	0	0	0	0.1	0	0.1	0
50b	0	0	0	0	0	0.1	0
52b	0	0	0	0	0	0.1	0
6a	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 9

sample	bone	bone burned	hair rodent	feather	hair	fur	scale	skin
18a	2	0.1	0.1	0.1	0	0	0	0
25a	1	0	1	0	0.1	0	0	0
14a	1	0.1	0	0	0.1	0	0	0
28b	0.1	0.1	0.1	0	0	0	0.1	0
36b	0.1	0	0	0	0	0	0	0
45b	0	0	0.1	0	0	0	0	0
47b	2	0	0.1	0	0	0	0	0
48b	0	0	0	0	0.1	0	0	0
53b	0.1	0	0	0	0	0	0	0
54b	0.1	0	0	0	0.1	0	0	0
55b	0.1	0	0.1	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 10

sample	fiber	glochids	spine	opuntia epidermis	mixed epidermis	allium	tissue
18a	3	0.1	0	0	0	0	0
25a	3	0.1	0	0	2	0	0
14a	7	0.1	0	2	2	1	0
28b	7	0.1	1	2	0	0	0
36b	5	0.1	1	4	0	2	0
45b	4	0.1	0.1	4	0	0	0
47b	7	0	0	2	0	0	0
48b	7	0	0	3	0	0	0
53b	7	0.1	0	2	0	0.1	0
54b	7	0	0	2	0	1	0
55b	7	0.1	0	2	0	1	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 11

sample	spine other	opuntia seed	opuntia seed broken	opuntia leptocaulis	echinocerus	coryphanthus	juglans
18a	0	0	0.1	0	0	0.1	0
25a	0	0	0.1	0	0	0	0
14a	0	0	0.1	0	0	0	0
28b	0	0	0	1	0	0	0
36b	0	0	0.1	0	0	0	0
45b	0	0	2	0	0	0	0
47b	0	0	0	0	0	0	0
48b	0	0	0	0.1	0	0	0
53b	0	0	0	1	0	0	0
54b	0.1	0	0	1	0	0.1	0
55b	0	0	0.1	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 12

sample	dasylirion seed	yucca seed	diospyros	celtis	prosopis	carex	chenopod	paniceae
18a	0	0	0	0	0	0	0	0
25a	0	0	0	0	0	0	0	0
14a	0	0	0.1	0	0	0	0	0
28b	0	0	0	0	0	0	0	0
36b	0	0	0	0	0	0	0	0
45b	0	0	0	0	0	0	0	0
47b	0	0	0	0	0	0	0	0
48b	0	0	0	0	0	0	0	0
53b	0	0	0	0	0	0	0	0
54b	0	0	0	0	0	0	0	0
55b	0	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 13

sample	sporobolus	poaceae	cenchrus	vitis	achene	solanaceae	monocot	unidentified d
18a	0.1	0	0	0	0	0	0	0
25a	0	0	0	0	0	0	0	0
14a	0	0	0	0	0	0	0	0
28b	0	0	0	0	0	0	0	0
36b	0	0	0	0	0	0	0	0
45b	0	0	0	0	0	0	0	0
47b	0	0	0	0	0	0	0	0
48b	0	0	0	0	0	0	0	0
53b	0	0	0	0	0	0	0	0
54b	0	0	0	0	0	0	0	0
55b	0	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 14

sample	unidentified e	unidentified f	unidentified g	unidentified h	unidentified i	Brassicaceae
18a	0	0	0.1	0	0	0
25a	0	0	0	0	0	0
14a	0	0	0	0	0	0
28b	0	0	0	0	0	0
36b	0	0	0	0	0	0
45b	0	0	0	0	0	0
47b	0	0	0	0	0	0
48b	0	0	0	0	0	0
53b	0	0	0	0	0	0
54b	0	0	0	0	0	0
55b	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 15

sample	epidermis noto	anobidae	crystals	bark	charcoal	leaf dicot	resin
18a	0	0	0	0	2	0	0
25a	0	0	0	0	1	0	0
14a	0	0	0	0	1	0	0
28b	0	0	0	0	0.1	0	0
36b	0	0	0	0	1	0	0.1
45b	0	0	0	0	0.1	0	0
47b	0	0	0	0	0.1	0	0
48b	0	0	0	0	0.1	0	0
53b	0	0	0	0	0.1	0	0
54b	0	0	0	0	0.1	0	0
55b	0	0	0	0	0.1	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 16

sample	snail	mussel	parasite	helminth	diptera	ptinidae
18a	0	0	0	0	0	0
25a	0	0	0	0	0	0
14a	0	0	0	0	0	0.1
28b	0	0	0	0	0	0
36b	0	0	0	0	0	0
45b	0	0	0	0	0	0
47b	0	0	0	0	0	0
48b	0	0	0	0	0	0
53b	0	0	0	0	0	0
54b	0	0	0	0	0	0
55b	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Stock (1983) – Part 17

sample	insect	inorganic	flakes
18a	0.1	4	0.1
25a	0	0.1	0
14a	0	0	0
28b	0	0.1	0
36b	0	0	0
45b	0.1	0.1	0
47b	0.1	0	0
48b	0	0	0
53b	0	0.1	0
54b	0	0.1	0
55b	0	0.1	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 1

Sample	**Bone**	**Fur**	**Opuntia big**	**Opuntia little**	**Opuntia leptocaulis**	**Opuntia broken**	**Juglans**	**Diospyros**
2	1	1	0	0	0	0	0	0
3	3	0	0	0	0	0	0	0
4	1	1	0	0	0	0	0	0
5	2	1	0	2	2	2	0	0
6	2	1	0	0	0	0	0	0
7	0.1	0	0	0.1	0.1	3	0	0
8	0.1	1	0	0	0	0.1	0	0.1
9	2	1	0	0	0	0.1	0	0
10	0.1	1	1	1	0	2	1	0.1
11	2	1	0	0	0	0.1	0	0
12	2	1	0	0	0.1	0.1	0.1	0
13	2	1	0.1	0.1	0	2	0	0
14	0.1	0	0	0	0.1	1	0	0
15	2	1	0	0.1	0	1	0.1	0
16	2	0	0	0	0	0.1	0	0.1
17	2	0	0	0	0.1	0.1	0	0
18	2	0	0	0	0	0.1	0	0
19	3	1	0	0	3	0.1	0	0
20	2	1	0	0	2	0	0	0.1
21	2	1	0	0	0.1	0	2	0
22	0.1	1	0	0.1	0	0.1	0	0
23	2	1	0	2	0	3	0	0
24	2	1	0	0	0.1	0.1	0	0
25	0	0	0	0	0	0.1	0	0
26	0.1	0	1	1	0	2	0	0
27	2	1	0	0.1	0.1	0.1	0	0
28	2	1	0	0.1	0.1	0.1	0	0
29	0.1	0	0	0	0	0.1	0	0
30	2	0	0	0	0	0	0	0
31	0.1	1	0	0.1	1	1	0	0
32	2	1	0	0	0	0.1	2	0
33	1	1	0	0	0	0	0	0
34	0.1	1	0.1	0.1	0	3	0	0
35	1	1	2	2	0	2	0	0
36	0.1	0	0	0	0	0.1	2	0.1
37	3	1	0	0	2	0.1	0	0.1
38	1	1	0	0.1	0.1	1	0	0
39	0.1	1	0	0	2	0.1	0	0
40	1	1	0	0	1	0	0	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 2

Sample	Celtis	Carex	Chenopodium	Amaranth	Cenchrus	Panicum	Poaceae
2	1	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0.1	0
11	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0.1
24	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0
40	0	0.1	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 3

Sample	Achene	Vitis	Dasylirion seed	Sporobolus	Yucca	Prosopis
2	0	0	0	0	0	0
3	0	0	0	0.1	0	0
4	0	0	0	0.1	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0.1
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0.1	0	0
11	0	0	0	0	0	0
12	0	0	0	0.1	0	0.1
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0.1	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0.1	0	0
20	0	0	0	0.1	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0.1	0	0
25	0	0	0	0.1	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0.1	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	0	0	0	0	0	0
33	0	0	0	0	0	0
34	0	0	0	0.1	0	0
35	0	0	0	0	0	0
36	0	0	0	0.1	0	0
37	0	0	0	0	0	0
38	0	0	0	0	0	0
39	0	0	0	0.1	0	0
40	0	0	0	0.1	0	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 4

Sample	Tissue	Allium	Fiber	Opuntia epidermis	Agave epidermis	Dasylirion epidermis
2	1	0	6	3	0	0
3	1	0	7	0	0	0
4	1	0.1	8	0	0.1	0
5	1	1	6	0.1	0.1	0
6	1	0	7	0	0	0
7	1	1	6	1	1	0
8	1	2	6	3	0.1	0.1
9	0	0	6	3	0.1	0
10	1	0.1	6	1	0.1	0
11	0	0.1	7	2	0	0
12	1	1	7	0	0.1	0
13	1	2	7	2	0.1	0
14	1	1	7	2	1	0
15	1	0	7	1	0.1	0
16	1	0	7	0	0.1	0
17	1	0	7	2	0	0
18	1	0	7	0.1	0	0
19	1	0	5	0	0	0
20	0	0	7	0	0	0
21	0	0	6	0.1	0	0
22	0	0	8	0.1	0.1	0
23	0	0	5	0	0	0
24	1	0.1	7	0.1	0.1	0.1
25	0	0	6	3	0	0
26	1	0	7	0	0.1	0
27	0	0	7	2	0	0
28	1	0	7	0	0	0.1
29	1	0	5	5	0	0
30	0	0	7	0	0	0
31	1	0	7	1	1	0
32	1	0	7	0.1	0	0
33	1	0	8	0	0	0
34	0	0	6	2	0	0
35	0	0	5	3	0	0
36	1	0	7	0.1	0.1	0
37	0	0	6	0	0	0
38	0	0.1	5	4	0.1	0
39	0	2	6	2	0	0
40	1	1	8	0	0.1	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 5

Sample	Bone	Fur	Opuntia big	Opuntia little	Opuntia leptocaulis	Opuntia broken	Juglans	Diospyros
41	3	1	0	0.1	0	2	0	0
42	0	0	0	0	0	0	0	0
43	1	1	0	0	0	0.1	3	0
44	2	1	0.1	0.1	0	1	0	0
45	2	1	0	0	0	0.1	0	0
46	2	1	0.1	1	0	2	0	0
47	0.1	1	0	0	0.1	0.1	0	0
48	0.1	1	0	0	0.1	0	0	0
49	0	0	0	0	0	0.1	0	0
50	0.1	1	0	0	0.1	0.1	0.1	0
51	0.1	0	0	0.1	0	0	0	0
52	1	1	0	0	0.1	0	0	0
53	2	1	0.1	2	0	7	0	0
54	7	1	0	0	0	0	0.1	0
55	0.1	1	0	0	2	0	0	0
56	2	1	0	0	0	0.1	0	0
57	2	1	0	0	0	0.1	0	0
58	3	1	0.1	1	0.1	1	0	0.1
59	3	0	0	0	0	0	0	0
60	0.1	1	0	0	1	0	0	2
61	3	1	0	0	0	0	0	0
62	0.1	1	0	0.1	0.1	0.1	0	0
63	2	1	0	0.1	0	0	1	0
64	2	1	0	0.1	0	0.1	0	0
65	2	1	0	0.1	0	1	0	0
66	2	1	0	0	0	0.1	0	0
67	0.1	1	0	2	0.1	2	0	0
68	1	1	0	0.1	1	1	2	0
69	1	1	0	1	1	1	0	0
70	1	1	0	1	0.1	2	0.1	0
71	0.1	0	0	0	0	0.1	0	0
72	2	1	0	0	0	0	0	0
73	0.1	0	0	0.1	0	2	0	0
74	2	1	0	0	0.1	0.1	0	0
75	1	1	0.1	1	0.1	3	0.1	0
76	2	1	0	1	0	6	1	2
77	2	1	0	0.1	0.1	0.1	0.1	0
78	1	1	0	0.1	0	1	0	1
79	0.1	0	0	0	0.1	0	1	0
80	0.1	1	0	0.1	0.1	0.1	0	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 6

Sample	Celtis	Carex	Chenopodium	Amaranth	Cenchrus	Panicum	Poaceae
41	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0
44	0	1	0	0.1	1	0	0
45	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0
47	0.1	0	0	0	0	0	0
48	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0
50	0	0	0.1	0	0	0	0
51	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0
53	0.1	0	0	0	0	0	0
54	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0
60	0	0	0.1	0	0	0	0
61	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0
64	0	0.1	0	0	0	0	0
65	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0.1
67	0	2	0	0	1	0	0
68	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0
71	0	0.1	0	0	0	0.1	0
72	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0
75	0	0	0	0	0	0.1	0
76	0	0	0	0	0	0.1	0
77	0	0	0	0	0	0	0
78	0	0	0	0	0	0	0
79	0.1	0	0	0	0	0	0
80	0	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 7

Sample	Achene	Vitis	Dasylirion seed	Sporobolus	Yucca	Prosopis
41	0	0	0	0.1	0	0.1
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0.1	0	0
45	0	0	0	0	0	0
46	0	0	0	0	0	0
47	0	0	0	0.1	0	0
48	0	0	0	0	0	0
49	0	0	0	0	0	0
50	0	0	0	0.1	0	0
51	0	0	0	0	0.1	0
52	0	0	0	0.1	0	0
53	0	0.1	0	0.1	0	0.1
54	0	0	0	0	0	0
55	0	0	0	0	0	0
56	0	0	0	0.1	0	0
57	0	0	0	0.1	0	0
58	0	0	0	0.1	0	0
59	0	0	0	0.1	0	0
60	0	0	0	0.1	0	0
61	0	0	0	0	0	0
62	0.1	0	0	0	0	0
63	0	0	0	0	0	0
64	0	0	0	0	0	0
65	0	0	0	0	0	0
66	0	0	0	0.1	0	0
67	0	0	0	0.1	0	0
68	0	0	0	0.1	0	0
69	0	0	0	0	0	0
70	0	0	0	0	0	0.1
71	0	0	0	0.1	0	0
72	0	0	0	0	0	0
73	0	0	0	0	0	0
74	0	0	0	0	0	0
75	0	0	0	0.1	0	0.1
76	0	0	0	0.1	0	0.1
77	0	0	0	0	0	0
78	0	0	0	0	0	0
79	0	0	0	0.1	0	0
80	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 8

Sample	Tissue	Allium	Fiber	Opuntia epidermis	Agave epidermis	Dasylirion epidermis
41	1	0	6	0	0	0
42	0	0	7	2	0.1	0
43	1	1	6	0.1	1	0
44	1	0	7	0.1	0	0
45	1	2	7	0.1	0.1	0
46	1	0	5	3	0.1	0
47	1	0	8	0.1	0.1	0
48	0	0.1	7	2	0.1	0.1
49	1	0	7	2	0	0
50	1	2	6	2	0	0
51	1	0	7	3	0.1	0
52	0	0	8	0	0	0
53	0	0	2	0	0.1	0.1
54	0	0	3	0.1	0.1	0
55	1	0	8	0	0	0
56	1	1	7	2	0.1	0
57	1	0.1	5	4	0.1	0
58	1	0	5	0	0	0
59	0	0	6	2	0	0
60	1	0.1	7	1	0.1	0
61	0	0	6	2	0	0
62	0	1	5	4	0.1	0
63	0	0	7	0	0	0.1
64	1	0	7	0	0	0
65	1	1	7	0.1	0	0
66	1	1	7	0	1	0
67	0	0	6	0	0.1	0
68	1	0.1	7	1	0.1	0
69	1	0	7	0.1	0.1	0
70	1	1	7	0.1	0.1	0
71	1	0	8	2	0.1	0
72	0	0	7	0	0	0
73	1	2	7	2	0.1	0
74	0	2	7	0.1	0.1	0
75	1	0.1	6	1	0.1	0
76	0	0	2	0.1	0.1	0
77	0	0.1	6	3	0	0
78	1	0.1	7	2	0	0.1
79	0	0	8	0	0	0
80	1	1	8	1	0	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 9

Sample	Bone	Fur	Opuntia big	Opuntia little	Opuntia leptocaulis	Opuntia broken	Juglans	Diospyros
81	1	1	0	1	0	2	0	0.1
82	1	1	0.1	0.1	0	0.1	0.1	0
83	0.1	0	0.1	0	0.1	0	0.1	0
84	1	1	0.1	0.1	0.1	1	0	0
85	2	1	1	2	1	2	0	0
86	0.1	1	0	0	2	0.1	0	0
87	2	1	0	0	0	0.1	0.1	0
88	2	1	0.1	0.1	0	2	0	0
89	0.1	1	0.1	0	3	0	0	0
90	3	1	0	1	0.1	3	0.1	0
91	2	1	0	1	1	0.1	0	0
92	1	1	0	0	2	0	2	0
93	2	1	0	1	0.1	0.1	1	0
94	0.1	1	0	0	0.1	0.1	0.1	0.1
95	2	1	0	0.1	0	1	0	0
96	2	1	0.1	0	2	0	0	0
97	2	1	0	0.1	0	3	0	0
98	0.1	0	0	0	0	0.1	0	0
99	2	1	0.1	0.1	0.1	2	0	0
100	0.1	0	0	0	0	0	0	0.1
102	1	1	0.1	0.1	2	0.1	0	2

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 10

Sample	Celtis	Carex	Chenopodium	Amaranth	Cenchrus	Panicum	Poaceae
81	0	0	0	0	0	0	0
82	0	0	0	0	0	0.1	0
83	0	0	0	0	0	0	0
84	0	1	0	0	0	0	0
85	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0
88	0	1	0	0	0	0	0
89	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0
97	0	0	0	0	0	0.1	0
98	0	0.1	0.1	0	0	0	0
99	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0
102	0	0	0	0	0	0.1	0

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 11

Sample	Achene	Vitis	Dasylirion seed	Sporobolus	Yucca	Prosopis
81	0	0	0	0	0	0.1
82	0	0.1	0	0.1	0	0.1
83	0	0	0	0.1	0	0
84	0	0	0	0.1	0	0
85	0	0	0	0	0	0
86	0	0	0	0	0	0
87	0	0	0	0	0	0.1
88	0	0	0	0	0	0
89	0	0	0	0	0	0
90	0	0	0	0.1	0	0
91	0	0	0	0.1	0	0
92	0	0	0	0.1	0	0
93	0	0	0.1	0	0	0.1
94	0	0	0	0	0	0
95	0	0	0	0.1	0	0
96	0	0	0	0	0	0
97	0	0	0	0.1	0	0
98	0	0	0	0.1	0	0
99	0	0	0	0	0	0.1
100	0	0	0	0	0	0
102	0	0	0.1	0.1	0	0.1

Macrofossil Data of Coprolite Specimens from Williams-Dean (1978) – Part 12

Sample	Tissue	Allium	Fiber	Opuntia epidermis	Agave epidermis	Dasylirion epidermis
81	1	0	7	1	0	0.1
82	0	0	8	0	0.1	0
83	0	0	8	1	0	0
84	1	0	7	1	1	0
85	0	0	5	0.1	0.1	0
86	0	0.1	7	0.1	0	0
87	0	2	7	1	1	0
88	1	0.1	7	1	0.1	0
89	1	0.1	5	2	0	0
90	0	0	5	0	0	0
91	0	2	7	2	0	0
92	0	0	7	0.1	0	0
93	1	1	7	0	1	0
94	1	0.1	7	3	0.1	0
95	1	0	7	0.1	0	0
96	0	0	7	0.1	0.1	0
97	0	0	6	0.1	0.1	0
98	1	2	7	0.1	0	0
99	0	0	7	0	0.1	0
100	1	0	8	0	0	0
102	1	0.1	6	2	0.1	0

APPENDIX B

COPROLITE DATA FROM OTHER SITES

Macrofossil Data of Coprolite Specimens from Conejo Shelter (Bryant 1974) – Part 1

Sample	Opuntia Fiber	Opuntia Seeds	Allium Bulbs	Chenopodium Seed	Setaria Seed	Bark	Grasshoppers
16	5	0	0	0	0	0	0
20	3	3	0	0	0	0	0
15	4	0	2	0	1	4	0
4	5	2	1	0	0	0	0
34	5	0	2	0	0	0	0
5	3	0	1	0	1	0	0
38	5	1	2	0	0	0	0
36	2	1	5	0	0	0	0
31	5	2	0	0	0	0	0
44	4	0	2	0	0	0	0
25	4	0	2	1	0	0	0
41	3	0	2	0	0	3	2
9	3	2	0	3	0	0	2
18	4	3	0	0	0	0	0
23	3	0	3	0	0	0	0
26	2	0	5	0	0	0	0
17	5	0	2	0	0	0	0
27	3	0	4	0	0	0	0
11	4	2	0	0	0	0	3
40	5	0	2	0	0	0	0
6	4	2	2	0	0	2	0
28	5	0	2	0	0	0	0
39	5	0	1	0	0	0	0
30	3	0	0	0	0	0	0
3	3	2	2	0	0	0	0
32	4	0	3	0	0	0	0
37	2	0	0	0	0	0	0
42	6	0	1	0	0	0	0
8	4	3	2	0	0	0	0
22	5	2	0	0	0	0	0
29	6	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Conejo Shelter (Bryant 1974) – Part 2

Sample	Mammal Bones	Reptile Bones	Fish Bones	Anthers	Grubs	Aquatic Monocot Fiber	Agave, Sotol, Yucca Fiber	Unk. Fiber
16	0	0	1	0	0	0	2	0
20	0	0	0	0	0	0	0	3
15	0	1	0	0	0	0	1	0
4	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	1	0
38	0	0	0	0	0	0	2	0
36	1	0	0	0	0	0	1	0
31	0	0	0	0	0	0	0	0
44	0	0	1	0	2	0	0	0
25	1	0	0	0	0	0	1	0
41	1	0	0	0	0	0	2	0
9	0	0	0	0	0	0	0	0
18	1	0	0	0	0	0	2	0
23	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	1	0
17	1	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
11	0	1	0	0	0	0	1	0
40	1	0	0	0	0	0	1	0
6	0	1	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
39	0	1	0	2	0	0	0	2
30	0	0	1	0	0	0	4	0
3	0	0	0	0	0	0	3	0
32	1	0	1	0	0	0	0	0
37	0	0	0	0	0	0	0	5
42	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	1	0

Macrofossil Data of Coprolite Specimens from Conejo Shelter (Bryant 1974) – Part 3

Sample	Opuntia Fiber	Opuntia Seeds	Allium Bulbs	Chenopodium Seed	Setaria Seed	Bark	Grasshoppers
19	3	2	1	0	0	0	0
21	5	2	2	0	0	0	0
43	4	0	0	0	0	0	0
13	0	0	0	0	0	0	0
10	0	0	0	0	0	3	0
24	3	2	0	0	0	0	0
14	4	3	0	0	0	0	0
7	4	3	0	0	0	0	0
33	2	0	0	0	0	0	0
2	4	0	0	0	0	0	0
12	0	0	0	0	0	0	2
35	2	0	1	0	0	0	0

Macrofossil Data of Coprolite Specimens from Conejo Shelter (Bryant 1974) – Part 4

Sample	Mammal Bones	Reptile Bones	Fish Bones	Anthers	Grubs	Aquatic Monocot Fiber	Agave, Sotol, Yucca Fiber	Unk. Fiber
19	1	0	0	0	0	0	3	0
21	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	2	0
13	0	0	0	0	0	0	0	6
10	0	0	0	0	0	0	0	4
24	0	0	0	0	0	3	2	0
14	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0
33	1	0	0	0	0	4	2	0
2	0	1	0	0	0	2	2	2
12	1	0	0	0	0	0	4	0
35	0	0	0	0	0	0	5	0

Macrofossil Data of Coprolite Specimens from Frightful Cave (Fry 1975) – Part 1

Sample Number	Ancistrocactus sp. seed	Allium sp. seed pod	Acacia sp. seed	Amaranthus sp. seed	Asclepius sp. seed	Bouteloua sp. seed	Celtis pallidus seed
1	0	0	0.8	0	0	0	0.95
2	0.03	0	0	0	0	0	0
3	0.33	2.1	0	0	0	0	3.37
4	0	0	0	0.15	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0
24	0	0	0	0	0.02	0	0
25	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0
31	0	0	0	0	0	0.07	0
34	0	0	0	0	0	0	0
35	0	0	0	0	40.86	0	21.22
38	0	0	0	0	0	0	0
40	0	0	0	0	0	0	1.17
41	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0.18
44	0	0	0	0.01	0	0	0
47	0	0	0	0.14	0	0	0
48	0	0	0	0.17	0	0	3.32

Macrofossil Data of Coprolite Specimens from Frightful Cave (Fry 1975) – Part 2

Sample Number	Chenopodiaceae seed	Cactaceae seed	Capsicum frutescens seed	Diospyros texana seed	Asteraceae seed	Helianthus sp. seed	Fabaceae seed
1	0	0	0	36.79	0	0	0
2	0.001	0.05	0	6.87	0	0	0
3	0	0	0	0	0.1	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0.92
13	0	0.03	0	0	0	0	0
14	0	0	0	0	0	0	0
15	0	0	0	0	0	0.14	0
21	0	0	0	0	0	0	0
24	0	0.02	0	0	0	0	3.09
25	0	0	0	0	0.35	0.07	0
27	0.02	0	0	0	8.95	4.27	0
28	0	0	0	0	0	0	0
29	0	0.06	0.3	0	0	0.52	0.7
30	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
34	0	0	0	33.92	0	0	0
35	0	0	0	0	0	0.11	0
38	0	0	0	0	0	0	0
40	0	0	0	0	0	0	9.08
41	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0
44	0	0	0	9.46	0	0	0
47	0	0	0	0	0	0	0
48	0	1.4	0	0	0.61	0.31	0

Macrofossil Data of Coprolite Specimens from Frightful Cave (Fry 1975) – Part 3

Sample Number	Opuntia imbricata seed	Opuntia lindheimeri seed	Opuntia sp. seed	Oryzopis sp. seed	Poaceae seed	Panicum sp. seed	Pistacia texana seed
1	0	35.18	0	0	0.03	0	2.54
2	0	47.24	0	0	0	0	4.38
3	0	1.3	0	0	0.04	0	0
4	0	56.8	0	0	0	0	0
5	0	0.36	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	23.9	0	0	0	0	0
8	0	0.26	0	0	0	0	0.07
9	0	0.14	0	0	0	0	0
10	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0.43
12	0	2.73	0	0	0	0	0
13	0	63.25	0	0	0	0	0
14	0	46.56	0	0	0	0	0
15	0	58.94	0	0	0	0	0
21	0	0.14	0	0	0	0	4.14
24	0	11.8	0	0	0	0.08	0
25	0	6.45	0	0.59	0	0	3.3
27	0.02	71.26	0	0	0	0	0
28	0	33.75	0	0	0	0	36.7
29	0.4	0	0	21.17	0.85	0	1.19
30	0	44.96	0	0	0	0	0
31	0	0	0	0	0	0	0
34	0	38.12	0	0	0	0	0
35	0	7.29	0	0	0	0	0
38	0	0	0	0	0	0	0
40	0	63.53	0	0	0	0	12.93
41	0.36	0	0	0	0	0	0
42	0	61.5	0.03	0	0	0	0.28
44	0.36	78.11	0	0	0	0	0
47	0	0	0	0	0.07	0	0
48	55.45	10.49	0	0	0	0	1.63

Macrofossil Data of Coprolite Specimens from Frightful Cave (Fry 1975) – Part 4

Sample Number	**Polygonum sp. seed**	**Prosopis juliflora seed**	**Rhus sp. seed**	**unknown seed**	**Rosaceae stem**	**Cactaceae epidermal**	**Cactaceae spines**
1	0	0	0	0.99	0	0.77	0
2	0	0	0	0.99	0	4.47	0
3	0	10.3	0	0	0	24.1	0.02
4	0	0.57	0	0.07	0	12.42	0.001
5	0	0	0	0	0	41.52	0
6	0	0	0	0.41	0	0	0.05
7	0	0	0	0.38	0	3.96	0.22
8	0	0	1.1	0.13	0	1.63	0.04
9	0	0	0	0	0.53	8.9	0
10	0	0	0	0	0	0	0
11	0	0	0	0	0	12.54	0
12	0	0	0	0.93	0	2.4	0.01
13	0	3.1	0	0	0	6.87	0
14	0	0	0	3.06	0	17.7	0
15	0	1.13	0	2.64	0	0	0
21	0	0	0	0	0	12.51	0.2
24	0	0	0	1.25	0	6.13	0
25	0	58.53	0	0.01	0	0	0
27	0	0	0	0	0	1.7	0.02
28	0	0	0	0	0	25.53	0
29	0	50.8	0	0.22	0	8.06	0.09
30	0	0	0	0.64	0	40.53	0
31	0	0	0	0	0	5.77	0.08
34	0	0	0	1.99	0	0.12	0
35	0	0	0	3.27	0	23.56	0
38	0	0	0	0	0	13.7	5.55
40	0	0	0	0.29	0	1.14	0
41	0	0	0	61.41	0	34.06	0.07
42	0	0	0	6.07	0	1.45	0
44	0	0	0	0.05	0	4.98	0
47	1.96	0	0	25.21	0	0.93	0.77
48	0	0	0	0.08	0	9.84	0.03

Macrofossil Data of Coprolite Specimens from Frightful Cave (Fry 1975) – Part 5

Sample Number	Cactaceae crystals	unknown crystals	unknown epidermal	unknown fiber	unknown stem	Charcoal	unknown hair
1	0	0	19.29	0.57	0.11	0.02	0.001
2	0	0	24.47	1.02	0.27	0.01	0.02
3	0	0	15.45	25.97	6.23	0.003	0.44
4	0.001	0	26.09	3.75	0.13	0.01	0.001
5	0.22	3.05	49.45	8.05	0	0.06	0.05
6	0	0	3.43	35.6	1.19	6.75	0.11
7	2.36	0.11	1	56.58	0	0.22	0.11
8	0	1.11	77.71	10.19	0.18	0.72	0.1
9	0.18	0	42.5	44.02	0.71	0.21	0.21
10	0	0	92.88	4.57	0.35	0.53	0.53
11	0	0	71.92	11.98	0.11	0.75	0.11
12	0.04	0	3.6	76.76	0.49	1	1.04
13	0	0	13.06	0.85	12.06	0.14	0.02
14	0.13	0	22.63	7.75	0.77	0.77	0.33
15	0	0	28.8	0.8	0.21	0	3.13
21	0	0	7.06	56.96	0	0.14	0.7
24	0	0	21.57	55.05	0.07	0.06	0.04
25	0	0	0.43	12.18	1.83	0.54	6.58
27	0	0	10.59	3.06	0	0.04	0.04
28	0.17	0	2.25	0.6	0.32	0	0.07
29	0	0	4.28	9.24	0.37	0.28	1
30	0	0	0	11.26	0.32	0.29	0.13
31	0	0	91.56	0.49	0.73	0.37	0.06
34	0	0	22.93	0.1	0	0	0.14
35	0	0	0.54	2.83	0	0.19	0.13
38	2.03	0	17.22	50.8	4.78	0.34	5.21
40	0	0	11.64	0.16	0	0.01	0.02
41	0.33	0	0.21	3.19	0.03	0.1	0.1
42	0	0	29.52	0.19	0	0	0.05
44	0	0	4.35	0.09	0	0.01	0.02
47	1.06	0	60.04	4.33	1.45	0.09	0.22
48	0	0	14.28	1.42	0.42	0.01	0.03

Macrofossil Data of Coprolite Specimens from Frightful Cave (Fry 1975) – Part 6

Sample Number	**human hair**	**Unidentified bone**	**Bird feather**	**Rodent bone**	**Lizard bone**	**Egg shell**
1	0	0	0	0	0	0
2	0	0	0	0	2.88	0
3	0	7.13	0	0	0	0
4	0	0.01	0	0	0	0
5	0	0	0	0	0	0
6	0	22.21	0	0	0	0
7	0	10.23	0	0	0	0
8	0	0.1	0	0	0	0
9	0	2.54	0	0	0	0
10	0	0	0	0	0	0.44
11	0	0	0	0	0	0
12	0	0.31	0	10.73	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	4.11	0	0	0	0
21	0	16.4	0.4	0	0	0
24	0	0	0	0	0	0
25	0	8.3	0.001	0	0	0
27	0	0	0	0	0	0
28	0	0.02	0	0	0	0
29	0.03	0	0.02	0	0	0
30	0	0.54	0	0	0	0
31	0	0.55	0	0	0	0
34	0	0	0	0	0	0
35	0	0	0	0	0	0
38	0	0	0	0	0	0
40	0	0	0	0	0	0
41	0	0	0	0	0	0
42	0	0.65	0	0	0	0
44	0	0	0	0	0	0
47	0	3.56	0	0	0	0
48	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Frightful Cave (Fry 1975) – Part 7

Sample Number	Reptile scales	plant resin	insect	grasshopper	grit
1	0	0	2.25	0	0
2	0	0	7.3	0	0
3	0	0.41	1.8	0	0.004
4	0	0	0.02	0	0
5	0	0	0.84	0	0.02
6	23.13	0	6.6	0	0.54
7	0	0	0.17	0	0.17
8	0	0	6.56	0	0.11
9	0	0	0.07	0	0
10	0	0	0.17	0	0.53
11	0	0	2.2	0	0
12	0	0	0.05	0	0.27
13	0	0	0.08	0	0
14	0	0	0.3	0	0
15	0	0	0.1	0	0
21	0	0	0	0	1.41
24	0	0	0.81	0	0
25	0	0	0.08	0	0.74
27	0	0	0	0	0.03
28	0	0	0	0	0
29	0	0	1.32	0	0
30	0	0	0.54	0	0.9
31	0	0	0.55	0	0
34	0	0	0	2.78	0
35	0	0	0	0	0
38	0	0	0.19	0	0.19
40	0	0	0	0	0.02
41	0	0	0.07	0	0.08
42	0	0	0	0	0.1
44	0	0	2.49	0	0
47	0	0	0.04	0	0.14
48	0	0	0.56	0	0

Macrofossil Data of Coprolite Specimens from Parida Cave (Riskind 1970) – Part 1

Sample	Opuntia Seeds	Opuntia Vascular Bundles	Opuntia Spines	Bark	Agave Fiber	Charcoal	Allium Bulbs	Pebbles
A	1	1	0	0	1	0	1	1
B	0	1	0	0	1	0	1	1
C	0	1	0	0	0	0	0	1
E	1	1	0	0	1	0	1	0
F	0	1	0	0	0	1	1	0
G	1	1	0	0	0	1	0	0
I	1	1	0	0	0	0	0	0
J	1	1	1	0	0	1	0	0
K	0	1	0	0	0	0	0	0
L	0	1	0	0	0	1	0	1
M	1	1	0	1	0	1	0	0

Macrofossil Data of Coprolite Specimens from Parida Cave (Riskind 1970) – Part 2

Sample	Clay Lumps	Prosopis Seed coats	Chitin	Grass Seed	Chert flakes	Stem	Sand	Hair	Mammal Bone
A	0	1	1	1	0	0	0	1	1
B	0	0	1	1	0	0	0	0	1
C	0	0	1	1	0	1	1	0	0
E	0	0	0	1	0	0	0	0	0
F	0	0	0	1	0	1	0	0	1
G	0	0	0	1	0	1	0	0	1
I	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	1
K	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0
M	1	1	0	0	1	0	0	0	1

Macrofossil Data of Coprolite Specimens from Baker Cave (Sobolik 1988) – Part 1

Sample	Fiber-Unknown	Fiber-Allium	Fiber-Opuntia	Fiber-Yucca	Fiber - Agave	Fiber - Dasylirion	Seed-Opuntia	Seed-Juniperus	Seed-Prosopis
1	0	0	7	0	0	0	0	0	0
2	5	0	0	0	0	0	0	0	0
3	3	0	1	0	0	1	0	0	0
4	1	0	2	0	0	0.1	0	0	0
5	1	0	7	1	0	1	1	0	0
6	4	0	1	0	1	0	0	0	0
7	2	0	0	0	0	0	8	1	0
8	1	0	1	0	1	0	7	1	0
9	2	0	0	2	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0
11	7	0	1	0	0	0	0.1	0	0
12	1	0	4	0	0	0	0	0	0
12b	0.1	0	6	0	0	0	0	0	0
13	4	0	1	0	0	0	0	0	0
14	3	0	3	2	0	0	0	0	2
15	2	0	6	0	0	0	0	0	0
16	4	0	0	0	0	0	0	0	0
17	4	0	0	0	0	0	4	0	0
18	3	2	0	0	0	3	0	0	0
19	6	0.1	2	0	0	0	0	0	0
20	1	0	3	0	1	0	0	0	0
21	7	1	0	0	0	0	0	0	0
22	0	2	7	0	1	0	0	0	0
23	1	3	0	0	0	0	0	0	0
24	3	0	0	0	0	2	0	0	0
25	0	7	0	0	0	1	0	0	0
26	4	1	0	0	0	0	0	0	0
27	0	4	0	0	0	0	0	0	0
28	0.1	3	2	0	0	0	0	0	0
29	4	0	0	0	0	0	0	0	0
30	2	0	7	0	0	0	0	0	0
31	5	0	1	0	0	1	0	0	0
32	4	3	0	0	0	0	0	0	0
33	4	3	0	0	0	0	0	0	0
34	7	0	0	0	0	1	0	0	0
35	5	0	3	0	0	0	0	0	0
36	5	0	0	1	1	0	0.1	0	0
37	7	0	0	0	0	1	0	0	0

Macrofossil Data of Coprolite Specimens from Baker Cave (Sobolik 1988) – Part 2

Sample	Seed-Chenopodium	Seed-Mamillaria	Seed-Brassicaceae	Seed-Celtis	Shell-Quercus	Shell-Juglans
1	0	0	0	0	1	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	2
5	0	0	0.1	0	0	0
6	0	1	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0.1	0	0	0
10	0	0	0	0	0	1
11	0	0	0	0	0	0
12	0	0	0	0	0	0
12b	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0.1	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	1	0	0	0	0
18	2	1	0	1	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	0	0	0	0	0	0
33	0	0	0	0	0	0
34	0	0	0	0	0	0
35	0	0	0	0	0	0
36	0	0	0	0	0	0
37	0	0	0	0	0	0

Macrofossil Data of Coprolite Specimens from Baker Cave (Sobolik 1988) – Part 3

Sample	Unknown Seed	Charcoal	CaOX Crystals	Spines	Thread balls	White Substance
1	0	0.1	0.1	0	0	0
2	0	0.1	0.1	0	0	0
3	0	0.1	0.1	0	0.1	0
4	0	0.1	2	0	0	0
5	0	0.1	0.1	0	0	0
6	0	0.1	1	0.1	0.1	1
7	0	0.1	0	0.1	0	0
8	0	0.1	0.1	0	0	0
9	0	0	0	0	0.1	0
10	0	0	1	0	0	0
11	0	1	1	0	0	0
12	0	0	0.1	0	0	0
12b	0.1	0	1	0	0	0
13	0	0.1	0.1	0	0	0
14	0	3	0.1	0.1	0	0
15	0	0.1	0.1	0	0	0
16	0	5	0.1	0	0	0
17	0	0.1	0.1	0	0	0
18	0	2	0	0	0.1	0
19	0.1	0	0	0	0	0
20	0	4	0.1	0	0	0
21	0	0.1	0.1	0	0	0
22	0	0	0.1	0	0	0
23	0	2	0.1	0.1	0	0
24	0	0.1	0	0.1	0	0
25	0	0.1	0.1	0	0	0
26	0	0.1	0.1	0	0	0
27	0	0.1	0.1	0	0	0
28	0	4	0.1	0	0	0
29	0	0.1	0.1	0	0	0
30	0	0.1	1	0	0	0
31	0	2	0	0	0	0
32	0	3	0.1	0	0	0
33	0	0.1	0.1	0	0	0
34	0	2	0.1	0	0	0
35	0	1	0	0	0	0
36	0	0.1	0	0	0	0
37	0	2	0	0	0	0

VITA

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