THESIS

A BINARY APPROACH TO THE ANALYSIS OF PREHISTORIC BISON DISTRIBUTION AND PALEOECOLOGY IN NORTHERN COLORADO AND SOUTHERN WYOMING

Submitted by

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ABSTRACT

A BINARY APPROACH TO THE ANALYSIS OF PREHISTORIC BISON DISTRIBUTION AND PALEOECOLOGY IN NORTHERN COLORADO AND SOUTHERN WYOMING

Bison exploitation is at the heart of prehistoric hunter-gatherer subsistence on the Great Plains and can reveal robust information regarding patterns of migration, chronology, and variability in paleoclimate. However, despite association with human subsistence practices, bison population and distribution patterns across time and space are unclear. This thesis presents a study of prehistoric bison distribution and population ecology in archaeological and natural contexts in northern Colorado and southern Wyoming.

Two methods are used here to reconstruct the diet and distributions of prehistoric bison populations. The first method involves identifying the known distribution of bison in archaeological and natural settings in the study area through an analysis of archival documentation. Cultural chronologies based on archaeological associations have long been valuable in regional research, but can be imprecise and of insufficient resolution for constructing detailed sequences of prehistoric events. Therefore, to expand knowledge of the regional archaeological distribution of bison, this research utilized a total of 272 archaeological sites containing faunal remains. In addition, 291 calibrated radiocarbon dates were used to compile and analyze bison presence and absence through sum probability distributions and statistical analyses. The second method explores the paleoecology of bison through the use of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) stable isotopes analysis of bone collagen from 35 prehistoric bison specimens. Stable isotopes analysis helps to characterize bison distribution and ecology through reconstruction of bison dietary forage and is compared with paleoclimate data in order to identify trends in bison migration and population patterns. This study adds significant chronological information to the regional record of bison presence in northern Colorado and southern Wyoming and helps to correlate bison distribution patterns with the paleoclimate record.

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CHAPTER 1

INTRODUCTION:

WHERE THE BUFFALO MAY HAVE ROAMED

The Great Plains and the American bison (*Bison bison*) possess a historically synonymous relationship. During the Holocene, the western Great Plains of northern Colorado and southern Wyoming were once covered with immense herds of bison (Hornaday 1889; Isenberg 2000; McDonald 1981), and bison were one of the most valuable subsistence sources for cultural groups on the Great Plains for much of prehistory. Yet it is not clear whether bison that lived on the plains also utilized higher altitudes in the adjacent mountains or whether distinct, smaller herds lived in limited geographical and altitudinal zones. In order to recognize the subsistence choices and behavior of human hunter-gatherers, it is also necessary to understand the foraging behavior and distribution of their prey. The reconstruction of bison diet and an analysis of bison distribution may help in the understanding of past bison migration patterns.

This thesis involves a study of prehistoric bison distribution and ecology in archaeological and paleontological contexts in northeast Colorado and southeast Wyoming. Distribution and ecology can be examined through reconstruction of bison dietary forage and compared with paleoclimate data. There are a number of methods that will be used to reconstruct the diet and distributions of prehistoric bison populations. The first method involves identifying the known distribution of bison in archaeological and natural settings in the study area through an analysis of archival documentation. The second method explores the paleoecology of bison through the use of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) stable isotopes analysis of bone collagen. The goals for this thesis are twofold. When used together, these two methods provide information regarding bison distribution in the study area over time and provide insight into the movements of the cultural groups who subsisted on them.

The first goal is to identify the absence/presence of bison in archaeological and/or natural contexts within geographical regions. The presence of bison in the study area can be identified by utilizing documentary sources such as excavation reports, archaeological site forms, literary sources, historic accounts, and journals. Studying bison distribution by altitude can yield important data on whether bison populated the mountains, mountain basins, and Great Plains equally across prehistory. An analysis of these data can yield distributional patterns of prehistoric bison population presence or absence in the study area across both space and time.

The second goal is to determine the migratory range of bison via their diet using ^{13}C and ^{15}N stable isotope studies. While several forms of stable isotopes can be utilized, carbon and nitrogen stable isotopes are commonly used for ecological and migratory research. Bison feed on vegetation with carbon isotope signatures of C_3 and C_4 photosynthetic pathways, each of which is associated with cool or warm season environments respectively (Sims et al. 1978). By analyzing the amount of carbon, specifically stable ^{13}C isotopes in bison remains, the range of environments an individual bison foraged in during its lifetime may be determined. Bison feeding ecology can aid in explaining relationships between bison migration patterns and the landscapes they used to help reconstruct human hunting strategies and mobility patterns in the archaeological record in relation to paleoenvironmental data (Bamforth 1988; Chisholm et al. 1986).

The Study Area

The study area is located in northern Colorado and southern Wyoming near the southwest periphery of the Northern Great Plains where they meet the Southern Rocky Mountains (Hunt 1967) (Figure 1-1). This area is a marginal transitional zone. It is not a zone that its human or animal inhabitants were necessarily forced into, but one which was exploited broadly and efficiently. The study area incorporates the Colorado counties of Boulder, Clear Creek, Gilpin, Grand, Jackson, Larimer, Park, and Weld. In Wyoming, Albany, Carbon, and Laramie Counties were included. Distinct variability in topographic relief characterizes the region – from the Great Plains, to the Rocky Mountains and alpine zones, and mountain basins and Wyoming Basin. This study area concentrates the research efforts into a limited region that is dense with both archaeological sites and bison remains.

Statement of Problem

The question of whether bison herds utilized ecologically isolated regions or migrated to different areas in their lifetimes seems as if it should have a straight-forward answer. However, the extirpation and near extinction of bison during the nineteenth century modified the natural behavioral patterns of this species (Bamforth 1987; Isenberg 2000; McDonald 1981). The surviving members were relegated to geographically isolated areas in parks, preserved areas and ranches, and were interbred with cattle in an attempt to rehabilitate their numbers (Meagher 1986). As a result, the knowledge of the natural migration patterns and behavior of these animals is uncertain. Prehistoric bison ecology is poorly understood, and much is inference. Ethnographic data and observations of modern bison populations can be helpful resources, but this information should be used with caution. Given this, the use of other methods for investigating past behaviors and ecology of bison, such as stable isotopes analysis, becomes especially important

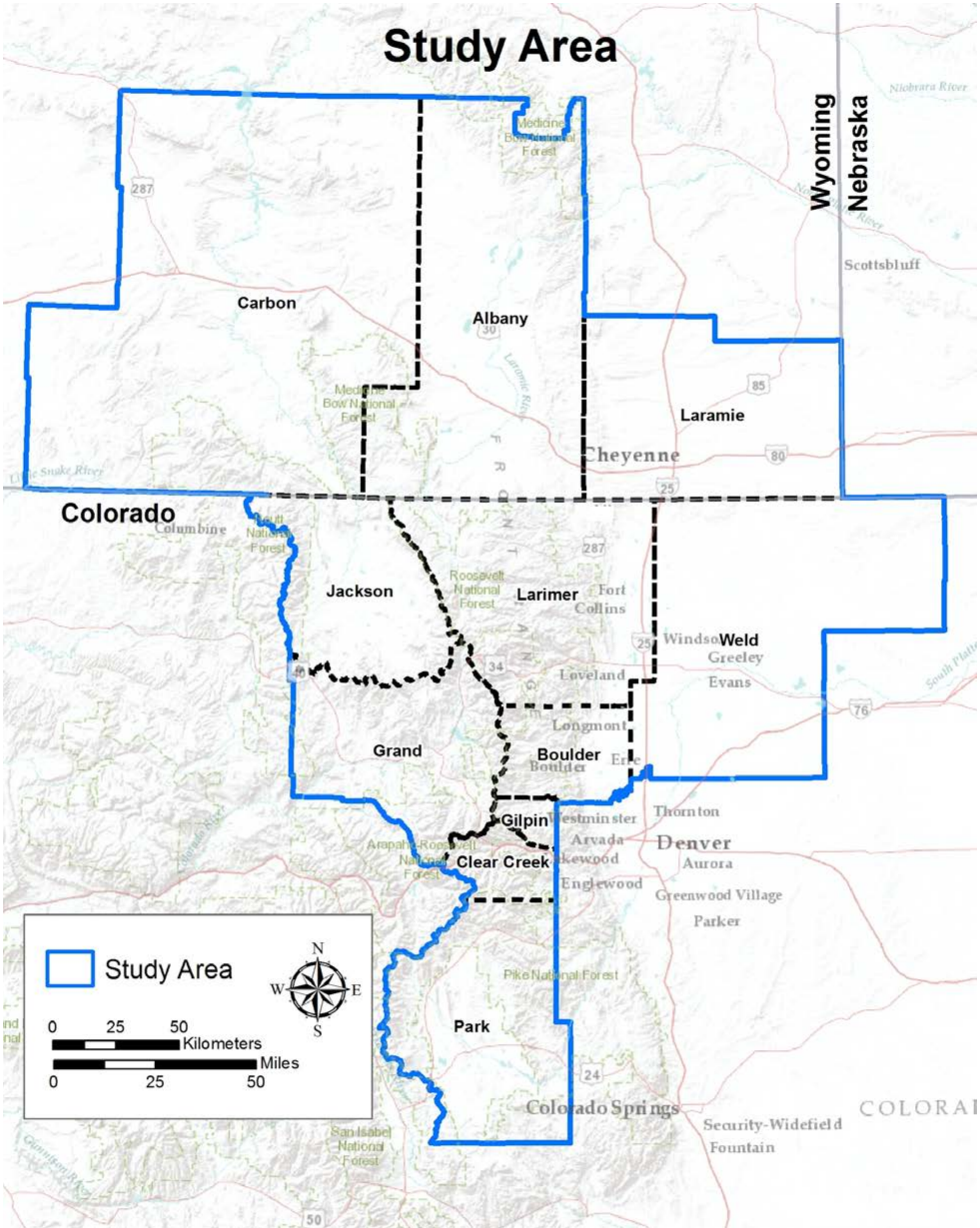

Figure 1-1. Study area location in northern Colorado and southern Wyoming.

(Britton2009; Chisholm et al. 1986; Gadbury et al. 2000; Hoppe 2006; Larson 1995). Such techniques, when used in conjunction with known archaeological distributions of bison, may be used to provide insight into their foraging patterns, seasonal landscape use, behavior, and human subsistence practices.

The Questions

Two main questions direct this research:

1. What is the known prehistoric distribution of bison in northern Colorado and southern Wyoming?
2. Did bison herds inhabit ecologically isolated regions or did they migrate across different areas in their lifetimes?

The research questions, associated data needs, methods, and hypotheses are laid out in an organizational matrix in Table 1-1. While it is expected that bison will be found in a variety of environments and altitudes (Bamforth 1987; Cooper 2011; Fryxell 1926, 1928; Lee and Benedict 2012; Warren 1927), the first hypothesis anticipates that bison will not be distributed evenly across space and time. This hypothesis is based on the assumption that bison were utilized by cultural groups at different times and locations on the landscape due to variations in paleoenvironmental conditions that affected distribution and availability of grassland forage, bison migration patterns, population sizes, and ultimately hunting practices. The absence/presence research of this thesis should identify what sites with bison are present, where they are on the landscape, and when these occurred.

The stable isotopes analysis portion of this research can help to answer *why* this patterning may have occurred. The diverse sources of dietary forage of bison are distributed differentially across the study area based on latitudinal, longitudinal, and altitudinal parameters – all of which are influenced by climatic conditions. Because of this, the distributional patterning of bison based on their dietary needs can be identified. Therefore, it is hypothesized that bison will be found in areas with limited range due to ecological needs and little migration between

Table 1-1. Matrix of Research Methods.

Research Question	Data Sources	Methods	Hypothesis
What is the known prehistoric distribution of bison in northeast Colorado and southeast Wyoming?	• Excavation Reports • Site Forms • Paleontological Specimens • Radiocarbon Data • Paleoclimate Data	• Sum Probability Distribution of Radiocarbon Data • Bison Absence/Presence Analysis • Collect New Radiocarbon Data	Bison are not distributed evenly across the study area over both time and space.
Did bison herds inhabit ecologically isolated regions or did they migrate across different areas in their lifetimes?	• Bison Bone • Paleoclimate Data • Stable Isotopes Data	• Process Bone Collagen • Stable Isotopes Analysis • Paleoclimate Comparison • Analyze Intraherd and Interherd Data Trends	Bison lived in ecologically distinct regions with little migration between different areas.

different ecological zones. This hypothesis is based on the assumption that bison were considered to be more prevalent throughout prehistory on the Great Plains than in the mountains. However, if the distribution of bison is more varied than expected, then inferences in mobility of both bison and their human hunters may be made.

The methods used to help answer these questions include analyzing paleoclimate data, compiling records of dated components of archaeological sites with faunal remains, examining patterns in altitudinal distributions of bison, and identifying extents of known grassland types to compare to stable isotopes dietary information. The following research methods were used to attempt to answer these questions:

1. Identify the presence or absence of bison in the study area from the archaeological record via analysis of known excavated sites with faunal remains and surface manifestations of bison remains in the study region.

2. Conduct ^{13}C and ^{15}N stable isotope analysis of bison bone collagen from specimens from different periods from archaeological sites and other contexts within the region.

3. Identify shifting trends in bison distribution and how different areas were utilized through time.

4. Compile the data and attempt to identify trends, data gaps, migration patterns, etc. in the bison record of the study area and relate the results with data from the broader regions of the Great Plains and Rocky Mountain west.

Organization of Thesis

This thesis analyzes the distribution and migration patterns of bison across both temporal and spatial approaches. The organization of the research is as follows.

Chapter Two provides a theoretical and cultural context for the study area. It then goes on to describe the environment of the study area and details the distribution of grasslands. This chapter also provides a detailed description of bison paleoecology and explains the paleoclimate trends of the area.

Chapter Three outlines the methods used to conduct the study of the absence and presence of bison. The absence and presence data results are presented. The results include analyses of radiocarbon data through sum probability and kernel density distributions. Mapping of sites across different altitudes through temporal analysis and Chi-square statistics are also included.

Chapter Four describes the methods used and results of the ^{13}C and ^{15}N stable isotopes analysis. Bone collagen was extracted from 35 specimens from five archaeological bison sites and four non-archaeological sites within the study area. Data is presented on the distribution patterns of the specimens across both space and time based on the results of the percentage of C_3

and C_4 grasses in the dietary forage. This information is analyzed from both altitudinal and chronological perspectives to help determine the potential range of migration of an animal through its life. The results were compared to paleoclimate models and broader regional stable isotopes data from previous bison studies.

Chapter Five brings these two areas of research together. The results of these analyses are incorporated into a broader regional perspective. These data are integrated with other research, both from known sites with bison remains and sites with bison that have had stable isotopic analyses. These results are compared to other areas of the Great Plains and Rocky Mountains. Trends, data gaps, and suggested areas of future research are discussed.

The significance of this study is in its varied approaches to regional data that are either incomplete or scattered across space and time. This research is an attempt to pull these data together in a way that can be utilized as useable background and informational sources for future researchers. An understanding of the distribution of bison prehistorically is not only important to understanding the archaeological record, but important to the biological and ecological records as well.

CHAPTER 2

CULTURAL AND ENVIRONMENTAL HISTORY OF THE GREAT PLAINS AND ROCKY MOUNTAINS

The cultural history of northern Colorado and southern Wyoming is as varied as that of the environment. The following chapter describes the diverse cultural background of the Great Plains, Rocky Mountains, and Wyoming Basin within an amalgamated format. This background is followed by a discussion of the environment trends during the Holocene for the region. Bison paleoecology is outlined in relation to the above histories. This chapter is designed to provide theoretical, historical, and environmental history of the region in this study in relation to bison paleoecology and evolution.

Theoretical Approach

Prehistoric bison migration patterns are not well understood. One way to try to determine bison population structure is to identify the locations of bison on the landscape via their presence in the archaeological record. Patterning of bison at different altitudes may help to model their foraging patterns. Seasonal transhumance models for cultural land use have been proposed for the High Plains and Rocky Mountain region (Benedict 1992; Benedict and Olson 1978; Black 1991) and for the Wyoming Basin (Creasman and Thompson 1997). These models include seasonal migrations of cultural groups that utilized all ecological zones – plains and basin interiors, foothills, and mountains in the spring and fall; summer in the mountains, and winter in the foothills. For the Colorado Front Range and Rocky Mountain alpine zones, a grand circuit model involving human migration between the mountains and Plains based on changing seasons was postulated by Benedict (1992). Black (1991) argued for a Mountain Tradition that included longer term occupations of the high country during the Archaic period. For the Wyoming Basin, Creasman and Thompson (1997) postulated seasonal mobility between the interior basins, basin margins, and surrounding mountains. Disagreements in these proposed transhumance models abound, especially when analyzing stone tool material dispersal and occupation areas at different times. However, the models do provide a basis for analyzing not only migration and land use patterns in different ecological zones by cultural groups, but similar patterns with bison as well.

In general, these models postulate the use of seasonal rounds of the mountains, basins, and Great Plains that likely occurred over various times in prehistory. Parsing out the varying details of transhumance models is beyond the scope of this work. However, the broad patterns of suggested transhumance are applicable. Specifically, in the early spring, groups moved into the basins or onto the plains from winter camps in the foothills to obtain edible roots and plants and to conduct small-scale hunting (Creasman and Thompson 1997). In the late spring and early summer, exploitation of floral resources on the plains and basin interiors intensified and hunting activities increased and groups began to move into the mountains and basins (Benedict 1992; Creasman and Thompson 1997). In the later summer and early fall, groups traveled into the higher mountains to obtain maturing plants and to hunt. It is during this season that large game animals such as bison, deer, and pronghorn coalesce into herds. During this time, these animals put on extra fat for the coming winter making the autumn the best time of year to hunt. Winter settlements were likely located in the foothills of the plains or basin margins (Benedict 1992; Creasman and Thompson 1992). These areas offered shelter, water, and access to game animals.

The identification of bison migration may follow similar patterns. The distribution of known sites with bison remains and the analysis of bison diet can be compared to paleoclimate data and seasonal round models. It can then be assumed that if bison were using only the plains their diets should reflect more C_4 forage whereas high altitude bison should have more C_3 forage in their diets. Such implications may help to support or contradict the transhumance models of hunter-gatherer groups.

CULTURAL CONTEXT

The following section details the cultural history of the study area and provides a contextual framework for the known cultural resources discussed in this thesis. The study area lies at the nexus of multiple cultural areas – the Northwest Plains, the Central Plains, the Southern Rocky Mountains, and the Wyoming Basin. The archaeological record in the study area shares characteristics with all of these surrounding regions. Because of this, the area acts as a nexus for migration, contact, and seasonal subsistence use by many cultures throughout time. It is important to note that the temporal and physical boundaries of the various chronologies are fluid as new data are added to the archaeological record. While the emphasis of bison paleoecology is the focus of this thesis, an understanding of the human occupation of the study area through time is essential to understanding bison subsistence practices.

The Wyoming Basin is located in south-central Wyoming and contains cultural influences from the Great Basin to the west, the Great Plains to the east, and the surrounding Rocky Mountains. The Great Plains region of the study area is at the juncture of the Northwest Great Plains and the Central Great Plains. The South Platte River chronology (Gilmore et al. 1999) is aimed toward Central Great Plains studies but is essentially similar to the Northwest Great Plains chronology (Kornfeld et al. 2010; Wood 1998). The Southern Rocky Mountains create the central portion of the study area and thus also fall within the zone of influence from both the Great Plains and the Great Basin. Figure 2-1 compares the Northwest Great Plains

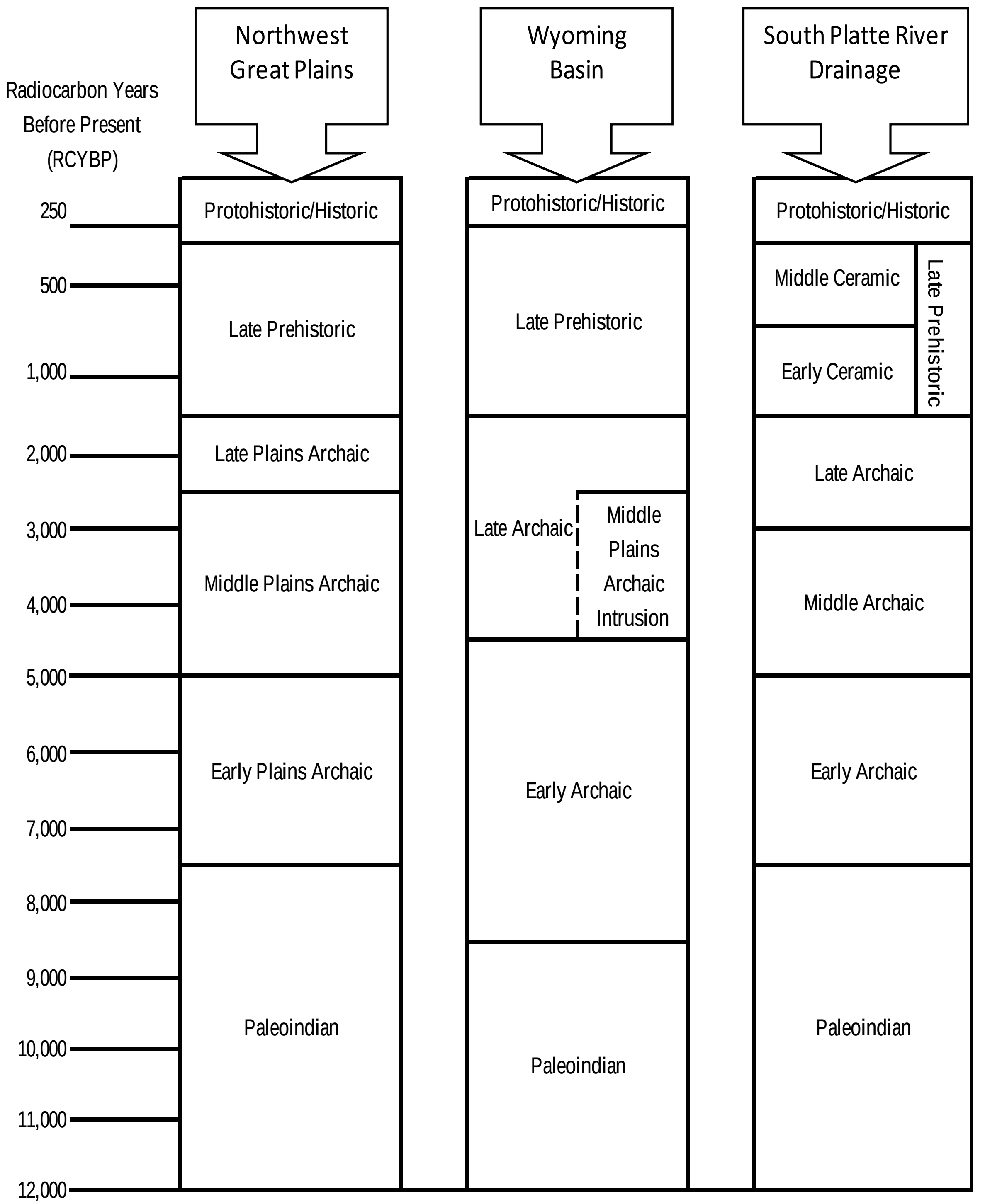

Figure 2-1. Chronologies of the Northwest Great Plains, Wyoming Basin, and South Platte River Basin. The Northwest Plains Chronology is adapted from Kornfeld et al. (2010). The Wyoming Basin Chronology is adapted from Metcalf (1987), Thompson and Pastor (1995), and Johnson and Pastor (2003). The South Platte Basin Chronology is adapted from Chenault (1999).

chronology with that of the Wyoming Basin chronology, and the South Platte River Basin chronology. While variations between the naming conventions of sub-periods and phases occur on a regional scale, larger chronological patterning is similar across the region. Overall, the Northwest Great Plains chronology dominates the region and is the primary cultural context discussed below. Each period is described based on characteristic cultural materials, settlement, and subsistence patterns with a special focus on bison hunting practices.

Paleoindian Period (12,000 – 7500 RCYBP)

The Paleoindian period is identified technologically by a series of tool kit assemblages and the employment of similar subsistence strategies throughout. During the Paleoindian period, the environment across large portions of North America was generally homogenous with cooler, wetter summers than at present. Lush grasslands supported an abundance of megafauna, including *Bison antiquus* (McNees 2006:46; Thompson and Pastor 1995:21, 100, 101).

Common material culture of the Paleoindian period included large, lanceolate and stemmed projectile points, spurred end scrapers, gravers, and borers (Kornfeld et al. 2010:39; Schroedl 1991). Throughout this period there are several assemblage types/complexes present that are typically named after distinctive projectile point styles such as Clovis, Goshen, Folsom, Cody, James Allen, and Angostura (Thompson and Pastor 1995:21; Zietz et al. 2010:25). Clovis, Goshen, and Folsom points date to the early portion of the Paleoindian period while the other varieties appear after 10,000 RCYBP (Kornfeld et al. 2010:84–94).

The earliest documented culture is the Clovis period (12,000-11,000 RCYBP). Clovis peoples utilized large fluted spear points to hunt Pleistocene megafauna such as mammoth. Clovis sites have been found in all regions of North America. Clovis sites but are rare. The Folsom period (11,000-10,000 RCYBP) follows Clovis. Folsom people were also big game hunters, but by Folsom times the Pleistocene megafauna had become extinct and bison were greater targets. The Folsom point was a finely made fluted lanceolate projectile point that differed in form from the earlier Clovis points. Folsom people established a bison hunting subsistence pattern that is common on the plains throughout the rest of prehistory. The Plano period on the Great Plains (10,800-7690 RCYBP) is associated with Late Paleoindian activities. Plano peoples on the plains still targeted bison, but Plano peoples may have hunted both *Bison antiquus* and an intermediate form or subspecies known as *Bison occidentalis* (Kornfeld et al. 2010:155). Large bison kills are more common in Plano sites than in preceding periods.

In the Wyoming Basin, climatic warming and drying during the Paleoindian period may have led to environmental changes earlier than on the Great Plains which resulted in lower availability of large game and a greater reliance on alternative food sources. The change in subsistence patterns at the transition from the Paleoindian period to the Archaic period is being pushed back to 8500 RCYBP due to evidence of an apparent early onset of the Archaic subsistence pattern and accompanying technological changes in the Wyoming Basin, Great Basin (Graf and Schmitt 2007) and western Colorado (Reed 2009).

This change in subsistence pattern is associated with a wide variety of Late Paleoindian projectile point types found in southern Wyoming and surrounding mountain-foothill areas (Frison 1991, McNees 2006:68, 69; Thompson and Pastor 1995:24). Frison (1991) identified these Foothill–Mountain Paleoindian groups as having not only a different variety of projectile point types, but also a different subsistence strategy from the Plains Paleoindian groups. Sites associated with the Foothill–Mountain Paleoindian date to the later portion of the period between 9400 RCYBP and 7800 RCYBP and include diversifying of subsistence practices to include a variety of plant and animal species (Kornfeld et al. 2010:95–106).

Archaic Period (7500 – 1500 RCYBP)

The date ranges for the Archaic period, which is divided into the Early, Middle, and Late Plains Archaic periods, are based on changes in subsistence strategies and tool assemblages in conjunction with broad climatic shifts. On the Great Plains, at approximately 7500 RCYBP, subsistence strategies trend away from primarily hunting to a generalized exploitation of plant foods and smaller animals (Johnson and Pastor 2003; Kornfeld et al. 2010).

The initial change from the Paleoindian period to the Early Plains Archaic period (7500–5000 RCYBP) is believed to be related to a shift to a hotter and drier climate. The shift, known as the Altithermal (Antevs 1955), is the subject of great debate on the severity, timing, duration, and effect on human and animal populations. It now appears that the climate became hotter and wetter in the summer, and cooler and drier in the winter (Huckell 1996). This drought resulted in the shift of vegetation zones upward in altitude and many areas of Great Plains grasslands became more desert-like. Bison populations were diminished, and prehistoric occupation of the mountains may have increased. Theories have been proposed in which the plains were virtually abandoned in favor of the mountains during this time (Benedict 1979). Current thought is that the plains were not abandoned, but occupation was diminished. Subsistence patterns shifted from bison to a variety of smaller game.

Ground stone implements (manos and metates), which are present in low numbers in Paleoindian sites, become more common in the Archaic period and probably reflect increasing use of plant resources (Johnson and Pastor 2003; Kornefeld et al. 2010). Projectile point forms changed substantially from Paleoindian types to stemmed, smaller lanceolate, side-notched, and corner-notched forms with the use of the atlatl. The great diversity of projectile points during the Archaic suggests the development of regionalized groups, a process that may have begun in the

Plano period (Pitblado 2003). Early Archaic sites are also known to contain small basin houses thought to represent brush or skin shelters. These Early Archaic features are quite commonly found from New Mexico through Wyoming, but they have also been found in Middle and Late Plains Archaic contexts (Shields 1998).

The Middle (5000-2500 RCYBP) and Late (2500–1500 RCYBP) Plains Archaic periods are distinguished from the Early Plains Archaic period by increased numbers of occupations, an increasing diversity in tool forms, and a return to bison hunting subsistence patterns, albeit the modern form of bison (*Bison bison*). These occurred with the return of cooler and wetter conditions, similar to today's climate. Occupation of the Great Plains increased substantially and communal large game hunting resumed.

One of the important periods of interest for the western portion of the study area is classified as the Middle Plains Archaic Intrusion (5000-2500 RCYBP). This intrusion occurred in the eastern Wyoming Basin and surrounding mountainous areas. The end of the Early Archaic and the beginning of the Late Archaic are overlapped temporally and spatially by the McKean Complex of the Middle Plains Archaic, 5000 – 2500 RCYBP (Kornfeld et al. 2010:114–122; Thompson and Pastor 1995:49–50). The McKean Complex was employed throughout the Northwest Great Plains and relied heavily upon the use of bison (Kornfeld et al. 2010:254–255; Thompson and Pastor 1995:49). McKean Complex sites are relatively rare in the Wyoming Basin but are easily identified by the presence of the McKean Complex projectile points (Kornfeld et al. 2010:91). McKean Complex sites appear to represent an occasional presence of plains peoples in the Wyoming Basin (Thompson and Pastor 1995:49, 50). It is likely that the Plains groups represented by the McKean Complex sites followed the ebb and flow of bison herds into the region. One example of this would be the Scoggin bison kill site in the study area in the eastern Wyoming Basin of south-central Wyoming. This site is utilized in this thesis and is comprised of a McKean complex associated with a bison arroyo pound dating to the Middle Archaic period (Lobdell 1974).

Late Prehistoric Period (1500 – 350 RCYBP)

The Late Prehistoric period (1500-350 RCYBP) is differentiated from the Archaic period by several technological developments and a modest shift in subsistence and settlement patterns. Technological developments include the replacement of the atlatl with the bow and arrow and the introduction of ceramic technology. Bison hunting intensified during the Late Prehistoric period (Kornfeld et al. 2010). This intensification included large-scale communal bison hunts. In addition to bison, a wide variety of small and medium-sized mammals were consumed (Thompson and Pastor 1995:54).

For the South Platte River Basin, the Late Prehistoric period has been subdivided by Gilmore et al. (1999) into two periods: Early Ceramic (1800-800 RCYBP) and Middle Ceramic (800-360 RCYBP). The Early Ceramic period is characterized by small corner-notched points, ground stone, cord-marked ceramics, and habitation structures. Some of the larger projectile points common in the Late Archaic persist into this period. While populations further east became more sedentary and practiced horticulture, the inhabitants of the area appeared to have retained much of their hunter-gatherer lifestyle.

The Middle Ceramic period is distinguished from the Early Ceramic by the addition of new ceramic types and triangular side-notched points. With few exceptions, Middle Ceramic components are found in multicomponent sites, suggesting cultural continuity with the Early Ceramic. The changes between these two periods are more subtle than it is in areas farther east on the plains. A decline in radiocarbon dates, a decrease in numbers of Middle Ceramic sites, and a decrease in artifact assemblage diversity suggests shorter occupations by smaller groups (Gilmore et al. 1999).

Protohistoric Period (400-100 RCYBP)

The Protohistoric period begins with the introduction of European trade goods into the region and terminates with Euroamerican exploration and occupation of the region for the fur trade. This period is characterized by a fundamental shift in Native American technology and subsistence practices and extensive demographic shifts and fluctuations, and is the period in which historically recognized tribes can be distinguished. The introduction of iron, steel, copper, and glass goods in the material record distinguishes the Protohistoric period from the Late Prehistoric period. The acquisition of the horse around A.D. 1600 changed subsistence patterns from hunter-gatherers traveling on foot to horse mounted hunters. Horses allowed groups to increase their mobility and to participate in larger scale bison hunts, seasonal migration, and expand trade networks.

Perhaps the greatest changes for Native Americans were population reductions caused by introduced diseases and competition for resources (West 1998). The Utes utilized the mountains and eastern Foothills of the Colorado Rocky Mountains, as did the Shoshone and Comanche to a lesser extent (Clark 1999:310). The Comanche and Ute drove the Apache out of Colorado by 1750. The Arapaho and Cheyenne moved into the area and were recognized as being in possession of the land between the North Platte and the Arkansas River in the 1851 Treaty of Fort Laramie. The Protohistoric period lasted until European fur trappers and explorers entered the region and started to generate written accounts of their interactions with Native American groups which initiated the beginning of the Historic period.

ENVIRONMENT

The study area encompasses the region between the North Platte River drainage in south-central Wyoming and the South Platte River drainage in northeast Colorado. This area includes not only the Great Plains, but foothills, mountains, alpine zone, intermountain basins, and the eastern periphery of the Wyoming Basin. These areas give this study a diversity of altitudes and ecological and climate zones from within a compact area for ease of study.

The study area is within the Southern Rocky Mountain physiographic province and the Great Plains and borders the Wyoming Basin at the western periphery (Hunt 1967). Altitudes in the area range from approximately 1340 m above mean sea level (amsl) (4400 ft amsl) in eastern Weld County, Colorado to over 4267 m amsl (14,000 ft amsl) in the high mountains. Most of the study area is located between 1829-2286 m amsl (6000-7500 ft amsl). Modern vegetation ranges from shortgrass steppe in the eastern portions with mixed grass prairie encroaching in areas of the Wyoming Northwest Great Plains (Bailey et al. 1994). The foothills and foothill-basin margins are primarily ponderosa forest. Higher altitudes transition into lodgepole pine forest and subalpine fir and spruce forest (Mutel and Emerick 1992). The intermountain basins are dominated by mountain grasslands and sagebrush communities (Bailey et al. 1994).

The western Great Plains of Colorado and Wyoming are situated at the boundary of the High Plains and the Northwestern Great Plains (Hunt 1967). Much of eastern Wyoming falls within the Northwestern Great Plains ecoregion which is classified as an irregular, mostly mixed-grass prairie (Bailey et al. 1994). The Colorado Piedmont Section of the Great Plains of northeast Colorado is comprised of relatively flat to dissected terrain of shortgrass steppe. Areas to the east contain sandhills and broken terrain. The region has a climate of cold, relatively dry winters and warm summers. Prehistorically, the High Plains and Northwest Great Plains were prime habitats for plains bison.

The eastern extent of the Wyoming Basin forms the northwest portion of the study area. This ecoregion is a broad, dry, intermontane basin, broken up by high hills and mountains, and dominated by semi-arid bunch grass grasslands and sagebrush shrublands (Bailey et al. 1994; Knight 1994). The region is drier than the Northwest Great Plains and is nearly surrounded by forest-covered mountains (Omernik and Griffith 2012). Prehistorically, the natural vegetation was primarily sagebrush steppe, with the eastern edge of the region containing more mixed grass prairie (Knight 1994; Omernik and Griffith 2012).

The Southern Rocky Mountains form the central and western spine of the study area and are composed of high altitude, steep, rugged mountains. Although coniferous forests cover much of the region, vegetation follows a pattern of elevation banding (Doerner 2007). The lowest altitudes are generally grass or shrub covered hogbacks and foothills interspersed with ponderosa pine forest or juniper. Mid-altitude terrain is covered by a variety of vegetation types including Douglas-fir, ponderosa pine, aspen, and juniper-oak woodlands. Middle to high altitudes largely consist of coniferous forests. The highest altitudes have sub-alpine and alpine tundra characteristics.

Within the Rocky Mountains of the study area are three high basins in Colorado and one in Wyoming. In Colorado the basins are North, Middle, and South Parks. Generally, these large, open valleys contain minimal forest and are largely composed of mountain grasslands. Sagebrush steppe is also common in North and Middle Parks. South Park is predominated by mountain grasslands. In Wyoming, the Laramie Basin is a high altitude mixed-grassland park similar to that of South Park. All of the intermontane basins are characterized by cold winters and hot summers with little precipitation. Prehistorically and historically, these regions were prime areas for large game species such as bison.

Grassland Types

Historically, bison grazing played a central role in maintaining grasslands through nutrient cycling and the diversifying of vegetation species structure and composition. Distribution of grasses with either the C_3 or C_4 photosynthetic pathway is highly correlated with variations in temperature and precipitation (Tieszen 1994). C_3 grasses tend to grow during the cool spring season whereas C_4 grasses grow best during the warmest months of summer. Most of the western and northern grasslands are dominated by C_3 vegetation. Temperature and precipitation vary across the Great Plains along both altitudinal and latitudinal gradients, as well as on a more regional basis (Boutton et al. 1980). Generally, the quantity of C_4 plants increases as latitude and altitude decrease. C_3 plants increase latitudinally and altitudinally as one moves northward, and from east to west across the Rocky Mountain region. A more detailed description of C_3 and C_4 photosynthesis is described in the methods section of Chapter 4.

The natural primary habitat of bison is grassland, but herds can be found in mountainous terrain, forests, arid zones, and deserts. Bison are mostly unselective grazers, meaning, they will feed on available grasses in all seasons (Meagher 1986). Graminoids (grasses) and sedges (cool season and wetland graminoids) make up the majority of their diet (Meltzer 2006; Peden 1972; Tieszen 1994). The proportion of C_3 and C_4 grasses in the diet is based on season of availability. There are arguments that bison are selective grazers when given the choice, choosing to feed on C_4 vegetation preferentially (Peden 1972). While possible under ideal modern conditions, little is known of the diet of prehistoric bison populations. Modern bison feed on the dominant grasses available in a given area which is based on season of growth. Bison thrive on the Great Plains but modern populations are prevalent in mountainous areas and northern latitudes in regions where C_3 grasses dominate.

Several primary grasslands are present in the study area at present. Paleoclimate models indicate that these grasslands were largely located at their modern extent during much of the Late Holocene (4500 RCYBP to present) (Bamforth 1988). Short-scale changes in temperature and precipitation patterns certainly occurred, and the boundaries of these grasslands likely fluctuated at different times in prehistory. It should also be noted that grassland boundaries are not solid lines and areas of different grassland types blend with other grassland species at regional, ecological, and sub-climate scales. The primary grasslands in the study area include the shortgrass steppe, the mixed-grass prairie, and the sagebrush-bunchgrass steppe. Mountain grassland communities are present at higher altitudes and within the intermontane basins. Table 2-1 outlines the dominant grass species for bison forage in each of the grassland ecosystems and their associated photosynthetic pathway.

Shortgrass Steppe - The shortgrass steppe is found primarily in the western portion of the western Great Plains. It extends east of the Rocky Mountains to the Nebraska Panhandle and south into Texas and New Mexico. Historically, the shortgrass steppe represented one of the richest areas of the Great Plains to support large bison populations. The shortgrass steppe is composed of a mix of C_3 and C_4 grasses with C_4 grasses dominating. In much of this grassland range, the primary graminoid species is blue grama grass (*Bouteloua* spp.). Temperature and precipitation have a significant impact and tallgrass and mixed-grass species may be present in varying abundances at different times, especially on more mesic (moderately wet) soils.

Northern/Central Mixed-grass Prairie - The mixed-grass prairie is arguably divided into Northern and Central components; however the species of grasses present in both are generally

Table 2-1. Grass Types and Photosynthetic Pathways (Adapted from Meltzer 2006).

Grassland Ecosystem	Primary Graminoid types	Common name	Photosynthetic pathway	Season of Growth
Mixed-grass Prairie				
	Pascopyrum smithii	Western wheatgrass	C3	Cool
	Schizachyrium scoparium	Little Bluestem	C4	Warm
	Bouteloua curtipendula	Sideoats grama	C4	Warm
	Andropogon gerardii	Big Bluestem	C4	Warm
	Hesperostipa comata	Needle and thread grass	C3	Cool
	Sporobolus heterolepis	Prairie dropseed	C4	Warm
	Bouteloua gracilis	Blue grama	C4	Warm
	Stipa spp.	Pear grass	C3	Cool
Shortgrass steppe				
	Bouteloua spp.	Blue grama	C4	Warm
	Buchloe dactyloides	Buffalograss	C4	Warm
	Hesperostipa comata	Needle and thread grass	C3	Cool
	Koeleria macrantha	Prairie junegrass	C3	Cool
	Pascopyrum smithii	Western wheatgrass	C3	Cool
	Aristida purpurea	Purple threeawn	C4	Warm
	Sporobolus cryptandrus	Prairie dropseed	C3	Cool
Sagebrush-Bunchgrass steppe				
	Achnatherum hymenoides	Indian ricegrass	C3	Cool
	Bouteloua gracilis	Blue grama	C4	Warm
	Elymus lanceolatus	Thickspike wheatgrass	C3	Cool
	Festuca spp.	Fescue species	C3	Cool
	Hesperostipa comata	Needle and thread grass	C3	Cool
	Pascopyrum smithii	Western wheatgrass	C3	Cool
	Poa secunda	Sandberg bluegrass	C3	Cool
	Pseudoroegneria spicata	Bluebunch wheatgrass	C3	Cool
	Bromus tectorum	Cheatgrass	C3	Cool
	Stipa spp.	Spear grass	C3	Cool
Montane Grassland				
Higher	*Agrostis* spp.	Spikebent	C3	Cool
Higher	*Carex* spp.	Sedge	C3	Cool
Lower and higher	*Festuca* spp.	Fescue	C3	Cool
Lower and higher	*Danthonia parryii*	Parry's Oatgrass	C3	Cool
Lower	*Bouteloua gracilis*	Blue grama	C4	Warm
Lower	*Hesperostipa comata*	Needle and thread grass	C3	Cool
Lower	*Pascopyrum smithii*	Western wheatgrass	C3	Cool
Lower	*Muhlenbergia* spp.	Mountain muhly	C4	Warm
Lower	*Pseudoroegneria spicata*	Bluebunch wheatgrass	C3	Cool

the same even if in somewhat different abundances. They are discussed as one here based on variability of reported distributions. The mixed-grass prairie extends from the Great Plains of southern Canada and into areas east of the Rocky Mountains and down into the Central Great Plains as far south as northern Texas. The mixed-grass prairie generally lies between the shortgrass steppe and the tallgrass prairie of the eastern Great Plains.

Due to this positioning, the mixed-grass prairie contains elements of both the shortgrass steppe and tallgrass prairie. This prairie system contains a mix of C_3 and C_4 vegetation that varies in abundance based on altitude and latitude. Eastern Wyoming is part of the mixed-grass prairie. Although the greater part of the mixed-grass prairie lies to the north and east of Colorado, the western extent of this grassland has probably moved in and out of eastern Colorado during the Holocene with variations in climatic conditions.

Sagebrush - Bunchgrass Steppe - The sagebrush-bunchgrass steppe forms one of the largest ecological systems west of the Rocky Mountains. This grassland is typically found in broad basins between mountain ranges, on plains, and foothills. In Colorado, the largest amounts are in the western half of the state. In Wyoming, the sagebrush-bunchgrass steppe covers much of the south-central and southwest part of the state in the Wyoming Basin and surrounding areas (Knight 1994; Omernik and Griffith 2012). This grassland can also extend into areas of the intermontane basins such as North Park and Middle Park. This grassland system is characterized by a dense shrubland of taller *Artemesia* species (sagebrush). This steppe also varies in type based on altitude, soil types, and precipitation patterns. Sagebrush species differ, and percentages of grasses differ, however, this grassland is dominated by cool season C_3 grasses. In areas where precipitation is scarce, warm season grasses never have a chance to take hold. Thus the steppe is not ideal for grassland development during the summer months and is generally poor in forage for bison except during multiple years of increased precipitation which would support grassland expansion.

Montane-Subalpine Grassland - This ecological system typically occurs at higher altitudes in open areas such as meadows or on lower sideslopes that are dry. These grasslands are intermixed with stands of spruce-fir, lodgepole and ponderosa pine, and aspen forests. Plant species present are variable depending on reasons such as slope, aspect, and precipitation, but generally lower altitude montane grasslands (foothills and Piedmont) are more xeric (Dry) while upper montane or subalpine grasslands are wetter. Although smaller montane grasslands are scattered throughout the Southern Rocky Mountains ecoregion, the largest area is on the valley floor of South Park in central Colorado. The lower altitude grasslands are similar to the mixed-grass prairie and will contain both C_3 and C_4 varieties. As altitude increases, the grasslands will increase substantially in the quantity of C_3 grasses and decrease in C_4.

PALEOCLIMATE

Paleoclimate reconstruction is not only important to the understanding of the climatic conditions of one specific time, but also to perceptions of human responses to changing climatic conditions throughout time. Developing regional climatic data help identify constraints of climatic variation at a local scale. The goals of paleoclimate reconstruction are to both understand specific site level conditions and to document change in environmental and climatological contexts. Paleoclimate data sources are used in this study in an attempt to identify the relationship of bison with their environment over time.

Proxies can be used to aid in determining changes in climate. Vegetation analyses (Williams 2009), studies of absence or presence of different types of fossil insects (Elias 1985), eolian deposition (Forman et al. 2001, Gilmore 2012; Muhs 1985), high-altitude treeline variations (Benedict 1992, 1999; Carrara 2011; Reasoner and Jodry 2000), and stable isotopes analyses (Holliday et al. 2011; Lovvorn et al. 2000; Nordt et al. 2007; Widga 2007) are just some of the methods that can be used. Ideally, more than one of these proxies are combined to better explain variations in climate over time in specific regions. Comparisons of paleoclimatic data sets show a great deal of variation in the dates of periods and conditions within them (Table 2-2).

Table 2-2. Cultural Periods Compared to Paleoclimate Episodes.

Era	Holocene	Age RCYBP	Conditions	Vegetation Type (Carrara 2011; Clark 2001; Forman et al. 2001;
Paleoindian	Early			
PreClovis		18,000-12,000	Full glacial early (Pinedale glacial maximum)	Mixed grassland and woodland
Clovis		12,000-11,000	Deglaciation and gradual warming, Late Clovis drought (Younger Dryas)	Mixed grassland and woodland
Folsom		11,000-10,000	Wetter conditions after drought and increased variation in seasonality	Mixed grassland and woodland
Plano	Middle	10,000-7500	Continued warming and drying.	More prairie grassland emerging, a mix of short and tall grass prairies, treelines raised in mountains, and eolian deposition in mountain basins increases
Archaic				
Early		7500-5000	Altithermal occurs, drought	Increased eolian deposition, treelines lower, dune formation
Middle	Late	5000-3000	Somewhat cooler and wetter than previous period	Mixed grasslands across area, fluctuating treelines
Late		3000-1800	Punctuated periods of drought and wet periods	Similar to modern grasslands of mixed and short-grass prairie
Late Prehistoric				
Early Ceramic		1800-800	More modern conditions set in, gradually warming and drying, with periods of wetter and cooler	Similar to modern grasslands of mixed and short-grass prairie
Middle Ceramic		800-400	Dryer than previous period, especially on Plains. Mountains maintained warm and moist	Similar to modern grasslands of mixed and short-grass prairie
Protohistoric		400-100	Slightly cooler and wetter than previous period. (Little ice age)	Similar to modern grasslands of mixed and short-grass prairie

This variation is partly due to the complexity of topography and precipitation regimes in the Rocky Mountain west that creates different microclimates. Because of this variation, paleoclimate is most reliably discussed in general trends.

The Pinedale Glaciation (30,000–10,000 RCYBP) was the last major ice age to occur in the Rocky Mountains. This glaciation was characterized by extensive expansion of mountain glaciers, rather than the ice sheets from the north in earlier glacial episodes. Paleoindian occupation in the area began during the Late Glacial phase (14,000–9500 RCYBP) at the end of the Pleistocene and Early Holocene transition (Wendland 1978). This period coincided with a shift in the earth's axis causing increased seasonality in the northern hemisphere (Eckerle 1997; Imbrie and Imbrie 1980). The region of the Great Plains was characterized by a more arctic steppe environment with mixed grasslands and forest (Nordt et al. 2007). Post-glacial transition occurred around 14,000 RCYBP. From approximately 12,000 to 10,000 RCYBP there was severe drought, known as the Clovis Drought (Haynes 1990). Late Glacial forests retreated and successive, mixed and diverse grasslands emerged (Nordt et al. 2007) Around 10,600 RCYBP the period of the Younger Dryas occurred with cooler though still dry conditions. According to Holliday et al. (2011), shortgrass steppe and mixed-grass prairie was in place in the Southern and Central Great Plains by the Younger Dryas, though more mixed than at later, warmer periods. The Younger Drayas event coincided with lowering of treelines in the Rocky Mountains indicated by variations in pollen ratios from this period (Carrara 2011; Reasoner and Jodry 2000). This data is supported by evidence of human occupation at higher altitudes around 9600 RCYBP (Benedict 1985, 1999).

The cooler and wetter climate became warm and dry again around 8500 RCYBP, coinciding with the Middle Holocene (Nordt et al. 2007; Wendland 1978). This warming period marked the beginning of the Altithermal period and coincided with the Early Archaic period (7500–5000 RCYBP). The Altithermal was a drying trend with increased seasonality (Antevs 1955). The Altithermal was a drought that affected regions of western North America to different degrees. The Great Plains suffered from north to south with a decreased precipitation trend (Holliday et al. 2011; Meltzer 1999; Nordt et al. 2007). Altithermal dune formation was prevalent across the Wyoming Basin and the Great Plains of eastern Colorado, indicating dry conditions and poor productivity and growth in vegetation communities (Forman et al. 2001; Gilmore 2012; Muhs 1985). Regional variability was likely present however and human and animal adaptation would have occurred acutely at the regional scale. At the transition of the Great Plains and Rocky Mountains, the effect of the Altithermal was likely influenced by altitude. Benedict and Olson (1978) suggested that the high mountains were more moderate in climate and may have acted as a refuge for both animals and people.

The Altithermal led into the neoglacial period (5000–2500 RCYBP), a return to wetter and cooler conditions though to a lesser degree than previously (Wendland 1978). The Middle Archaic period coincides with this episode at the beginning of the Late Holocene. This episode was a time of cyclical and seasonal temperature and precipitation patterns that resemble modern conditions. Grasslands expanded again after the Altithermal dry period and continued to evolve into shortgrass and mixed grass prairie in the study area region.

Late Holocene reconstruction of the paleoenvironment for the region post-5000 RCYBP suggests a trend towards a relatively cooler and moister climate than the previous Altithermal period of the Middle Holocene with shorter period fluctuations in glacial advance and retreat in the mountains (Benedict 1992). Treelines fluctuated in the mountains, to a lesser degree than previous periods, which indicated a more gradual change to modern conditions (Carrara 2011). Cooler conditions and regional pollen analyses suggest that there was an increase in the development of sagebrush and grasslands across the Great Basin and Southern Rocky Mountains, and further expansion of grasslands on the Great Plains (Doerner 2007; Eckerle 1997). By the beginning of the Late Prehistoric period and onward, conditions were similar to present.

While the climate was far from tropical, variations in the moisture trend over time would be evidenced in the quantity of grasslands that could support large ungulates such as bison. Bison dietary compositions of mixed C_3 and C_4 signatures indicate more mesic, or moderate, climate conditions. Those with a higher percentage of C_3 grass in the diet more strongly correlate with cooler conditions, whereas those with a high percentage of C_4 vegetation in the diet would suggest a warmer and drier environment, similar to today.

BISON PALEOBIOLOGY

The understanding of bison paleobiology in North America is complicated by time, poor preservation of bison remains, and lack of consensus by paleobiologists and others about the phylogenetic relationships among of the various species (Burns 1996; Meagher 1986, Wilson et al. 2008). McDonald (1981) proposed that the earliest bison to enter North America were steppe bison (*Bison priscus*) from Asia during the middle Pleistocene, 300,000–130,000 years ago. These crossed the Beringian land bridge in alternating waves when the corridor became ice-free. Bison moved south into the grasslands of central North America when the ice sheets retreated at 130,000-75,000 years RCYBP, evolving there into a large form called *Bison latifrons* (McDonald 1981).

During the ensuing Wisconsin Glaciation, *Bison antiquus* evolved south of the Laurentide ice sheet (110,000-12,000 years RCYBP), Beringian and southern bison populations became separated as the Laurentide ice sheet extended into western Canada (Burns 1996; Wilson 1996).

Geographic separation had significant evolutionary effects. Based on taxonomic, biological, and paleoclimatic evidence, a complete division between the northern and southern populations occurred at the time of the Last Glacial Maximum (20,000- 18,000 years RCYBP). Most evidence points to the hypothesis that modern bison are descended entirely from populations south of the ice sheet before the Last Glacial Maximum (Shapiro et al. 2004; Wilson et al. 2008). Southern bison underwent rapid evolutionary changes during the early Holocene from *Bison antiquus* to a possible intermediate form or subspecies of *Bison antiquus*, called *Bison occidentalis*, which evolved into the modern form of *Bison bison* by 5000 RCYBP (Wilson et al. 2008). During the Holocene, North American bison continued to diminish in body size while at the same time increase in numbers (Guthrie 1980).

When the continental ice sheets began to melt, bison migrated into the ice-free corridor from the south where thawing and melting occurred first. The occurrence of the two modern North American subspecies (plains bison and wood bison) is somewhat debatable, but evidence suggests that *Bison bison* diverged into two subspecies after 5,000 years ago (Gates et al. 2001; van Zyll de Jong 1986). The wood bison (*Bison bison athabascae*) was the most recent divergence to occur in Alaska, the Yukon, and Northwest Territories. Plains bison (*Bison bison bison*) are the most recent subspecies in the majority of the rest of North America (van Zyll de Jong 1993). For the purposes of this research, the modern form of bison is referred to simply as *Bison bison* as the exact subspecies of the specimens in this research is unknown.

Historical and archaeological records demonstrate that plains bison thrived on the grasslands of the Great Plains (Hornaday 1889; Isenberg 2000). Explorers, settlers, and Euroamerican hunters described enormous herds of plains bison, with population estimates ranging from 15 to 100 million (Dary 1989; Isenberg 2000; Shaw 1995). Several methods have been used to attempt to estimate pre-Euroamerican bison abundance, including ethnographic accounts, ecological carrying capacity calculations, and counts/estimates of bison killed for market in the late 1800s. Even when used in combination, these methods are imprecise and uncertain due to variables such as climatic conditions over time, inaccuracies and exaggerations in historic accounts, and subjective population estimates (Shaw 1995). Bison populations likely fluctuated due to environmental conditions, predation, and cultural hunting practices. For example, after the introduction of the horse, hunting methodologies changed greatly from previous techniques and the number of animals that could be taken at one time increased. Regardless, there is little doubt that prior to Euroamerican settlement, plains bison likely numbered in the millions (Shaw 1995).

Bison Behavior

Little is known of the true behavior of bison prehistorically. The extirpation and near extinction of bison during the nineteenth century eliminated the natural behavioral patterns of this species (Bamforth 1987; Isenberg 2000; McDonald 1981). The surviving members were relegated to geographically isolated areas in parks, preserved areas and ranches, and interbred with cattle in an attempt to rehabilitate their numbers (Meagher 1986). As a result, the knowledge of the historical natural migration patterns and behavior of these animals is uncertain.

It is important to note that the modern environment has been significantly modified by human and climatic actions including cattle grazing, fires, drought, agriculture, and climate change. Few natural environments remain; especially large expanses of natural prairie grasslands which once supported wild bison. Modern bison are thus not truly analogous to historical bison ecologically or behaviorally. Caution should be used when comparing historical bison data to modern specimens.

Modern bison are gregarious, forming herds according to sex, age, season, foraging conditions, and habitat. Bison are generally unselective grazers who live in small, nomadic herds including mature bulls and immature males, cows, and calves. These herds vary in size from less than 20 to more than 50 individuals (Gogan et al. 2010; Meagher 1986). Group size may be related to habitat composition and the stability of these groups is variable based on seasonal needs (van Vuren 1983). Adult males (over 4 years old) disperse from the cow groups and form bachelor herds or travel as loners until they gain access to cows during the late summer to early autumn rut. However, females of all ages, calves, and the majority of young males under three years of age remain in mixed herd groups throughout much of the year (Gogan et al. 2010; McHugh 1972; Meagher 1986). Whether or not the composition of modern bison herds is similar to that of prehistoric bison behavior is unknown.

Most bison reach sexual maturity between two and four years of age. The breeding season in most herds occurs during the late summer into early fall resulting in large aggregations of multiple herds and bachelor bulls (Meagher 1986). Gestation is around 285 days (Gogan et al. 2010; Haugen 1974), with the calving season extending from April to the end of May. Calves nurse for at least seven or eight months and weaning is normally completed before the end of their first year (McHugh 1972).

Herd Dynamics

Little is known about prehistoric behavioral herd dynamics. Observations of modern herds show that herds are generally composed of groups of females and young males. They are organized via female hierarchy and cow groups tend to exhibit cohesion (McDonald 1981; Meagher 1986; 266). Prehistoric herds may have been similar kin groups that spent their lives together. However, modern herd dynamics indicate that groups come together and split apart during the summer rut. By fall and early winter, the groups split into smaller, dispersed populations again. This dispersion may account for evidence of some herds exhibiting similar dietary forage whereas others do not. Minor variability in dietary compositions of different herds grazing in broader regions is more visible across spatial and temporal categories. Additionally, males in modern herds tend to disperse seasonally or permanently, depending on status and the summer rut (McDonald 1981; Meagher 1986). They graze in bachelor herds for much of their lives, and this may take them into differing ecological zones than the main female groups (Meagher 1986).

Understanding the prehistoric migration patterns of bison is complicated by their near extirpation in the 19th century. However, by applying general patterns of wild ungulate behavior, bison migration and movement patterns likely evolved due to ecological and selective pressures. Bison may have spent their lifetimes in limited home ranges, or they may have undertaken deliberate seasonal migrations within a range of environments throughout life (Baker 1978). Modern herbivores in mountainous regions often migrate seasonally. This behavior is found in some modern populations of bison and may be driven by changes in seasonal food availability, variations in temperature and precipitation, and snow cover (Britton 2009; Cannon 2007; van Vuren 1983; van Vuren and Bray 1986). Additionally, larger scale migrations across latitudinal or altitudinal gradients may have been motivated by climatic changes and human hunting pressures.

SUMMARY

The relationship between cultural periods and environmental conditions is compelling. It links with the paleoecology of bison in inextricable ways. This thesis research attempts to relate the ecology of the study area with the distribution of bison via the availability of grassland forage at different periods and different altitudes. These data can reveal not only patterning in bison across time, but may help to explain human occupation in relation to bison as well.

CHAPTER 3

HIGH OR LOW, WHERE DID THEY GO?:

BISON ABSENCE OR PRESENCE IN THE STUDY AREA

By understanding the distribution of bison in the archaeological record, we can analyze the hunting practices and mobility of those who hunted them. One method of looking at how bison were utilized is by studying their distribution over time and space. Additionally, by comparing bison presence or absence to paleoclimate proxy data through altitude, trends or variability in the predicted distribution of these animals ecologically may be identified.

METHODS

Several methods of study were used to attempt to answer the research question outlined in Chapter 1. Pertinent information was collected from all excavation data with faunal remains within the study area. Surface recorded sites with bison remains and natural occurrences of bison were also analyzed; of special interest were sites with radiocarbon dated components. These dates were calibrated and compared to altitude and paleoclimate proxies from the region in an attempt to correlate the presence or absence of bison over time.

Only a handful of bison absence/presence studies have been conducted in the United States. Tom Dillehay (1974) investigated the absence or presence of bison in the late Quaternary period on the Southern Great Plains in an attempt to determine shifts in bison populations. That research identified absence and presence periods of bison in relation not only to cultural events, but with the paleoclimatic record. The results indicated that bison absence did correlate with the Altithermal period of the Early Archaic. Butler (1992) utilized the research of Dillehay (1974) in a bison absence or presence study in eastern Colorado and western Nebraska to determine if similar patterns of bison distribution occurred as on the Southern Great Plains. The results of Butler's (1992) analysis supported the trends reported by Dillehay (1974) for the Altithermal period on the Great Plains. Both studies indicated a decrease in the number of bison in those study areas.

Another study was conducted in 1993 that identified the distribution of known natural or archaeological bison specimens over much of Colorado (Meaney and van Vuren 1993). This study looked at a broad distribution of bison remains from museum and private collections but did not provide detailed provenience data and no effort was made to date the remains. Cooper (2008) conducted her dissertation research on the presence of bison across much of the Southern Great Plains, including portions of Colorado, during the Late Prehistoric period. She analyzed records of bison from various State Historic Preservation Offices and compiled these data into her discussion (Cooper 2008). Lohse et al. (2014) expanded upon the absence/presence models of Dillehay (1974) in the extreme Southern Great Plains region by collecting AMS data from bison specimens from the past 6000 RCYBP. Their studies involved looking at different absence and presence periods of bison via AMS dating and sum probability distributions. They found similar results of bison absence or presence as Dillehay (1974) but with more refined dating techniques (Lohse et al. 2014). These studies were of import to the current research as they helped to provide background information and establish periods in which hypotheses regarding bison presence or absence could be formulated.

An additional aspect of research for the current study was to identify the absence or presence of bison at different altitudes within the Rocky Mountains in particular. Bison presence studies have primarily been focused in areas of the Great Plains. If similar trends were established for the mountains, then it is possible that absence or presence of bison at higher altitudes could reveal valuable data relating to prehistoric bison distribution across a greater area. Most previous studies have focused on the *presence* of bison in the archaeological record rather than their *absence*. Discussing trends in bison absence is an improvement on many of these earlier studies and makes the current study more distinct.

Data Collection

Three sources of data were incorporated into this study. The first included research of all excavated archaeological sites in the study area that contained faunal remains. This step involved analysis of reports of excavated sites that either contained bison remains, other faunal remains, or a combination of bison and other faunal remains. Data collection for excavated sites with faunal remains other than bison was an important aspect of study to exhibit instances when bison are absent from the archaeological record. Non-bison faunal sites may show evidence of changing subsistence practices or technologies that relied on various other species rather than bison. Sites with no faunal remains were not included in this study. By compiling a database of excavated sites with faunal remains, it was possible to examine the *absence* of bison at different altitudes and time periods.

The second source of archaeological bison information was a search of all surface recorded sites containing faunal remains in the study area and identification of those that contain bison remains. Surface sites that contained other forms of faunal data but did not contain bison were excluded from further study. This was done for several reasons. First, the amount of data for surface recorded sites is vast. Second, surface recordings of archaeological sites tend to be less detailed in recording techniques. Often bone is not identified to any genus or species. Bison bone is easy to identify and thus is often acknowledged even in cursory surface recordings. While the surface recording of bison does not contribute to the absence portion of this research, it aided in identifying the overall distribution of known bison in the study area which helped to support the arguments presented.

Lastly, data from natural occurrences of bison found within the study area were incorporated. These include data collected by Lee and Benedict (2006; 2012) from high altitude bison specimens. Additional sources of bison information included known natural occurrences of bison from specimens in the CSU archaeological repository. These included all documented and provenienced bison remains that had been, or could be, dated. These data were more ambiguous and difficult to track down yet provided valuable information to add to the overall data set.

Collecting the appropriate bison data set was an important prerequisite. Functional data was necessary for analyses relating to the bison absence or presence study. These data included records on site age, site type, altitudes, environment information, faunal type, etc. To be able to use these data effectively, an encoding system was developed by this researcher for a database in which data could be input as efficiently and consistently as possible. Appendix A includes the raw data results from the encoding database.

For this study, excavated sites were defined as those that contained greater than 2 m^2 of formal excavation units. Any sites with subsurface reporting from either auger or shovel testing that covered less than 2 m^2 was classified as a surface recording due to the limited amount of subsurface research. However, sites that were less than 10 m^2 in size and had features that were excavated, even if less than 2 m^2 in size were also included in these excavation data. This was common in the Wyoming records as many sites that are classified as tested are in fact small salvage excavations of single feature sites. Some subjective observations of the amount of excavated area in relation to results were made in instances in which site size or degree of excavation were not apparent. Any sites that contained subsurface bison remains, even if only minimally excavated or recorded as eroding out of the subsurface (e.g. cutbanks or eolian deposits) were included in the analysis of excavated sites.

File Search

The purpose of the file searches was to obtain all known records of faunal data from archaeological contexts in the study area. This work required conducting research through the History Colorado Office of Archaeology and Historic Preservation (OAHP) and the Wyoming Cultural Records Office (WYCRO). The research incorporated excavation reports and surface manifestations of bison remains on sites. These two state offices house all of the records from archaeological surveys and excavations conducted by universities, cultural resource management firms, and government agencies within each state. A formal file search allows for a request of specific information on sites that is not available to the general public. State personnel can query the state databases and identify archaeological data relevant to this project. The formal file searches were returned as spreadsheet data from which the relevant information for this project was extracted. WYCRO provided excavation reports and site forms upon request. The OAHP records were analyzed in person at the office in Denver. In addition, GIS data clips were requested because many site records did not contain accurate or complete locational information. These data were used for mapping across the landscape and to collect altitude information. The collected data were used to identify the variation of bison distributions in the study area through spatial and temporal analysis.

History Colorado Methods

The search of records at the OAHP included a preliminary examination of the COMPASS online database. While helpful in a general way, this database interface does not allow a search of the specific parameters of this project. The OAHP was contacted and a formal file search was conducted. The formal file search entailed an internal search of OAHP databases by OAHP personnel based on specific search parameters. Spatial data were requested and provided in shape files. The personnel at OAHP searched the internal database for sites containing keywords such as bison, faunal, mammal, animal, excavation, data recovery, testing, etc., to aid in identifying the most relevant reports and site forms in their database (see Appendix A). The results of the formal search were broken into several Excel spreadsheets by the OAHP personnel in an attempt to cover all possible sources of data pertinent to this research. The final file search spreadsheets included information for all sites, surveys, and reports within my search parameters (Table 3-1). These were physically limited to Boulder, Clear Creek, Gilpin, Grand, Jackson, Larimer, Park, and Weld Counties.

Table 3-1. Preliminary File Search Parameters from Colorado OAHP.

OAHP File Search Tables	Description	OAHP Description	Number of Documents in Spreadsheet
17339_faunal docs	Faunal Documents	Six reports found by OAHP based on title keywords	6
17339_docs	All Documents in Counties	All documents in counties specified; by looking at title, document type fields, etc.	5027
17339_sites_by term	Spreadsheet with sites by different faunal terms delineated in tabs	Excel workbook with six tabs, each which contain sites in counties specified that contain artifacts that match a term of interest (e.g., bison, faunal, mammal); columns K and L indicate related report numbers and title	Bison (n=41), Faunal (n=8), animal (n=33), animal+ (n=64), mammal (n=17)
17339_s	Sites	All prehistoric sites in the counties specified (OAHP removed historic resources the prehistoric resources were sufficient)	9795
17339_sy	Surveys	Surveys that have taken place in the counties specified (survey reports); these should all be in the 17339_docs spreadsheet, except for the multiple county documents (document numbers coded MC.XX.XX)	4209

The formal file search yielded thousands of inventory and excavation reports and site forms containing fields of potentially useful data. It was soon apparent that much of these data were not applicable in this study and became obsolete. By analyzing each field in the spreadsheets from the OAHP, the search was limited to reports that were identified as excavations, data recovery, or testing, in the database. Surface sites were researched and limited to fields that described sites containing faunal remains, bison, bone, mammal, etc. This preliminary search for reports and site forms that needed to be investigated included 264 excavation reports, including theses, dissertations, and articles in the archives, and 204 site forms.

Once identified, a list of all sites and excavation reports was sent to OAHP and hardcopies of the requested site forms and excavation reports were pulled by OAHP personnel from the archives. This researcher spent several days at the OAHP office in Denver going through each of these site forms and excavation reports. Relevant data were input into the database of this researcher at that time. A spreadsheet of the master list of reports and site forms examined at OAHP was created to log comments during the research process. This master list helped to delineate which site forms and excavation reports had been encoded into the database and special notes, and which had been eliminated. Site forms were investigated for the presence of bison remains. Any sites with surface manifestations of bison were input into the database. Site forms were removed from the data that did not contain bison data.

The excavation reports were examined for associated excavated sites. Some reported only one site, while others described multiple excavated sites. Some reports were duplicate copies of the same report. Some reports contained descriptions of other sites that were either not excavated or tested, and these were not included in the final site numbers unless these contained bison remains. The site numbers and associated data were then put into the database.

Wyoming Cultural Records Office Methods

The search of the WYCRO data began with a preliminary search of the Wyoming Cultural Records Information System (WYCRIS) online database to attempt to determine the extent of the records available for this research. Upon consultation with personnel at WYCRO, a formal file search was submitted for all site forms and excavation reports in Albany, Laramie, and Carbon Counties that were relevant to this research. Due to the nature of the internal database at WYCRO, the results of the file search were more easily tailored to the research needs (Table 3-2). Excavation reports were delineated in the WYCRO database and a search by WYCRO personnel returned a comprehensive spreadsheet of excavated sites, all sites in the counties with faunal remains, and sites with bison remains.

Table 3- 2. Preliminary File Search Parameters from WYCRO.

WYCRO File Search Tables	Description	WYCRO Description	Number of Documents in Spreadsheet
All_Excav	All excavated sites	A list of all sites attached to Excavation/Mitigation reports. From the master accessioning database (WYCRIS)	101
WYCRIS_Excav_ Faunal	All excavated sites search with faunal remains	All encoded sites that have been excavated and contain some kind of faunal remains. Typically bison are encoded in the 'LgMammal' category. Antelope, deer, sheep, etc. are 'MedMammal,' and everything else (rabbits, etc.) is 'SmMammal.'	17
WYCRIS_All_Faunal	All sites with faunal remains	All encoded sites, excavated or not, containing faunal remains.	349
Not_Encoded	Sites not encoded	A list of those sites attached to Excavation/Mitigation reports that have not yet been digitized.	40

The results of the WYCRO file search yielded 141 site forms and excavation reports that needed to be input into the encoding database. The resulting spreadsheet from WYCRO contained only site numbers. Therefore, the WYCRIS database was utilized to download all site forms and excavation data. A request was sent to WYCRO for additional data and excavation reports that that were not encoded. All spatial data were provided in shape files. The forms and reports were inspected individually and pertinent information was input into this researcher's database.

Issues with the Data

The advantages and disadvantages of both WYCRIS and OAHP encoding systems became apparent early in the process. The WYCRO data were organized into a more searchable format for both their personnel and user searches. The database in Wyoming is organized in a logical and relatively complete way for research. On the other hand, no useable data for the encoding fields was provided with the WYCRO database search. It was necessary to download or request copies of all pertinent forms or reports and manually input all data from the forms and reports into the database. The OAHP data also had advantages and disadvantages. Advantages included more complete file search database fields. Information such as altitude, UTMs, recording dates, etc., was already input in many of the fields and could be copied directly into the research database. However, the OAHP database was not as user-friendly for research purposes. Data are not input into the OAHP database regularly, or by easily searchable means. This issue proved true for both OAHP personnel and this researcher. This necessitated a more time-consuming approach by weeding out useful data from a much larger and irrelevant data set than was required for this research.

The use of archaeological records of this nature can be problematic. Excavation and site recording techniques vary over time and between different investigators. The analysis of faunal remains is often more challenging. The fragmentary nature of many faunal remains in archaeological contexts often precludes identification of bone specimens. During the course of this research, it was found that faunal specimens were often recorded as absent or present with no attempt made to identify the specimen. In some recordings, specimens were classified as small, medium, or large mammal. Bison remains, fortunately, are easily recognizable due to their large size and robusticity.

Assumptions are necessary to allow for the comparison of unrelated data. These assumptions can create validity issues if they are not accurately defined. Some assumptions do not apply to all cases. An example of this is the assumption that excavation information was more detailed than that of surface recorded sites. In addition, there are large portions of the study area that have not been subject to archaeological inventory whereas other areas (especially western Carbon County) have been subject to intensive survey. This potentially skews these data towards trends in bison distribution that contain qualities of the Wyoming Basin. For this reason, these trends are only minimally discussed, and the results of this part of the analysis should take this into account.

To be able to analyze different data collection results as a whole, the main assumption was that the original recording data were accurate. Upon analysis of the archival records, it became apparent that some faunal species or tools may have been misclassified. In these instances these data were left as originally recorded. There are inconsistencies present between the original recordings, but attempting to reclassify some recorded data without assessing others would introduce reliability issues with this analysis. Therefore, the results presented in all previous records were assumed to be correct.

It should be noted that overall this data set should not be considered an exhaustive list of known bison remains in the study area. Data sources from private collections, museums, and other universities were not utilized in this study. New data are always emerging and being made public or added to the archaeological record. This list is complete as of the 2012 file search dates. Any bison remains or excavation data reported past that date are not included in this data set. It should also be noted that there are vast expanses of private and public land that have not been subject to archaeological research. The information presented here should instead be viewed as a suggestive trend of the distribution of prehistoric bison in the study area. As new data are discovered, these trends may shift or become strengthened. Such is the nature of archaeological, and indeed, all scientific research.

Analyses

A primarily qualitative study was undertaken using the information from all excavations with faunal remains and surface sites with bison remains in the study area. This approach was utilized due to the high degree of variability in the methods and terminology used for site recording. By conducting analyses that do not rely on parametric assumptions, it is possible to maintain dependability of the analyses and ensure validity in the database. The qualitative analyses consisted of a series of inductive and deductive comparisons of information in the data fields to identify relationships. Minimal analyses were conducted as well to calculate the number of data sources within specific parameters (e.g. number of bison, number of open camps, etc.) All fields were examined and the important relationships are summarized in the results section below.

Two non-parametric statistical analyses are included in this analysis. First, a Chi-square test of bison absence or presence by geographic location examined the spatial patterning of sites to see if any significant patterning in bison distribution across different altitudes was present. The Chi-square test is a measure of whether the variables are dependent and therefore related. Second, a kernel density analysis was conducted on all sites assigned to cultural components and those with radiocarbon dates to estimate the density of sites in the study area. A kernel density test applies a user-defined radius around each map plotted site point, and these are statistically compared with neighboring site points to define a smoothed area of estimated probability density distribution.

Radiometric data were an important source of information for each of the analyzed sites. All radiocarbon dates were compiled, calibrated, and reported in calibrated years before present (cal BP). These were examined via sum probability distributions. Sum probability distributions allow for the analysis of the total variance between neighboring dates with similar probabilities to recognize the sum variation across all periods (Eighmy and LaBelle 1996; Oinonen et al. 2010; Peros et al. 2009; Williams 2011).

RESULTS

The data from both WYCRO and OAHP records were combined into one data set to analyze the overall presence and absence of bison in archaeological contexts in the study area. In addition, non-archaeological bison specimens utilized in this study were included in the final data set and mapping of the study area. The results of this analysis are presented as follows. First, a broad discussion of trends in the data is presented. This includes a quantitative discussion of site types in the study area and which are associated with bison or non-bison remains. Also, a brief quantitative analysis is included of sites with other faunal remains and what those remains are. This is followed by a more detailed discussion which includes distribution trends of faunal sites via radiocarbon analysis and a more generalized analysis of sites with tool technologies that are assigned to cultural chronologies. These data were compared against altitudinal trends using the statistical application of a kernel density analysis and a Chi-square test.

The entire file search yielded 834 sites with faunal remains in the study area (Figure 3-1). These sites include both excavated sites and those that were surface recorded only. Site forms from surface recordings only were analyzed for the presence of bison remains. Surface sites that did not have indications of bison remains were excluded from further study. Excavation reports were reviewed for the presence and absence of bison, and presence of other faunal remains. Upon completion of the records review of the 834 sites, the final number of excavated sites with faunal remains and surface only sites with bison remains totaled 272 (see Appendix A). One hundred forty-one of these sites were located in the WYCRO records and 131 of these sites were identified in the OAHP records. Of the 272 total sites, 206 were excavations with faunal remains present (including excavations with or without bison present). Surface recorded and natural occurrences of bison remains totaled 66 out of the 272 sites. Out of the 272 sites utilized in this study, 156 contain bison remains and 116 sites do not have bison remains present.

Faunal Remains Discussion

For the purposed of this research, sites were divided into three categories. These include sites that contain only bison remains; sites that contain bison remains but also possess other mixed faunal remains; and sites that contain other mixed faunal remains and no bison. Of the 156 sites with bison, 96 contained *only* bison remains. However, 57 of the 156 sites in which bison were present also contained other faunal remains. Table 3-3 details the frequency and percentage

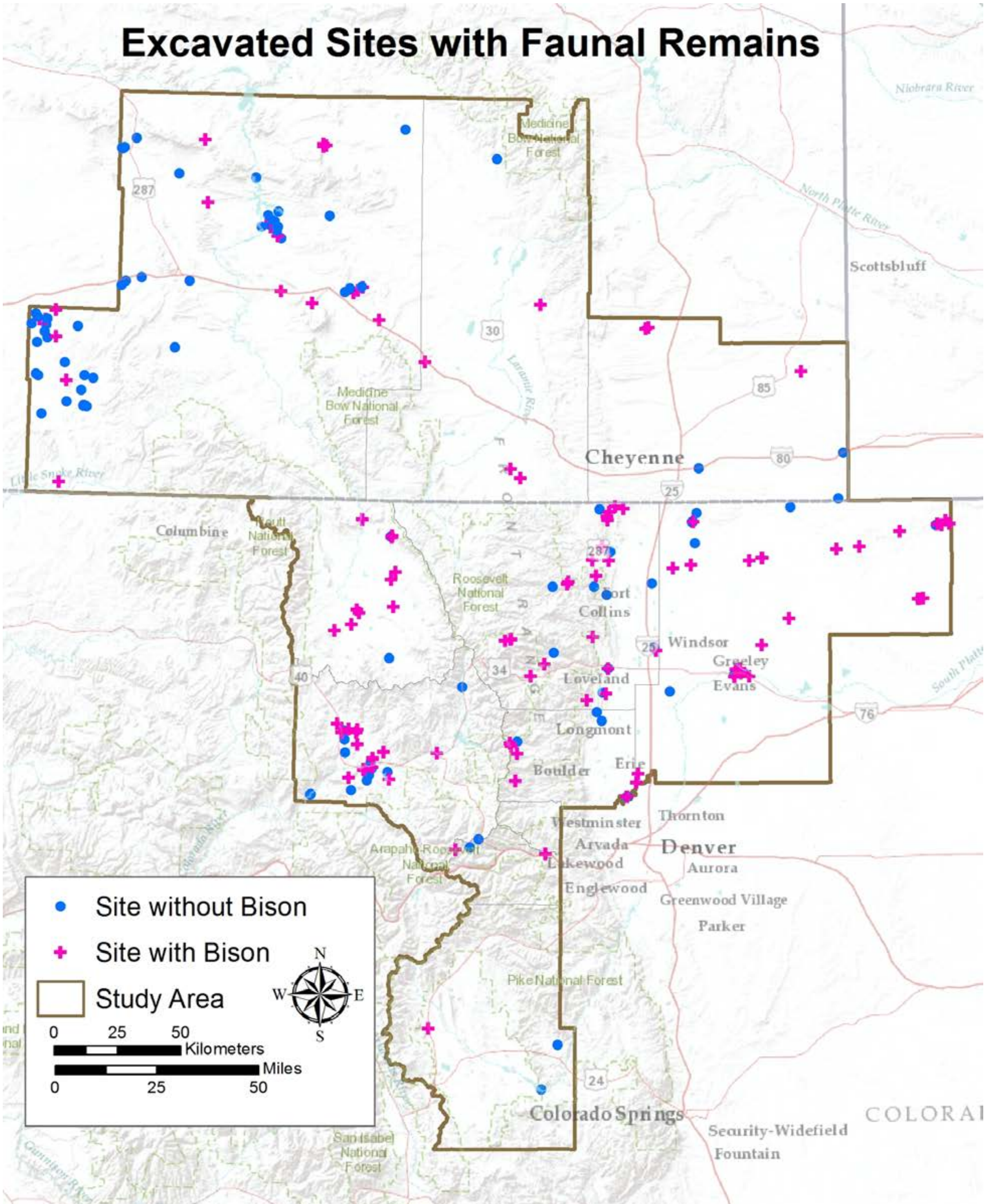

Figure 3-1. All faunal sites in study area.

Table 3-3. Species Presence on Bison and Non-bison Sites.

Species*	Presence on Bison Sites (n=156)	Presence on Bison Sites (% / Ratio)	Presence on Non-bison Sites (n=116)	Presence on Non-bison Sites (% / Ratio)	Ratio of Presence on Bison and Non-bison
Bird	4	2.5 (1:39)	4	3.4 (1:29)	1:1
Elk	6	3.8 (1:26)	6	5.2 (1:19.3)	1:1
Rodent	7	4.5 (1:22.3)	8	6.9 (1:14.5)	1:1.14
Other	8	5.1 (1:19.5)	7	6 (1:16.6)	1.14:1
Rabbit	8	5.1 (1:19.5)	18	15.5 (1:6.4)	1:2.25
Deer	12	7.7 (1:13)	4	3.4 (1:29)	3:1
Pronghorn	17	10.9 (1:9.2)	11	9.5 (1:10.5)	1.5:1
Small Mammal	13	8.3 (1:12)	25	21.6 (1:4.6)	1:1.9
Medium Mammal	13	8.3 (1:12)	28	24.1 (1:4.1)	1:2.2
Large Mammal	22	14.1 (1:7)	29	25 (1:4)	1:1.3
Unspecified	40	25.6 (1:3.9)	74	63.8 (1:1.6)	1:1.85

* Some sites contain multiple species that are counted more than once in the above categories. Each category is exclusive. Therefore, it should be noted that the columns do not add up to the total number of sites or total to 100 percent.

of the different types of faunal remains across the entire set of sites in the study. It should be noted that some of the sites identified multiple species. Sites without bison remains (n=116/272) consisted primarily of unidentified bone (n=74), meaning bone was noted on the site but no attempt was made to identify species. Nearly all of the sites, except sites containing bison only, consisted of bone that was only identified to the level of small, medium, or large mammal bone that were not identified to any mammalian species level. Many of the identified faunal remains are from ungulates such as bison, deer, elk, and pronghorn. It is likely that many of the unidentified medium and large mammal specimens could be classified as ungulates. Small mammals, such as rabbits, are less common but tend to be identified more commonly on sites without bison. Pronghorn and deer were found more often in association with bison than by themselves.

Radiocarbon Results

This section presents the results of the analysis of radiocarbon dated components that contain faunal remains from within the study area. Upon completion of the records review, the number of these sites that contained radiocarbon dates was 152 out of the 272 total sites. Most of the radiocarbon dates came from charcoal samples from within hearth features. Only a small portion of radiocarbon dates resulted from the faunal remains themselves. Sixty-four of the excavated sites with radiocarbon dates yielded more than one date, either from multiple components, or different hearth features. In addition, 13 natural occurrence bison specimens with radiocarbon data were included in this analysis. The total number of radiocarbon dates used in this analysis was 291.

Provenience data from sites with multiple radiocarbon dates was necessary to correlate bison remains with appropriate dates. The use of excavation data helped in this regard as the reports generally provided detailed information on components, provenience, and excavated features. Bison remains on these sites could, at the very least, be linked with a dated component level. The total number of radiocarbon dates that could be associated with bison remains and bison with other faunal remains was 100 out of the 291 radiocarbon dates. These account for 34 percent of the total radiocarbon dated occurrences. The remaining 191 radiocarbon dates are associated with non-bison faunal dates (66 percent). The lower number of overall radiocarbon dates associated with bison rather than other faunal remains was taken into account when analyzing the overall distribution of dates.

Calibration

The radiocarbon dates analyzed from the excavation results were primarily reported as conventional dates in excavation reports and site forms. However, production of ^{14}C has not remained constant and varied in the atmosphere at different times (Stuiver and Reimer 1993). This is due to fluctuations over time in solar activity, changes in CO_2 ventilation and biomass in the atmosphere, and shifts in the earth's magnetic fields (Mauquoy et al. 2004). To compensate for these variations, radiocarbon dates are calibrated against tree ring records which have known radiocarbon dates and are correlated with calendar years. When a radiocarbon date is calibrated, that date is synchronized with the tree ring record and this provides a new range of dates adjusted for the amount of radiocarbon present in the atmosphere at the time of the date. Calibration of a ^{14}C age allows the determination of a calendar age for the sample that can be reported as calibrated years before present (cal BP) or by calendar years A.D./B.C. For the purposes of this study, the calibrated radiocarbon dates are reported as cal BP to better compare with paleoclimate studies which are primarily reported in RCYBP.

All radiocarbon dates obtained for this research were calibrated using the CALIB 7.0 software and the IntCal13.143 calibration curve and reported in cal BP (Stuiver et al. 2005). This program converts radiocarbon ages to calibrated calendar years by calculating the true age of a radiocarbon date through a probability distribution. All conventional radiocarbon dates were calibrated, even when previously calibrated dates were available from former researchers, to maintain consistency in the calibration method results. The output of the probability confidence interval of 68.3% (1 sigma δ) on the calibration curve was used. The calibrated radiocarbon data is presented in Appendix B.

The calibrated radiocarbon data were analyzed as a grouped sum probability or distribution of pooled radiocarbon probabilities. Often, single radiocarbon dates, uncalibrated RCYBP dates, or calibrated date range averages are used in analysis. However, presenting averaged dates for large groups of dates pose inaccuracies as these do not show the amount of variation within individual date ranges or provide complete data on dates that overlap. There is a great deal of depth and variation in radiometric measurement. Instead, by pooling the distribution of calibrated date ranges into a sum probability, the sum of overlapping dates can show patterns for periods of high probability (Eighmy and LaBelle 1996:56). The use of summed probability plots of radiocarbon data is prevalent in archaeology to aid in identifying paleoclimate trends (Buchanan et al. 2008; Peros et al. 2010; Surovell et al. 2009) and in prehistoric occupation studies (Eighmy and LaBelle 2006; Peros et al. 2009; Surovell and Brantingham 2007). The sum probability distributions highlight periods in the past where both the greatest (with the potential to exceed 1) as well as lowest cumulative probability for prehistoric bison utilization occurs.

Increased use of sum probability distributions in archaeological research has also revealed several limitations (Surovell et al. 2009; Williams 2011). First, intra-site sampling of radiocarbon dates is often based on stratigraphic exposures of dateable material. This sampling method does not necessarily constitute a representative sample of site occupation or far more serious, can over-represent site occupation. Multiple radiocarbon dates taken from the same occupation can skew the sum probability data erroneously. An attempt was made to alleviate this issue during the research phase by eliminating repeated radiocarbon dates from the same occupation on sites in which multiple contemporaneous dates had been collected. Care was taken to utilize radiocarbon dates that represented all occupations of the site while not over representing one occupation over another.

A second limitation of sum probability data is that an adequate sample size is necessary. Too few radiocarbon dates in a study severely limits the utility of this analysis method (Williams 2011). A robust sample size is necessary for repeatability of data and the sample size chosen for this research is adequate. Third, effects from calibration of radiocarbon dates should be considered. The calibration curve may introduce errors into the sum probability distribution that cannot be avoided. With an adequate sample size, these errors should be moderated.

Fourth, the problem with taphonomic bias is inherent in all radiocarbon data. In the archaeological record, there is often a logarithmic increase in the number of radiocarbon dates with younger sites. This often leads to an overrepresentation of dates from younger deposits than older ones. Since taphonomic processes (destructive processes such as erosion, weathering, etc. that destroy the archaeological record) increase with age, it is important to recognize that sum probability distributions will reflect this issue.

Statistical methods that attempt to correct for taphonomic bias have been conducted (Surovell and Brantingham 2007; Surovell et al. 2009; Williams 2011). These statistical corrections are not without their own introduced error to the overall analysis. Therefore, corrections for taphonomic bias are acknowledged but are beyond the scope of this work. Instead, the influence of destructive processes on archaeological sites in this study is recognized as an inherent issue with this type of data. The restrictions of sum probability distributions are acknowledged here but the utility of this analysis tool surpasses these limitations. Sum probability data therefore assumes that the frequency of dates is best interpreted as reflecting general trends in bison utilization. In this study, sum probability distributions were preferable to calibrated midpoint dates and took into account the distribution of bison across more finely-tuned temporal and spatial scales within the study area.

Problems with Sample Size

The general sum probability data reveal that bison are present across the study area through much of prehistory, though in variable distributions based on altitude and time. While this is certainly an effect of the archaeological record, it should be noted that the distribution of sites in the study is also affected by the constraints and extents of the study region general. Figure 3-2 displays the percentage of radiocarbon dates per altitudinal range. It is apparent from this figure that certain altitudes are better represented than others. Table 3-4 exhibits the square kilometers and percentage of the study area within each altitude range. The table further shows the ratio of bison and non-bison sites to km^2 at each altitude range. This reveals that sites are not distributed evenly across the study area. Most sites fall within the 1500 to 2500 m altitude ranges. Fewer bison and non-bison sites are found at altitudes over 2500 m. Several explanations for this variability are possible. The area below 1500 m has the smallest percentage (7.3 percent) of area in the study. In addition, the lack of sites in this region may be biased due to this being an area with little archaeological inventory due to private lands which are generally not subject to archaeological investigations. The altitudes between 1500-2500 m cover much of the study area (63.3 percent) and have also benefited from more archaeological investigations. The altitude range from 2500-3000 m has also been subject to little investigation. A further issue is that this area is primarily sub-alpine and consists of dense forest and steep slopes, neither of which is amenable to site preservation, cultural habitation, and these in turn preclude the ability to discover archaeological deposits. The range over 3000 m in altitude consists of harsh alpine environments that are not amenable to good faunal preservation.

The study area covers 73,973 km^2. The altitude range of 2000-2500 m amsl possesses the highest representation of dates (n=140). This misbalance stems from the fact that a majority of the study area (40.6 percent) is located in this altitude range. In addition, the areas of Carbon County in Wyoming that fall within the 2000-2500 m amsl altitude also possess a higher number of radiocarbon dated sites than most other areas. Conversely, the portions of the study at the altitude extremes (less

Table 3-4. Area and Percentage of each Altitude Range in the Study Area

Altitude Range (m)	Area in km^2	% of Study Area	Bison Site/ km^2	Non-bison Site/ km^2
< 1500 m	5,460	7.3	1/287 km^2	1/910 km^2
1500-2000 m	16,776	22.7	1/399 km^2	1/419 km^2
2000-2500 m	30,003	40.6	1/400 km^2	1/484 km^2
2500-3000 m	15,167	20.5	1/1517 km^2	1/3033 km^2
>3000 m	6,567	8.9	1/657 km^2	1/2189 km^2
Total	73,973	100	1/474 km^2	1/638 km^2

than 1500 m and greater than 3000 m) possess the fewest number of dates due to a smaller amount of the total area and a lower number of radiocarbon dated sites. Regardless, even with the acknowledgement of inherent biases introduced by natural and human processes that interfere with identifying true site distributions, enough data are available to analyze and thus make inferences about bison distribution across time and space.

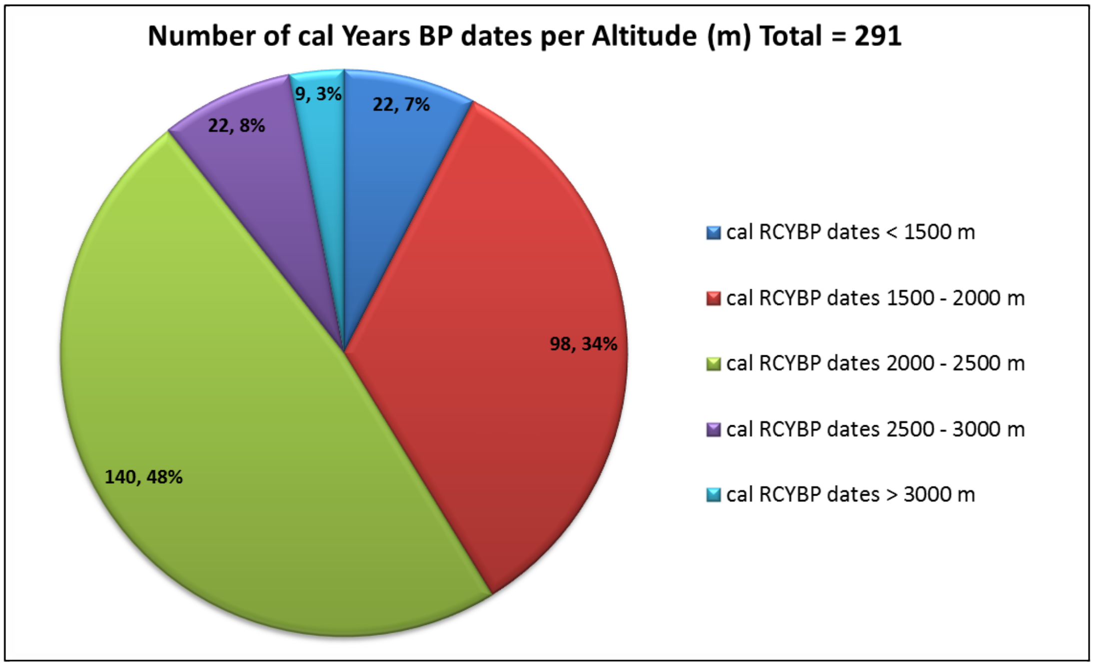

Figure 3-2. Number of cal Years BP per altitude range.

Spatial and Temporal Analysis

The spatial and temporal sum probability distribution of all 291 radiocarbon dates is shown in Figure 3-3. This figure represents all dated faunal contexts in the study area including dates for bison

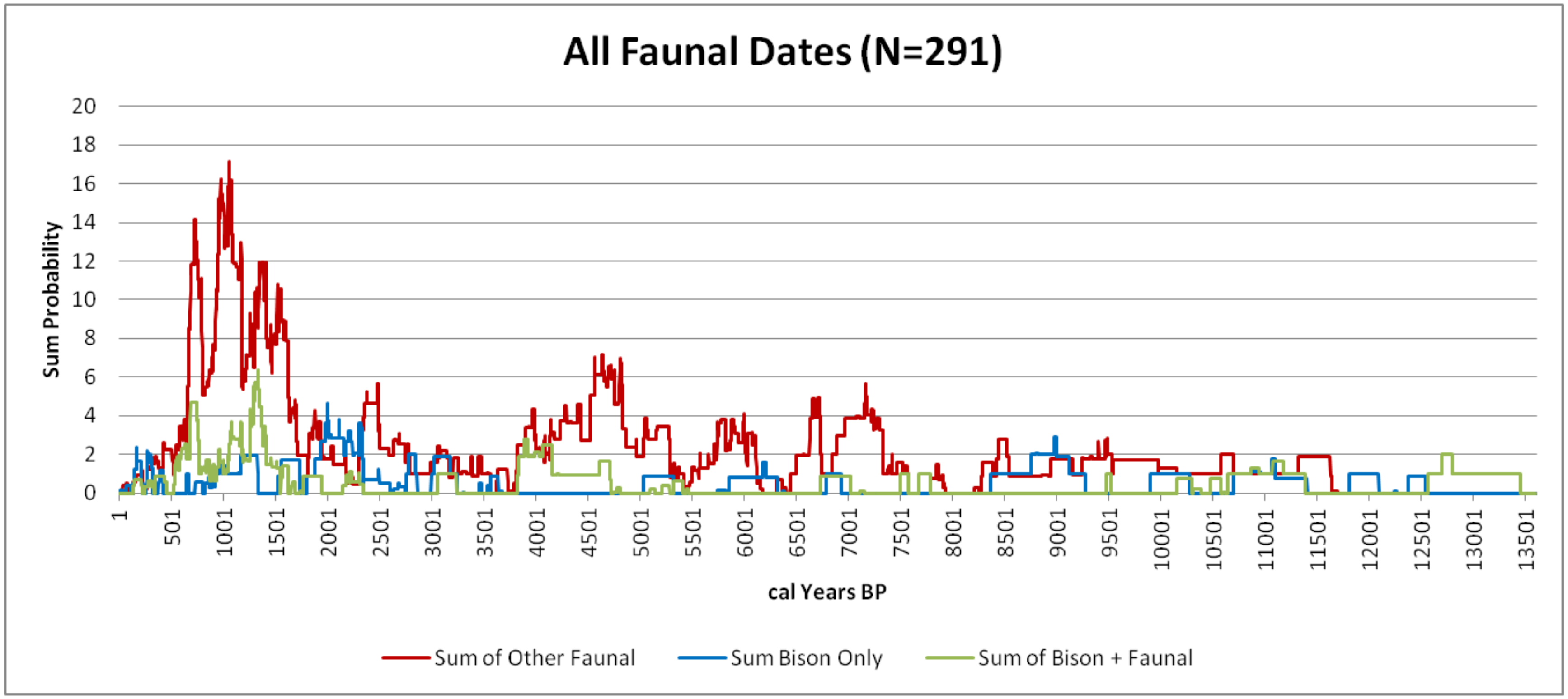

Figure 3-3. Sum Probability distribution of all 291 radiocarbon dates from faunal contexts in the study area.

and other faunal dates at all altitude ranges. These data represent the sum probability values associated with specific calibrated date ranges resulting from individual years and indicates areas that exhibit the highest (may exceed 1) to the lowest probabilities (may be less than 1) for prehistoric bison presence or absence in relation to other faunal remains.

The results of the analysis indicate that a majority of the radiocarbon dates occur post-1650 cal BP. This is true for sites with bison remains and especially for those with other types of faunal remains. The sum probability distribution indicates greater representation from the Late Prehistoric period than any other period. Progressively older dates have less representation, likely influenced by taphonomic processes (Surovell and Brantingham 2007). The sum probability distribution for all dates indicates a general trend of increasing and decreasing probability of dates over time, which may represent variations in use of the region at different times due to climate conditions, availability of food sources, and changing technological, cultural, and subsistence practices.

Periods with more representation, such as the Late Prehistoric, may indicate that conditions were favorable for site preservation or that human occupation and utilization of the region increased during these peak times. It should be noted that the relative decreased effect of taphonomic processes on progressively younger deposits is to be expected (Surovell and Brantingham 2007). Therefore, unexpected gaps in the sum probability distribution over various time periods become clearer and more informative. Table 3-5 and Figure 3-4 reveal gaps in the radiocarbon record in which the sum probability distribution reaches zero. The scarcity of sites during the Paleoindian period is to be expected. The plateau effect of the calibration curve coupled with the small sample size likely exacerbates this issue. This trend is not necessarily due to a lack of occupation, but instead by increased pressure of taphonomic processes disturbing intact cultural deposits resulting in a small sample size of radiocarbon dates.

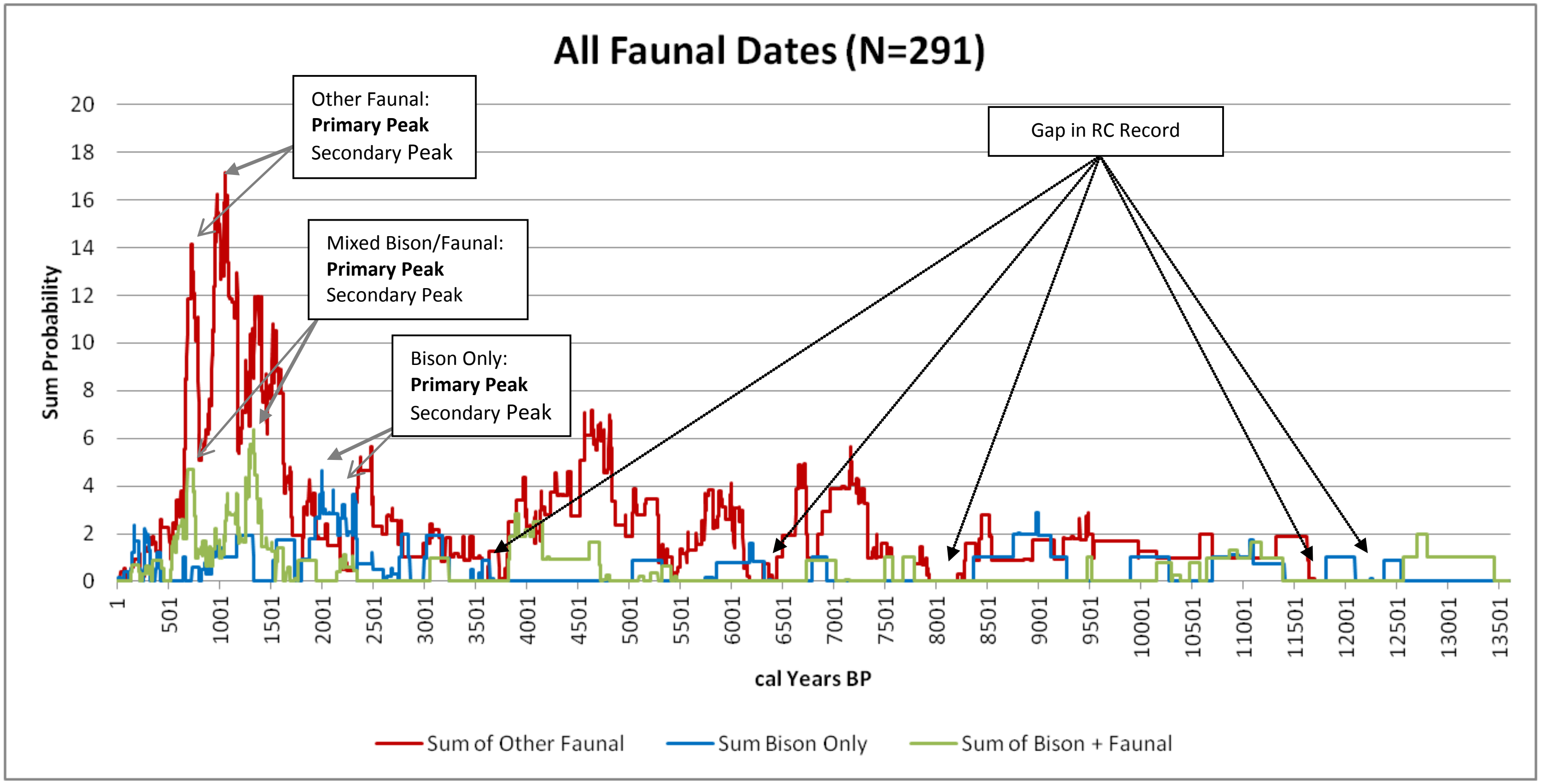

Figure 3-4. Sum probability of all faunal dates highlighting primary and secondary peaks for other faunal dates, bison only dates, and mixed faunal/bison dates. Major gaps in which the radiocarbon record reaches zero are also emphasized.

Table 3-5. Years without Representation in the Radiocarbon Record (cal BP).

Beginning cal BP Date	Ending cal BP Date	Gap in Years
3761	3734	27
6451	6410	41
7685	7586	99
8210	7937	273
11,663	11,652	11
11,817	11,707	110
12,381	12,272	109
12,567	12,547	20

However, during the vast Archaic period, more varied trends in the sum probability distributions are evident. This is especially true from 7937 cal BP to 8210 cal BP. This 273 year period is the longest gap in the radiocarbon record for the study area and is interesting to note.
In fact, prior to 7900 cal BP until roughly 7500 cal BP, there is low and staggered evidence of occupation.

Several other instances in which there are data gaps include the period around 3700 cal BP. and the period around 6500 cal BP. These dates are associated with the Middle Archaic and Early Archaic periods, respectively. While the data gaps associated with these periods are brief (see Table 3-5), they do indicate areas of decreased occupation and utilization of faunal species. During variable spans of the Archaic period, there appear to be definitive periods in which human use of the area is minimal. Data gaps in the radiocarbon data become more common post-11,500 cal BP. Again, this is to be expected due to preservation issues emphasized by time.

Figure 3-4 also delineates primary and secondary peaks in dates with bison remains only, dates of bison mixed with other fauna, and non-bison faunal dates. The primary and secondary peaks of dates for bison only fall within the Late Archaic period. The peaks for bison with mixed faunal and non-bison occurrences fall within the Late Prehistoric period.

Ratio of Bison versus Non-bison Radiocarbon Dates

Figure 3-5 displays the ratios of bison associated dates to non-bison faunal dates across time. This analysis was conducted to highlight periods in which bison are more or less represented in the archaeological record. As previously noted, the sample sizes are small with comparably older dates. For example, the Paleoindian period may be representative of only a handful of dates. This potentially skews the ratio analysis and over-exaggerates the ratios of bison to non-bison occurrences. Extreme spikes in the ratio data are a result of comparison with sum probability data that totaled less than 1. Therefore, only the ratios of well-represented periods are discussed here. The Middle Archaic period exhibits a ratio that slightly favors non-bison faunal exploitation over bison. However, the ratio figures indicate a greater preponderance of bison over other faunal during the Late Archaic period and Protohistoric period. Interestingly, during the Late Archaic period, the ratio of bison to non-bison sites is quite extreme. This result is significant and indicates a greater reliance on bison than non-bison species during this period.

The Late Archaic period bison preponderance abruptly drops at the beginning of the Late Prehistoric period, specifically during the Early Ceramic period. Possible causes of this drop off may have been overhunting of bison during a time when human populations were increasing or changes in climatic conditions that affected bison populations in the area. During the remaining Late Prehistoric period, the ratio of bison to non-bison dates still remains low. The older periods of the Early Archaic and Paleoindian indicate a somewhat greater representation of bison but this data is skewed due to low (< 1) sum probability distribution data due to small sample size. Overall, the ratio trends are compelling. The preponderance of bison utlization in the Late Archaic period is a significant result.

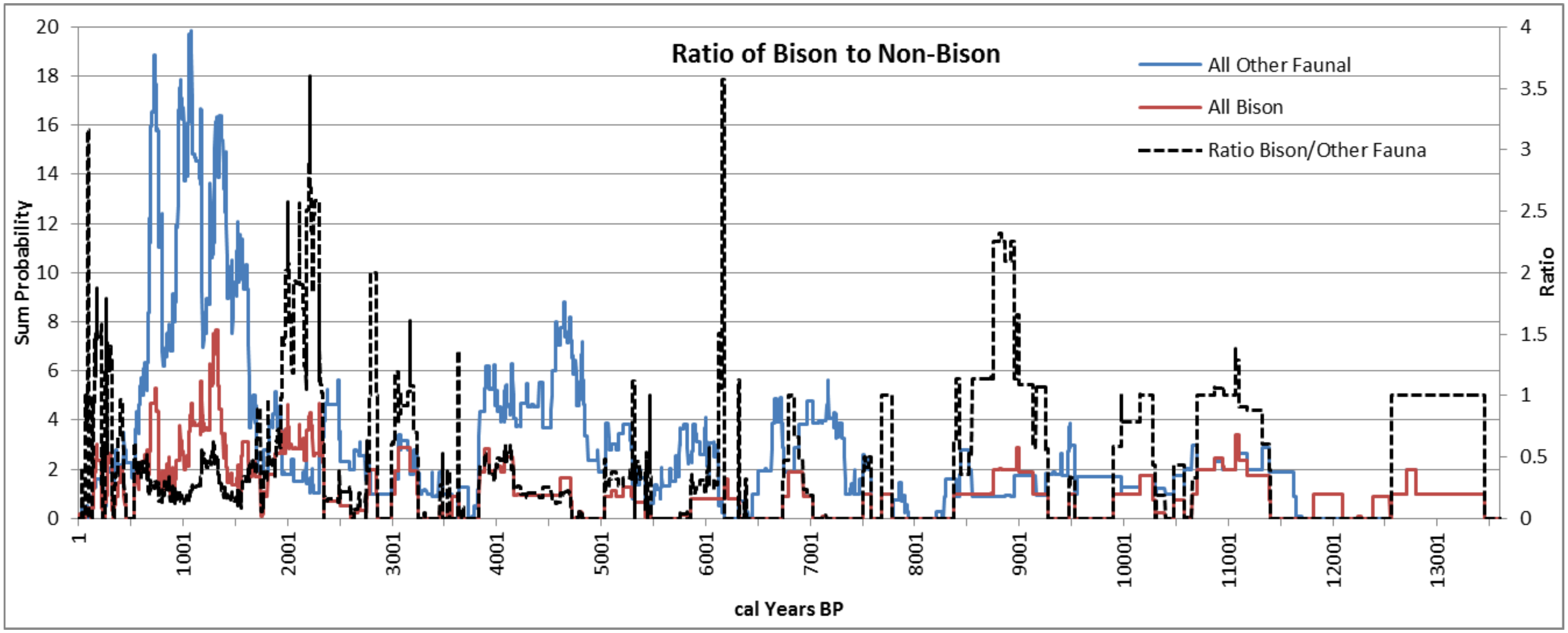

Figure 3-5. Sum Probability Distribution of the ratio of bison to non-bison radiocarbon dates.

Probability of bison

The information from radiocarbon dates from different ages and different altitudes are not particularly telling when expressed separately. However, when these two forms of data are combined, patterns do emerge. To better understand the relationship between bison and their environment, altitude and associated number of dates was also investigated.

Figures 3-6 to 3-10 display the sum probability of faunal distribution, with a particular focus of discussion in identifying trends in bison distributions, at different altitudes over time. The altitude data can be discussed in broad trends related to climate and vegetation zones. As mentioned previously, the modern altitude distribution of ecozones is not necessarily representative of those in the past. Climate fluctuations over time would have caused shifts in the locations of different ecozones. Therefore, the altitude ranges are discussed and analyzed here in arbitrary 500 m increments.

Below 1500 m amsl (<4920 ft) only dates with bison or bison with other faunal remains are represented in the radiocarbon distribution (Figure 3-6). These are represented by 22 radiocarbon occurrences on the Great Plains in eastern Larimer and Weld Counties, Colorado. Most of these dates fall within the Late Archaic to Late Prehistoric periods. The dates associated with bison peak during the Late Archaic period whereas the dates from bison with mixed fauna peak during the Late Prehistoric period. The Early and Middle Archaic periods are lacking in dates. However, three dates with bison remains occur during the Paleoindian period. The fact that there is a lack of sum probabilities for non-bison other faunal remains is noteworthy. The areas below 1500 m only cover the extreme eastern portions of the study area (7.3 percent of the study area). Much of this area has not been subject to intensive cultural resource studies and excavation data in these areas are limited. Also, while non-bison surface sites were eliminated from this study, undated non-bison faunal remains have been found on surface sites in this area. From 1500-2000 m amsl (4920-6560 ft) the area is composed of the Great Plains abutting the foothills of the Rocky Mountains (22.7 percent of the study area). The Late Prehistoric period is best represented, especially with dates from faunal occurrences other than bison (Figure 3-7).

Bison dates are generally lower in representation, especially during the Early Archaic period. These data support the paleoclimate data for the Altithermal drought during this time. Bison were thought to have largely disappeared from the plains and these data support this thought. Bison presence appears to become more common at this altitude range in the Late Archaic period, lowers again during much of the Late Prehistoric period, and then increases during the Protohistoric. Meanwhile, other faunal subsistence increases significantly during the Late Prehistoric period and drops off during the Protohistoric. This tends to coincide with changing tool technologies and subsistence practices.

The altitude range from 2000-2500 m amsl (6560-8200 ft) is the best represented in the sum probability distributions (Figure 3-8). This is primarily due to the fact that this altitude range is the most abundant in the study area (40.6 percent of the study area), representing the mountain parks and much of the lower altitude areas of the Wyoming portion of the study. While these data may be skewed due to the fact that much of the study area falls within this altitude range, it is noteworthy that the number of bison dates from the same altitude range is not higher as well. Bison do occur more commonly during the Late Prehistoric period and during the Paleoindian period at this altitude range. Bison are present in lower sum distributions during the Archaic, though small peaks of distributional patterning do occur during the Middle Archaic. Non-bison faunal distributions tend to trend higher during the Archaic period. Interestingly, other

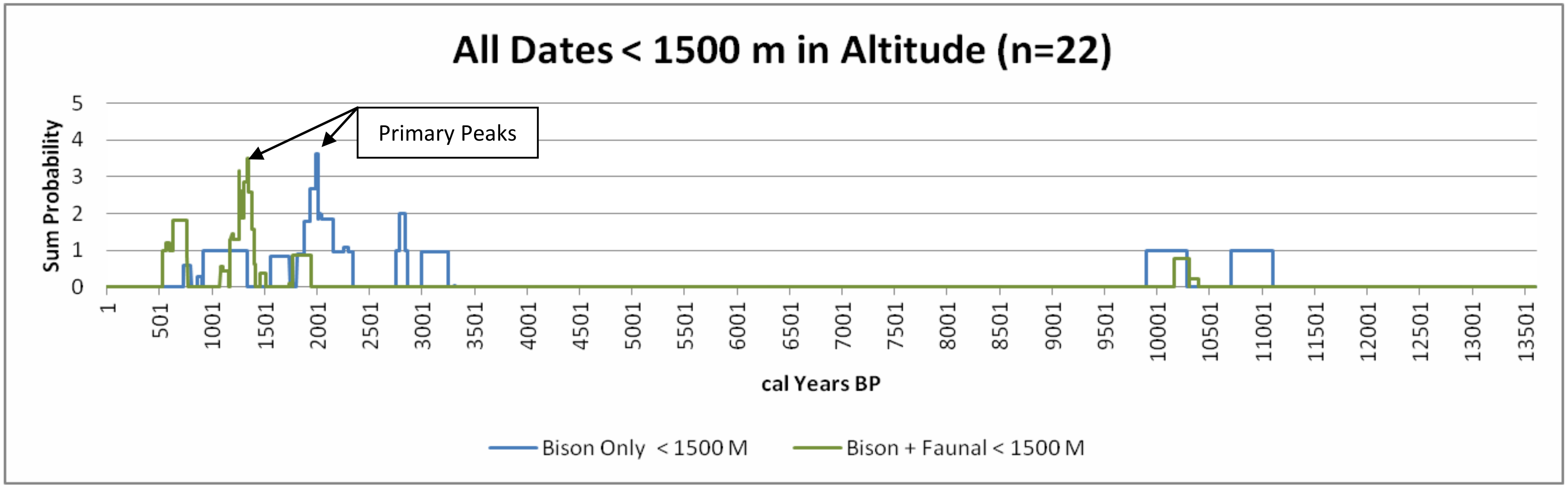

Figure 3-6. Sum Probability Distribution of faunal dates (n=22) below 1500 m in altitude.

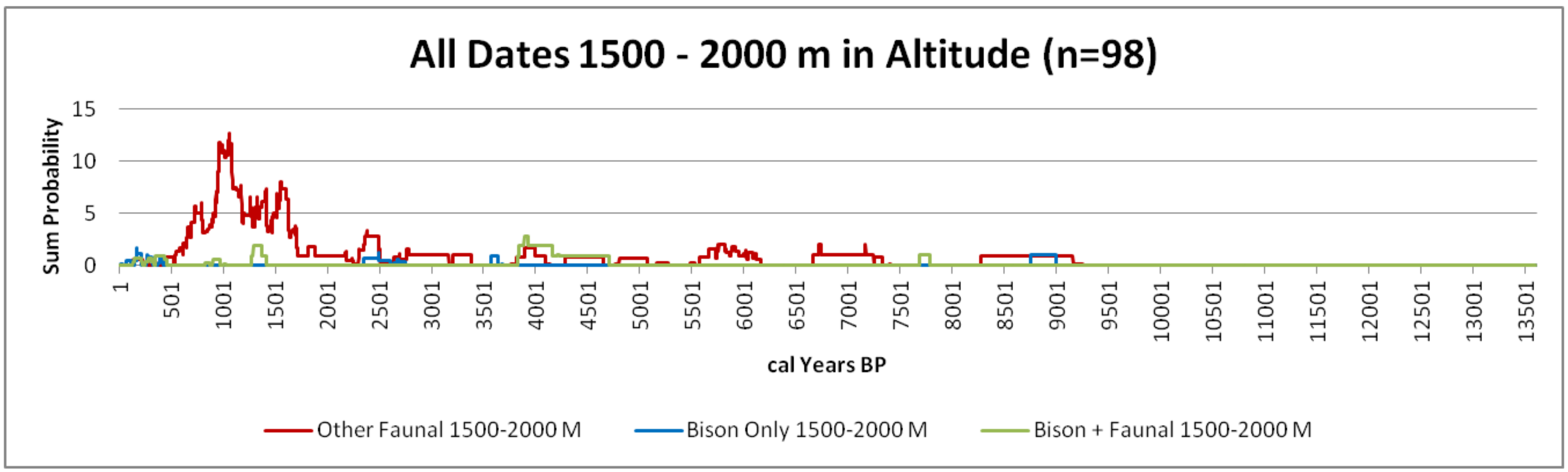

Figure 3-7. Sum Probability Distribution of faunal dates (n=98) between 1500-2000 m in altitude.

faunal distributions for the Late Prehistoric and Paleoindian periods follow similar trends as those of bison, which may indicate that the mountain basin areas and Wyoming Basin were prime areas for hunting a variety of game, including bison, during these periods.

Of note is the paucity of bison in dated components from 2500-3000 m amsl (8200-9240 ft) and the lack of other faunal remains in sites above 3000 m amsl (Figures 3-9 and 3-10). The sample sizes from these areas is minimal. Only 22 radiocarbon dates from 2500-3000 m and 9 dates from greater than 3000 m are identified in the study. Bison presence data fall primarily during the Early Archaic and Paleoindian periods. One occurrence from the Late Archaic period is observed too. The low number of dates is possibly an excavation bias and poor faunal preservation rather than a real result. High altitude regions were well utilized by prey species and their human hunters. Additionally, high altitude excavations certainly have occurred (Benedict 1992; Benedict and Olson 1978). In addition, the bison dates from above 3000 m are all from natural occurrence bison remains. Therefore, several factors may be interfering with these data.

First, while excavations do occur at high altitude, the file search results indicate that none of these contain faunal remains. Preservation of bone at high altitudes is poor, as evidenced from the lack of bone found on alpine sites. Soil deposition above tree line is generally negligible.

Additionally, the areas above 2500 m amsl are often composed of steep slopes within the sub-alpine zone, and these areas are poor locations for human habitation and especially for intact site preservation. The sub-alpine forest has thick pine duff and ground vegetation, precluding the ability to identify surface archaeological sites. Regardless, people utilized the high altitude zones to hunt animals as evidenced from stone tools, game drives, and camps (Benedict 1999; Lee and Benedict 2012).

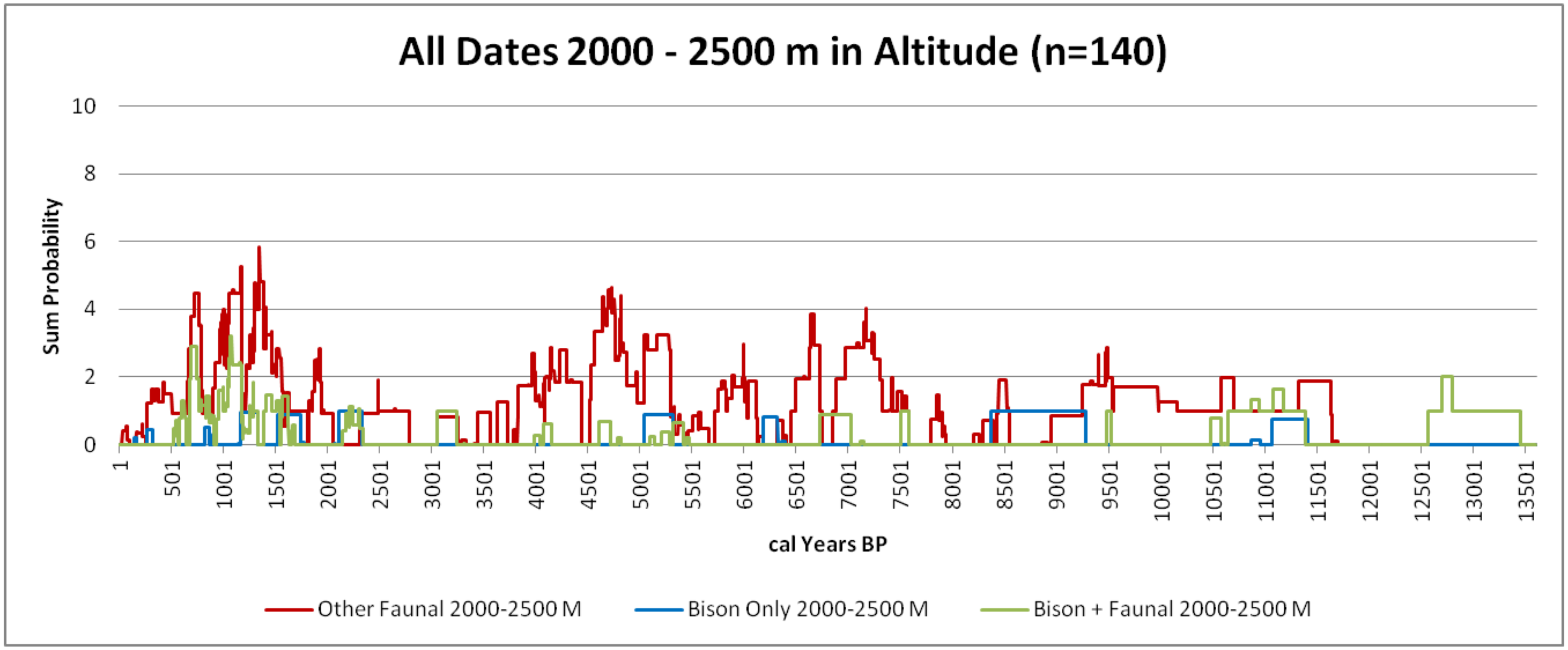

Figure 3-8. Sum Probability Distribution of faunal dates (n=140) between 2000-2500 m in altitude.

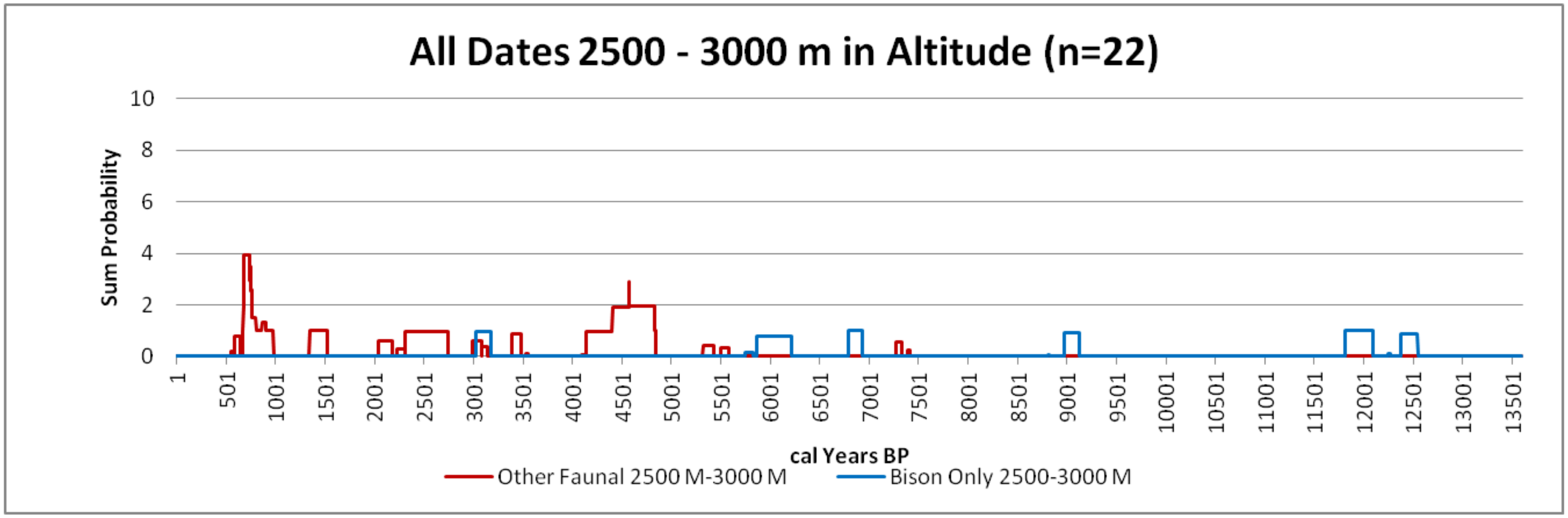

Figure 3-9. Sum Probability Distribution of faunal dates (n=22) between 2500-3000 m in altitude.

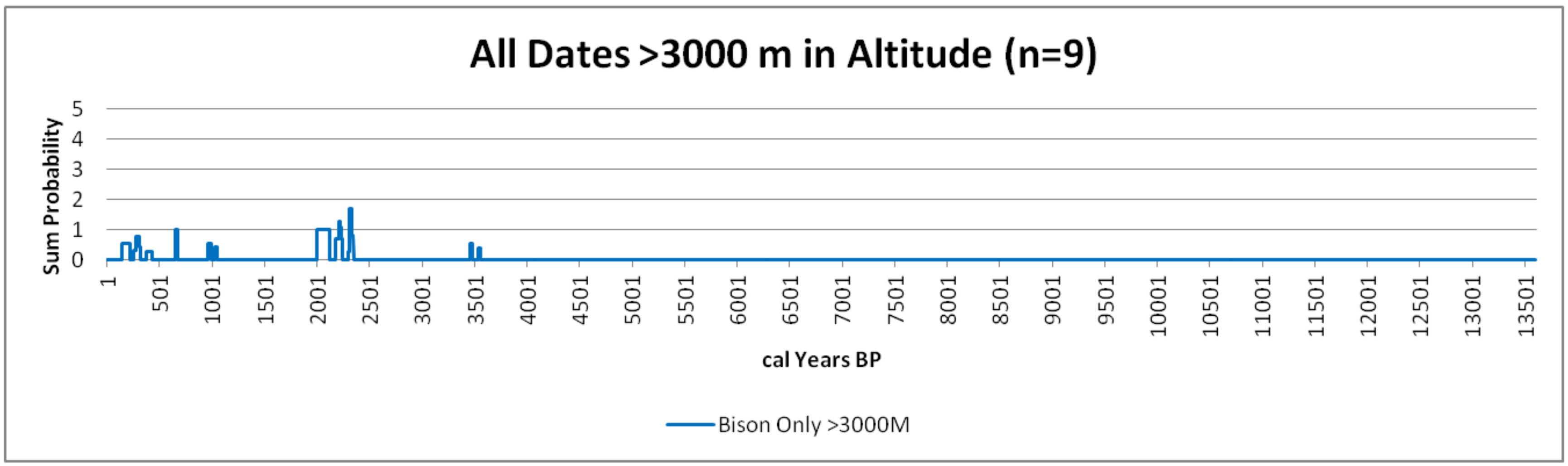

Figure 3-10. Sum Probability Distribution of faunal dates (n=9) over 3000 m in altitude.

Bison Absence via Sum Probability

The above discussion focuses on the presence of bison in the archaeological record. However, this research is also interested in the *absence* of bison data. Figure 3-11 is the sum probability distribution of only radiocarbon dates associated with bison (either bison only or bison and mixed fauna). The figure identifies 28 gaps in which the radiocarbon record reaches zero. These gaps occur in all periods except for the Early Ceramic of the Late Prehistoric period and the entire Late Archaic period.

Table 3-6 totals the number of years absent in each cultural period. The Middle Archaic period contains the most gaps but for shorter duration. The longest gaps in the radiocarbon data occur during the Early Archaic and Paleoindian periods. The longest gap is 582 years from 8372-7790 cal BP. These dates correlate with the beginning of the Altithermal drought.

Table 3-6. Gaps in the Radiocarbon Record in Bison Associated Dates.

Cultural Period	No. of Times Radiocarbon Record Reaches Zero	Total Gap Years in Period
Protohistoric	1	22
Late Prehistoric	2	82
Late Archaic	0	0
Middle Archaic	10	943
Early Archaic	6	1249
Paleoindian	9	1987

Archaeological Component Dating

While the use of radiocarbon dating via sum probability distributions is enlightening, the data only consists of a portion of the entire data set, and gaps in the radiocarbon record were identified. Since only a little over one-half of the 272 total sites in this study (56 percent)

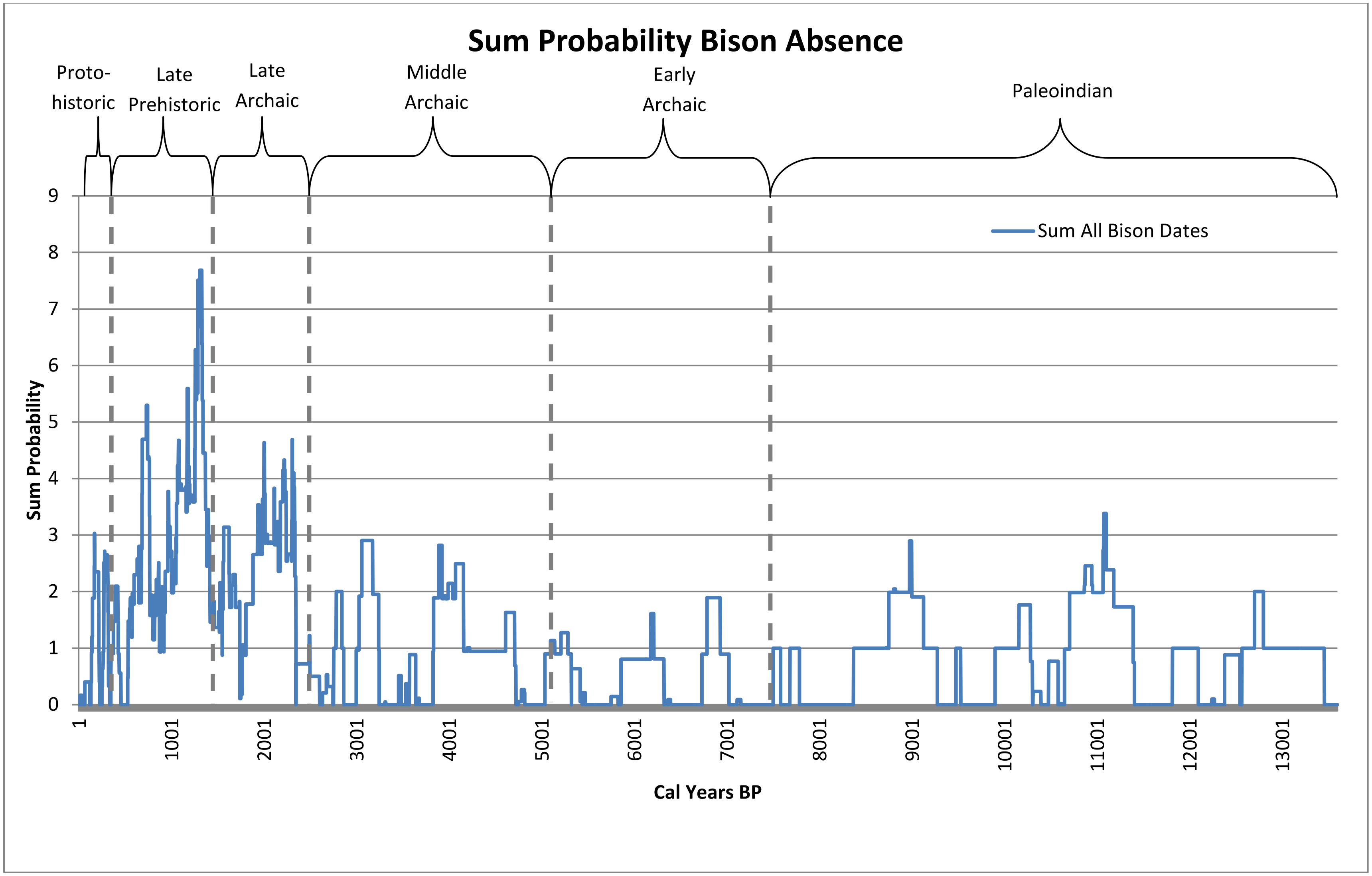

Figure 3-11. Sum probability distribution of bison only sites highlighting gaps in the data.

contained radiocarbon dates, other dating methods of these sites were used to evaluate bison distribution. Sixty of the 272 sites in the study area contained information on temporally diagnostic tools that could be associated with different human occupation eras, and in turn, could be used to fill in some of the period gaps. These sites were dated via archaeological remains such as tool technologies or feature typology in an attempt to place the site in a broad archaeological context.

In the end, 212 out of the 272 total sites were used in this portion of the analysis. These sites include the 60 sites with cultural component data, and the 152 sites containing radiocarbon data. These 212 sites were used to map the bison sites versus the non-bison faunal site distribution to determine if these data correlated with the patterning derived from the sum probability distributions. The data presented here are more generalized, and based on the previous recorders information and ability to identify tool types (primarily projectile point typologies) associated with cultural chronologies.

For ease of study, the data were analyzed in general distributions within established cultural periods (see Figure 2-1, Chapter 2). These are the Paleoindian period; the Early, Middle, and Late Archaic periods, Late Prehistoric, and Protohistoric/Historic periods, as described in Chapter 2. These were then plotted via GIS into altitudinal ranges based on 500 m increments, similar to the radiocarbon data portion of this research. These data represent a majority (78 percent) of the sites (212 out of 272) used in this study. The remaining 60 sites out of the total 272 did not report any sort of dateable material, and these were eliminated from this portion of the study. In addition, many of the sites utilized here contained multiple components from different periods. Each of the components was plotted on the appropriate map for the corresponding period resulting in some sites being represented on multiple maps (Figures 3-12 through 3-14).

Paleoindian Bison Distribution

Sites dating to the Paleoindian period are expectedly few in number (n=26). Of these sites, 65.4 percent are associated with bison while 34.6 percent are non-bison sites. These 26 sites are distributed across all regions of the study area (see Figure 3-12). However, a larger proportion of these sites are located in Middle Park within the Rocky Mountains of Colorado. Both sites with bison and those without are situated in this mountain basin. Sites are also found in the North Park basin to the north. Faunal sites on the lower altitudes of the Great Plains are primarily bison sites. Few bison sites are found in the Wyoming Basin during this time.

Early Archaic Bison Distribution

Thirty sites are associated with the Early Archaic period. During the Early Archaic, there is a general paucity of bison sites (30 percent) compared to non-bison sites (70 percent) across the study area. This is especially true of the lower altitude regions of the Plains and in the Wyoming Basin. Sites with bison still show up in Middle Park and along the periphery of the Rocky Mountains with the Great Plains. Other faunal sites are also comparatively scarce during this period, though they are distributed more evenly across all altitudes. According to these results, during the Altithermal drought (ca. 7500 to 5000 RCYBP) bison appear to abandon the Great Plains area but are still present at higher altitudes. These data support the sum probability distributions of the radiocarbon dated sites.

Middle Archaic Bison Distribution

During the Middle Archaic period, the number of faunal sites in the study area increases (n=44). Bison presence (34.1 percent) on the plains is still scarce, though sites containing bison begin to show up more commonly in the Wyoming Basin. Other faunal sites (65.9 percent) also appear more often in the Wyoming Basin whereas the Great Plains is still low in site numbers. Bison still appear in the mountains in low numbers.

Late Archaic Bison Distribution

The Late Archaic period exhibits a gradual increase in the number of faunal sites across the study area (n=59). Sites containing bison are more prevalent (62.7 percent) than non-bison sites (37.7) during this period. Bison sites on the Great Plains increase dramatically. However, the data indicate that bison do not abandon the mountains during this time, as evidenced by a number of high altitude (>3000 m) specimens. Non-bison sites continue to remain more prevalent in the Wyoming Basin than on the Great Plains.

Late Prehistoric Bison Distribution

The Late Prehistoric period contains the highest number of sites (n=128). Both bison and non-bison sites are represented equally. All altitudes of the study area exhibit evidence of both bison and non-bison sites. Bison are found again in relative abundance in Middle Park and extend into North Park. The eastern Wyoming Basin and the Great Plains both exhibit a significant bison presence, while non-bison sites remain prevalent in the Wyoming Basin portion.

Protohistoric Bison Distribution

During the Protohistoric period, the number of faunal sites is markedly decreased (n=23). This is a common attribute of the archaeological record for the region. Sites containing bison (65.2 percent) are generally distributed at the foothills and Great Plains margin or along the North Platte River drainage in Wyoming. Non-bison sites (34.8 percent) appear more commonly at higher altitudes.

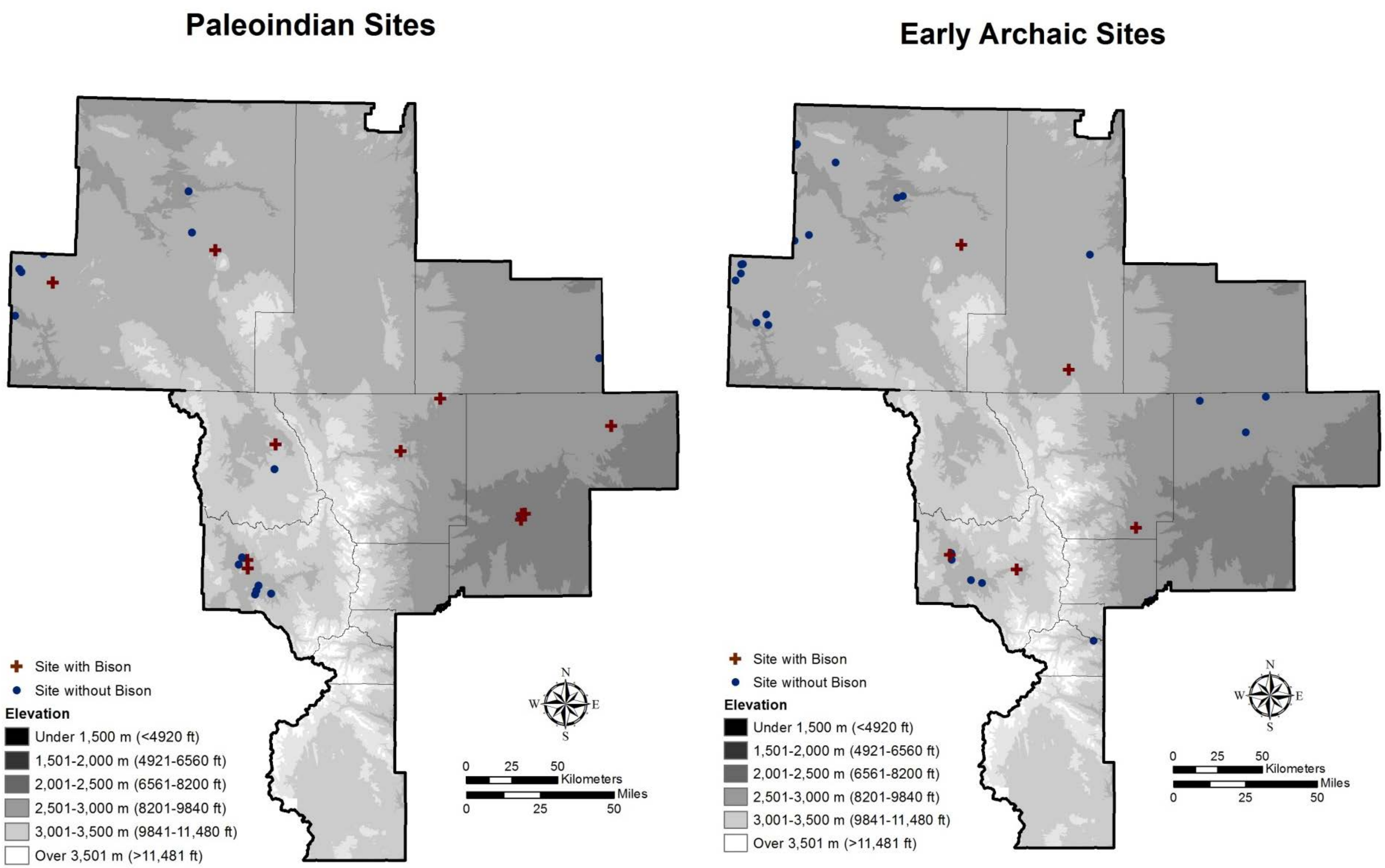

Figure 3-12. Paleoindian and Early Archaic faunal site distributions by altitude.

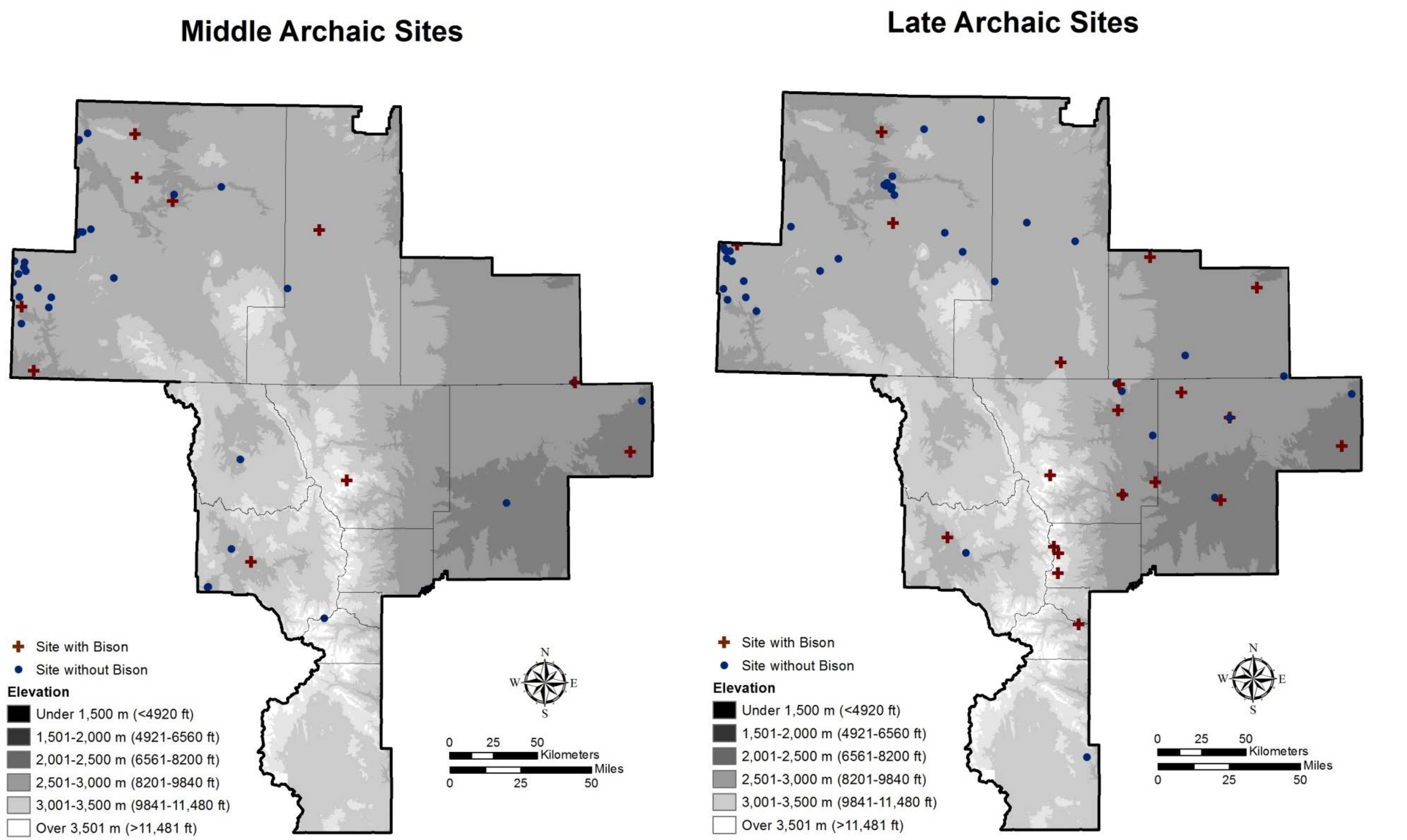

Figure 3-13. Middle Archaic and Late Archaic period faunal distribution by altitude.

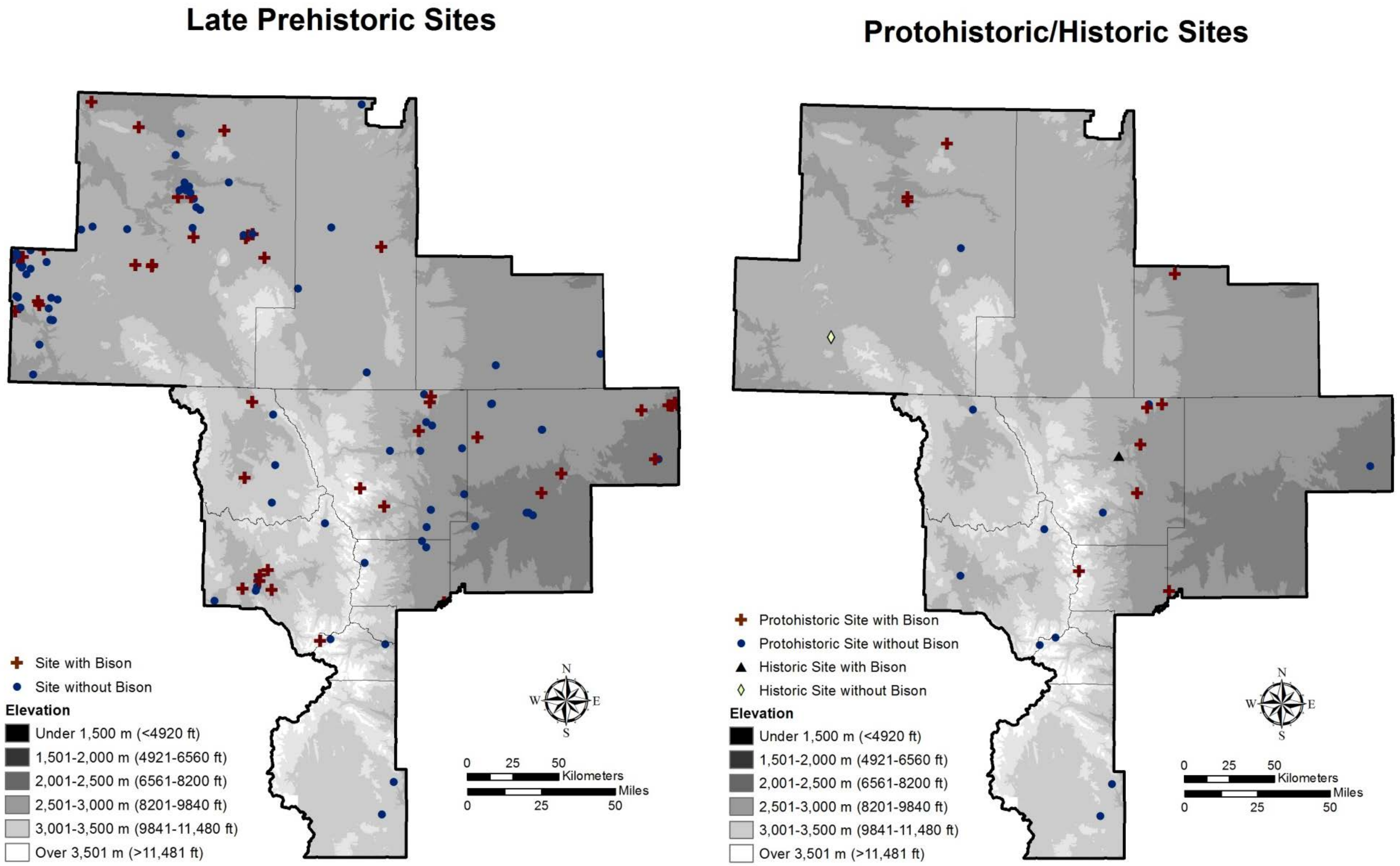

Figure 3-14. Late Prehistoric and Protohistoric/Historic period faunal site distributions by altitude.

Overall, these altitude trends are telling, especially regarding bison distribution. The above discussion and data indicate that bison were distributed in low numbers at high altitudes, but over all of the periods discussed. At lower altitudes, their presence appears to fluctuate more significantly, especially during the Early and Middle Archaic periods. This indicates that a bison presence in the mountains may have been more regular than previously thought. This is especially true for the region of Middle Park in Colorado. Bison are present in that area through much of prehistory (Kornfeld 2013). This implies that a local population of bison may have existed or that it was part of a significant seasonal migration route between areas to the north in the Wyoming Basin or across the high mountains to the Great Plains to the east.

Kernel Density Analysis of Site Distribution

A kernel density statistical analysis was conducted to test the above distribution data and the results were plotted on the study area maps via ArcGIS. A kernel density analysis is a non-parametric quadratic function that calculates the magnitude per unit area (in this case per km^2) from a central site point using a kernel function of ArcGIS to fit a smooth surface radius around each site point. The purpose of a kernel density test is to attempt to identify the probability of density in a population of points that otherwise seem random.

In concept, a kernel density analysis creates a smoothed density estimate, in this case a comparison of the density of bison sites versus non-bison sites, in a user-defined area based on known site point locations. A radius area is selected and the calculated density for each cell around the central point is multiplied by the appropriate factor. Only those site points that fall within the search area are calculated into the density of that entire search area, or neighborhood. The density value is highest at the location of the site point and diminishes with an increasing radius around that point and reaches zero at the perimeter of the search radius. A larger radius produces smoother, more generalized density data and a smaller search area produces visually tighter and less generalized data. Ideally, a search radius that falls within the two extremes should yield a smooth, generalized plot of the estimated density.

Analyses of bison and non-bison faunal sites were conducted to estimate variability in site densities in different regions of the study across time. A radius of 30 km for each site point was selected for this analysis as this delivered a relatively tight density search radius while providing a visually interpretable basis of map analysis of density distribution that was neither too general nor too isolated.

Figures 3-15 to 3-18 provide a side by side comparison of the kernel density results for each cultural period. The first set of plots in Figure 3-15 consist of all 272 sites utilized in the study. These plots indicate that the overall bison presence in the study area is more widespread than non-bison sites. To further analyze this trend, the following plots compare the density estimate for bison versus non-bison sites from the Paleoindian period up through the Protohistoric/Historic periods.

In general, these plots exhibit the trend of increasing site density from older to younger periods. The Paleoindian period plots for both bison and non-bison sites are sparse in site density as expected from all of the results presented thus far. The Early Archaic period site plots contain a similar pattern. Site density in the northwest portion of the study area begins to increase at this time for non-bison sites. This period coincides with the Altithermal drought, and the lack of site density on the Great Plains reflects this drought impact. Little change occurs in site density between the Early and Middle Archaic periods. Bison begin to show up more in the Wyoming Basin.

By the Late Archaic period (Figures 3-16), the plots reveal a significant increase in bison density across many areas, especially on the Great Plains. The plains have recovered from the Altithermal dry period by this point, and bison populations were utilizing this region yet again. Interestingly, non-bison sites on the Great Plains during the Late Archaic appear to be considerably lacking. When compared with the sum probability data for the Late Archaic period from 1500-2000 m amsl on the Great Plains, the data correlate well. The trend of more non-bison sites than those with bison in the northwest portion of the area continues.

The Late Prehistoric period (Figure 3-17) is represented well in the density plots, as expected, based on the large number of radiocarbon dates in this research. As mentioned previously, this is at least partially due to taphonomic processes (Surovell and Brantingham 2007). However, the relative decreased effect of taphonomy on younger archaeological deposits aside, human populations increase in density across North America, partially as a result of a more moderate climate post-Altithermal. As expected, this increases the representation of both sites with bison and those without. Protohistoric and Historic period sites are far less dense than the Late Prehistoric period (see Figure 3-18). This density corresponds with the sum probability distributions that exhibited a sharp downturn of radiocarbon dates. The kernel density plots show that the Wyoming Basin of western Carbon County is dominated by non-bison sites through much of prehistory. Bison presence appears to increase in that area only marginally during the Late Archaic and Late Prehistoric periods while relatively low during other periods. Conversely, bison presence in the mountains, especially in Middle Park of Colorado, is nearly constant, with decreased density only during the Early and Middle Archaic periods and the Protohistoric period. Non-bison sites in the mountains appear to be more common during the Paleoindian and Early Archaic periods and then diminish in density. The Great Plains exhibit the greatest variation over

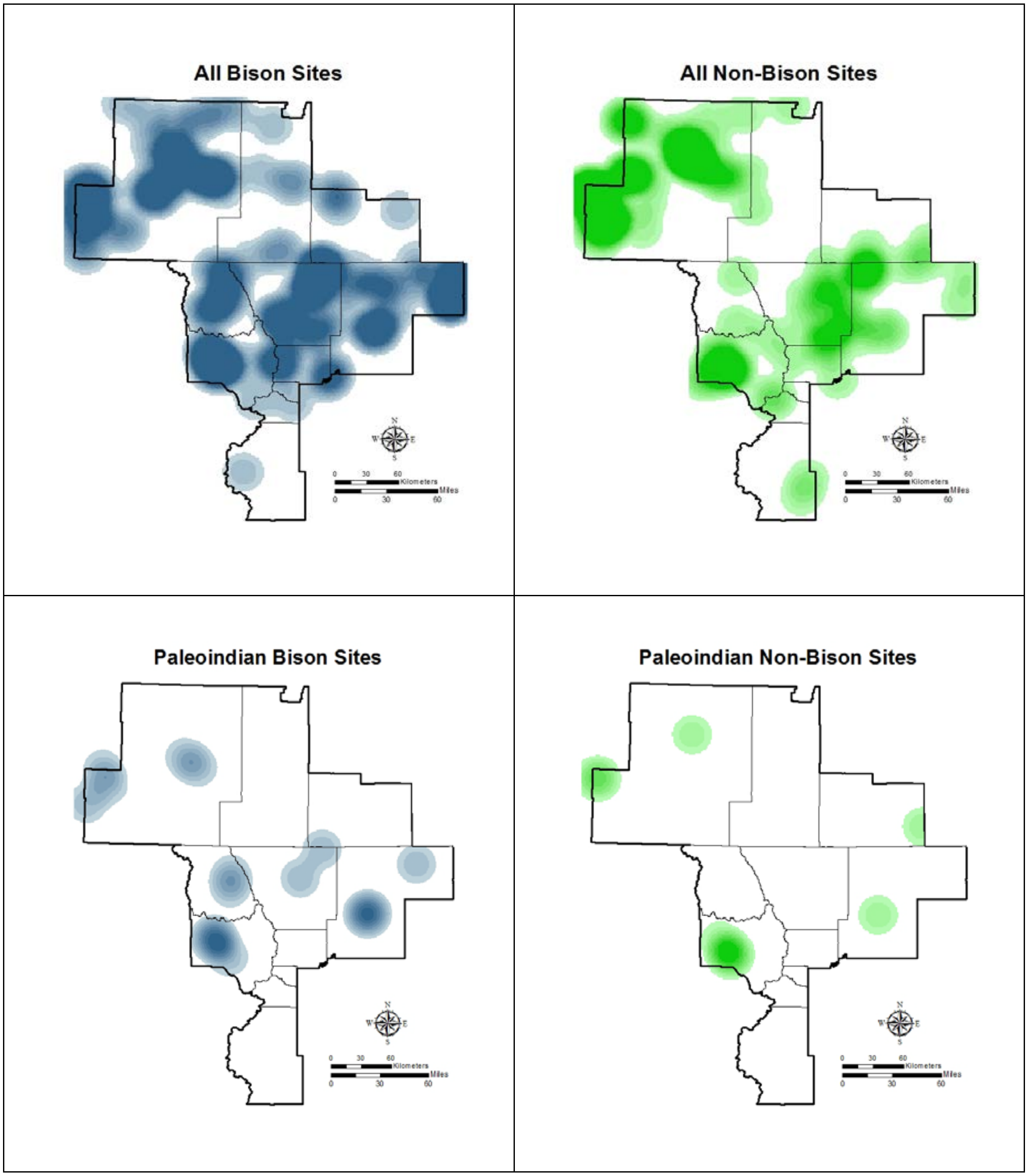

Figure 3-15. Kernel density analysis comparative maps of all bison (on left) and non-bison (on right) sites in the study area (top) and Paleoindian period bison and non-bison comparative maps (bottom).

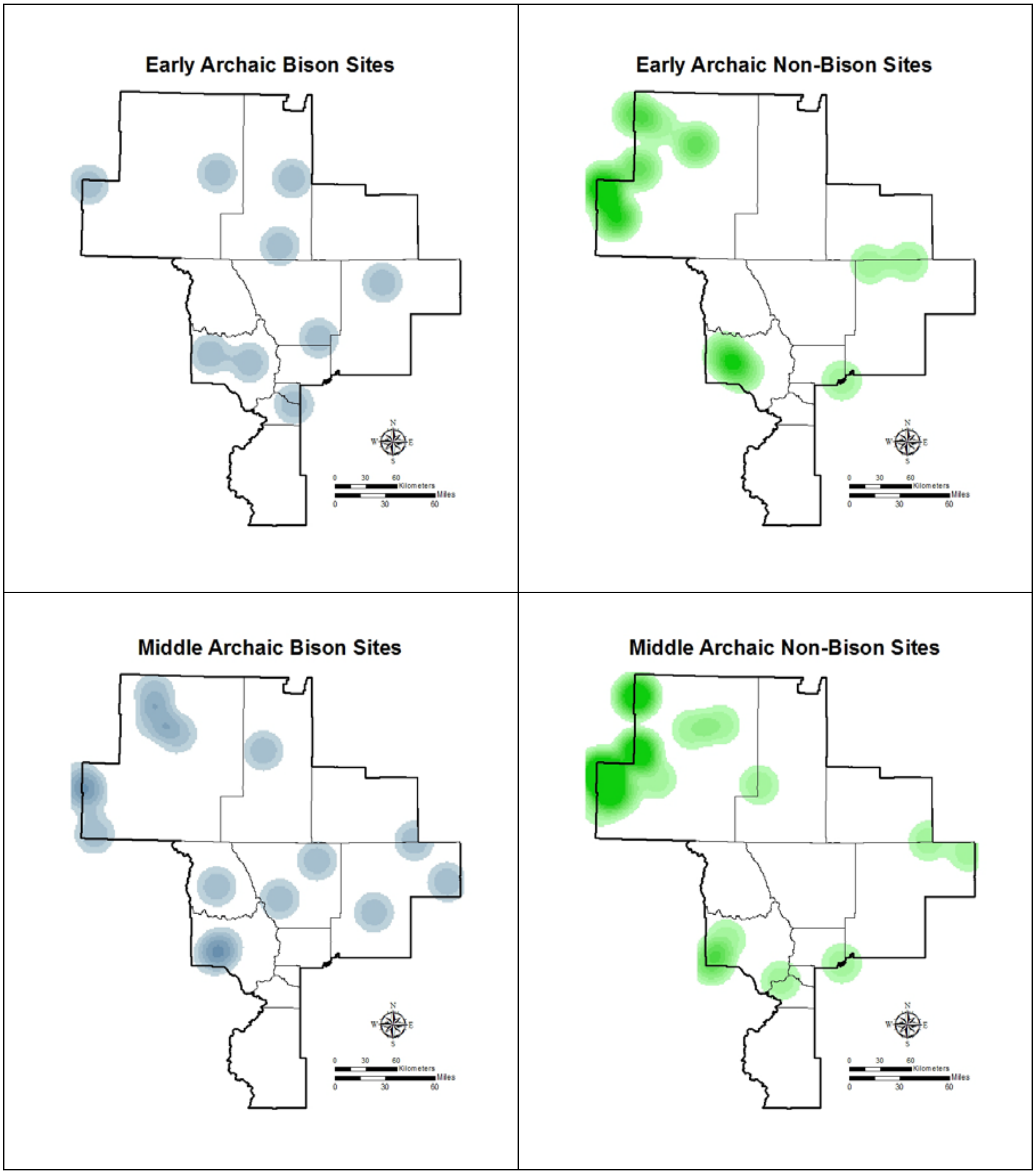

Figure 3-16. Kernel Density Analysis Results. Early Archaic period comparison maps (top) and Middle Archaic period (bottom).

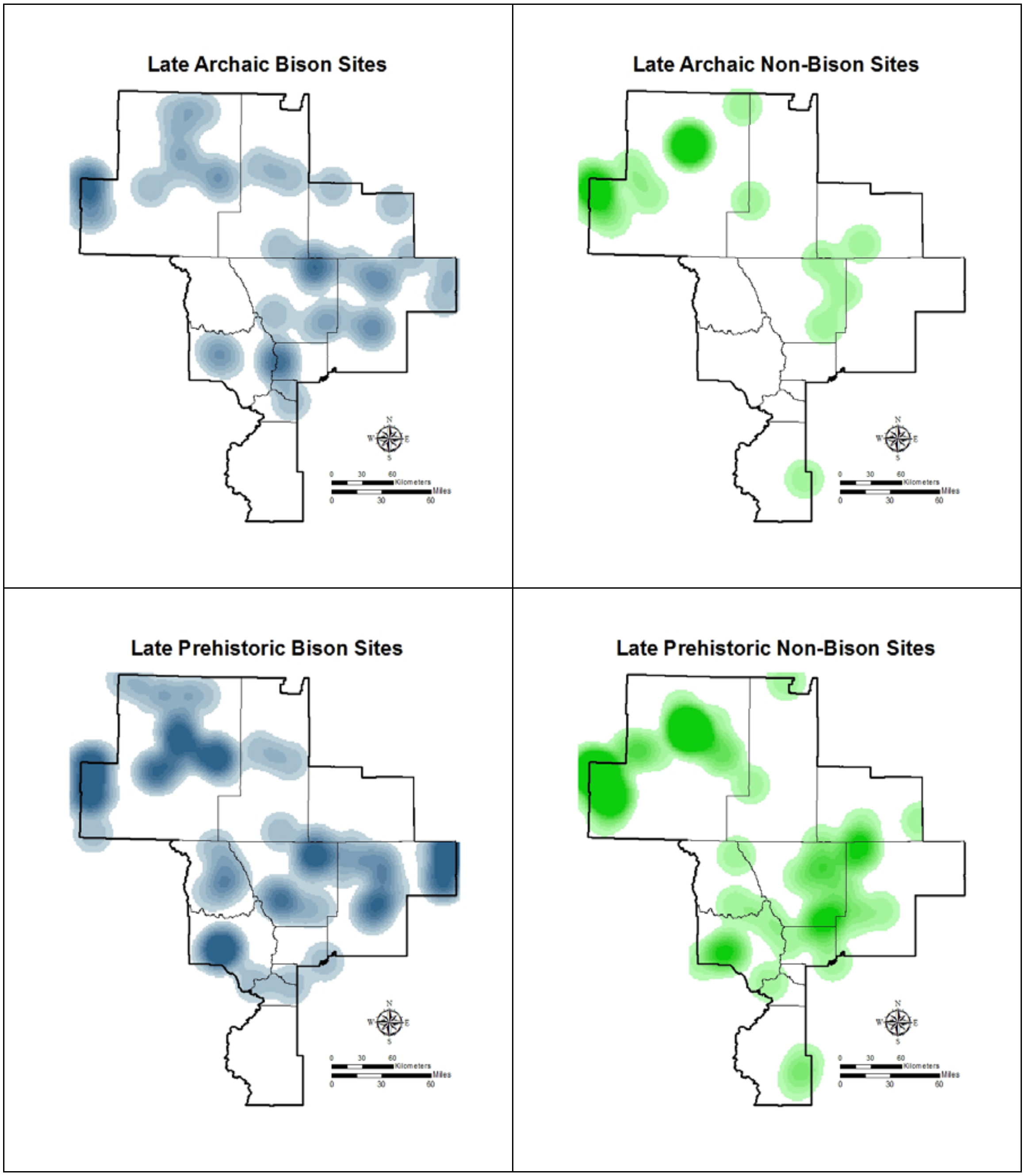

Figure 3-17. Kernel Density Analysis Results. Late Archaic period comparison maps (top) and Late Prehistoric period (bottom).

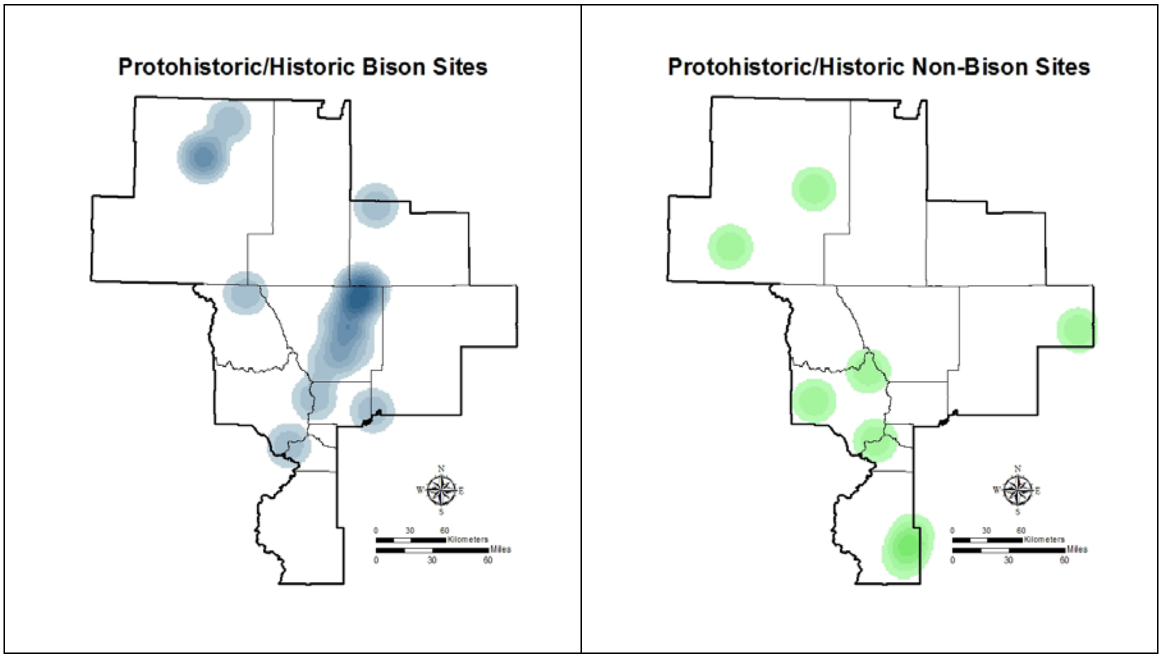

Figure 3-18. Kernel Density Analysis results for Protohistoric/Historic period sites.

time in site density. During the Paleoindian and much of the Archaic, site density for both bison and non-bison sites is low. Bison presence on the Great Plains expands during the Late Archaic and Late Prehistoric periods whereas non-bison site densities lag and don't increase until the Late Prehistoric period.

In all, the kernel density analysis supports the sum probability and cultural chronology data presented in this chapter. Both bison and non-bison sites exhibit increased density from older to younger dates. Some of the gaps in the total sites data plots may be representative of poor site preservation, lack of archaeological investigation, or a combination of both. However, many of these gaps are telling, and trends in bison absence or presence are visible and supported by other evidence outlined in this chapter.

Chi-Square Analysis of Bison Distribution

To further determine whether or not there is patterning to bison presence at different altitudes and regions of the study area, a Chi-square statistical test was employed. The Chi-square test is a measure of whether variables are independent of each other. It measures if the observed instances of an occurrence vary significantly from the number that would be expected in a hypothetical normal distribution. If a calculated Chi-square value is larger than the hypothetical critical value then the null hypothesis can be rejected, and dependence between the variables is supported. If the chi-square value is smaller than the critical value, then the null hypothesis cannot be rejected.

The Chi-square test investigated whether there is a relationship between bison presence or absence and altitude zones. All 272 sites in the study area were used for this analysis. The null hypothesis for this test was that in sites with faunal remains, sites containing bison are not distributed differently by altitude than those without bison. The alternate hypothesis is that, in sites with faunal remains, sites containing bison are distributed differently by altitude than sites without bison. The sites included in the Chi-square analysis are listed by altitude and presence or absence of bison in Table 3-7.

The Chi-square value at the 85 percent confidence level (P-Value = .15) was larger than the critical value. The analysis is significant at this level and could reject the null hypothesis. This confidence level supports the alternate hypothesis that there is a difference in bison and non-bison site distribution at different altitudes. At the 90 percent confidence level (P-Value = .10) the Chi-square value was very close to significant. The Chi-square value for this test was smaller than the critical value at the 95 percent confidence level (P-Value = .05). Therefore, the analysis could not reject the null hypothesis at this confidence level. There are several reasons why trends identified in the other analyses are not significant in this analysis. First, the more categories there are in an analysis, the stronger a trend has to be to be significant under the Chi-square test because more degrees of freedom require a larger Chi-square statistic to show significance. In addition, the distribution of bison is likely not equal across the area for physical reasons such as taphonomy, areas of steep slope, or amount of archaeological inventory coverage.

Table 3-7. Chi-square Analysis of Bison Distribution at Different Altitudes.

Altitude/Bison Presence	Observed (O)	Expected (E)	(O-E)2/E	DF	Critical Value at P=0.05	Critical Value at P=.10	Critical Value at P=.15
<1500 m Bison	19	14.34	1.514337517	4	9.49	7.78	6.74
<1500 m No Bison	6	10.66	2.037110694	4	9.49	7.78	6.74
1500-2000 m Bison	42	47.03	0.537973634	4	9.49	7.78	6.74
1500-2000 m No Bison	40	34.97	0.723503003	4	9.49	7.78	6.74
2000-2500 m Bison	75	78.57	0.162210767	4	9.49	7.78	6.74
2000-2500 m No Bison	62	58.43	0.21812254	4	9.49	7.78	6.74
2500-3000 m Bison	10	8.6	0.227906977	4	9.49	7.78	6.74
2500-3000 m No Bison	5	6.4	0.30625	4	9.49	7.78	6.74
>3000 m Bison	10	7.46	0.864825737	4	9.49	7.78	6.74
>3000 m No Bison	3	5.54	1.164548736	4	9.49	7.78	6.74
Chi-Square Value 7.756789606							

A visual examination of the data shows that the Chi-square values in most of the categories are low, suggesting that there is no significant patterning of bison compared to non-bison sites by altitude. The frequency of sites with or without bison is variable between different altitudes. Below 1500 m the observed number of bison vs. non-bison is higher. Some patterning is present from 1500-2000 m in that the observed ratio of bison to non-bison occurrences is nearly equal. Above 2000 m the Chi-square value does not appear to show patterning. The analysis of bison vs. non-bison at altitudes above 2000 m are in fact making the values at lower altitudes seem insignificant because of the Degrees of Freedom. The Chi-square test at the 95 percent confidence level does not correlate well with the rest of the results presented in this chapter. This is not to say that the test is not accurate, but instead that the data set cannot statistically show significant patterning in bison distribution. If this test was re-run with fewer categories or if a larger data set was incorporated, trends may become significant.

In summary, the Chi-square test at the 95 percent confidence interval does not support that bison are distributed across the study area with significant patterning. At the 85 percent confidence interval, patterning in bison distribution is readily observed. This interval supports the individual altitude zone patterning. This confidence level is supported by the kernel distribution analysis in the previous section (see Figure 3-15, top row) which displays the estimated density of all bison and non-bison sites in the study area. Regions of these maps exhibit greater or lesser presence which can partially be attributed to altitude.

DISCUSSION

The results of this analysis were compared to broader data sets from other bison absence/presence studies in other regions of North America. This was completed to see if the trends identified in this study correspond or differ from other data sets.

Dillehay (1974) conducted one of the earliest absence/presence studies of bison. His research on the Southern Great Plains of Texas and Oklahoma identified two significant gaps in the bison record from an analysis of 150 sites. According to his analysis, bison are present on the Southern Great Plains during the Paleoindian period but virtually disappear from approximately 7500 - 4550 RCYBP during the Early Archaic period. This period corresponds with the Altithermal drought (7500-5000 RCYBP across much of the west (Antevs 1955). In 1992, Butler expanded on and tested Dillehay's analysis and studied the absence and presence of bison on archaeological sites of the Central Great Plains of eastern Colorado and western Nebraska (Butler 1992). His results were consistent with Dillehay's findings ,and while bison were not completely absent during the Early Archaic period, they were few in number. The data presented in this thesis generally corresponds well with Dillehay’s and Butler's analyses of this period. As discussed above, bison presence is low during this period in the study area which indicates that the dry climatic conditions negatively impacted bison populations on both the Southern and Central Great Plains. It is likely that bison populations were not only diminished but had moved elsewhere. Therefore, the Early Archaic diminished bison population in this study indicates that bison were likely not moving to, or from, the Southern Great Plains, thus supporting either a northward or westward migration.

Dillehay (1974) and Lohse et al. (2014) identified a second gap in the bison record of the Southern Great Plains from approximately 1450-650 RCYBP during the Late Prehistoric period. Butler's analysis did not support this data gap and found that bison were present on the Central Great Plains of eastern Colorado and western Nebraska (Butler 1992). The current study also found that bison had a significant presence during this period, thus supporting Butler's results. However, the sum probability distribution and the ratio of sum probabilities indicate that bison were low in number compared to the Late Archaic period. While this data appears correct, the kernel density analysis and site distribution data indicate that bison are present in relatively high numbers during the Late Prehistoric period. These results imply that climate conditions on the Central Great Plains during the Late Prehistoric period, especially during the Middle Ceramic period of northern Colorado, were amenable to grassland expansion whereas in the Southern Great Plains, climatic conditions may have been harsher. It is possible that bison from the Southern Great Plains moved north into the Central Great Plains. Judith Cooper (2008) analyzed the presence of bison across much of the Great Plains region for the Late Prehistoric period in her dissertation work. Her study supports a decrease in bison populations on the Southern Great Plains during the Late Prehistoric period while on the Central Great Plains her observations show that bison presence is moderate (Cooper 2008). On the west Central Great Plains (in the vicinity of the current study), her analysis of bison presence is very low during the Late Prehistoric period. This last observation by Cooper (2008) diverges from the current study results. Based on the analysis, there is a distinct bison presence in the Great Plains region of the study area during the Late Prehistoric period as evidenced by the finding presented in this chapter. Therefore, these results suggest that bison presence in the region may be influenced by altitudinal and climatic influences on a finer scale than was observed in the previous studies.

SUMMARY

In all, the results presented here indicate trends of bison absence and presence over time and space. The sum probability distribution for all dates exhibit trend of fluctuating probability of dates over time, which may represent variations in human use of the region due to variability in climate conditions, availability of food sources, and changing technological, cultural, and subsistence practices. The scarcity of sites during the Paleoindian period is to be expected due to increased impacts of taphonomic processes disturbing intact cultural deposits resulting in a small sample size of radiocarbon dates (Surovell and Brantignham 2007). Taphonomic processes alone, however, cannot explain the variability in bison presence or absence in the record, especially over the Archaic period. The Early Archaic period exhibits a distinct lack of bison and non-bison sites. This is likely due to the drought of the Altithermal period in which human, bison, and other faunal populations were either diminished in number or were living elsewhere. Bison numbers appear to be slow to rebound during the Middle Archaic period, especially on the Great Plains. Likely, there is a lag in ecological rebound and a subsequent lag in the timing of bison repopulation. By the Late Archaic period, bison populations increased across much of the area. Periods with more representation, such as the Late Prehistoric, indicate that conditions were favorable for site preservation or that human occupation and utilization of both the region and bison increased.

Bison population and density trends at different altitudes over time are more informative, especially regarding bison distribution at higher altitudes. The above discussion and data indicate that bison were distributed in generally lower numbers at higher altitudes (likely a result of small sample size due to poor site preservation and lack of archeological discovery) yet were consistently present over all periods discussed. This suggests a nearly continual presence of bison at high altitude ranges across prehistory, especially in the high mountain basins. At lower altitudes, bison presence appears to fluctuate more significantly, especially during the Early and Middle Archaic periods. These results suggest that local populations of bison may have been present at different altitudinal ranges or bison from higher altitudes were part of significant seasonal migrations between areas to the north in the Wyoming Basin or to the Great Plains to the east.

CHAPTER 4

"BISOTOPES": AN ANALYSIS OF CARBON AND NITROGEN STABLE ISOTOPES IN BISON BONE

The analysis of bison absence or presence across spatial and temporal dimensions is a useful tool for understanding bison distribution. In addition, the proposed distribution may help to help reconstruct human hunting strategies and mobility patterns (Bamforth 1988). Bison distribution can be further analyzed by studying the diets of the animals in question. Bison feeding ecology can aid in explaining relationships between bison migration patterns and paleoclimate. This analysis can be done by collecting information on the amount of different types of forage in the diet and comparing that information with paleoclimate data. The data can be compared to known paleoclimate models, or can be used to build on or create new paleoclimate information. In this chapter, the paleoecology of bison in the study area is explored through the use of stable isotopes analysis.

Bison are primarily unselective grazers that forage across a landscape of edible grasses, feeding on vegetation with carbon isotope values relating to C_3 and C_4 photosynthetic pathways, each of which is associated with cool or warm season environments respectively (Sims et al. 1978). During photosynthesis, plants metabolize these two forms of carbon, and in turn, they are passed up through the food chain (Reitz and Wing 2008; Tieszen 1994). These carbon isotopes are then deposited in the organic components of bone and can reveal the nature of the environments the animals spent most of their lives.

The use of ^{13}C and ^{15}N stable isotopes in bone collagen of faunal remains on archaeological sites can be an important source of secondary information to help determine the potential range of migration of an animal through its life. These data are used here to compare paleoclimate information and bison distribution patterns. Additionally, this isotopic information can aid archaeologists in making assumptions on early human subsistence practices, movement of humans and herds (Bamforth 1988; Tieszen 1994), and relationships and divergences to known environmental data.

For this portion of thesis research, 35 specimens from five bison kill sites and four non-archaeological bison specimens were utilized for dietary analysis through the use of ^{13}C and ^{15}N stable isotopes in bone collagen. The analysis was completed to determine the percentage of the contribution of C_3 and C_4 forage to the diet of each individual animal to determine the range that the animal lived in over its life. In addition to stable isotopes analyses, nine specimens were submitted for AMS radiocarbon dating to determine the age of the non-archaeological specimens and two of the archaeological sites.

Previous Isotope Studies

The scientific examination of isotopes originated in the fields of physics, biochemistry, and geology and began to be utilized in the fields of archaeology and anthropology in the 1970s and 1980s (Bumstead 1981; DeNiro and Epstein 1978; van der Merwe 1989). Over time, methods and techniques improved and stable isotopes analysis became a routine form of bioarchaeological study (Ambrose and Krigbaum 2003). Although stable isotopes of carbon, nitrogen, oxygen, and strontium in modern animals and humans provide useful information on environment or biology, preservation of some isotopic values is poor for most fossil materials (Kohn and Cerling 2002). Consequently, nearly all archaeological stable isotope studies focus on the best-preserved tissues such as bone, dentin, enamel, scales, keratin, and shell. These tissues have been utilized in various types of biological and ecological studies to determine animal migration and diet and have translated into the field of archeology (Tieszen 1994).

Stable isotopes have been used in various applications across the field of anthropology. Early hominin diets are an important area of current research in paleoanthropology to help determine mobility and migration of hominins out of Africa, through Europe, the Middle East, and Asia (Levin et al. 2008; Sponheimer and Lee-Thorp 1999). Isotopic dietary reconstructions have also been applied to sites such as Laetoli in Africa to help reconstruct paleoecology and early hominin migration (Kingston and Harrison 2006). Neanderthal diets have also received significant study. Stable isotope data has helped to support evidence that Neanderthals were high-level carnivores while early humans utilized more varied dietary sources (Richards and Trinkaus 2009). Along the Danube in southeastern Europe, studies of dietary isotopes, predominately carbon and nitrogen, have revealed that diets varied significantly from the early Neolithic to the Mesolithic, possibly indicating more reliance on terrestrial food sources earlier, and more dependence on aquatic food sources later (Bonsall et al. 2004:298).

Paleoanthropological isotopic studies of faunal diets have helped to reveal paleoclimate and paleoecology data in African herd mammals (Sponheimer et al. 2003). These indicators show nutritional variability that can also be applied to the humans who subsisted on them. Comparing the isotope data between hominins and other species has revealed ecological niche use and preference (Lee-Thorp et al. 2003). Stable isotope research has yielded paleoclimate and paleogeography indicators of environmental change in Miocene and Pliocene grasslands through mammalian dental enamel (Zin-Maung-Maung-Thein et al. 2011). These diet studies have reflected shifting paleoclimates and responses by individuals and groups through adaptation of available food resources.

Archaeological stable isotopes research in the Americas tends to focus on climate, ecological variables, and geographical range of different human groups based on diet. For example, a study of the remains of coastal populations in Peru from Pre-Contact to the Colonial period (1500-500 RCYBP) utilized human dentition to study the diet of a sub-culture to attempt to determine the geographical range of these groups based on what they ate through oxygen and carbon stable isotopes (Brown 2012). The results of the analysis showed that diet intake was related to low altitudes. The proliferation of maize throughout the Americas is an important line of research in understanding the mobility and migration of people, their trade and communication networks, and development of sedentism and agriculture (Schoeninger and Moore 1992; Tykot 2007). Isotope studies from skeletal remains of Mayan populations indicated increased quality of health upon the utilization maize agriculture (Ritchie-Parker 2011).

Many types of stable isotope studies have been conducted across North America, including those with archaeological bison specimens. The use of bison dentition is a common method of research. Multiple studies of ^{13}C in bison dentition have been conducted with varying degrees of success (Widga 2007; Hoppe et al. 2006; Larson et al. 2001). Widga (2007) conducted a large-scale analysis of the Middle Holocene record of subsistence practices partially through stable isotopes analysis in bison enamel. The study found that bison were the main prey choice by hunter-gatherers, a not unexpected result, in which dentition exhibited the seasonality of bison kills. In 2006, an analysis of enamel from modern bison specimens was conducted to determine the efficacy of enamel carbonate data in identifying vegetation photosynthetic pathways (C4 vs. C3) as a correlate for paleoecological studies (Hoppe et al. 2006). The results of the study found that stable isotopes data from this method reflected local abundance and could be a useful proxy to identify local grassland types.

Larson et al. (2001) conducted a stable isotopes dentition study from the Glen Rock bison kill site in central Wyoming. They attempted to identify a paleodietary model of the bison but failed to utilize the proper sampling techniques. Their results could only generally provide paleodietary data and highlighted some of the complications in stable isotopes techniques (Larson et al. 2001).

A majority of stable isotopes studies from archaeological bison bone contexts have focused on bison remains from the Northwest Great Plains region. In 1986, a large study of bison foraging via stable isotopes in southern Canada resulted in the identification of varying bison isotope values on a latitudinal scale, especially in relation to availability of C_4 vegetation (Chisholm et al. 1986). This study utilized ^{13}C stable isotopes to analyze migration patterns of bison between different types of grasslands in the Northwest Great Plains and Rocky Mountains from archaeological contexts. Their results demonstrated that bison undertook seasonal migrations between different types of grasslands due to differences in the quantity of C_3 versus C_4 grass types in the different environments and this was reflected in the ^{13}C values of the bison bone (Chisholm et al. 1986).

Leyden and Oetellar (2001) conducted a similar study from the same region and modeled bison isotopes values from archaeological sites in Alberta, Canada. Their study focused primarily on modeling stable isotope values against known climatic variables. Their study suggested that the observed change in bison diets over time was reflected in the paleoenvironmental data. For example, Altithermal period specimens (7500-5000 RCYBP) contained higher percentages of C_4 grasses in the bison diets than younger or older period specimens. This result implied an expansion of warm season C_4 grasses into areas that generally possessed few C_4 grasses. This may indicate that these grasses moved north during this period of warmth and drought (Leyden and Oetallar 2001).

A paleoclimate study from bison bone from Paleoindian sites in eastern Wyoming investigated changes in climate and C_4 vegetation during the early Holocene (Lovvorn et al. 2001). The study looked at variability in Paleoindian occupation and bison utilization between the Younger Dryas and the Altithermal drought. Stable isotopes data was compared to climate trends and supported demographic responses to climate change (Lovvorn et al. 2001).

Britton (2009) conducted a multiple stable isotopes study from both North American bison and caribou bone collagen and enamel in modern and archaeological specimens in an attempt to determine foraging behavior patterns. By sampling sequentially ordered dentition, she identified a model for intra-animal and inter-animal quantitative isotope analysis. This analysis technique was then applied to an archaeological data set from France to identify seasonal use of reindeer and bison during the Middle Paleolithic (Britton 2009).

Little work has been done in southern Wyoming or northern Colorado in relation to stable isotopes studies in archaeological contexts. Carbon isotope data have been collected during radiocarbon dating of sites and these have implications for ecological studies, but little is discussed in the literature. Fenner and Frost (2009) carried out a study of stable isotopes in modern and archaeological pronghorn teeth and from local sagebrush populations from southwest Wyoming to study the relationship of plants and underlying geology through the analysis of carbon, strontium, and oxygen isotopes in an attempt to understand regional variations of ecozones. Their results identified a correlation between oxygen isotopes in sagebrush and pronghorn with relative humidity. Temperature was tied to humidity and sagebrush, but not with pronghorn. Strontium isotopes in both sagebrush and pronghorn reflected regional geology (Fenner and Frost 2008).

The above studies reveal that while previous research has been conducted, there are gaps in these data, and little work has been done to correlate stable isotopes results to paleoenvironmental information in the study area. The Northern Great Plains studies point toward limited movement of bison in ranges with little variability in ecology. However, the transitional zone from plains to mountains is different from the gradual ecological shifts on the plains. Most studies have focused on the Northern Great Plains or from Early Holocene contexts. However, little work has been done with stable isotopes research in the west-central Great Plains and none that are focused on the Middle to Late Holocene. It is hoped that the results presented here will help to fill in that data gap. While many of the above studies apply to anthropological research, for the purposes of this thesis, the use of stable isotope studies in paleoclimate, diet, and migration research are the primary focus. These domains of research are interconnected, and trends in one aspect will likely correlate to trends in the other domains.

Reconstructing Bison Movements in the Past

A number of methods are currently used to explore bison paleoecology. Modern correlates are commonly used, but this is problematic when studying bison in prehistory. Little is known of their true migratory habits except from historical records. The near extirpation of this species has essentially created a new species which has new ranging habits based on restricted habitats and diet.

Grasslands are affected by many factors including grazing, fires, climate change, drought, and agriculture. The modern environment has been significantly modified by human actions. Few environments similar to prehistoric conditions remain, especially large expanses of natural prairie grasslands which once supported wild bison. Modern bison are thus not truly analogous to historical bison ecologically or behaviorally. Caution should be used when comparing historical bison data to modern specimens.

Significant variations in the postulated historical migratory patterns of bison have been reported. Historical data and archaeological investigations demonstrate that prehistoric bison not only roamed the Great Plains, but lived in the high mountain basins, foothills, and high country of the Rocky Mountain west (Cannon 1997, 2007; Fryxell 1926, 1928; Lee and Benedict 2006, 2012). Yet it is not clear whether bison that lived on the plains also utilized higher altitudes or whether distinct groups remained in limited geographical and altitudinal zones. Pre-nineteenth century historic accounts report that bison on the Great Plains undertook long distance migrations (Bamforth 1987, 1988; Hamilton et al. 2006; Isenberg 2000). However, other accounts and modern bison populations indicate that some populations remain in restricted areas or home ranges (Britton 2009; Meagher 1986).

Today, some free-range populations exhibit sedentism or undertake seasonal altitudinal ranging (Britton 2009; van Vuren 1983; van Vuren and Bray 1986). It is not known whether these changes result from natural behavior, or if the limited range of modern bison populations is more heavily influenced by human action. Therefore, comparing the grazing habits of modern bison should be used cautiously when attempting to understand behaviors of prehistoric bison populations. Investigations into foraging patterns, grassland development, animal behavior, intraherd variability, and the analysis of paleoclimate have all been investigated and utilized here to provide insight into the archaeological and non-archaeological specimens in this study.

What are Stable Isotopes?

Understanding the complexity of stable isotopes in scientific applications is daunting, but they can provide useful data. In brief, isotopes are atoms of the same element (e.g. characterized by the same number of protons) which have a different number of neutrons, resulting in slightly different atomic mass (Peterson and Fry 1987; Tykot 2007). The isotopes that have the greater atomic mass due to the presence of an extra neutron(s) are termed heavy, while those with the lower atomic mass are referred to as the light isotope (Fry 2006; Peterson and Fry 1987). Light isotopes are generally far more abundant than the heavy isotopes. Isotopes are divided into two fundamental groups, those that are stable and those that are radioactive or unstable. Radioactive isotopes (e.g. ^{14}C) decay over time, whereas stable isotopes (e.g. $^{12}C/^{13}C$) do not. Isotope values can be measured in the tissues of all plants and animals and are passed through the food chain from the environment. The common stable isotopes used in anthropological research are carbon ($^{12}C/^{13}C$), nitrogen ($^{15}N/^{14}N$), oxygen ($^{18}O/^{16}O$), and strontium ($^{87}Sr/^{86}Sr$). The application of stable isotope analysis is based upon the premise of a relationship between a consumer and its environment. The environment includes underlying geology (strontium), soils and plants (carbon and nitrogen), and ingested water (oxygen) (Peterson and Fry 1987).

Stable isotopes occur naturally in the environment, but their natural abundance differs in the terrestrial food web due to various environmental conditions and the phenomena of fractionation. Fractionation is at the heart of stable isotopes analysis. As strictly defined, fractionation is the variation in isotope ratios caused by chemical processes such as photosynthesis and metabolism (Tykot 2007). Atmospheric carbon dioxide is photosynthesized by plants and metabolized into complex molecular compounds categorized as carbohydrates, proteins, and lipids (Tykot 2007). Fractionation is the result of the chemical or kinetic processes that affect the relative abundance of isotopes of the same element but with different number of neutrons, where some are heavier and some are lighter. For example, ^{12}C is the most common carbon isotope (containing six protons and six neutrons in the nucleus) and makes up 98.8 percent of all carbon atoms. ^{13}C (containing six protons and seven neutrons) is much more rare and accounts for approximately 1 percent of carbon atoms. With an extra neutron, ^{13}C has greater mass and thus is discriminated against in physical and chemical reactions.

Fry (2006) describes fractionation as the "hidden power controlling isotope distributions on this planet, and the fundamentals of fractionation are in the chemical details" (Fry 2006:12).Stable isotope studies are based on the observation that stable isotopes are maintained within the tissues of an organism following death (Schoeninger and Moore 1992). In the case of this research, fractionation can be described as the changes in isotope values between diet and consumer tissues (e.g. bone) while being aware that the fractionation is due to both biochemical integration of dietary components and by isotopic discrimination or enrichment.

Isotope values are expressed in the δ notation relative to a standard:

$$\delta X_{STD} = [(R_{SAMPLE}/R_{STANDARD}-1)] \times 1000$$

where δX_{STD} is the isotope ratio in delta units relative to a standard difference in the element in question (e.g. ^{13}C), and R is the ratio of the heavy isotope to the light isotope (e.g. $^{13}C/^{12}C$) (Fry 2006). Due to the tiny amount of actual heavy isotope material in the resulting value, the final multiplication by 1000 magnifies the minute differences measured between standards and samples and the resulting isotopic composition is measured and reported in parts per mil or thousand (‰). Samples with higher δ values are generally enriched or heavier in the heavy isotopes and those with lower δ values are commonly enriched in the lighter isotope.

The international standard for stable carbon isotope analysis is based upon the CO_2 composition of limestone from the Pee Dee Belemnite (PDB) formation in South Carolina, USA with $\delta^{13}C$ content 0.011180‰ (Phillips 2012). The PDB is now exhausted, and current measurements are correlated with the non-exhausted standard Vienna Pee Dee Belemnite (VPDB). The international standard for stable nitrogen isotope analysis is Ambient Inhalable Reservoir (AIR) standard with a $\delta^{15}N$ content of 0.0036765‰ (Fry 2006; Phillips 2012). The analysis of ^{15}N provides information on trophic level and inferences on temperature and water availability in the environment.

Stable Isotopes in Animal Tissues

Stable isotope values can vary significantly within different geographical areas and ecosystems. In the archaeological record, these isotopic signatures are primarily found in bone, enamel, and dentine (DeNiro and Epstein 1978, 1981). Fractionation occurs throughout the metabolic pathways of the consumer, resulting in different isotope values in the different tissues under analysis (DeNiro and Epstein 1978,1981). Bone collagen was chosen for this study due to the ability of preserved collagen to provide diet data from the overall life of an animal. While tooth enamel and dentine often preserve better in a buried context, these only provide data from the early portion of an animal's life. When teeth stop forming, no further dietetic information is absorbed. This short-term data is valuable for many studies; however the current study is interested in broader comparisons over an animal's lifetime.

When analyzing archaeological bone samples, post-depositional alteration, or diagenesis, must be considered closely in stable isotope analysis. Diagenesis refers to the post-mortem chemical alterations of both the protein and mineral fractions of bone that may occur in the depositional environment due to contamination, replacement, or alteration of the chemical composition from substances in the surrounding environment (Schoeninger and Moore 1992). These impacts can alter stable isotope values to reflect the surrounding environment rather than the stable isotope values in the animal organic tissue. Care must be taken when choosing archaeological bone as it is highly susceptible to this process. This is especially true with increasing age and fossilization. The younger the sample, the less impact occurs from diagenesis. Therefore, only Middle to Late Holocene specimens were chosen to minimize the effects of this process.

Carbon Isotopes

The modern $\delta^{13}C$ value of atmospheric CO_2 is approximately -8‰. Prior to the burning of fossil fuels, the $\delta^{13}C$ value of atmospheric CO_2 was closer to -7‰ (Larson 1995). As mentioned above, during photosynthesis, lighter weight isotopes (^{12}C) react faster, using less energy than the heavier isotope (^{13}C). This creates changes in the $^{13}C/^{12}C$ ratio known as fractionation. When a plant fixes CO2 during photosynthesis, a net fractionation of approximately 20‰ occurs between atmospheric CO2 at -8‰ δ13C and the -28‰ sugars in plant leaves, though this can be variable seasonally and regionally (Fry 2006). Carbon isotope fractionation is discrimination against ^{13}C during any process preferring the lighter isotope of ^{12}C. Therefore, during diffusion into plant leaves the lighter carbon isotope (^{12}C) is positively selected during this process, due to fractionation, while ^{13}C is depleted, or discriminated against (O'Leary 1995). During photosynthesis, the fractionation of ^{13}C persists. This occurs due to the chemical uptake of CO_2 (carboxylation) and the physical transport of CO_2 (diffusion) through plant membranes (O'Leary 1995). The degree of fractionation varies depending on whether the photosynthetic pathway of the plant is C_3 or C_4 (Figure 4-1). This results in more negative $\delta^{13}C$ plant values in C_3 plants than C_4 plants. $\delta^{13}C$ values for most C_3 plants lie between -22 to -35‰, and between -9 to -16‰

for C_4 plants (Smith and Epstein 1971). When plants are consumed by herbivorous animals, metabolic processes reverse the direction of fractionation, increasing the proportion of the heavier carbon isotope in the body tissues, otherwise described as enrichment (Tykot 2007). This enrichment allows the relative contributions of each type of plant to the diet of the consumer to be assessed from the $\delta^{13}C$ values of body tissues (DeNiro and Epstein 1978: 505).

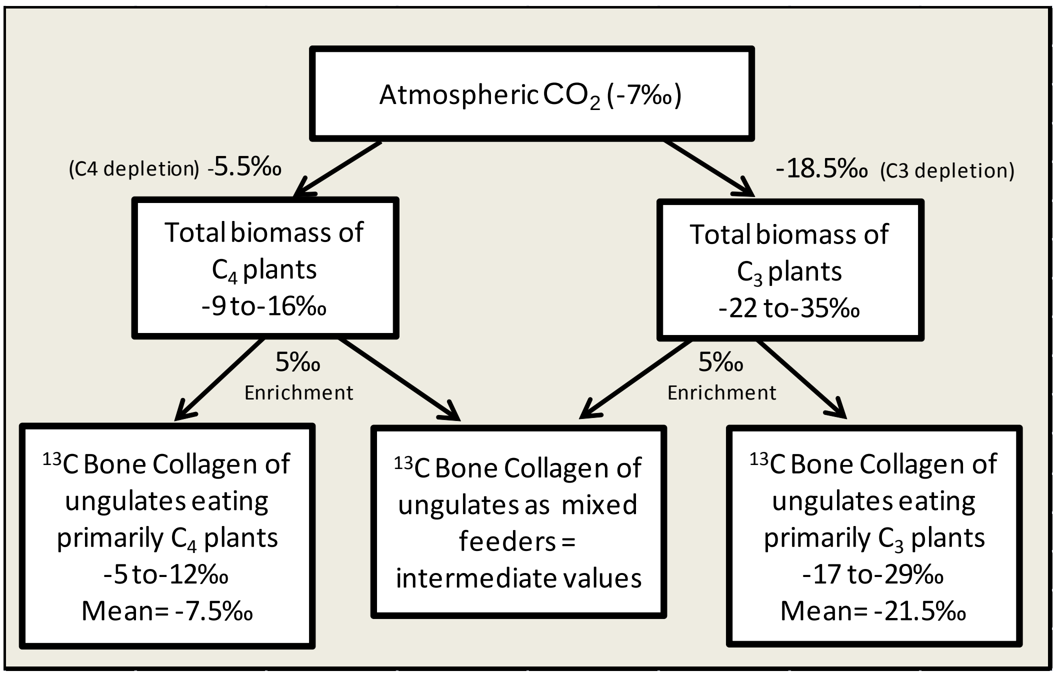

Figure 4-1. The carbon cycle of ^{13}C through the food chain of the bison (adapted from van der Merwe 1989:110; Larson 1995:71).

The fractionation factor for ^{13}C in bone collagen is based on multiple studies of carbon intake in different body tissues of animals. In 1989, van der Merwe concluded that bone collagen in ungulates (herbivores) was enriched by approximately 5‰ relative to their diet. Since that study, various projects have conducted similar studies with both controlled animal diet studies and studies of wild animals and have reported a range of ^{13}C enrichment of 1-4‰ (Bocherens and Drucker 2003; De Niro and Epstein 1978) or 4-6‰ (Tieszen 1994; O'Connell et al. 2001; van der Merwe 1989) across various herbivorous species. This variability can be problematic and debated but most herbivorous artiodactyl bone collagen studies have reported the 5‰ enrichment relative to dietary forage and thus that value was utilized in this study (Ambrose and Krigbaum 2003; Britton 2009; Chisholm et al. 1986; Larson 1995; Leyden and Oetellar 2001; Lovvorn et al. 2001; O'Connell et al 2001; Passey et al. 2005; Tieszen 1994; van der Merwe 1989).

Thus, a bison diet consisting of 100 percent C_3 forage would be expected to produce $\delta^{13}C$ ratios in bone around an average value of -21.5‰ (-26.5‰+ 5‰). Conversely, a diet of exclusively C_4 plants would produce mean $\delta^{13}C$ values of -7.5‰ (-12.5‰+ 5‰) (Chisholm et al. 1986; Leyden and Oetellar 2001). Dietary $\delta^{13}C$ values for bison therefore should range between -21.5‰ and -7.5‰, where a value of -7.5‰ would reflect a diet composed entirely of C_4 plant material while a value of -21.5‰ would represent a diet of primarily C_3 plants.

Nitrogen Isotopes

The naturally occurring isotope of ^{15}N is a biochemical indicator of trophic level of an organism. Bison are primary consumers. Nitrogen isotopes are also used to study variations in the local environment such as decreased precipitation causing dietary stress (Britton 2009; DeNiro and Epstein 1981; Minagawa and Wada 1984; Schwarcz et al. 1999). The primary reservoir for the nitrogen cycle is atmospheric nitrogen, largely in the form of nitrogen gas (N_2), nitrogen oxides (NO_X), and ammonia (NH_3) (Heaton et al. 1997). The nitrogen deposition into soil from the atmosphere is variable and dependent upon whether the deposition is wet (through precipitation), dry (through particles or vapor), or throughfall (through forest vegetation) (Heaton et al. 1997). Nitrogen is incorporated into soils usually in the form of ammonium (NH_4^+), nitrates (NO_3^-), nitrites (NO_2^-), and amino acids (Högberg 1997). Nitrogen is then integrated into biological systems by bacteria and soil microorganisms with plants and primary producers exhibiting a range of values, depending on local environmental conditions. Very little fractionation occurs during biological nitrogen fixation and fractionation is affected by the types of soil microorganisms present and the condition of the soil and substrate (Högberg 1997).

The $\delta^{15}N$ values of soil nitrogen are highly variable and can range between both negative and positive values. These values are dependent on both direct (chemical alteration) and indirect (climate) processes. Any loss in nitrogen fractionates against ^{15}N which results in enriched ^{15}N with increased soil depth (Hobbie and Ouimette 2009). Isotopic fractionation occurs during the uptake of these enriched ^{15}N substrates (Högberg 1997).

The ^{15}N content of animal tissues is magnified step-wise up the food chain by trophic level (Minagawa and Wada 1984). $\delta^{15}N$ data from different biological compounds exhibit fractionation between different materials (e.g. atmospheric nitrogen and integrated organic matter) and animal excretion of ^{14}N via urine and sweat further enriches tissues in ^{15}N (Ambrose 1991; France et al. 2007). Therefore, fractionation results in enrichment of ^{15}N by approximately 2-3‰ per trophic level (DeNiro and Epstein 1981; Minagawa and Wada 1984). However, trophic level shifts of between 1.7 and 6.9‰ have also been observed (Bocherens and Drucker 2003). Additionally, young animals tend to possess higher ^{15}N values than adults based on the offset caused by maternal milk during suckling and weaning (Schoeninger and Moore 1992).

It should be noted that while ^{15}N stable isotopes are incorporated in this study they are only minimally analyzed or discussed here. The processes that control soil and plant ^{15}N are many and complex (e.g. nitrogen fixation, deposition, denitrification, leaching, intra-plant variation, soil microorganisms, etc.). Due to these factors, the use of ^{15}N isotopes in the current study is limited because of the reported complexity and variability in ^{15}N values in different tissues across different trophic levels. This variability cannot be easily observed in archaeological specimens due to temporal, spatial, and post depositional processes that all influence ^{15}N in ways that cannot be seen or accurately accounted for (Högberg 1997). Thus, only general dietary stress is discussed in this research.

Study Area Ecology

The environment of the study area is described in detail in Chapter 2. C_3 grasses tend to grow during the cool spring season whereas C_4 grasses grow best during the warmest months of summer. Most of the western and northern grasslands are dominated by C_3 vegetation (Table 4-1). Temperature and precipitation vary across the Great Plains along both elevational and latitudinal gradients, as well as on a more regional basis (Boutton et al. 1980). Generally, biomass of C_4 plants increases as latitude and elevation decrease. C_3 plants increase latitudinally and altitudinally as one moves northward, and from east to west across the Rocky Mountain region. The Wyoming Basin in the northwest portion of the study area is dominated by C_3 grasses. Mountain grasslands and the northern mixed-grass prairie also have a high percentage of C_3 vegetation. Moving southward on to the Central Great Plains, the grasslands are primarily shortgrass steppe, composed of both a mix of C_3 and C_4 grasses (C_3 still dominating, but to a lesser degree than the northern mixed-grass prairie). Moving further east and south onto the Eastern and Southern Great Plains, grasslands are composed of the tallgrass prairie which is dominated by C_4 grasses.

Sims et al. (1978) reported that the shortgrass steppe is composed of 30 percent C_4 vegetation; the northern mixed-grass prairie is composed of 20 percent C_4 vegetation; and the sagebrush-bunchgrass steppe consisted of only 1 percent C_4 vegetation. These ecozones varied in both vegetation composition and range over time depending on climatic shifts. Therefore, the relative contribution of C_3 and C_4 grasses to the diets of the animals tested should reveal something of the nature of the ecology in the various regions at the time of each bison death event. These estimated grassland compositions are utilized as a base for dietary compositions of the specimens in this study.

Table 4-1. Major Western North American Grasslands and Percent of C_3 and C_4 of Plant Biomass (Adapted from Sims et al 1978; Larson 1995).

Grassland Type	General Grassland Location	% Grasses	% Forb	% Shrubs	% Succulents	% C_3	% C_4
Bunchgrass Steppe	West of Rocky Mountains, Great Basin (Southwest Wyoming)	65	10	25	n/a	99	1
Northern Mixed Prairie	Northeastern Great Plains (Eastern Wyoming)	90	5	5	<1	80	20
Shortgrass Steppe	Western Central Plains (Eastern Colorado)	40	10	30	20	70	30
Tallgrass Prairie	Eastern Great Plains	95	5	n/a	n/a	5	95

METHODS

Specimen Selection

Bison bone specimens from five kill sites and four natural death occurrences were utilized for this portion of this research (Figure 4-2). Multiple specimens were used from each kill site resulting in 35 overall samples.

While only a small sample of bone was needed, stable isotopes analyses are a destructive form of testing. Bone was chosen for this study as the ^{13}C in collagen reflects the average contribution of C_3 and C_4 forage to the diet of the animal over the course of its life. The turnover rate in bone is slow, approximately 10-15 years (Chisholm 1986). While small, seasonal changes in diet are obscured by this slow rate of turnover, the overall diet of the animal throughout its lifetime can be observed.

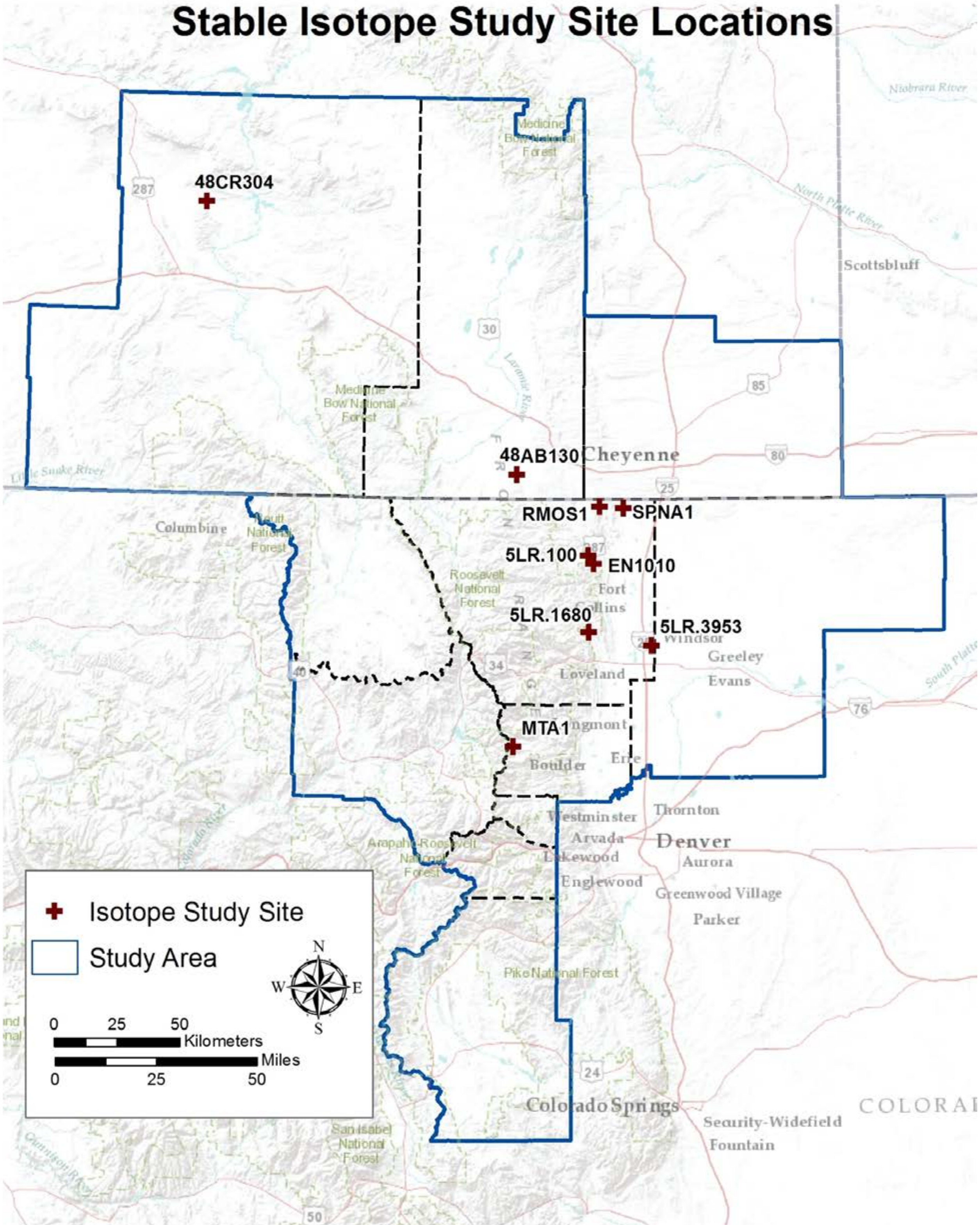

Figure 4-2. Locations of archaeological and non-archaeological sites used in the stable isotopes analysis.

Most previous studies either do not elaborate on, or consistently use, bone specimens from the same body source or element. The use of a single skeletal element type is essential for a kill site so that it can be assured that the elements analyzed are from different animals. Bison kill sites often result in a jumbled bone bed and the only way to ensure that the specimens are from different individuals is to identify specimens that can be paired (e.g. left and right humerus, or left and right mandible). By choosing only specimens of the same element type and same side of the animal, it can be assured that an individual is being sampled only once. For this study, same side mandibles were utilized when available to allow for a general determination of age of the specimen sampled.

Specimens from Archaeological and Non-archaeological Locations

The sites in this study primarily occur at the foothills and plains margin in northern Colorado. Two additional sites are located in Wyoming. One is located at the southern extent of the Laramie Basin, in relatively close proximity to the Colorado specimens. The other Wyoming site is located in the eastern Wyoming Basin at the margin of the basin with the Northwest Great Plains. Three of the non-archaeological specimens were found at the foothills and Great Plains margin in northern Colorado and the other specimen originated in the alpine zone of the Southern Rocky Mountains. The purpose of studying specimens from a restricted location for isotopic research was twofold. First, these sites and specimens all had dated or dateable remains and adequate quantities of bone to analyze for stable isotopes values. Second, by analyzing specimens from a narrow region at a marginal zone, an attempt to correlate dietary forage distribution at different elevational zones could be identified across a temporal scale.

<u>Scoggin Site (48CR304)</u> –The Scoggin site is a bison kill located west of Seminoe Reservoir in Carbon County, Wyoming. The specimens from this site are housed at the University of

Wyoming Archaeological Repository (UWAR) in Laramie. This area is within the western portion of the Wyoming Basin. This large kill site represents at least two different kill events that occurred during the Middle Archaic period (4540 +/-110 RCYBP). Mandibles were not sampled from this site due to poor preservation. Therefore, five right radius specimens from young adult animals were utilized from this site.

Kaplan-Hoover (5LR3953) – This site is bison bonebed located in eastern Larimer County in the town of Windsor, Colorado. The site was excavated by Colorado State University in the late 1990s by L.C. Todd (Todd et al. 2001). The site dates to 2724 +-35 RCYBP placing it in the Late Archaic period. The specimens from Kaplan-Hoover are housed at the Archaeology Repository of CSU. A total of eight right side mandibles from adult specimens were sampled.

Willow Springs (48AB130) – This site is a bison pound located in the southern extent of the Laramie Basin in southern Wyoming. The specimens are housed at the UWAR. The site contains a mixed bonebed containing stone tools that date from the Middle Archaic to Late Prehistoric periods, but is dominated by Late Prehistoric tools (Bupp 1981). Six left mandibles from adult specimens were chosen for this study. In addition, one bone sample from one of these specimens was sent to AEON laboratories for AMS dating.

Roberts Bison Jump (5LR100) – This bison jump in located at the margin of the foothills and plains in northern Colorado near the southern extent of the Laramie Basin (Witkind 1971). This site dates from the Late Prehistoric to Protohistoric period. The specimens are housed at the Archaeological Repository of CSU. Eight left side mandibles from adult specimens were sampled.

Blanz Site (5LR1680) – This bison kill is located in the hogbacks of the foothills in northern Colorado. The collection from this site is curated by the Archaeological Repository of CSU. The site consists of almost exclusively bison bone. Flakes, tools, and pottery were found intermixed with the bison bone. No formal excavation report was ever written. Four right side mandibles from adult specimens were sampled from this site. In addition, one bone sample from one of these specimens was sent to AEON laboratories for AMS dating.

Eagles Nest Open Space Specimen (EN1010) – This single sample is from a small collection of bison bone excavated by Dr. Jason LaBelle and represents a natural occurrence (LaBelle Personal Communication 2014). These specimens are housed at the Center for Mountain and Plains Archaeology (CMPA) at CSU. These bones were eroding out of a cutbank in the Eagles Nest Open Space near Fort Collins, Colorado. This area is within the foothills near the margin of the Great Plains. The specimen used for this research was a left metatarsal from an adult animal. One bone sample was sent to AEON laboratories for AMS dating.

Mount Audubon Specimen (MTA1) – This specimen is an isolated humerus collected from Mount Audubon, a peak in the Southern Rocky Mountains in Colorado. It was donated to the CMPA. This high elevations specimen provides an outlier to the rest of the lower elevation stable isotopes data set. One bone sample was sent to AEON laboratories for AMS dating.

Red Mountain Open Space Specimen (RMOS1) – This specimen is located in the CMPA collection. The specimen was found at Red Mountain Open Space north of Fort Collins, Colorado in an area at the margin of the foothills and Great Plains. It is a bison skull from an adult animal. A bone sample was collected from the palate. One bone sample was sent to AEON laboratories for AMS dating.

Soapstone Prairie Natural Area Specimen – Wire Draw (SPNA1) – This specimen is located in the CMPA collection. The specimen was found in Wire Draw at Soapstone Prairie Natural Area north of Fort Collins, Colorado. This area is within marginal zone of the foothills and plains boundary. It is a bison skull from an adult animal. A bone sample was collected from the palate. One bone sample was sent to AEON laboratories for AMS dating.

AMS Radiocarbon Analysis

Two of the sites, Willow Springs (48AB130) and Blanz (5LR1680), and the four non-archaeological bone specimens had not been previously radiometrically dated. Because of this, one bone sample from each of the two sites and one sample from each of the four individual bison were sent to Aeon Laboratories, LLC (Aeon) in Tucson, Arizona for radiocarbon dating by accelerator mass spectrometry (AMS). The AMS results are discussed in the individual sites discussion in the results section of this chapter. The AEON results are located in Appendix C. In addition, ^{13}C and ^{15}N analyses were run by Aeon on each of the specimens to act as a comparative and control procedure for the main analysis run by this researcher at CSU.

Aeon Laboratories Procedures

The following briefly outlines the Aeon lab methods as described by their internal protocols (Aeon 2014). The samples submitted to Aeon were subjected to a series of pretreatment processes designed to isolate a pure sample of carbon for radiocarbon dating. For bone, the sample was pretreated to remove surface contaminants by cleaning and washing, and broken into fragments. The bone was then demineralized in dilute hydrochloric acid (HCl) to retrieve the protein of collagen. The AEON methods of collagen extraction are similar to those described and conducted by this researcher in the following section. For the AMS radiocarbon measurement, the carbon sample was chemically isolated and a portion was selected for carbon extraction. The AMS procedure involved several steps. The sample was preheated under vacuum to remove adhering atmospheric gases, including CO_2, and combusted in the presence of excess high-purity oxygen. Excess oxygen is removed and the CO_2 is purified.

Water and other contaminants were removed and the resulting pure CO_2 gas was measured. A tiny amount of the CO_2 gas was utilized for stable isotope ($\delta^{13}C$) analysis. The remaining CO_2 was converted to graphite. The $^{14}C/^{12}C$ and $^{13}C/^{12}C$ isotope ratios in the graphite test sample were then subject to the AMS process. The process was repeated several times and the data were averaged to international standards, and fractionation corrections applied (Aeon 2014).

Collagen Extraction Procedures at CSU

Extraction of bone collagen and subsequent stable isotope analysis was conducted by this researcher at the Natural Resource EcoCore Laboratory (EcoCore) at Colorado State University. Bone samples were prepared for collagen extraction via protocols outlined by Stafford (personal communication 2013); Stafford et al. (1991); and Britton (2009). These protocols include ultra-filtration of the collagen to ensure that as many known contaminants as possible are eliminated. It should be noted that no one technique has been proven to definitively remove all contaminants. However, collagen extraction techniques have improved greatly since their inception and a general consensus of currently approved extraction techniques now exists. A detailed description of the collagen extraction laboratory procedures can be found in Appendix D.

The initial step in this process was to extract a sample of cortical bone from each specimen. Cortical bone is the outer, hardest layer of bone and is ideal for collagen studies. A one square-inch section of bone was cut from each specimen using a rotary tool with a diamond cutting disk. The disk was replaced between samples to minimize cross contamination of carbon material. Each sample of bone was weighed and bagged separately. Surface contaminants were removed such as soil, roots, and any cancellous bone (spongy bone) from the sample. This involved manual removal via brushing, scraping, and washing in deionized water.

All laboratory glassware was heated in a muffle furnace to 500 degrees C to remove contaminants. Each bone sample was broken into 5-10 mm sized fragments and weighed out (1 g) into 20 ml test tubes. These were then soaked in an acid solution of dilute 0.5 molar (M) hydrochloric acid (HCl) and solubilized at low temperature (4 degrees C) to decalcify the samples until the collagen was extracted and the mineral content dissolved. This step took from one to four days, dependent on the amount of minerals present. The bone was considered to be demineralized when the samples became soft and gelatinous and CO_2 production (visible as effervescence) had ceased (Britton 2009). The samples were then rinsed liberally in deionized water.

After demineralization, the samples were soaked in a base solution of dilute potassium hydroxide (KOH) to remove humates and fulvic acids. The samples soaked at low temperature (4 degrees C) for 24 hours, rinsed thoroughly in deionized water, and placed in a freezer. Upon freezing, the samples were lyophilized (freeze-dried) overnight. The next step was to gelatinize the samples. During this process proteins were freed into solution under the effects of high temperatures and low pH. This separated the collagen from any remaining bone matrix or other contaminant materials and facilitated the successive ultra-filtration step. The fibril structure of collagen denatures at approximately 58^{o}C and studies have demonstrated that the samples stabilize at these higher temperatures (Britton 2009). Each test tube was filled with fresh 0.5 M HCl and sealed. The tubes were placed in a heat block and heated to 90-100 degrees C for up to two hours. This step was complete when the samples dissolved.

The liquid gelatin was then cooled and filtered through a teflon (PTFE) 0.45 μm filter assembly into glass vials to further purify the samples and remove any remaining particulates. These samples were then frozen. This step was followed by a second lyophilization. When complete, the final collagen yield had a light, dry, spongy consistency. At this point the samples were ready for isotope ratio mass spectrometry (IRMS).

IRMS Analysis of Bone Collagen

Stable isotopic measurements were conducted by this researcher at the EcoCore facility of the EcoCore lab at Colorado State University using a VG Isochrom continuous flow IRMS (Isoprime Inc., Manchester, UK), coupled to a Carlo Erba NA 1500 elemental analyzer (EcoCore 2013). The minimal carbon sample size that can be utilized by this instrument is 1 micromole (µmol) for carbon and 2 µmol for nitrogen. The run time per sample is 6 minutes with a precision for ^{13}C of 0.2‰ and 0.3‰ for ^{15}N.

The collagen samples were weighed into tin capsules for stable isotope analysis. For ^{13}C and ^{15}N analysis, only very small amounts are required. A microbalance was used to weigh 0.15-0.55 mg of each sample into the tin capsules. This was done using metal tweezers which were cleaned between each sample with methanol. The tin capsules were closed and compressed, placed into labeled trays and were ready to be analyzed. The mass of each sample was recorded individually. Internal laboratory standards were included in every isotopic run for calibration and to ensure that the isotopic values were acceptable. The raw laboratory stable isotopes data is presented in Appendix E.

Both stable isotopes of ^{13}C and ^{15}N were analyzed for this study. Carbon isotopes data are the main focus of this study due to their importance in paleocology studies. While nitrogen stable isotopes were analyzed, they provided baseline data on trophic level and comparative control data, they were not analyzed in depth for this study.

Given a δ^{13}C value for an archeological bone sample, it is possible to calculate the relative contributions of C_3 and C_4 plant species in that particular animal's diet using a mixing model. A mixing model is based on mass balance and provides a percentage of a single isotope value measured in the bone of the collagen and two diet sources (C_3 and C_4) (Phillips 2012). The mixing model notation is expressed as follows:

$$f_1 = \frac{\delta^{13}C_{mix} - \delta^{13}C_2}{\delta^{13}C_1 - \delta^{13}C_2}$$

$$f_2 = 1 - f_1$$

where $\delta^{13}C_{mix}$ represents the $\delta^{13}C$ value obtained from the sample and $\delta^{13}C_1$ and $\delta^{13}C_2$ represent the average contribution of C_3 and C_4 plants to the diet respectively. It is important to remember to apply the bone collagen fraction factor (enrichment) of 5‰ to the ^{13}C values of the C_3 and C_4 plants. The resulting f_1 and f_2 data solutions will indicate the percentage of assimilated diet of the bison. As previously mentioned, herbivore tissues, in this case bison, are normally enriched in ^{15}N by approximately 2-3‰ compared to the plant matter that they consume which is magnified going up the food chain (DeNiro and Epstein 1981).

RESULTS

The stable isotopes results are presented in the following sequence. First is a general discussion of the overall trends in stable isotopes values across an interherd (between different herds) analysis of the entire study region. This is followed by a detailed intraherd (within the same herd) discussion from each archaeological site and non-archaeological specimens. Finally, the results are discussed in relation to observed altitudinal and chronological trends with paleoclimate data.

The overall trend of the stable isotope values from an analysis of the grouped data indicate that the dietary compositions correspond well with the known distribution of C_3 and C_4 grasses across the Great Plains and Rocky Mountains (Table 4-2). The $\delta^{13}C$ values cover a wide range from -18.56 to -7.76‰. These values indicate a relatively low percentage of C_3 vegetation when compared to the values presented in the studies from the Northern Great Plains (Chisholm et al. 1986; Leyden and Oetellar 2001). The values from the sites and individual specimens in the eastern portion of the study area tend to have an equal or higher percentage of C_4 grasses in their diets than C_3. Whereas, the specimens from the western portions of the study area are more closely associated with C_3 grasses. Based on the general latitudinal and longitudinal distributions of these grasses, the results are not unexpected. The specimens from intermountain basins and the high altitude specimen all coincide with mixed-grass species that are found in the intermountain basins. They have a marginally higher percentage of C_3 in their diets, indicating lives at higher altitudes, latitudes, or farther west in longitude. None of the specimens show a diet comprised entirely of C_3 vegetation which would be expected if they lived at high altitude or far western longitudes for most of their lives.

The $\delta^{15}N$ values possess a spread of 4.99 to 8.06‰, with most values (n=29/35) falling within the 5-7‰ range. These values are within the normal range of values for bovines at a primary consumer trophic level feeding in open grassland (Ambrose 1991, France et al. 2007). None of the values fall outside of the normal range to indicate dietary stress. The results are similar to modern ^{15}N values from grazing herbivores (Ambrose 1991), suggesting that climatic conditions were similar to today. Due to this lack of variability, the ^{15}N stable isotopes values are not discussed further.

The information from within each kill site is of more interest from an intraherd dynamic viewpoint. Figure 4-3 plots the ^{13}C and ^{15}N values from each analyzed specimen. The following details the findings from within each kill site and the variations or similarities of the isotope

Table 4-2. Stable Isotopes Values of all Specimens and Percentage C_3 and C_4 Contribution to Diet.

Site No. - Sample No.	Site Age RCYBP	Elevation (m)	$\delta^{13}C$ of collagen (‰)	$\delta^{15}N$ of collagen (‰)	% C_3 of diet	% C_4 of diet
48CR304-45	4540	2103	-18.56	5.59	79	21
48CR304-46	4540	2103	-14.91	6.42	52.9	47.1
48CR304-47	4540	2103	-17.34	7.02	70.2	29.8
48CR304-48	4540	2103	-16.09	6.50	61.4	38.6
48CR304-49	4540	2103	-14.43	7.19	49.5	50.5
RMOS1	3375	1829	-13.33	5.34	41.6	58.4
5LR3953-24	2700	1487	-10.41	6.49	20.8	79.2
5LR3953-136	2700	1487	-10.21	6.65	19.4	80.6
5LR3953-215	2700	1487	-11.51	6.26	28.6	71.4
5LR3953-258	2700	1487	-7.76	6.34	1.9	98.1
5LR3953-276	2700	1487	-9.15	5.95	11.8	88.2
5LR3953-298	2700	1487	-11.33	4.99	27.4	72.6
5LR3953-328	2700	1487	-10.5	5.75	21.4	78.6
5LR3953-619	2700	1487	-10.05	5.87	18.2	81.8
MTA1	2240	3048	-16.53	5.90	64.5	35.5
48AB130-D1917	1325	2335	-17.48	5.02	71.3	28.7
48AB130-D1981	1325	2335	-17.61	5.44	72.2	27.8
48AB130-D2667	1325	2335	-16.25	5.23	62.5	37.5
48AB130-D4350	1325	2335	-16.43	5.82	63.8	36.2
48AB130-D4417	1325	2335	-16.08	5.26	61.3	38.7
48AB130-D4568	1325	2335	-14.83	5.25	52.3	47.7
5LR100-18	200	1777	-17.53	5.52	71.6	28.4
5LR100-19	200	1777	-13.49	6.61	42.8	57.2
5LR100-20	200	1777	-17.19	5.80	69.2	30.8
5LR100-22	200	1777	-14.09	6.64	47.1	52.9
5LR100-23	200	1777	-15.59	6.03	57.8	42.2
5LR100-25	200	1777	-11.29	7.19	27.1	72.9
5LR100-28	200	1777	-15.24	6.78	55.3	44.7
5LR100-32	200	1777	-13.62	6.29	43.7	56.3
EN1010	200	1829	-11.77	8.06	30.5	69.5
5LR1680-6	160	1707	-13.25	6.22	41.1	58.9
5LR1680-124	160	1707	-10.95	6.93	24.6	75.4
5LR1680-241	160	1707	-11.76	6.96	30.4	69.6
5LR1680-274	160	1707	-13.68	6.61	44.1	55.9
SPNA1	130	1829	-17.87	5.36	74.1	25.9

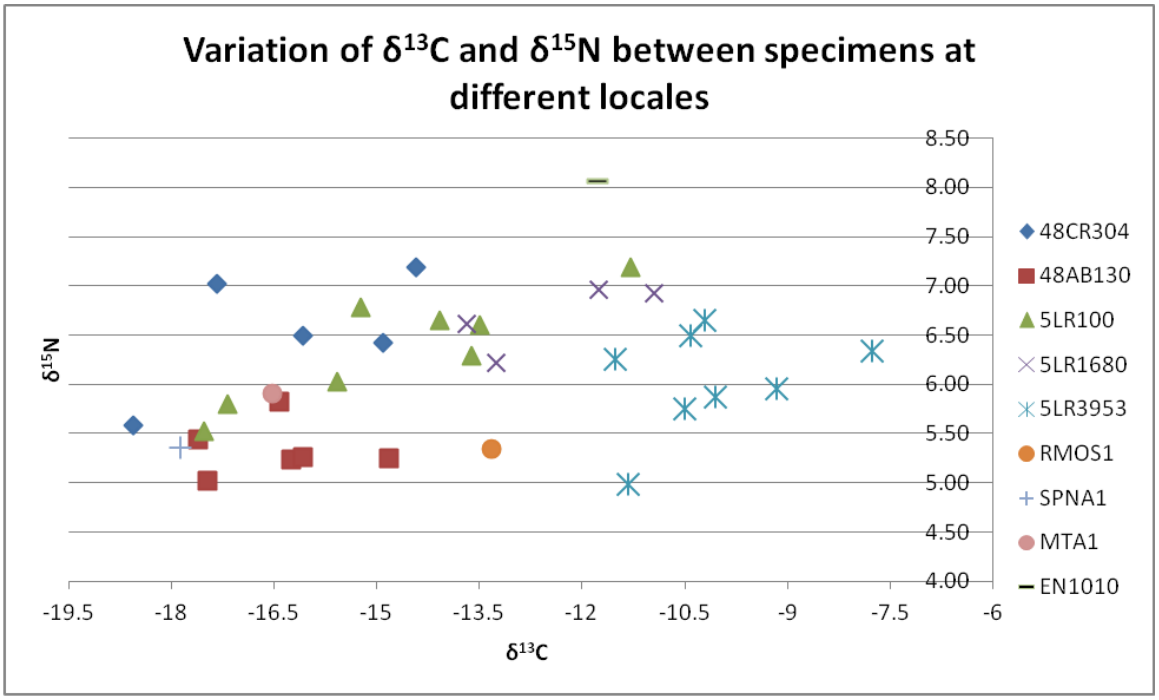

Figure 4-3. Scatter plot exhibiting the variation of ^{13}C and ^{15}N between individual specimens at different locales.

values are discussed. The individual site discussions are carried from the oldest site to the youngest.

Scoggin Site (48CR304)

Five right side bison radii from young adult animals were chosen for this study. This site dates (4540 +/-110 RCYBP) to the Middle Archaic period with a calibrated date range of 5038-5323 cal BP. The results for ^{13}C indicate that all of the animals had a mixed C_3 and C_4 diet (see Table 4-2 and Figure 4-3). Based on the ^{13}C results, three of the specimens (Specimen No. 45, 47, and 48) are more closely correlated in diet (comparatively higher proportions of C_3 forage than C_4) than Specimens 46 and 49. One of the former specimens (45) diet corresponds well with the photosynthetic pathway of the northern mixed-grass prairie whereas the diets of specimens 47 and 48 generally follow the trend of the shortgrass steppe. On the other hand, Specimens 46 and 49 are more similar in foraging behavior and possess a near even ratio of C_3 and C_4 grasses in their diet. These do not correspond to any of the major, modern grassland photosynthetic compositions. Their dietary composition varies enough from the other specimens to indicate lives grazed in areas with warmer, dryer conditions.

<u>Red Mountain Open Space Specimen (RMOS1)</u>

This site consists of a single specimen from a non-archaeological context. A sample was sent for AMS dating and returned a date of 3375 +/-35 RCYBP, which when calibrated, yielded a date range of 3575–3642 cal BP, placing this site within the Middle Archaic period. The site is situated at the margin of the foothills and plains which are a region open to various ecological zones. The results for ^{13}C indicate that this animal had a mixed diet composed of 41.6 percent C_3 vegetation. This diet suggests a foraging range predominately on the Great Plains shortgrass steppe. Some movements into the Laramie Basin to the north may also have occurred.

<u>Kaplan-Hoover (5LR3953)</u>

Eight adult specimens were examined from this Late Archaic period kill site (2724 +-35 RCYBP), which when calibrated, yielded a date range of 2755-2844 cal BP. The results for ^{13}C are the most unusual of any sites in the study. The results indicate that these bison have the highest percentages of C_4 diet of any specimen analyzed. All of the Kaplan-Hoover specimens contain greater than 70 percent C_4 dietary forage (see Table 4-2). This indicates that these animals likely spent all of their time on the Great Plains, and possible extensive periods on the eastern Great Plains in areas of tallgrass prairie which is composed primarily of C_4 forage. These results are interesting, indicating eastern migration patterns and little movement into higher elevations. There is significant variability in the composition of dietary forage between the animals at Kaplan-Hoover. The diet of Specimen 215 consisted of the lowest quantity of C_4

grasses at 71.4 percent. Specimen 258 contained the highest amount of C_4 forage at 98.1 percent. The remaining specimens fall between these two extremes

Mount Audubon Specimen (MTA1)

This site consists of a single specimen from a non-archaeological context. A sample was sent for AMS dating and returned a date of 2240 +/-30 RCYBP, which when calibrated, yielded a date range of 2179–2249 cal BP, placing this site within the Late Archaic period. The specimen was situated in the alpine zone of Mount Audubon, a peak in the Southern Rocky Mountains. The results for ^{13}C indicate that this animal had a

mixed diet composed of 64.5 percent C_3 vegetation. This diet suggests a foraging range predominately in the mountain basins and little to no movement onto the Great Plains.

Willow Springs (48AB130)

Six adult individuals were analyzed from this site. In addition, one specimen (D1917) was sent for AMS dating. The AMS analysis returned a date of 1325 +/-30 RCYBP, which when calibrated, yielded a date range of 1259-1294 cal BP, placing this component into the Late Prehistoric period. The results for ^{13}C indicate that all of the animals had a mixed C_3 and C_4 diet. Four of the specimens had similar diets (> 60 percent C_3) which are similar to the photosynthetic pathways of the modern mixed grass prairie (see Table 4-2). Only one of the specimens (D4568) yielded a more equally mixed signal of C_3 and C_4 vegetation. This signature does not match any of the modern grasslands but does indicate a more Plains oriented foraging pattern.

Roberts Bison Jump (5LR100)

Eight specimens were analyzed from the Roberts bison jump site. This site dates to the Prehistoric-Protohistoric period. with calibrated date ranges of 395-424 cal BP and 170-217 cal BP The results for ^{13}C indicate that all of the animals had a mixed C_3 and C_4 diet (see Table 4-2).

Four of the specimens had dietary compositions composed of higher percentage of C_3 (>55 percent to 71 percent). Three of the specimens contained diets composed of greater than 40 percent C_3 and the remaining specimen had only 27 percent of C_3 in its diet. These variable diets suggest that these animals were grazing on both the Great Plains shortgrass steppe and into the mixed grass prairie of the mountains or Laramie Basin at various magnitudes. The site is situated at the margin of the foothills and plains which are a region open to various ecological zones.

Blanz Kill Site (5LR1680)

Four specimens were analyzed from the Blanz bison kill. In addition, one specimen (241) was sent for AMS dating. The AMS analysis returned a date of 160 +/-20 RCYBP, which when calibrated, yielded a date range of 172–218 cal BP, placing this site within the Protohistoric period. The results for ^{13}C indicate that all of the animals had a mixed C_3 and C_4 diet. The composition of the dietary forage of these specimens is similar to those of the Roberts bison jump. Here, the dietary composition is 40 percent C_3 in two of the specimens and 24 and 30 percent C_3 in the other two specimens, respectively (see Table 4-2). These diets indicate foraging predominately on the Great Plains with possible foraging in the Laramie Basin and surrounding mountains. The site is situated in the hogbacks at the margin of the foothills and plains which is a region open to various ecological zones.

Eagles Nest Open Space Specimen (EN1010)

This site consists of a single specimen from a non-archaeological context. A sample was sent for AMS dating and returned a date of 200 +/-25 RCYBP, which when calibrated, yielded a date range of 150–173 cal BP, placing this site within the Protohistoric period. The site is situated at the margin of the foothills and plains which are regiona open to various ecological zones. The results for ^{13}C indicate that this animal had a mixed diet composed of 30.5 percent C_3

vegetation. This diet suggests a foraging range predominately on the Great Plains in the shortgrass steppe.

Soapstone Prairie Natural Area Specimen (SPNA1)

This site consists of a single specimen from a non-archaeological context. A sample was sent for AMS dating and returned a date of 130 +/-25 RCYBP, which when calibrated yielded a date range of 68–118 cal BP, placing this site within the Protohistoric to Historic period. The site is situated at the margin of the foothills and plains which are a region open to various ecological zones. The results for ^{13}C indicate that this animal had a mixed diet composed of 74 percent C_3 vegetation. This diet suggests a foraging range predominately in the mixed grasslands of the mountains or mountain basins such as the Laramie Basin to the north.

Intraherd Dynamics Discussion

An examination of the dynamics of bison feeding ecology is examined for each herd in relation to itself. In general, the variability within the bison ecology at each site is greater than expected. The implication for this outcome include variations in herd make-up due to seasonal influences such as breeding; or the potential for multiple kill events at different times.

Scoggin Site (48CR304)

The specimens from the Scoggin site show more variation in diet composition between each other than expected. Several reasons for this variability are possible. Overall, these results indicate that the animals from the former (Specimens 45, 47, and 48) and latter (Specimens 46 and 49) groups are not members of the same herd. Indeed, it is also possible that the former three specimens are not from the same primary herd either. Their dietary compositions are varied enough to indicate noticeable variability in grazing forage. These differences in diet imply that bison herds were comingling at the time of their deaths.

The most likely scenario is that at least some of the specimens come from different kill events as has been suggested for the Scoggin site (Kornfeld et al. 2010:254-55; Miller 1986; Niven and Hill 1998). While provenience information from this site is poor, the dietary compositions of the specimens tested suggest at least two different herd groups. Whether these kill events occurred in the same year or in consecutive years in unknown. Niven and Hill (1998) proposed that the two separate kill events occurred in the summer-early autumn, and late autumn to early winter, respectively. The summer-early autumn event would correlate with the timing of large group aggregations that may have consisted of several coalesced herds and bulls. The variation between all of the diets of the specimens could support this. However, the variability between the diets of the specimens suggests at least two different groups with varied dietary forage, indicating at least two kill events. Specimens 46 and 49 have a different enough dietary composition from the other three specimens to support the evidence of multiple herd kills.

Kaplan-Hoover (5LR3953)

The specimens from Kaplan-Hoover exhibit a great deal of variability in their dietary composition from animal to animal. Several reasons for this variability are possible. Overall, these results indicate that not all of these animals are from the same herd. While all of their diets contain significant quantities of C_4 vegetation, their dietary compositions are varied enough to indicate noticeable variability in grazing forage. These differences in diet imply that bison herds were comingling at the time of their deaths.

It is possible that the specimens from Kaplan-Hoover come from different kill events. However, based on excavation analysis, Todd et al. (2001) suggest a single kill event based on site patterning and taphonomic processes. Further, they estimated the kill event occurred during the early fall based on mandibular molar eruption analysis (Simcox in prep; Todd et al.

2001:137). In addition, skeletal morphology analyses indicated a mixed herd of bulls and cows (Todd et al. 2001:137). The early fall kill event would correlate with the timing of large group aggregations for the rut that may have consisted of several coalesced herds of cows and bulls. The dietary results indicate that all of these herds would have likely been localized to the Great Plains and not the mountains. The differences in dietary forage between the animals at Kaplan-Hoover support this overall scenario.

Willow Springs (48AB130)

The specimens from Willow Springs exhibit less variability in their dietary composition than both the Scoggin and Kaplan-Hoover sites. This suggests that these bison may have been members of the same herd for much of their lives, or consisted of comingling herds that had similar foraging environments. Specimen D4568 is the only outlier in this sample. This indicates that this animal is either from a different region and herd, or that this specimen is from a different kill event than the others. Either scenario is possible. Willow Springs is a multi-component event that dates from the Middle Archaic period through the Late Prehistoric period based on tool morphology (Bupp 1981). The single radiocarbon date collected during this study only supports the Late Prehistoric component of this site which is consistent with the predominance of Late Prehistoric lithic tools found on the site (Bupp 1981). In addition, the site contains poor provenience and archival data which complicates the identification of specimens with different components. Therefore, it is possible that Specimen D4568 is from another component and kill event.

Roberts Bison Jump (5LR100)

The specimens from the Roberts bison jump exhibit significant variability in their dietary composition. This suggests two possible reasons. First, the variability may indicate more than one kill event occurred at this location during the period of the kill. Multiple radiocarbon dates have been collected from this site which implies that this was a single kill event (Christopher Johnston, personal communication 2014). However, the variability within the dietary forage of these animals suggests other possibilities. This site may represent multiple herds coming together for the late summer into early fall rut. This scenario is complicated by the presence of fetal bison remains in the faunal assemblage which would suggest a late fall or early winter kill event (Johnston in prep 2014; Christopher Johnston, personal communication 2014). By that time, many of the herds would have dispersed into their original groups which should consist of animals with similar dietary compositions. Therefore, it is possible that herds are not as dynamic as suggested and may comingle across their lives. Yet, even if grouped differently, the overall dietary makeup for bison foraging in the same environments at the same time should be relatively similar. It is possible that this site is not a single kill event and may instead represent at least two separate kills that occurred over consecutive seasons or several years. An analysis of herd composition and molar eruption patterns would need to be conducted on the assemblage to help in determining possible variations in seasonality of the kill event.

Blanz Kill Site (5LR1680)

No formal report has been produced for the Blanz site. Therefore, only inferences can be made about intraherd dynamics based on stable isotopes data. The specimens from the Blanz site exhibit some of the greatest variability in dietary composition of any of the sites. Two of the specimens have dietary compositions between 41 and 44 percent C_3 forage whereas the other two consist of 25 and 30 percent C_3 forage. These results suggest that two separate grazing groups may have been killed at this site. While no information on seasonality has been collected, it is certainly possible that this site represents a late summer to early fall kill event in which two groups had coalesced. It is also possible that this site represents multiple kills events, though this scenario seems unlikely. A cursory examination of the remaining assemblage suggests that this kill site consisted of a small group of animals which precludes the probability of multiple kill events in this location.

Paleoclimate Analysis

The results of the stable isotopes analysis was compared to the paleoclimate data from the region by evaluating vegetation trends of C_3 and C_4 grassland distribution. In general, there is a correlation with the age and altitude of the site and the amount of C_3 vegetation in the diet of the bison. Figure 4-4 illustrates this relationship of site age with the percentage of C_3 dietary forage. There is a great deal of variability in the percentage of C_3 and C_4 in the diets of each animal and this is discussed below. Only the Late Archaic period specimens from Kaplan-Hoover exhibit significantly greater abundance of C_4 dietary forage. Figure 4-5 graphically demonstrates the relationship between site altitude and percentage of C_3 bison dietary forage. This graph exhibits a general trend of greater C_3 representation with increased altitude (and by extension increased latitude). This result was not unexpected. The following section describes the climatic conditions of each site from oldest to youngest.

The specimens dating to the Middle Archaic period (Scoggin site [48CR304] and RMOS1 specimen) exhibit paleodiets suggestive of a transitional climatic period. However, it is a period of instability and the regional conditions were likely still influenced by the previous dry period. The diets from the Scoggin site specimens generally correlate with the suggested paleoclimatic conditions of the area during the Late Holocene as converting to more mesic conditions after the Altithermal period (7500-5000 RCYBP). None of the diets correlate with the modern sagebrush-bunchgrass steppe environment which contains grasses that are almost

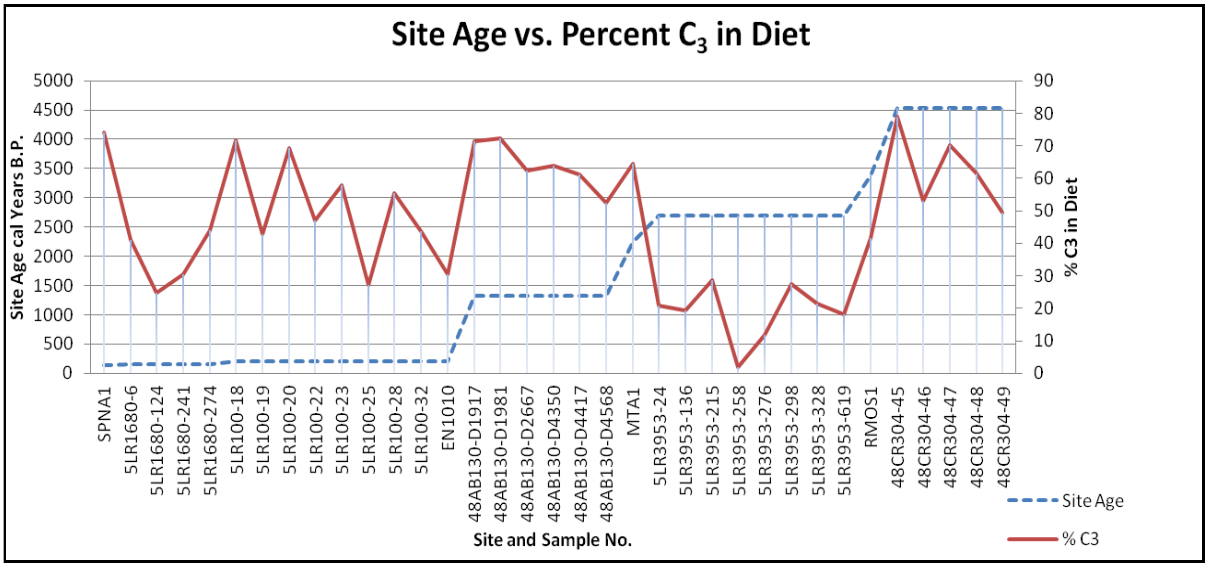

Figure 4-4. Graphical representations of the age of the site vs. the quantity of C_3 forage in the diet of each bison specimen via 13C stable isotopes.

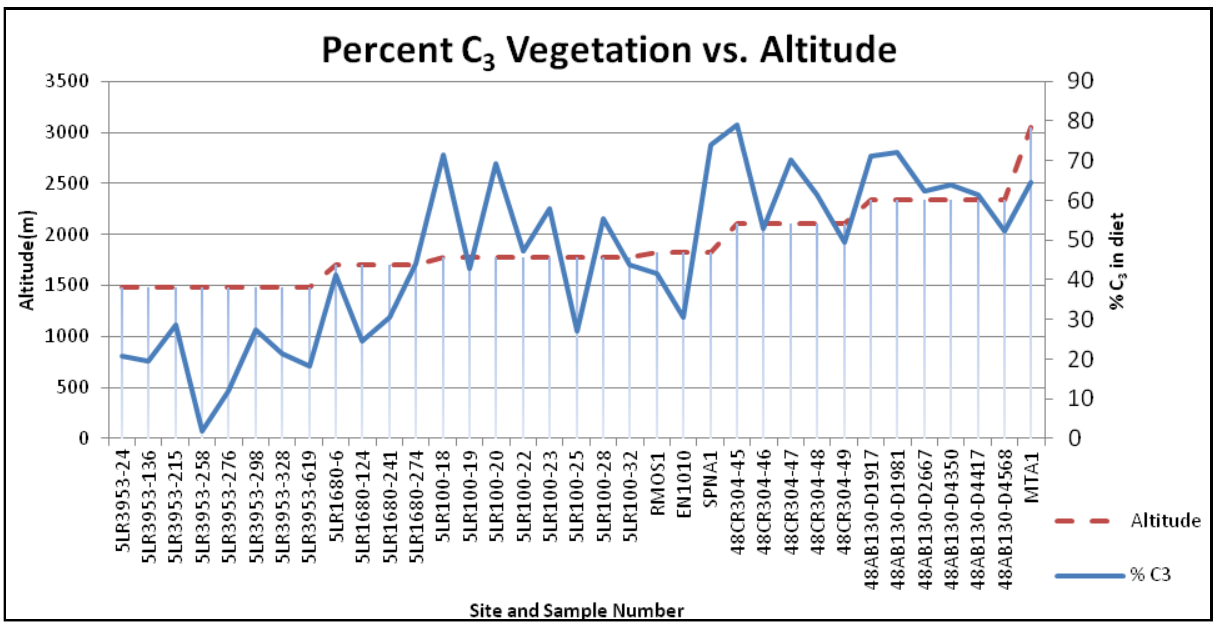

Figure 4-5. Graphical analysis of the percent of C_3 in the diet of each specimen compared to altitude.

entirely of the C_3 photosynthetic pathway (Sims et al. 1978; Larson 1995).

This result suggests two potential scenarios for the Scoggin site bison. First, that the local environment of the Scoggin site at the time of the kill was likely more of a mixed-grass prairie or shortgrass steppe. Based on the expected climatic changes (relatively cool and wet) that occurred during the Middle Plains Archaic period, the expansion and presence of a variety of grass species is possible. The second possible scenario is that the present ecological conditions of a sagebrush-bunchgrass steppe existed at the time of site formation. If this was the case, then it is likely that the herds were migrating along the North Platte River valley to the east and were utilizing not only the river valley but migrating into the foothills and higher elevations of the Sierra Madre and Medicine Bow Mountains to the south and/or the Laramie Mountains to the east. The areas along the North Platte River and into the mountains would likely have been composed of mixed grassland vegetation which would have included both C_3 and C_4 grasses. In addition, the smaller mountain ranges of the Shirley Mountains to the east and the Ferris Mountains to the north may have had enough grassland variability to account for some of the variation in C_3 and C_4 diet contributions. With present ecological conditions, bison would have likely had to migrate at least seasonally to the eastern grasslands, or to the mountain regions for edible forage that could correspond to the ^{13}C stable isotope values found in the specimens at Scoggin. Therefore, either the paleoenvironment was not the same as today or the bison migrated between different areas.

The single specimen from Red Mountain Open Space (RMOS1) exhibits a diet that correlates with foraging on the Great Plains and potentially into the Laramie Basin to the north. This specimen also dates to the Middle Archaic period. The Northwest Great Plains experienced increased moisture during this time whereas evidence suggests that the central Great Plains experienced a period of drier conditions and an expansion of grasslands (Wendland 1978:280). Therefore, if conditions were drier, then this specimen may have spent much of its time at lower elevations in the region where it died. Interestingly, the diet from this animal correlates well with the specimens from the same region that date to the Late Prehistoric-Protohistoric period. This implies that modern grasslands were well in place, at least in the west-central Great Plains by the Middle Archaic period.

The Late Archaic period and the beginning of the Late Holocene coincide. The specimens from the Kaplan-Hoover site and the Mount Audubon specimen date to this period. The climate contained punctuated periods of drought and increased moisture during the Late Archaic before equalizing in the Late Prehistoric period. The climate was approaching modern values, however dune formation over northeast Colorado suggests significant drought in the area from approximately 3000-1500 RCYBP (Forman et al. 2000; Muhs 1985) and decreased occupation of the region (Benedict 1985). The Kaplan-Hoover site is situated on the Colorado Piedmont section of the Great Plains of northern Colorado. Shortgrass steppe dominates the modern environment and likely did at the time of the kill. The foothills of the Rocky Mountains are near which makes the dietary data from this site so interesting. The most likely scenario is that the bison from Kaplan-Hoover were migrating to the east or south into regions that contained high quantities of C_4 vegetation. If the climate was unstable with short periods of drought and wet conditions, then it is possible that the bison in the region developed migration patterns that trended to the east where conditions may have been more favorable. It is also possible that the significant period of drought suggested by Muhs (1985) and Benedict (1985) would have supported significant expansion of C_4 dominated grasslands in the area. The low percentage of C_3 diet in all of the bison from this site indicates that these animals were not regularly migrating into the mountains.

The specimen from Mount Audubon was found in the high alpine region of the Rocky Mountains. The diet of this specimen suggests a life spent in the mountain basins during the Sub-Atlantic episode of the Late Archaic period. The high percentage of C_3 in the diet of this animal implies a higher altitude diet than that of the Plains. The results suggest that, like the trend from the bison of Kaplan-Hoover, this specimen likely did not migrate out onto the Great Plains. This was an extended period of flux however, and the date from this specimen and the Kaplan-Hoover specimens deviates by approximately 500 years and climatic conditions may have altered. Regardless, these results suggests that for at least portions of the Late Archaic period, separate bison populations may have utilized the mountains or the Plains respectively and these groups were not comingling.

The Late Prehistoric period specimens from the study area all correlate with Late Holocene conditions similar to today. The Willow Springs site (48AB130) is situated within the Laramie Basin which is a high altitude mountain basin composed of primarily a mixed-grass prairie. Modern conditions are similar to those of the Late Prehistoric period and the modern grassland of the Laramie Basin is composed of mixed-grass prairie which can contain 80 percent C_3 grasses, or higher, depending on elevation (Sims et al 1978; Larson 1995). Based on the relatively high percentage of C_3 in the diets of five of the specimens, it is likely that these animals spent much of their lives in the basin region. The mixed-grass prairie is one that is more diverse in makeup and likely fluctuates more readily in composition of grasses based on climatic conditions than other grasslands. Additionally, it is possible that the bison from Willow Spring may have migrated out of the basin to the south and east and spent at least part of their time on the Great Plains within the shortgrass steppe. The Laramie Basin extends south and is within a natural migration corridor that empties onto the Great Plains. Specimen D4568 exhibits the highest percentage of C_4 dietary composition (47.7 percent), suggesting that this animal may have spent more time on the Great Plains than the others.

The Roberts bison jump (5LR100) is situated near the foothills and plains margin near the southern extent of the Laramie Basin. The diets from these bison also generally correlate with the suggested paleoclimate conditions of the Late Prehistoric-Protohistoric period. Modern conditions are similar to what was predicted for the Late Prehistoric and the modern grassland of the region would have been composed of mixed-grass prairie interspersed with shortgrass steppe. This site is a hop, skip, and a bison jump south of the Willow Springs site. The stable isotopes results indicate that the Roberts bison may have been utilizing both the shortgrass steppe to the east and the mixed-grass prairie of the Laramie Basin to the north. The Blanz bison kill site (5LR1680) is situated in the hogbacks of the foothills and plains margin and is of a similar date as that of the Roberts bison jump. The stable isotopes results indicate that the bison of the Blanz site were likely utilizing primarily the shortgrass steppe. Since these animals were killed within the foothills region, they were obviously using this region and the Colorado Piedmont for at least portions of their lives.

Both the Eagles Nest Open Space specimen (EN1010) and the Soapstone Prairie Natural Area specimen (SPNA1) date to the Protohistoric period. Again, climatic conditions were similar to modern conditions and the modern grassland of the region would have been composed of shortgrass steppe. The EN1010 specimen was found in the foothills at the margin of the plains and foothills. The stable isotopes results indicate that this bison likely foraged primarily on the shortgrass steppe, possibly during period of dry conditions Interestingly, The SPNA1 specimen stable isotopes results indicate that this bison likely foraged primarily in the mountains or mountain basins based on a higher percentage of C_3 than would be expected on the Great Plains. The diet of this animal correlates more with the Scoggin site specimens of the Middle Archaic period and the Mount Audubon specimen from the Late Archaic period. This strongly suggests that this bison spent much of its time in the mountains rather than the plains. However, since this animal was found on the Great Plains at the transition of the plains and foothills, this bison was likely migratory. While it is possible that there was a period of cooler conditions, such as the Little Ice Age (~300 RCYBP) in which more C_3 vegetation may have been present in the area than at present However, the ratio of C_3 and C_4 grasses was not likely far different than modern conditions during this time, thus the evidence suggests a mountain dwelling bison that was found on the plains.

DISCUSSION AND SUMMARY

The stable isotopes analysis presented here attempts to fill in a gap in the paleodiet record for bison that roamed the west central Great Plains. Overall, the results are promising. Most previous bison isotopes studies have focused on the Northern Great Plains. The results of those studies generally coincide with high latitude grasslands that are dominated by C_3 vegetation. Leyden and Oetellar (2001) presented results on bison bone collagen with mean ^{13}C values that ranged from -17 to -19‰. These correspond to approximately 18 to 30 percent C_4 in the diet of the bison. These results are strengthened by the Chisholm et al. (1986) study from the Northern Great Plains in which bison bone collagen ^{13}C values ranged from approximately -18- to -20‰.

Stable isotopes data from the Southern Great Plains are more scarce. The Harrel bison kill site in western Oklahoma dates to the Late Archaic period and contained C_4 forage data from bison from the upper and lower portions of the site (Carlson and Ozan 2013). The lower component dietary data consisted of 85 percent C_4 forage and 65 percent C_4 forage for the upper component. The Certain site, also a Late Archaic period bison kill in Oklahoma contained ^{13}C results that yielded 60 to 75 percent C_4 dietary forage (Bement and Buehler 2000). These results implied variability in climatic conditions over the Late Archaic period yet high percentages of C_4

compared to C_3 vegetation were present throughout the Southern Great Plains region.

Cannon (2007) reported the stable isotopes results from a single Late Prehistoric period bison from high altitude in northeastern Utah. The stable isotopes analysis resulted in a -18.8‰ ^{13}C value and suggests a high quantity of C_3 forage which is consistent with both high altitude grasslands and grasses associated with the sagebrush bunchgrass steppe of the Great Basin (Cannon 2007). Cannon compared his results with specimens from the Central Plains and high latitudes. The Central Great Plains specimens (Kansas and Nebraska) yielded ^{13}C values of -13.8‰ and -15.9‰ respectively (Cannon 2007). These results suggest that the trend of higher quantities of C_3 vegetation at higher latitudes and higher amounts of C_4 grasses at lower latitudes is reflected in bison diet.

The results of this thesis study indicate more mixed diets of both C_3 and C_4 vegetation, while the higher latitude or altitude specimens trend toward higher C_3 values. The data corresponds well with the latitudinal trend of increasing C_4 vegetation with decreasing latitude. This study area is centrally located between most of the previous research areas and supports the north to south variation in vegetation distribution. *These results also suggest that bison in different ecological regions of the Great Plains tended to remain within these different regions with little evidence of long distance migration*. Vast seasonal migrations from north to south or vice versa that were postulated in historic accounts is unlikely. Instead, bison likely utilized smaller geographical regions and only migrated to farther regions during periods of climatic stress.

The data from this study is less informative in terms of paleoclimate conditions. The data suggests that the paleoclimate was in flux throughout much of the Archaic period and balanced out during the Late Prehistoric period. However, during the latter part of the Late Prehistoric into the Protohistoric period conditions may have been in flux again. While inferences can be made about possible climatic impacts to bison populations, the data also shows that there is a great deal of variability between individual bison from within the same herd. The intraherd variability tends to be great with many of these specimens and differentiating this variability from the regional climate is difficult.

In all, the stable isotopes analyses from the 35 specimens indicate diets that correlate well with the known grasslands in the study area. The observed diets of the bison through interherd analysis follow the trends of C_3 vegetation in the northern and higher elevation regions. C_4 vegetation contribution to diet increases eastward onto the Great Plains. From an intraherd analysis, many of the kill sites show evidence of seasonality through mixed herds. This is evidenced in the mixed diets between different animals at the same kill site. These overall results indicate that bison were utilizing different regions of the study area at different times. In addition, some of the dietary evidence implies that at least some populations may have foraged in geographically distinct regions that did not overlap with other populations.

CHAPTER 5

DISCUSSION AND CONCLUSION

The results from this study have created a large data set pertaining to the spatial and temporal distribution patterns of prehistoric bison across the study area. The analysis presented here has only begun to provide insights into the data set for both bison absence and presence and stable isotopes dietary information. When reviewing the separate methods used here, it became clear that these two approaches are not mutually exclusive. In fact, when used in conjunction, these two methods strengthen the argument that bison were found across the study region, and definitely in the mountains. In concluding this thesis, both the absence and presence data and stable isotopes results are revisited and discussed as a complimentary whole. Potential future research directions are also presented.

In all, the results presented here indicate trends of bison utilization over time and space. Two hypotheses drove this research. The first hypothesis anticipated that bison would not be distributed evenly across space and time. This hypothesis was based on the assumption that bison were utilized by cultural groups both temporally and spatially due to variations in paleoenvironmental conditions that affected distribution and availability of grassland forage, bison migration patterns, population sizes, and ultimately hunting practices. This hypothesis could not be rejected. This thesis identified both chronological and altitudinal trends in bison absence or presence in the study area.

The second research goal hypothesized that bison would be found in areas with limited range due to ecological needs resulting in little migration between different ecological zones. This hypothesis was supported. The results of the stable isotopes analysis presented suggestions of increased bison mobility during different chronological periods based on their dietary information. However, the results were complicated by the dynamics of intraherd variability. Because of this, the distributional patterning of bison based on their dietary needs could only be analyzed through conjecture. The data suggests increased mobility among bison populations due to paleoenvironmental conditions and seasonal mobility. The complicated results of intraherd variability in itself suggests that different populations with different dietary intake were coming together seasonally, thus migration occurred.

The variations in bison occupation of different altitudes may be indicative of paleoclimate variables. The relatively low and variable distribution of bison between 1500-2000 m during much of prehistory seems contradictory to the archaeological, historical, and ethnographic records from the greater Great Plains region. This may be a matter of this region being within a relatively narrow band of topography between the Great Plains and the Rocky Mountain Front Range and thus an issue of area sample size. Further to the east in the study area in which altitudes are lower (< 1500 m), the study suggests a higher probability of bison presence, especially during the Late Archaic and Late Prehistoric periods, and to a lesser degree, the Paleoindian period. This may also be an indication that the Great Plains were not utilized by bison and their hunters during periods of climate stress. These data support the studies by Dillehay (1974), Butler (1992), and Lohse et al. (2014) who suggest periods of bison absence on the Great Plains due to variability in climatic conditions such as the Altithermal drought. Dillehay (1974) and Lohse et al. (2014) found that bison were present on the Southern Great Plains during the Paleoindian period but virtually disappear from approximately 7500 - 4550 RCYBP during the Early Archaic period and coinciding with the Altithermal drought (7500-5000 RCYBP). Butler (1992) analyzed Central Great Plains bison populations and found a similar trend. The data presented in this thesis generally corresponds well with these previous findings. The scarcity of sites during the Paleoindian period is to be expected due to increased impacts of taphonomic processes disturbing intact cultural deposits resulting in a small sample size of radiocarbon dates (Surovell and Brantingham 2007). However, small sample size and taphonomic processes cannot alone explain the lower number of bison as they are demonstrated on the Southern Great Plains in the previous studies.

Based on the radiocarbon sum probability distributions and the absence and presence models, bison presence is low during the Early Archaic period in the study area. This supports evidence that the dry climatic conditions negatively impacted bison populations on both the Southern and Central Great Plains. It is likely that bison populations were not only diminished but had moved elsewhere. The Middle and Late Archaic periods exhibit a variable trend of absence and presence of bison across the study area. Bison numbers appear to be slow to rebound during the Middle Archaic period, especially on the Great Plains. This may be due to a delay in ecological rebound and a subsequent interruption in recovery of bison repopulation. By the Late Archaic period, bison populations increased across much of the area. The results of the sum probability distributions are supported by the kernel analysis.

Periods with more representation, such as the Late Prehistoric, indicate that conditions were favorable for site preservation and that human occupation and utilization of both the region and bison increased during this period. Cooper (2008) analyzed bison distribution across the Great Plains during the Late Prehistoric period. Her study supports a decrease in bison populations on the Southern Great Plains during the Late Prehistoric period while on the Central Great Plains her observations show that bison presence is moderate and on the west Central Great Plains, her analysis of bison presence suggested a very low bison presence during the Late

Prehistoric period (Cooper 2008). This result differs from the results of this thesis research. There is in fact a diverse bison presence in the Great Plains region of the study area during the Late Prehistoric period. Therefore, these results suggest bison presence or absence in the region may be influenced by altitudinal and climatic influences on a finer scale than was observed in previous studies.

The radiocarbon dates for the altitudes below 1500 m on the Great Plains demonstrate that bison were present and absent from that area at different times. One way to test this potential abandonment is to look at eolian dune deposits. Grassland formation is tied closely to precipitation. During periods of drought, the lack of grasslands induces the accumulation of eolian deposits. During periods of increased precipitation, grasslands reform and help to stabilize the accumulated sand dunes (Forman et al. 2001). Age control for Holocene dune activity can be found in radiocarbon data from stratigraphic analysis. In northeastern Colorado, dune deposits along the South Platte River span the past 20,000 RCYBP (Forman et al. 2001; Holliday et al. 2011). Muhs (1985) identified extensive eolian deposits from 13,130-11,000 RCYBP, associated with the Younger Dryas. The radiocarbon dates presented here for bison indicate a stronger presence at higher altitudes during that time. Additionally, Forman et al. (2001) report on major eolian deposits near Kersey, Colorado that radiocarbon date to 7000-5500 cal BP. These dates correlate strongly with the Altithermal drought. Bison presence on the plains in the study area during this time is lacking. Dune formation rebounded over northeast Colorado from approximately 3000-1500 RCYBP (Forman et al. 2000; Muhs 1985). The Kaplan-Hoover site dates to this period and is situated on the Colorado Piedmont section of the Great Plains of northern Colorado. It is possible that the significant period of drought suggested by Forman et al. (2000), Muhs (1985), and Benedict (1985) would have supported significant expansion of C_4

dominated grasslands in the area, such as shortgrass steppe. In conjunction with what appears to have been a comparatively warm and arid climate, collagen samples from the Kaplan-Hoover bison show a significant increase in C_4 consumption. The low percentage of C_3 diet in all of the bison from this site indicates that these animals were not regularly migrating into the mountains. The above data suggest that the Great Plains were subject to periods of drying and increased likelihood that bison and other species did not inhabit this area in great numbers during these periods.

At altitudes between 2000-2500 m amsl, the results suggest that bison were present more regularly throughout all of prehistory. While the number of dates for bison from these altitudes is low, they do indicate a trend of steady bison occupation at higher altitudes. Benedict (1979) argues that the mountains were likely less impacted by climatic events such as the Altithermal drought. The data suggest that bison were utilized at higher altitudes more regularly over time but with fewer numbers. This supports the rotary model of seasonal transhumance postulated by Benedict (1992). If bison presence in the mountains was predictable, then fitting mountain bison procurement into seasonal rounds is possible. Further, if populations of bison in the mountains were more localized and less migratory to the plains, then they may have provided hunter-gatherer groups with a reliable food source.

These results further indicate that bison in the mountains, especially the mountain basins such as Middle Park, may be a separate population than those on the plains. While no dietary stable isotopes analyses were conducted during this study on bison remains in Middle Park, some evidence from the Upper Twin Mountain site are available. This Paleoindian site yielded a bone collagen ^{13}C value of -18.47‰ (Kornfeld 2013:89). This yielded 76 percent C_3 grasses in the bison diet; suggesting a bison that fed on primarily C_3 forage which would have been abundant during the Late Pleistocene. This result also supports the reasoning behind excluding older samples from the stable isotopes data set as older samples would likely have been biased toward C_3 vegetation.

These summary observations indicate that while bison may have disappeared on the Great Plains during portions of the Archaic period, they were still present in the mountains. The results of this thesis study indicate more mixed bison diets of both C_3 and C_4 vegetation, while the higher latitude or altitude specimens trend toward higher C_3 values. This study area is centrally located between most of the previous research areas and supports the north to south variation in vegetation distribution. These results also suggest that bison in different ecological regions of the Great Plains may have remained within these different regions with little evidence of long distance migration. Vast seasonal migrations from north to south or vice versa that were postulated in historic accounts are unlikely. Instead, bison likely utilized smaller geographical regions and only migrated to farther regions during periods of climatic stress. The data suggests that the paleoclimate was in flux throughout much of the Archaic period and balanced during the Late Prehistoric period. If this is so, then during the Altithermal, human groups that may have moved into the mountains from the plains likely utilized this already available subsistence base. Human groups may not have followed bison in to the mountains during this period of climatic stress. Instead, the bison were already there.

Future Directions of Research

The data presented here only begins to scratch the surface of its potential. To help strengthen the posited arguments, several other methods of research could be conducted. Firstly, the study area could be expanded to include areas to the west and more mountain regions to the south. By expanding the search area, the presence or absence of bison in those areas at different periods could help to expand distributional and population bison studies. Study expansion to the east would also be helpful. Butler's (1992) study of bison absence and presence in eastern Colorado could be expanded upon by analyzing the sites that he collected through calibrated radiocarbon data in a sum probability distribution. While Butler (1992) and Dillehay (1974) postulate bison absence on the Central and Southern Great Plains during the Altithermal, other studies (Chisholm et al. 1986; Leyden and Oetellar 2001) may indicate increased bison population in other regions.

Areas in the current study with data gaps (such as eastern Wyoming) simply need more research. Many areas of private land have not been subjected to cultural resource investigations. Data from biological analyses, museum collections, and historical data can provide information on high altitude bison (Fryxell 1928; Lee and Benedict 2012; Meaney and van Vuren 1993). Some of these data were utilized in this research, however most historical accounts do not contain accurate provenience data or accurate dating methods and can only be discussed in general trends.

Further investigation will be required to determine whether Holocene climate changes ultimately forced the Middle and Late Holocene development of specific bison population patterns, or instead caused their suppression during the Altithermal drought. Although isotopic analyses appear to have great potential for use in the investigation of prehistoric ecological relationships, specific problems will require further investigation. While ^{13}C values in the collagen of bison are directly related to the forage composition of their diets, the proportions in which bison ingest these plant species may change in response to selective consumption. Selective consumption of certain grass types appears to occur as a predictable response to specific climatic occurrences. As long as there is an awareness of regional differences in both seasonal duration and the basic distribution of local vegetation, changes in diet may be predictable in response to shifts of specific climatic conditions.

Although stable carbon isotope analyses have had success in application to ecological and archaeological problems, more investigations involving bison populations should attempt to embrace regional and temporal specific approach such as this current study. Another way to expand upon the current research is to collect more stable isotopes from known collections. While the data set collected here is not a small undertaking, this form of data analysis benefits from larger sample sizes. Comparative data from the greater Great Plains region were utilized to a degree, but an in depth study of all known stable isotopes data collected through consistent methods could provide a more complete picture of foraging patterns across space and time.

Further areas of research include expanding the study to include all excavated sites in the study area region which would include those without faunal remains. This area of research may exhibit spatial and temporal patterning in cultural land use that corresponds or deviates from the current study. In addition, many of the sites analyzed during this research did not contain detailed information on the faunal remains found. It is likely that some of the unidentified remains on sites are those of bison. A revisit of sites and collections from these excavations by a zooarchaeologist for faunal identification could add valuable bison data to this area.

More research should be directed towards identifying and understanding the regional and temporal variability of bison behavior. Certain ecological characteristics, such as vegetation distribution and forage quality have an important influence upon behavior regardless of geographic or temporal context. Stable isotope analyses may be uniquely appropriate to the investigation of such problems. As demonstrated, this technique can provide data concerning interrelated aspects of a bison's diet and its environment. Thus, the stable isotope analysis of archaeological bone provides a unique opportunity for detailed paleoecological investigations.

In summary, although bison dietary behavior may fluctuate in response to a variety of climatic events, an increase in selective foraging and a resulting change in the C_3 to C_4 plant ratio within the diet of bison should primarily occur as a response to the specific stresses of variable environments. In general, this prediction appears to be reflected in the bison absence and presence data investigated over the course of this project.

Shifts among human and bison populations that are evident in the archaeological record during the Holocene give evidence of the influence of significant changes among a variety of ecological shifts. Regardless of the exact cause, the diet differences among the different bison populations analyzed are important in that they represent the first direct evidence of paleodietary forage, grassland distribution, and potential differences in population structure for Middle and Late Holocene bison in the west Central Great Plains region. These findings, together with the absence and presence data developed through this study, help to characterize the complex ecological nature of the Central Great Plains and Rocky Mountain region, and further, help define the intricate relationships between bison, humans, and the Holocene environment.

REFERENCES CITED

Aeon Laboratories
2010 Methods and Procedures. Electronic document, http://aeonlaboratories.com/?page=methods, accessed October 2, 2014.

Ambrose S H.
1991 Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science* 18:293–317.

Ambrose, S.H. and J. Krigbaum
2003 Bone chemistry and bioarchaeology. *Journal of Anthropological Archaeology* 22:193-199.

Antevs, E.
1955 Geologic-Climate Dating in the West. *American Antiquity* 20(4):317-335.

Baker, R.R.
1978 *The Evolutionary Ecology of Animal Migration.* Hodder and Stoughton, London England.

Bailey, R.G., Avers, P.E., King, T., and McNab, W.H., eds.
1994 Ecoregions and subregions of the United States (map), supplementary table of map unit descriptions compiled and edited by McNab, W.H., and Bailey, R.G. Washington, D.C., USFS, scale 1:7,500,000.

Bamforth, D.B.
1987 Historical Documents and Bison Ecology on the Great Plains. *Plains Anthropologist* 32(115):1-16.

1988 *Ecology and Human Organization on the Great Plains*. Plenum Press, New York, New York.

Bement, L.C. and K.J. Buehler
2000 Archaeological Survey of Late Archaic Bison Kill Sites in Beckham County, Oklahoma. *Archeological Resource Survey Report No. 41*, Oklahoma Archeological Survey, Norman.

Benedict, J.B.
1979 Getting Away from it All: A Study of Man, Mountains, and the Two-drought Altithermal. *Southwestern Lore* 45(3): 1-11.

1985 Arapaho Pass. Glacial geology archeology at the crest of the Colorado Front Range. *Center for Mountain Archaeology, Research Report* 3:1-197.

1992 Footprints in the snow: High altitude cultural ecology of the Colorado Front Range. *Arctic and Alpine Research* 24:1-16.

1999 Effects of Changing Climate on Human use of the Colorado High Country Since 1000 B.C. *Arctic and Alpine Research* 31(1):1-15.

Benedict, J. B. and B. L. Olson
1978 *The Mount Albion Complex: A Study of Prehistoric Man and the Altithermal*. Research Report No. 1. Center for Mountain Archaeology. Ward, Colorado.

Black, K.D.
1991 Archaic Continuity in the Colorado Rockies: The Mountain Tradition. *Plains Anthropologist* 36(133): 1-29.

Bocherens, H., and D. Drucker
2003 Trophic Level Isotopic Enrichment of Carbon and Nitrogen in Bone Collagen: Case Studies from Recent and Ancient Terrestrial Systems. *International Journal of Osteoarchaeology* 13:46-53.

Bonsall, C., G.T. Cook, R.E.M. Hedges, T.F.G. Highman, C. Pickard, and I. Radovanovic
2004 Radiocarbon and Stable Isotope Evidence of Dietary Change from the Mesolithic to the Middle Ages in the Iron Gates: New Results from Lepenski Vir. *Radiocarbon* 46(1):293-300.

Boutton, T.W., A.T. Harrison, and B.N. Smith
1980 Distribution of Species Differing in Photosyntheitc Pathway along an Altitudinal Transect in Southeastern Wyoming Grassland. *Oecologia,* 45(3):287-298.

Britton, K. H.
2009 Multi-isotope analysis and the reconstruction of prey species paleomigrations and palaeoecology. Ph.D. dissertation, Department of Archaeology, Durham University, Durham, United Kingdom.

Brown, L.E.
2012 Stable Isotope Analysis of Human Remains from Early Contact Period Site of La Capilla Del Nino Serranito at La Capilla Santa Maria Magdalena De Eten. Master's thesis, College of Arts and Sciences, Georgia State University, Atlanta.

Buchanan, B., M. Collard, and K. Edinborough
2008. Palaeo-Indian Demography and the Extraterrestrial Impact Hypothesis. *Proceedings of the National Academy of Sciences* 105:11651-11654.

Bumstead, P.M.
1981 The Potential of Stable Carbon Isotopes in Bioarchaeological Anthropology. Research Report 20: *Biocultural Adaptation Comprehensive Approaches to Skeletal Analysis*, Paper 12.

Bupp, S.L.
1981 The Willow Springs Bison Pound: 48AB130. Unpublished Master's thesis, Department of Anthropology, University of Wyoming, Laramie.

Burns, J.A.
1996 Vertebrate paleontology and the alleged ice-free corridor: The meat of the matter. *Quaternary International* 32:107-112.

Butler, W.B.
1992 Bison Presence and Absence in Colorado. *Southwestern Lore* 58(3):1-13.

Byerly, R.M.
2010 *On the Buffalo Trail: Late Holocene Archaeology and Arapaho Ethnogeography in Northern Colorado*. Colorado Archaeological Society, Northern Chapter.

Cannon, K.P.
1997 The Analysis of a Late Holocene Bison Skull from Fawn Creek, Lemhi County, Idaho, and its Implications for Understanding the History and Ecology of Bison in the Intermountain West. Report prepared for USDA Salmon-Challis National Forest, Salmon, Idaho.

2007 "They Went as High as They Choose": What an Isolated Skull Can Tell Us about the Biogeography of High-Altitude Bison. *Arctic, Antarctic, and Alpine Research* 39(1):44-56.

Carlson, K. and L. Ozan
2013 *National Register of Historic Places Nomination Form, Harrel Bison Kill Site, Oklahoma.* Oklahoma Archaeological Survey, Norman.

Carrara, P.E.
2011 *Deglaciation and Postglacial Treeline Fluctuation in the Northern San Juan Mountains, Colorado*. Professional Paper 1782. U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia.

Chenault, M.L.
1999 Introduction. In *Colorado Prehistory: Context for the Platte River Basin*. Colorado Council of Professional Archaeologists and Colorado Archaeological Society, Denver.

Chisholm, B., J. Driver, S. Dube, and H.P. Schwarcz
1986 Assessment of Prehistoric Bison Foraging and Movement Patterns via Stable Carbon Isotope Analysis. *Plains Anthropologist* 31(113):193-205.

Clark, B.
1999 The Protohistoric Period. Chapter 7. In *Colorado Prehistory: A Context for the Platte River Basin. Colorado* Council of Professional Archaeologists and Colorado Archaeological Society, Denver.

Cooper, J.R.
2008 Bison Hunting and Late Prehistoric Human Subsistence Economies in the Great Plains. Ph.D. dissertation. Dedman College, Southern Methodist University, Dallas, Texas.

Creasman, S. D. and K. W. Thompson
1997 Archaic Settlement and Subsistence in the Green River Basin of Wyoming. In *Changing Perspectives on the Archaic of the Northwest Plains*, edited by M. L. Larson and J. E. Francis, pp. 242-304. University of South Dakota Press, Vermillion, South Dakota.

Dary, D.A.
1989 *The Buffalo Book: the Full Saga of the American Animal*. Swallow Press, Chicago, Illinois.

Dillehay, T.D.
1974 Late Quaternary Bison Population Changes on the Southern Plains. *Plains Anthropologist* 19(65):180-196.

DeNiro, M.J., and S. Epstein
1978 Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta,* 42:495-506.

1981 Influence of diet on the distribution of nitrogen isotopes in animals. *Geochemica et Cosmochima Acta*, 45:341-351.

Doerner, J.P.
2007 Late Quaternary Prehistoric Environments of the Colorado Front Range. Editors Brunswig, Robert H. and Bonnie L. Pitblado. In *Frontiers in Colorado Paleoindian Archaeology, From the Dent Site to the Rocky Mountains.* University of Colorado Press, Boulder.

Eckerle, W.
1997 Geoarchaeological Models in the Wyoming Basin. In *Changing Perspectives of the Archaic on the Northwest Plains,* edited by M. L. Larson and J. Francis, University of South Dakota Press, Vermillion.

EcoCore
2013 Instrumentation. Natural Resource Ecology Laboratory, Colorado State University, Fort Collins. Electronic document, http://ecocore.nrel.colostate.edu/instruments/, accessed May 15, 2013.

Eighmy, J.L., and J.M. LaBelle
1994 Radiocarbon Dating of Twenty-seven Plains Complexes and Phases. *Plains Anthropologist, 41*(155):53-69.

Elias, S.A.
1985 Paleoenvironmental Interpretations of Holocene Insect Fossil Assemblages from Four High Altitude Sites in the Front Range, Colorado, U.S.A. *Arctic and Alpine Research* 17:31-48.

Fenner, J.N. and C.D. Frost
2009 Modern Wyoming plant and pronghorn isoscapes and implications for archaeology. *Journal of Geochemical Exploration* 102:149-156.

Forman, S.L., R. Oglesby, and R.S. Webb
2001 Temporal and Spatial Patterns of Holocene Dune Activity on the Great Plains of North America: Megadroughts and Climate Links. *Global and Planetary Change* 29:1-29.

Frison, G.C.
1991 *Prehistoric Hunters of the High Plains*, second edition. Academic Press. San Diego.

1992 The Foothills-Mountain and Open Plains: The Dichotomy in Paleoindian Subsistence Strategies Between Two Ecosystems. In *Ice Age Hunters of the Rockies*, edited by D. J. Stanford and J. S. Day, pp. 323-342. Denver Museum of Natural History and the University Press of Colorado, Niwot, Colorado.

France, C.M., P.M. Zelanko, A.J. Kaufman, and T.R. Holtz
2007 Carbon and nitrogen isotopic analysis of Pleistocene mammals from the Saltville Quarry (Virginia, USA): Implications for trophic relationships. *Palaeogeography, Palaeoclimatology Palaeoecology* 249:271-282.

Fry, B.
2006 *Stable Isotope Ecology*. Springer Science-Business Media, LLC, New York, New York.

Fryxell, F.M.
1926 A New High Altitude Limit for the American Bison. *Journal of Mammalogy* 7(2):102-109.

1928 The Former Range of Bison in the Rocky Mountains. *Journal of Mammalogy* 9(2):129-139.

Gadbury, C., L. Todd, A.H. Jahren, and R. Amundson
2000 Spatial and temporal variations in the isotopic composition of bison tooth enamel from the Early Holocene Hudson-Meng Bone Bed, Nebraska. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 157, 79-93.

Gates, C.C., J. Mitchell, J. Wierzchowski, and L. Giles,
2001 *A Landscape Evaluation of Bison Movements and Distribution in Northern Canada*. Axys Environmental Consulting, Calgary, Alberta, Canada.

Gilmore, K.P.
2012 Footprints in the Mud: A Holocene Drought Record from a Pocket Fen and the Implications for Middle Archaic Cultural Ecology on the Great Plains. *Southwestern Lore* 78(1):58-65.

Gilmore, K.P., Marcia Tate, M.L. Chenault, B. Clark, T. McBride, and M. Wood
1999 *Colorado Prehistory: A Context for the Platte River Basin*. Colorado Council of Professional Archaeologists, Denver, Colorado.

Gogan, P.J., N.C. Larter, J.H. Shaw, and J.E. Gross
2010 Chapter 6, General Biology, Ecology and Demographics. In *American Bison: Status Survey and Conservation Guidelines 2010*. Edited by C. Cormack gates, Curtis H. Freece, Peter J.P. Gogan, and Mandy Kotzman. IUCN, Gland, Switzerland.

Graf, K.E. and D.B. Schmitt (editors)
2007 *Paleoindian or Paleoarchaic? Great Basin Human Ecology at the Pleistocene-Holocene Transition*. First ed. University of Utah Press, Salt Lake City.

Guthrie, R.D.
1980 Bison and man in North America. *Canadian Journal of Anthropology* 1:55-73.

Hamilton, S., N. Wiseman, and D. Wiseman
2006 Extrapolating to a more ancient past: Ethnohistoric images of northeastern Plains vegetation and bison ecology. *Plains Anthropologist* 51:281-302.

Haugen, A.O.
1974 Reproduction in the Plains Bison. *Iowa State Journal of Research* 49(1):1-8.

Haynes, V.C. Jr.
1990 Geoarchaeological and Paleohydrological Evidence for a Clovis-Age Drought in North America and its Bearing on Extinction. *Quaternary Research* 35:438-450.

Heaton, T.H.E., B. Spiro, S. Madeline, and C. Robertson
1997 Potential canopy influences on the isotopic composition of nitrogen and sulphur in atmospheric deposition. *Oecologia* 109: 600-607.

Hill, M.E.
2007 A Moveable Feast: Variation in Faunal Resource Use among Central and Western North American Paleoindian sites. *American Antiquity* 72(3): 417-438.

Hobbie, E.A., and A.P. Ouimette.
2009 Causes of nitrogen isotope patterns in terrestrial soil profiles. *Biogeochemistry* 95:355-371.

Hobson, K.A.
1999 Tracing Origins and Migration of Wildlife Using Stable Isotopes: A Review. *Oecologia* 120(3):314-326.

Högberg, P.
1997 Tansley Review No. 95 15N natural abundance in soil–plant systems. *New Phyto*l 137:179-203.

Holliday, V.T., D.J. Meltzer, and R. Mandel
2011 Stratigraphy of the Younger Dryas Chronozone and Paleoenvironmental Implications: Central and Southern Great Plains. *Quaternary International* (22):520-533.

Hoppe, K.A., A. Paytan and P. Chamberlain
2006 Reconstructing grassland vegetation and paleotemperatures using carbon isotope ratios of bison tooth enamel. *Geology* 34:649-652.

Hornaday, W.T.
1889 *The Extermination of the American Bison.* Smithsonian Institution Press, Washington and London.

Huckell, B.B.
1996 The Archaic Prehistory of the North American Southwest. *Journal of World Prehistory* 10(3):305-373.

Hunt, C. B.
1967 *Physiography of the United States*. W. H. Freeman and Company, San Francisco.

Imbrie, J. and J.Z. Imbrie
1980 Modeling Climatic Response to Orbital Variations. *Science* 207(4434):943-953.

Isenberg, A.C.
2000 *The Destruction of the Bison, An Environmental History 1750-1920*. Cambridge University Press, Cambridge, United Kingdom.

Johnson, D. and J. Pastor
2003 *The Blue Point site: Paleoindian/Archaic Transition in Southwest Wyoming.* Western Archaeological Services, Rock Springs, Wyoming.

Kingston, J.D. and T. Harrison
2006 Isotopic Dietary Reconstructions of Pliocene Herbivores at Laetoli: Implications for Early Hominin Paleoecology. *Paleogeography, Paleoclimatology, and Palaeoecology.*

Knight, D.
1994 *Mountains and Plains: The Ecology of Wyoming Landscapes.* Yale University. Thompson-Shore, Dexter, Michigan.

Kohn, M. J. and T.E. Cerling
2002 Stable Isotope Compositions of biological Apatite. *Phosphates. Geochemical, Geobiological, and Materials Importance, Reviews in Mineralogy and Geochemistry* 448:455-488.

Kornfeld, M.
2013 *The First Rocky Mountaineers: Coloradans before Colorado*. University of Utah Press, Salt Lake City.

Kornfeld, M., G.C. Frison, and M.L. Larson
2010 *Prehistoric Hunter-Gatherers of the High Plains and Rockies*, 3rd ed. Left Coast Press, Inc. Walnut Creek, California.

Larson, R.M.
1995 Bison Paleoecology: Developing Applications for Hunter-Gatherer Subsistence Models and Former Ecosystems. Unpublished Master's thesis. Colorado State University, Fort Collins.

Larson, R.M., L. C. Todd, E.F. Kelly, and J.M. Welker
2001 Carbon Stable Isotope Analysis of Bison Dentition. *Great Plains Research* 11: 25-64.

Lee, C.M. and J.B. Benedict
2012 Ice Bison, Frozen Forests, and the Search for Archaeology in Colorado Front Range Ice Patches. *Southwestern Lore* 78(1):41-46.

Lee, C.M., J.B. Benedict, and J.B. Lee
2006 Ice patches and remnant glaciers: Paleontological discoveries and archeological possibilities in the Colorado High Country. *Southwestern Lore* 72(1):26 – 43.

Lee-Thorp, J.A., M. Sponheimer, and N.J. van Der Merwe
2003 What do Stable Isotopes tell us about Hominid Dietary and Ecological Niches in the Pliocene? *International Journal of Osteoarchaeology* 13:104-113.

Levin, N.E., S.W. Simpson, J. Quade, T.E. Cerling, and S.R. Frost
2008 Herbivore Enamel Carbon Isotopic Composition and the Environmental Context *Ardipithecus* at Gona, Ethiopia. *The Geological Society of America Special Paper 446:*215-233.

Leyden, J.J. and G. Oetelaar
2001 Carbon and Nitrogen Isotopes in Archaeological Bison Remains as Indicators of Paleoenvironmental Change in Southern Alberta. Great Plains Research: *Great Plains Research* 11(1):3-23.

Lobdell, J.E.
1974 The Scoggin Site: A Study in McKean Typology. *Plains Anthropologist* 19(64):123-128.

Lohse, J.C, B.J. Culleton, S.L. Black, and D.J. Kennett
2014 A Precice Chronology of Middle to Late Holocene Bison Exploitation in the Far Southern Great Plains. *Journal of Texas Archaeology and History* 1:94-126.

Lovvorn, M.B., G.C. Frison, and L. Tieszen
2001 Paleoclimate and Amerindians: Evidence from Stable Isotopes and Atmospheric Circulation. *Proceedings of the National Academy of Sciences of the United States of America* 98(5):2485-2490.

Mauquoy, D., B. van Geel, M. Blaauw, A. Speranza, and J. van der Plicht
2004 Changes in Solar Activity and Holocene Climatic Shifts Derived from 14C Wiggle-match Dated Peat Deposits. *The Holocene* 14(1):45-52.

McDonald, J.N.
1981 *North American Bison: Their Classification and Evolution*. University of California Press, Berkeley.

McHugh, T.
1972 Social behavior of the American buffalo (Bison bison). *Zoologica* 43(1):1-40.

McNeees, L.
2006 *Cultural Resource Overview of the Pinedale Field Office, Bureau of Land Management, Wyoming*. Report prepared for the BLM, Pinedale Field Office by TRC Mariah Associates, Inc. Laramie, Wyoming.

Meagher, M.
1986 Bison bison. *Mammalian Species* 266:1-8.

Meaney, C.A. and D. van Vuren
1993 Recent Distribution in Colorado West of the Great Plains. *Proceedings of the Denver Museum of Natural History* 3(4):1-10.

Meltzer, D.J.
1999 Human Response to Middle Holocene (Altithermal) Climates on the North American Great Plains. *Quaternary Research* 52:404-416.

2006 *Folsom: New Archaeological Investigations of a Classic Paleoindian Bison Kill.* University of California Press, Berkeley.

Metcalf, M. D.
1987 Contributions to the Prehistoric Chronology of the Wyoming Basin. In *Perspectives on Archaeological Resources Management in the Great Plains*, edited by A. J. Osborn and R.C. Hassler, pp 233-261. I & O Publishing Company, Omaha, Nebraska.

Miller, M.E.
1986 *Some Basic Research and Management Considerations for the Scoggin Site in Southcentral Wyoming.* Report submitted to the Bureau of Land Management, Rawlins District, Wyoming.

Minagawa, M. and E. Wada
1984 Stepwise enrichment of 15N along food chains: further evidence and the relation between 15N and animal age. *Geochimica et Cosmochimica Acta* 48:1135-1140.

Muhs, D.
1985 Age and Paleoclimatic Significance of Holocene Sand Dunes in Northeastern Colorado. *Annals of the Association of American Geographers* 75(4)566-582.

Mutel, C. F. and J. C. Emerick
1992 *From Glacier to Grassland: The Natural History of Colorado and the Surrounding Region*. Johnson Books, Boulder, Colorado.

Niven, L.B. and M.G. Hill
1998 Season of Bison Mortality at Three Plains Archaic Kill Sites in Wyoming. *Plains Anthropologist* 43(163):5-26.

Nordt, L., J. Von Fischer, L. Tieszen, and J. Tubbs
2008 Coherent Changes in Relative C4 Plant Productivity and Climate During the Late Quaternary in the North American Great Plains. *Quaternary Science Reviews* 27:1600-1611.

O'Connell, T.C., R.E.M. Hedges, M.A. Healey, A.H. Simpson
2001 Isotopic Comparison of Hair, Nail and Bone: Modern Analyses. *Journal of Archaeological Science* 28:1247-1255.

O'Leary, M.
1981 Carbon Isotope Fractionation in Plants. *Phytochemistry* 20, 553-567.

1995 Environmental Effects on Carbon Isotope Fractionation in Terrestrial Plants. In: E. Wada, T. Yoneyama, M. Minagawa, T. Ando & B.D. Fry (Eds.) *Stable Isotopes in the Biosphere.* Japan, Kyoto University Press, pp. 78-91.

Omernik, James M. and Glenn E. Griffith
2012 Ecoregions of Wyoming (EPA). Electronic document, http://www.eoearth.org/view/article/152236, accessed June 2014.

Oinonen, M., P. Pesonen, and M. Tallavaara
2010 Archaeological Radiocarbon Dates for Studying the Population History in Eastern Fennoscandia. *Radiocarbon* 52:393-407.

Passey, B.H., T.F. Robinson, L.K. Ayliffe, T.E. Cerling, M. Sponheimer, M.D. Dearing, B.L. Roeder, and J. R. Ehleringer
2005 Carbon isotope fractionation between diet, breath CO2, and bioapatite in different mammals. *Journal of Archaeological* Science 32:1459-1470.

Peden, D.G.
1972 The Trophic Relations of *Bison bison* to the Shortgrass Plains. Ph.D. dissertation, Colorado State University, Fort Collins.

Peros, M.C., S.E. Munoz, K. Gajewski, and A.E. Viau
2009 Prehistoric demography of North America inferred from radiocarbon data. *Journal of Archaeological Science* 37(3):656-664.

Peterson, B. G. and B. Fry
1987 Stable Isotopes in Ecosystems Studies. *Annual Reviews Ecology System* 18:293-320.

Phillips, D.L.
2012 Converting isotope values to diet composition: the use of mixing models. *Journal of Mammalogy* 93(2):342-352.

Pitblado, B. L.
2003 *Late Paleoindian Occupation of the Southern Rocky Mountains: Early Holocene Projectile Points and Land Use in the High Country.* University Press of Colorado. Boulder, Colorado.

Reasoner, M.A., and M.A. Jodry
2000 Rapid response of alpine timberline vegetation to the Younger Dryas climate oscillation in the Colorado Rocky Mountains. *Geology* 28:51–54.

Reed, Alan D. (editor)
2009 *Rockies Express Pipeline Archaeological data Recovery project, Moffat County, Colorado*. Report prepared by Alpine Archaeological Consultants, Inc. Montrose, Colorado.

Reitz, E.J. and E.S. Wing
2008 *Zooarchaeology*, 2nd Edition. Cambridge University Press, New York.

Richards, M.P. and E. Trinkaus
2009 Isotopic Evidence for the Diets fo Europena Neanderthals and Early Modern Humans. *PNAS* 106(38):16034-16039.

Ritchie-Parker, D.Y.
2011 Late and terminal Classic Maya Subsistence: Stable Isotope Analysis at Chac Balam and San Juan on Northern Ambergris Caye, Belize. Master's Thesis, Department of Anthropology, University of Texas at Arlington.

Schoeninger, M.J. and K. Moore
1992 Bone Stable Isotope Studies in Archaeology. *Journal of World Prehistory* 6(2):247-296.

Schroedl, Alan R.
1991 Paleo-Indian Occupation in the Eastern Great Basin and Northern Colorado Plateau. *Utah Archaeology* 4(1):1-15.

Schwarcz, H.P., T.L. Dupras, and S.I. Fairgrieve
1999 15N Enrichment in the Sahara: In Search of a Global Relationship. *Journal of Archaeological Science* 26: 629-636.

Shapiro, B., A.J. Drummond, A. Rambaut, M.C. Wilson, P.E. Matheus, A.V. Sher, O.G. Pybus, M.T. Gilbert, I. Barnes, J. Binladen, E. Willerslev, A.J. Hansen, G.F. Baryshnikov, J.A. Burns, S. Davydov, J.C. Driver, D.G. Froese, C.R. Harington, G. Keddie, P. Kosintsev, M.L. Kunz, L.D. Martin, R.O. Stephenson, J. Storer, R. Tedford, S. Zimov, and A. Cooper
2004 Rise and fall of the steppe bison. *Science* 306:1561-1565.

Shaw, J.H.
1995 How many bison originally populated western rangelands? *Rangelands* 17(5):148-150.

Shields, W.L.
1998 Basin Houses in Colorado and Wyoming: Delineation of a Culture Area and Parsing Hunter-Gatherer Modeling. Unpublished Master's thesis, Department of Anthropology, University of Colorado, Boulder.

Sims, P.L., J.S. Singh, and W.K. Lauenroth
1978 The structure and function of ten western North American grasslands. *Journal of Ecology* 66:251-285.

Smith, A.B. and S. Epstein
1971 Two categories of 13C/12C ratios for higher plants. *Plant Physiology* 47:380-384.

Sponheimer, M. and J.A. Lee-Thorp
1999 Isotopic Evidence for the Diet of an Early Hominid, *Australopithecus africanus*. *Science* 283:368-369.

Sponheimer, M., J.A. Lee-Thorp, D.J. DeRuiter, J.M. Smith, N.J. van der Merwe, K. Reed, C.C. Grant, L.K. Ayliffe, T.F. Robinson, C. Heidelberger, and W. Marcus
2003 Diets of Southern African Bovidae: Stable Isotope Evidence. *Journal of Mammalogy* 84(2):471-479.

Stafford, T.W., Jr., P.E. Hare, L.A. Currie, A.J.T. Jull, and D. Donahue
1991 Accelerator radiocarbon dating at the molecular level. *Journal of Archaeological Sciences* 18: 35-72.

Stanford, D.J.
1999 Paleoindian archaeology and late Pleistocene environments in the plains and southwestern United States. R. Bonnichsen and K.L. Turnmire (eds.), In *Ice Age People of*

North America: Environments, Origins, and Adaptations, pp.281-339, Center for the Study of First Americans, Corvallis Oregon.

Stuiver, M. and Reimer, P. J.
1993 Extended 14C database and revised CALIB radiocarbon calibration Program. *Radiocarbon* 35:215-230.

Stuiver, M., P.J. Reimer, and R.W. Reimer
2005 CALIB 5.0. Electronic document, http://calib.qub.ac.uk/calib/manual/reference.html, accessed February 10, 2014.

Surovell, T.A. and P.J. Brantingham
2007 A note on the use of temporal frequency distributions in studies of prehistoric demography. *Journal of Archaeological Science* 34(11):1868-77.

Surovell, T.A., J. Finley, J. Smith, J.P. Brantingham, and R. Kelly
2009 Correction temporal frequency distributions for taphonomic bias. *Journal of Archaeological Science* 36(8):1715-24.

Thompson, K.W., and J.V. Pastor
1995 *People of the Sage: 10,000 Years of Occupation in Southwest Wyoming.* Cultural Resource Management Report No. 67. Archaeological Services, Western Wyoming College, Rock Springs.

Tieszen, L.L.
1994 Stable isotopes on the plains: vegetation analyses and diet determinations. In *Skeletal Biology in the Great Plains* Owsley, D.W., Jantz, R.G. (Eds.),. Smithsonian Institution Press, Washington, pp. 261–282.

Todd, L.C., D.C. Jones, R.S. Walker, P.C. Burnett, and J. Eighmy
2001 Late Archaic Bison Hunters in Northern Colorado: 1997-1999 Excavations at the Kaplan-Hoover Bison Bonebed (5LR3953). *Plains Anthropologist* 46(176):125-147.

Tykot, Robert H.
2007 Isotope Analyses and the Histories of Maize. In *Stable Isotope Analysis and Human Diet*, Chapter 10, pp. 131-142.

van der Merwe, N.J.
1989 Natural variation in 13C concentration and its effect on environmental reconstruction using 13C/12C ratios in animal bones. In *The Chemistry of Prehistoric Human Bone,* edited by T. Douglas Price, pp. 105-125. Cambridge University Press, Massachusetts.

van Vuren, D.
1983 Group-Dynamics and Summer Home Range of Bison in Southern Utah. *Journal of Mammalogy* 64:329-332.

van Vuren, D. and M.P. Bray
1986 Population Dynamics of Bison in the Henry Mountains, Utah. *Journal of Mammalogy* 67:503-511.

van Zyll de Jong, C.G.
1986 *A Systematic Study of Recent Bison, with Particular Consideration of the Wood Bison (Bison bison athabascae Rhodes 1898).* Publications in Natural Sciences No. 6. National Museums of Canada, Ottawa, Ontario.

1993 Origin and geographic variation of recent North American bison. *Alberta: Studies in the Arts and Sciences* 3(2):21-35.

Warren, E. R
1927 Altitude limit of bison. *Journal of Mammalogy* 8:60-61.

Wendland , W.M.
1978 Holocene Man in North America: The Ecological Setting and Climatic Background. *Plains Anthropologist* 23(82):273-287.

West, E.
1998 *The Contested Plains: Indians, Goldseekers, and the Rush to Colorado*. University of Kansas Press. Lawrence.

Widga, C.C.
2007 Bison, bogs, and big bluestem: The subsistence ecology of middle Holocene hunter-gatherers in the eastern Great Plains. Ph.D. dissertation, Department of Anthropology, University of Kansas, Lawrence.

Williams, A.N.
2012 The use of summed radiocarbon probability distributions in archaeology: a review of methods. *Journal of Archaeological Science* 39:578-589.

Williams, J.J.
2009 Quaternary Vegetation Distribution. In *Encyclopedia of Paleoclimatology and Ancient Environments, Encyclopedia of Earth Sciences Series.* Edited by V. Gornitz, pp. 856-861. Springer, Netherlands.

Wilson, M.C.
1996 Late Quaternary vertebrates and the opening of the ice-free corridor, with special reference to the genus *Bison*. *Quaternary International* 32:97-105.

Wilson, M.C., L.V. Hills, and B. Shapiro
2008 Late Pleistocene northward-dispersing *Bison antiquus* from the Bighill Creek Formation, Gallelli gravel pit, Alberta, Canada, and the fate of *Bison occidentalis*. *Canadian Journal of Earth Sciences* 45(7):827-859.

Witkind, M.
1971 An Archaeological Interpretation of the Roberts Buffalo Jump Site, Larimer County, Colorado. Unpublished Master's thesis, Department of Anthropology, Colorado State University, Fort Collins.

Wood, R.E.
1998 *Archaeology of the Great Plains.* University of Kansas Press, Lawrence.

Zietz, V., S. Phillips, J. Kennedy, P. Burnett, M. Bandy, and N. Crumbley
2010 *Class III Cultural Resource Investigation for the Druckley Dune Field in Sublette County, Wyoming*. Report Prepared by SWCA Environmental Consultants, Denver, Colorado.

Zin-Maung-Maung-Thein, Mansanaru Takai, Hiaru Uno, J.G. Wynn, Naoko Egi, Takehisa Tsubamoto, Thang-Htike, Aung-Naing-Soe, Maung-Maung, Takeshi Nishimura, and Minoru Yoneda
2010 Stable Isotope Analysis of the Tooth Enamel of Chaingzauk Mammalian Fauna (late Neogene,Myanmar) and its Implication to Paleoenvironment and Paleogeography. *Paleogeography, Paleoclimatology, Palaeoecology* 300:11-22.

APPENDIX A

RAW ABSENCE/PRESENCE DATA

Appendix A Database Matrix Key

Database Code	Definition
SITE NO	Smithsonian site number or other identifier
STATE	CO - Colorado; WY - Wyoming
BISON	Bison present or absent
DEER	Deer present or absent
PRHORN	Pronghorn present or absent
ELK	Elk present or absent
RABBIT	Rabbit present or absent
BIRD	Bird present or absent
UNSPEC	Unspecified bone present or absent
SMMAMM	Small mammal bone present or absent
MDMAMM	Medium mammal bone present or absent
LGMAMM	Large mammal bone present or absent
OTHER	Other species not listed above present or absent
SITETYPE	Site type specified on site form or report: Open camp (OC), Lithic Scatter (LS), Kill Site (K), Processing site (PR), Bone Bed (BB), Rockshelter (RS), Historic (H), Habitation site (HAB), House pit (HP), Human burial (HB), Multicomponent (MC), (IF) Isolated Find
AGESPEC1; AGESPEC2; AGESPEC3; BISON AGE	Cultural Component Ages for sites and bison remains: (NA) Not Applicable,(P) Paleoindian, (A) Archaic, (EA) Early Archaic, (MA) Middle Archaic, (LA) Late Archaic, (LP) Late Prehistoric, (PR) Protohistoric
ELEVM	Site Elevation in meters
VEG1; VEG2	VEG1 - Primary vegetation community at site; VEG2 - Secondary vegetation community at site: Not specified (NA) Alpine (AP), Subalpine Forest (SAF), Lodge pole (LP), Ponderosa Pine (PP), Montane Forest General (MF), Aspen (AP), Oak (OAK), Juniper (JP), Sagebrush/Desert Shrub (SG), Mountain grassland (MGS,) Plains grassland (PGS), Barren (BR), Sand dunes (SD), Riparian (RP)

Table A-1. Raw Absence/Presence Database Information for Site Type, Site Age, Elevation, and Vegetation Zones.

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
5BL.10547	CO	IF	NA	NA	NA	NA	Y	1596	PGS	NA
5BL.18	CO	RS	LP	NA	NA	NA	N	1723	PGS	NA
5BL.2431	CO	OC	A	LP	NA	NA	N	1668	MGS	NA
5BL.2712	CO	OC	EA	MA	LP	NA	N	1596	PGS	SG
5BL.3424	CO	OC	LP	NA	NA	LP	Y	1594	PGS	SG
5BL.81	CO	OC	A	LP	NA	NA	N	3003	SAF	NA
5CC.389	CO	LS	EA	LA	LP	LA	Y	2251	MF	PP
5CC.62	CO	LS	A	LP	NA	NA	N	3017	SAF	NA
5CC.79/5GA.306	CO	MC	MA	PR	NA	NA	N	3448	AL	NA
5GA.11	CO	MC	A	LP	NA	NA	N	2255	MGS	MF
5GA.1119	CO	IF	NA	NA	NA	NA	Y	2257	MF	RP
5GA.1155	CO	IF	NA	NA	NA	NA	Y	2248	SG	MGS
5GA.1166	CO	LS	P	EA	NA	NA	N	2314	MGS	MF
5GA.1172	CO	Q	LP	NA	NA	LP	Y	2344	MGS	SG
5GA.1208	CO	MC	P	LP	NA	NA	N	2429	MGS	SG
5GA.1217	CO	OC	EA	NA	NA	NA	N	2486	SAF	MGS
5GA.1219	CO	OC	MA	LP	NA	NA	N	2091	RP	NA
5GA.1499	CO	OC	PR	NA	NA	NA	N	2342	MF	SG
5GA.1513	CO	K	P	NA	NA	P	Y	2537	MF	MGS
5GA.1598	CO	OC	EA	NA	NA	EA	Y	2294	MGS	SG
5GA.1602	CO	OC	EA	NA	NA	NA	N	2294	SG	NA
5GA.1609	CO	OC, HP	P	EA	MA	NA	N	2280	SG	NA
5GA.178	CO	OC	LA	LP	NA	LP	Y	2437	SG	NA
5GA.1847	CO	OC, K	P	NA	NA	NA	Y	2348	SG	NA
5GA.186	CO	K	LA	NA	NA	LA	Y	2506	SG	MF
5GA.195	CO	OC	P	LP	NA	NA	N	2325	SG	MF
5GA.217	CO	OC	A	LP	PR	NA	N	2683	SAF	MGS
5GA.2524	CO	OC	LP	NA	NA	LP	Y	2313	SG	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
5GA.2526	CO	OC	MA	NA	NA	MA	Y	2318	SG	NA
5GA.3222	CO	OC	P	LP	NA	LP	Y	2395	SG	NA
5GA.3841	CO	PR	NA	NA	NA	NA	Y	2315	SG	RP
5GA.639	CO	K	P	NA	NA	P	Y	2476	SG	PP
5GA.660	CO	OC	MA	NA	NA	NA	N	2100	SG, MGS	MGS
5GA.869	CO	OC	EA	NA	NA	EA	Y	2500	SG	NA
5GA.9	CO	LS	MA	LP	NA	LP	Y	2246	SG	NA
5GA.965	CO	OC	NA	NA	NA	NA	N	2300	SG	MGS
5JA.1068	CO	OC	A	LP	NA	NA	N	2643	MF	NA
5JA.239	CO	K	A	LP	NA	LP	Y	2488	SG	NA
5JA.257	CO	OC	A	NA	NA	NA	Y	2487	SG	NA
5JA.273	CO	OC	MA	NA	NA	NA	Y	2492	SG	MGS
5JA.276	CO	OC	NA	NA	NA	NA	Y	2516	SG	NA
5JA.344	CO	OC	NA	NA	NA	NA	Y	2502	SG	NA
5JA.421	CO	OC, PR	P	LP	NA	P	Y	2486	SG	NA
5JA.58	CO	OC	LP	NA	NA	NA	N	2629	MF	NA
5JA.7	CO	K	LP	PR	NA	LP	Y	2405	MGS	NA
5JA.712	CO	K, HAB	A	NA	NA	A	Y	2411	SG	NA
5JA.758	CO	IF	NA	NA	NA	NA	Y	2628	SG	NA
5JA.762	CO	IF	NA	NA	NA	NA	Y	2653	SG	NA
5JA1183	CO	OC	P	A	LP	NA	Y	2531	MGS	NA
5LR.100	CO	K, OC	LP	NA	NA	LP	Y	1779	PGS	NA
5LR.104	CO	RS	NA	NA	NA	NA	Y	1819	PGS	NA
5LR.1062	CO	RS	LA	LP	NA	NA	N	2212	SG	MGS
5LR.108	CO	K	LP	PR	NA	LP	Y	1939	PGS	NA
5LR.1085	CO	HAB	A	LP	NA	LA	Y	1604	PGS	NA
5LR.1112	CO	RS	NA	NA	NA	NA	Y	1729	PGS	NA
5LR.11724	CO	OC	PR	NA	NA	PR	Y	1925	PGS	NA
5LR.12/5LR.612	CO	HAB	NA	NA	NA	NA	Y	2387	PGS	NA
5LR.12174	CO	OC	A	LP	NA	NA	N	1470	PGS	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
5LR.13	CO	K, OC	P	NA	NA	P	Y	2039	PGS	SG
5LR.1370	CO	OC	LP	PR	NA	LP	Y	2459	PGS	NA
5LR.159	CO	K	NA	NA	NA	NA	Y	1871	SG, PGS	PGS
5LR.1680	CO	K	NA	NA	NA	PR	Y	1707	PGS	SG
5LR.1683	CO	HB	LP	NA	NA	NA	N	1764	PGS	NA
5LR.1785	CO	OC	EA	NA	NA	EA	Y	1650	PGS	NA
5LR.1800	CO	OC	NA	NA	NA	NA	N	1506	PGS	SG
5LR.252	CO	OC	MA	LP	NA	LA	Y	1859	PGS	NA
5LR.263	CO	OC	LA	LP	NA	LP	Y	1892	PGS	NA
5LR.300	CO	HB	NA	NA	NA	NA	N	1655	PGS	NA
5LR.3953	CO	K	LA	NA	NA	LA	Y	1489	PGS	NA
5LR.42	CO	HB	LP	NA	NA	NA	N	1664	PGS	NA
5LR.5280	CO	HAB	LA	LP	NA	NA	N	1606	SG	PGS
5LR.532	CO	OC	A	LP	NA	NA	N	1982	PGS	NA
5LR.544	CO	MC	H	NA	NA	H	Y	2124	PGS	NA
5LR.549	CO	OC	A	NA	NA	NA	N	2180	PGS	PP
5LR.579	CO	OC, K	NA	NA	NA	NA	Y	2167	PGS	NA
5LR.9455	CO	HAB	NA	NA	NA	NA	Y	1788	PGS	PP
5LR.9812	CO	RS	LP	NA	NA	NA	N	1658	PGS	NA
5LR.99	CO	HB, OC	P	A	NA	P	Y	2099	PGS	NA
5LR.9991	CO	OC	LA	LP	NA	NA	N	1590	PGS	NA
5PA.1764	CO	HAB	LP	PR	NA	NA	N	2634	MF	NA
5PA.693	CO	OC	NA	NA	NA	NA	Y	2885	MGS	NA
5PA.813	CO	OC	LA	LP	PR	NA	N	2522	MF	NA
5WL.1368	CO	K	P	NA	NA	NA	N	1412	PGS	NA
5WL.1369	CO	OC	P	NA	NA	P	Y	1416	PGS	NA
5WL.1478	CO	RS	LP	NA	NA	NA	N	1777	PGS	NA
5WL.1479	CO	RS	LP	NA	NA	NA	N	1770	PGS	NA
5WL.1480	CO	RS	LP	NA	NA	NA	N	1780	PGS	NA
5WL.1481	CO	RS	LA	LP	NA	LA	Y	1776	PGS	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
5WL.1483	CO	OC	LP	NA	NA	LP	Y	1471	PGS	NA
5WL.1555	CO	OC	MA	LA	LP	NA	Y	1407	PGS	NA
5WL.1656	CO	OC	LA	LP	NA	LA	Y	1560	PGS	NA
5WL.1683	CO	OC	NA	NA	NA	NA	Y	1633	PGS	NA
5WL.1794	CO	OC	LA	LP	NA	LA	Y	1402	PGS	NA
5WL.1845	CO	RS	NA	NA	NA	NA	Y	1424	PGS	NA
5WL.1851	CO	RS	NA	NA	NA	NA	Y	1421	PGS	NA
5WL.1856	CO	RS	LA	LP	NA	LP	Y	1415	PGS	NA
5WL.1997	CO	RS	NA	NA	NA	NA	Y	1431	PGS	NA
5WL.2224	CO	IF	NA	NA	NA	PR	Y	1539	PGS	NA
5WL.23	CO	K	NA	NA	NA	NA	Y	1595	PGS	NA
5WL.268	CO	PR	P	NA	NA	P	Y	1407	PGS	NA
5WL.27	CO	HAB	LP	NA	NA	LP	Y	1423	PGS	NA
5WL.2857	CO	OC	MA	NA	NA	NA	N	1421	PGS	NA
5WL.306	CO	OC	NA	NA	NA	NA	N	1665	PGS	NA
5WL.31	CO	RS	LP	NA	NA	LP	Y	1371	PGS	SG
5WL.32	CO	OC	LA	LP	NA	LP	Y	1422	PGS	SG
5WL.33	CO	OC	LP	NA	NA	LP	Y	1404	PGS	SG
5WL.38	CO	HAB	LP	NA	NA	LP	Y	1420	PGS	NA
5WL.397	CO	IF	NA	NA	NA	NA	Y	1561	PGS	NA
5WL.40	CO	RS	MA	NA	NA	MA	Y	1426	PGS	NA
5WL.41	CO	RS	PR	NA	NA	NA	N	1425	PGS	NA
5WL.43	CO	RS	LP	NA	NA	LP	Y	1428	PGS	NA
5WL.453	CO	OC	LP	NA	NA	NA	N	1464	PGS	NA
5WL.47	CO	HB, OC	LP	NA	NA	LP	Y	1431	PGS	NA
5WL.48	CO	HB, OC	LP	NA	NA	NA	N	1404	PGS	NA
5WL.4872	CO	K	P	NA	NA	P	Y	1574	PGS	NA
5WL.49	CO	OC	LP	NA	NA	LP	Y	1707	PGS	NA
5WL.53	CO	OC, PR, K	P	NA	NA	P	Y	1406	PGS	NA
5WL.556	CO	OC	NA	NA	NA	NA	Y	1608	PGS	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
5WL.5588	CO	OC	EA	NA	NA	NA	N	1612	PGS	NA
5WL.5597	CO	OC	EA	NA	NA	NA	N	1835	PGS	NA
5WL.6465	CO	OC	LP	NA	NA	LP	Y	1591	PGS	NA
5WL2386	CO	OC	EA	LA	LP	NA	Y	1557	PGS	NA
BPG (Buchanan Pass Glacier specimen) (Lee and Benedict 2012)	CO	NAT	PR	NA	NA	PR	Y	3588	AP	NA
EN1010 (Eagles Nest Open Space specimen)	CO	NAT	NA	NA	NA	NA	Y	1829	PGS	NA
HCIP (Horseshoe Creek Ice Patch specimen)(Lee and Benedict 2012)	CO	NAT	LA	NA	NA	LA	Y	3465	AP	NA
IPG (Icefield Pass Glacier specimen) (Lee and Benedict 2012)	CO	NAT	MA	NA	NA	MA	Y	3639	AP	NA
JPIP (Jones Pass Ice Patch specimen)(Lee and Benedict 2012)	CO	NAT	LP	PR	NA	LP	Y	3843	AP	NA
LLIP1 (Lake Louise Ice Patch specimen 1) (Lee and Benedict 2012)	CO	NAT	LP	NA	NA	LP	Y	3621	AP	NA
LLIP2 (Lake Lousie Ice Patch specimen 2) (Lee and Benedict 2012)	CO	NAT	LP	NA	NA	LP	Y	3621	AP	NA
MAIP (Mt. Audubon Ice Patch specimen) (Lee and Benedict 2012)	CO	NAT	NA	NA	NA	NA	Y	3736	AP	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
MTA1 (Mt. Audubon specimen)	CO	NAT	NA	NA	NA	NA	Y	3048	AP	NA
RMIP (Rowe Mtn. Ice Patch specimen) (Lee and Benedict 2012)	CO	NAT	LA	NA	NA	LA	Y	3561	AP	NA
RMOS1 (Red Mountain Open Space specimen)	CO	NAT	NA	NA	NA	NA	Y	1829	PGS	NA
SPIP1 (Spotted Pony Ice Patch specimen) (Lee and Benedict 2012)	CO	NAT	LA	NA	NA	LA	Y	3662	AP	NA
SPNA1 (Soapstone Prairie Natural Area specimen)	CO	NAT	NA	NA	NA	NA	Y	1829	PGS	NA
AB1	WY	OC, PR, K	EA	LA	LP	LP	Y	2104	SG	RP
AB1165	WY	OC	MA	LA	LP	MA	Y	2104	PGS	NA
AB129	WY	K	NA	NA	NA	NA	Y	2227	SG	NA
AB130	WY	K	LA	LP	NA	LA	Y	2332	PGS	NA
AB1432	WY	RS	LP	NA	NA	NA	N	2159	MF	PGS
AB18	WY	OC, PR	MA	LA	LP	NA	N	2384	SG	PGS
AB4	WY	PR	EA	NA	NA	EA	Y	2256	MGS	NA
AB651	WY	K, HAB	NA	NA	NA	NA	Y	2634	MGS	AP
AB865	WY	OC, K	NA	NA	NA	NA	Y	2000	SG	NA
CR1146	WY	OC	P	LP	NA	LP	Y	2012	SG	NA
CR122	WY	HAB	MA	LP	NA	MA, LA	Y	1942	SG	NA
CR1229	WY	OC, PR	LA	LP	NA	LP	Y	2299	MGS	SG
CR123	WY	OC	A	NA	NA	NA	N	2104	SG	PGS
CR131	WY	OC	NA	NA	NA	NA	Y	2134	SG	PGS
CR135	WY	OC	MA	LP	NA	NA	N	1957	SG	NA
CR1388	WY	K	NA	NA	NA	NA	Y	2098	SG	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
CR1420	WY	HB, OC	NA	NA	NA	NA	N	1939	SG	SD
CR145	WY	OC, PR	P	LP	NA	LP	Y	2072	PGS	NA
CR1529	WY	OC	P	LA	LP	NA	N	2076	SG	SD
CR1548	WY	OC, HP	MA	LP	NA	NA	N	2040	SG	NA
CR1586	WY	HAB	NA	NA	NA	NA	Y	2195	SG	PGS
CR1680	WY	OC	MA	NA	NA	NA	N	2085	SG	PGS
CR1681	WY	OC	LA	LP	NA	LP	Y	2056	RP	SG
CR1751	WY	OC	A	NA	NA	NA	N	1991	SG	SD
CR1777	WY	OC	LA	NA	NA	NA	N	2082	SG	NA
CR1790	WY	OC, HP	EA	MA	LP	NA	N	2079	SG	PGS
CR182	WY	K	P	NA	NA	P	Y	2100	SG	NA
CR1849	WY	OC	LP	NA	NA	NA	N	2098	SG	NA
CR1880	WY	OC	LA	LP	NA	NA	N	2043	SG	PGS
CR1929	WY	OC	MA	NA	NA	NA	N	2104	SG	NA
CR1946	WY	OC	EA	MA	NA	NA	N	2043	SG	NA
CR2200	WY	OC	EA	MA	LP	NA	N	2043	SG	NA
CR2215	WY	OC	LA	NA	NA	NA	N	2079	SG	SD
CR2300	WY	HAB	LA	PR	NA	PR	Y	1976	SG	SD
CR2312	WY	HAB	LP	PR	NA	PR	Y	1951	SG	PGS
CR2353	WY	OC, HP	P	EA	LP	NA	N	1982	SG	SD
CR2371	WY	OC	LA	NA	NA	NA	N	2000	SG	NA
CR2411	WY	OC, PR	EA	LA	LP	NA	N	1951	SG	SD
CR2429	WY	OC	NA	NA	NA	NA	N	1933	SG	SD
CR2434	WY	OC	LA	LP	NA	NA	N	1951	SG	SD
CR2491	WY	OC, PR	LP	NA	NA	LP	Y	2034	SD	SG
CR2550	WY	OC	LA	LP	NA	NA	N	1973	SG	NA
CR2618	WY	HAB	LP	NA	NA	NA	N	1976	SG	NA
CR2653	WY	OC	LA	NA	NA	NA	N	1927	SG	NA
CR2699	WY	OC	LA	LP	NA	NA	N	1982	SG	NA
CR2708	WY	OC	LP	NA	NA	LP	Y	2085	SG	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
CR2726	WY	PR	MA	NA	NA	NA	Y	2037	SG	PGS
CR304	WY	K	MA	NA	NA	MA	Y	2079	SG	NA
CR325	WY	HAB, K, PR, HB	LA	LP	NA	LP	Y	2287	SG	NA
CR332	WY	OC	MA	LP	NA	MA, LP	Y	1960	SG	RP
CR341	WY	OC	LP	NA	NA	NA	N	2171	SG	PGS
CR3473	WY	OC	LA	LP	NA	NA	N	2005	SG	NA
CR3493	WY	OC	LA	LP	NA	LP	Y	2210	SG	PGS
CR3502	WY	HAB	MA	LP	NA	NA	N	1936	SG	NA
CR3503	WY	OC, PR	M	LP	NA	NA	N	1982	SD	SG
CR3814	WY	OC	MA	LA	NA	NA	N	2165	SG	PGS
CR3961	WY	OC, PR	EA	LA	LP	LP	Y	2090	SG	NA
CR4089	WY	OC	MA	LA	LP	MA	Y	1994	SG	NA
CR4094	WY	OC, PR	P	LA	LP	LA	Y	2195	SG	NA
CR4112	WY	OC, PR	NA	NA	NA	NA	Y	1920	SG	NA
CR4114	WY	OC	MA	LP	NA	MA	Y	1921	SG	NA
CR4139	WY	OC	MA	NA	NA	NA	N	2040	SG	NA
CR4156	WY	K	NA	NA	NA	NA	Y	2171	SG	PGS
CR4157	WY	K	NA	NA	NA	NA	Y	2171	SG	PGS
CR4278	WY	OC	PR	NA	NA	NA	N	2220	SG	PGS
CR436	WY	OC	NA	NA	NA	NA	Y	2128	SG	NA
CR4393	WY	OC, PR	NA	NA	NA	NA	Y	2134	SG	NA
CR440	WY	OC, PR	NA	NA	NA	NA	Y	2079	SD	NA
CR4419	WY	OC, HP	LP	NA	NA	LP	Y	2085	SG	PGS
CR4520	WY	K	P	NA	NA	P	Y	2274	MGS	PGS
CR4624	WY	OC, HP	EA	MA	NA	NA	N	2030	SG	NA
CR4689	WY	OC, HP	EA	MA	NA	NA	N	2037	SG	NA
CR4791	WY	K	LP	NA	NA	LP	Y	2043	SG	NA
CR4820	WY	OC	NA	NA	NA	NA	Y	1936	SG	NA
CR4891	WY	OC	LP	NA	NA	NA	N	1939	SG	NA
CR502	WY	OC	NA	NA	NA	NA	N	2098	SG	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
CR513	WY	OC	LP	NA	NA	NA	N	2018	SG	NA
CR5188	WY	OC	LA	NA	NA	NA	N	2119	SG	NA
CR5345	WY	OC	NA	NA	NA	NA	Y	2012	SG	NA
CR5511	WY	OC	LA	LP	NA	LA	Y	2146	SG	PGS
CR556	WY	OC	NA	NA	NA	NA	Y	2110	SG	PGS
CR5699	WY	OC, HP	EA	NA	NA	NA	N	2024	SG	NA
CR5844	WY	OC	H	NA	NA	NA	N	2210	SG	RP
CR6147	WY	OC	MA	LA	NA	NA	N	2067	SG	NA
CR6194	WY	HAB	LA	LP	NA	LA	Y	1817	SG	NA
CR6203	WY	OC	LP	NA	NA	LP	Y	2055	SG	NA
CR6208	WY	OC	EA	MA	NA	NA	N	2043	SG	NA
CR6267	WY	HAB	NA	NA	NA	NA	N	2091	SG	NA
CR6592	WY	LS	NA	NA	NA	NA	Y	2159	SG	PGS
CR6732	WY	OC, PR	NA	NA	NA	NA	Y	2037	SG	NA
CR6735	WY	OC	NA	NA	NA	NA	Y	2088	SG	PGS
CR6766	WY	OC	NA	NA	NA	NA	Y	2213	SG	PP
CR6767	WY	OC	LP	LP	LP	NA	N	2220	SG	PGS
CR6781	WY	OC	LP	NA	NA	LP	Y	2226	PGS	SD
CR6798	WY	OC	EA	NA	NA	EA	Y	2207	SG	NA
CR6840	WY	HAB	LP	NA	NA	LP	Y	2177	SG	PP
CR6841	WY	OC	LP	NA	NA	NA	N	2165	SG	PGS
CR6959	WY	LS	NA	NA	NA	NA	Y	2183	SG	NA
CR697	WY	K	PR	NA	NA	PR	Y	2195	SG	NA
CR6979	WY	OC, HP	EA	NA	NA	NA	N	2088	SG	PGS
CR7035	WY	OC, HP	EA	NA	NA	NA	N	2088	SG	NA
CR704	WY	OC	LP	NA	NA	NA	N	1994	SG	NA
CR7161	WY	HAB	LP	NA	NA	LP	Y	1872	SG	NA
CR7178	WY	OC	NA	NA	NA	NA	Y	2046	SG	JP
CR7244	WY	OC	MA	NA	NA	NA	N	2037	SG	SD
CR7308	WY	OC	MA	NA	NA	NA	N	2037	SG	SD

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
CR7309	WY	OC	MA	LP	NA	NA	N	2037	SG	NA
CR7327	WY	OC, PR	NA	NA	NA	NA	N	2104	SG	SD
CR7447	WY	OC	LP	NA	NA	NA	N	2021	SG	PGS
CR763	WY	HAB	A	LP	NA	NA	N	2012	SG	SD
CR7697	WY	OC, HP	P	A	LP	NA	N	1823	SG	SD
CR773	WY	HAB	NA	NA	NA	NA	N	2003	SG	NA
CR7745	WY	OC, PR	LA	LP	NA	LP	Y	2195	SG	JP
CR7747	WY	OC, PR	NA	NA	NA	NA	Y	2152	SG	JP
CR7914	WY	OC	LA	LP	NA	NA	N	2085	SG	PGS
CR8107	WY	OC	LP	NA	NA	NA	N	2155	SG	SD
CR8545	WY	OC	MA	NA	NA	NA	N	2030	SG	NA
CR8818	WY	OC, HP	EA	MA	LP	NA	N	2024	SG	NA
CR8875	WY	OC	EA	NA	NA	NA	N	2073	SG	SD
CR8895	WY	OC	LP	NA	NA	NA	N	2073	SG	NA
CR9357	WY	OC	MA	LP	NA	NA	N	2079	SG	NA
CR9359	WY	OC	LP	NA	NA	NA	N	1991	SG	PGS
CR9360	WY	OC	LA	NA	NA	NA	N	1992	SG	PGS
CR9361	WY	OC	EA	NA	NA	NA	N	1994	SG	PGS
CR9363	WY	OC	LP	NA	NA	NA	N	1997	SG	NA
CR9501	WY	OC	LA	LP	NA	LP	Y	2076	SG	NA
CR9601	WY	OC, PR	NA	NA	NA	NA	Y	2134	SG	SD
CR983	WY	OC	NA	NA	NA	NA	Y	1997	SG	PGS
CR986	WY	OC	NA	NA	NA	NA	N	2073	SG	SD
LA1104	WY	K	LA	NA	NA	LA	Y	1607	PGS	NA
LA1141	WY	K	LA	NA	NA	LA	Y	1841	MGS	NA
LA1153	WY	K	PR	NA	NA	PR	Y	1835	SG	MGS
LA1380	WY	HAB	NA	NA	NA	NA	Y	1884	PGS	NA
LA223	WY	HAB	MA	LA	NA	MA	Y	1646	PP	PGS
LA3006	WY	OC	MA	NA	NA	NA	N	1618	PGS	NA
LA312	WY	HAB	P	A	LP	NA	N	1607	PGS	NA

SITE NO	STATE	SITETYPE	AGESPEC1	AGESPEC2	AGE SPEC3	BISON AGE	BISON	ELEV M	VEG1	VEG2
LA325	WY	OC	LA	LP	NA	NA	N	1814	PGS	NA

Table A-2. Raw Absence/Presence Data of Different Faunal Types.

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
5BL.10547	CO	Y	N	N	N	N	N	N	Y	N	N	Y	N
5BL.18	CO	N	N	N	N	N	N	N	Y	Y	Y	N	N
5BL.2431	CO	N	N	N	N	N	Y	N	Y	Y	N	Y	N
5BL.2712	CO	N	N	N	N	Y	Y	N	Y	Y	Y	Y	N
5BL.3424	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5BL.81	CO	N	N	N	N	N	N	N	N	N	N	Y	Y
5CC.389	CO	Y	N	N	N	N	N	N	Y	N	Y	N	Y
5CC.62	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5CC.79/5GA.306	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5GA.11	CO	N	N	N	N	N	N	Y	N	N	Y	N	N
5GA.1119	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5GA.1155	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5GA.1166	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5GA.1172	CO	Y	N	N	Y	N	Y	N	Y	Y	N	Y	N
5GA.1208	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5GA.1217	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5GA.1219	CO	N	N	N	N	N	N	N	Y	Y	N	N	N
5GA.1499	CO	N	N	N	Y	N	N	N	Y	N	N	N	N
5GA.1513	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5GA.1598	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5GA.1602	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5GA.1609	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5GA.178	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5GA.1847	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5GA.186	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5GA.195	CO	N	N	N	N	N	N	N	Y	Y	Y	Y	N
5GA.217	CO	N	N	N	Y	N	N	N	Y	N	Y	Y	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
5GA.2524	CO	Y	N	N	N	N	N	N	Y	N	N	Y	N
5GA.2526	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5GA.3222	CO	Y	N	N	Y	N	N	N	Y	Y	Y	Y	N
5GA.3841	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5GA.639	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5GA.660	CO	N	Y	N	N	N	N	N	Y	Y	N	Y	N
5GA.869	CO	Y	Y	N	N	Y	N	N	Y	Y	Y	Y	Y
5GA.9	CO	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N
5GA.965	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5JA.1068	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5JA.239	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5JA.257	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5JA.273	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5JA.276	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5JA.344	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5JA.421	CO	Y	Y	Y	Y	N	N	N	Y	N	N	N	N
5JA.58	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5JA.7	CO	Y	Y	Y	Y	N	N	N	Y	N	N	N	N
5JA.712	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5JA.758	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5JA.762	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5JA1183	CO	Y	N	N	N	N	N	N	Y	N	Y	N	N
5LR.100	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.104	CO	Y	Y	N	N	N	N	N	N	N	N	N	N
5LR.1062	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5LR.108	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.1085	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.1112	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.11724	CO	Y	N	N	N	N	N	N	N	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
5LR.12/5LR.612	CO	Y	N	N	N	N	N	N	N	N	N	Y	N
5LR.12174	CO	N	N	N	N	N	N	N	Y	Y	Y	N	N
5LR.13	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5LR.1370	CO	Y	Y	N	N	Y	N	Y	N	N	N	N	Y
5LR.159	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.1680	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.1683	CO	N	N	N	N	Y	N	Y	N	N	Y	N	N
5LR.1785	CO	Y	Y	N	N	Y	N	N	N	N	N	N	N
5LR.1800	CO	N	N	N	N	N	N	N	Y	N	N	Y	N
5LR.252	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5LR.263	CO	Y	N	Y	N	N	N	N	N	N	N	N	N
5LR.300	CO	N	N	N	N	N	N	N	Y	N	N	N	Y
5LR.3953	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.42	CO	N	N	N	N	N	N	N	Y	N	N	N	Y
5LR.5280	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5LR.532	CO	N	Y	N	Y	N	N	N	Y	N	Y	N	Y
5LR.544	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.549	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5LR.579	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.9455	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5LR.9812	CO	N	N	N	N	N	N	N	Y	N	Y	N	N
5LR.99	CO	Y	N	N	Y	N	Y	N	Y	N	N	N	N
5LR.9991	CO	N	N	N	N	N	N	N	Y	Y	N	N	Y
5PA.1764	CO	N	N	N	N	N	N	N	Y	Y	N	N	N
5PA.693	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5PA.813	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.1368	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.1369	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5WL.1478	CO	N	N	N	N	N	N	N	Y	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
5WL.1479	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.1480	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.1481	CO	Y	N	Y	N	N	N	N	Y	N	N	N	N
5WL.1483	CO	Y	Y	Y	N	Y	N	N	N	N	N	N	Y
5WL.1555	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.1656	CO	Y	N	N	N	Y	N	Y	Y	N	N	Y	N
5WL.1683	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.1794	CO	Y	Y	N	N	N	N	N	N	N	N	N	N
5WL.1845	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5WL.1851	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.1856	CO	Y	N	Y	N	N	N	N	N	N	N	N	N
5WL.1997	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5WL.2224	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.23	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.268	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.27	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5WL.2857	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.306	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.31	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5WL.32	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.33	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5WL.38	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.397	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.40	CO	Y	N	Y	N	Y	Y	N	Y	N	N	N	Y
5WL.41	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.43	CO	Y	N	N	N	N	N	N	Y	N	N	N	N
5WL.453	CO	N	N	N	N	N	N	N	Y	N	Y	Y	N
5WL.47	CO	Y	N	N	N	N	N	N	N	N	N	N	Y
5WL.48	CO	N	N	N	N	N	N	N	Y	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
5WL.4872	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.49	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.53	CO	Y	N	Y	N	N	N	N	N	N	N	N	N
5WL.556	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL.5588	CO	N	N	N	N	N	N	N	Y	N	Y	N	N
5WL.5597	CO	N	N	N	N	N	N	N	Y	N	N	N	N
5WL.6465	CO	Y	N	N	N	N	N	N	N	N	N	N	N
5WL2386	CO	Y	N	N	N	N	N	N	Y	N	N	Y	N
BPG (Buchanan Pass Glacier specimen) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
EN1010 (Eagles Nest Open Space specimen)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
HCIP (Horseshoe Creek Ice Patch specimen) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
IPG (Icefield Pass Glacier specimen) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
JPIP (Jones Pass Ice Patch specimen)(Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
LLIP1 (Lake Louise Ice Patch specimen 1) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
LLIP2 (Lake Lousie Ice Patch specimen 2) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
MAIP (Mt. Audubon Ice Patch specimen) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
MTA1 (Mt. Audubon specimen)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
RMIP (Rowe Mtn. Ice Patch specimen) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
RMOS1 (Red Mountain Open Space specimen)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
SPIP1 (Spotted Pony Ice Patch specimen) (Lee and Benedict 2012)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
SPNA1 (Soapstone Prairie Natural Area specimen)	CO	Y	N	N	N	N	N	N	N	N	N	N	N
AB1	WY	Y	Y	Y	N	Y	N	N	N	N	N	N	N
AB1165	WY	Y	N	N	N	N	N	N	N	N	N	N	N
AB129	WY	Y	N	N	N	N	N	N	N	N	N	N	N
AB130	WY	Y	Y	Y	N	N	N	N	N	Y	N	N	N
AB1432	WY	N	N	N	N	N	N	N	N	N	N	Y	N
AB18	WY	N	N	Y	Y	Y	Y	N	N	Y	N	Y	N
AB4	WY	Y	N	N	N	N	N	N	N	N	N	N	N
AB651	WY	Y	N	N	N	N	N	N	N	N	N	N	N
AB865	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR1146	WY	Y	N	N	N	N	N	N	N	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
CR122	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR1229	WY	Y	N	N	N	N	N	N	Y	N	N	N	N
CR123	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR131	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR135	WY	N	N	N	N	N	N	N	Y	N	N	Y	N
CR1388	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR1420	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR145	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR1529	WY	N	N	N	N	Y	Y	N	N	Y	Y	Y	N
CR1548	WY	N	N	N	N	Y	Y	N	Y	Y	Y	N	N
CR1586	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR1680	WY	N	N	Y	N	N	N	N	N	N	N	N	N
CR1681	WY	Y	N	Y	N	N	N	N	Y	Y	N	N	N
CR1751	WY	N	N	Y	N	Y	N	N	N	N	N	N	N
CR1777	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR1790	WY	N	N	Y	N	Y	N	N	N	N	N	N	N
CR182	WY	Y	N	N	N	N	N	N	N	N	N	Y	N
CR1849	WY	N	N	N	N	Y	N	N	N	N	N	N	N
CR1880	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR1929	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR1946	WY	N	N	N	N	Y	N	N	N	N	N	N	N
CR2200	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR2215	WY	N	N	N	N	N	N	N	N	Y	Y	Y	N
CR2300	WY	Y	N	Y	N	N	N	N	N	Y	N	Y	N
CR2312	WY	Y	N	N	N	N	N	N	Y	N	N	Y	N
CR2353	WY	N	N	N	N	N	N	N	Y	Y	Y	Y	N
CR2371	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR2411	WY	N	N	N	N	N	N	N	N	Y	N	Y	N
CR2429	WY	N	N	N	N	N	N	N	N	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
CR2434	WY	N	N	N	N	N	N	N	N	Y	N	N	N
CR2491	WY	Y	N	N	N	N	N	N	N	N	Y	N	N
CR2550	WY	N	N	N	N	N	N	N	N	N	N	Y	N
CR2618	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR2653	WY	N	N	N	N	N	Y	N	N	N	N	N	N
CR2699	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR2708	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR2726	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR304	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR325	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR332	WY	Y	N	N	N	N	N	N	Y	Y	Y	Y	N
CR341	WY	N	N	N	N	N	Y	N	N	N	N	N	N
CR3473	WY	N	N	Y	N	N	N	N	N	N	N	N	N
CR3493	WY	Y	N	N	N	N	N	N	N	N	Y	Y	N
CR3502	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR3503	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR3814	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR3961	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4089	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4094	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4112	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4114	WY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CR4139	WY	N	N	N	N	Y	N	N	Y	Y	Y	N	Y
CR4156	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4157	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4278	WY	N	N	N	N	Y	N	N	N	Y	Y	N	N
CR436	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4393	WY	Y	Y	Y	N	N	N	N	N	N	N	N	N
CR440	WY	Y	N	N	N	N	N	N	N	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
CR4419	WY	Y	N	Y	N	N	Y	N	Y	Y	Y	Y	Y
CR4520	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4624	WY	N	N	Y	N	Y	N	N	N	N	Y	Y	N
CR4689	WY	N	N	Y	Y	N	Y	N	N	N	N	N	Y
CR4791	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR4820	WY	Y	N	N	N	N	N	N	N	N	Y	N	N
CR4891	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR502	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR513	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR5188	WY	N	N	Y	N	N	N	N	N	N	N	N	N
CR5345	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR5511	WY	Y	N	N	N	N	N	N	N	Y	N	N	N
CR556	WY	Y	N	Y	N	N	N	N	N	Y	N	N	N
CR5699	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR5844	WY	N	N	N	N	N	N	N	Y	N	Y	Y	N
CR6147	WY	N	Y	N	Y	N	N	N	N	N	Y	Y	N
CR6194	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6203	WY	Y	N	N	N	N	Y	N	Y	Y	N	Y	N
CR6208	WY	N	N	N	N	N	N	N	N	N	Y	N	N
CR6267	WY	N	N	N	N	N	N	N	Y	N	N	Y	N
CR6592	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6732	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6735	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6766	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6767	WY	N	N	Y	N	N	N	N	N	N	Y	N	N
CR6781	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6798	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6840	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6841	WY	N	N	N	N	N	N	N	Y	N	N	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
CR6959	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR697	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR6979	WY	N	N	N	N	N	N	N	Y	Y	N	N	N
CR7035	WY	N	N	N	N	N	N	N	Y	Y	N	N	N
CR704	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR7161	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR7178	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR7244	WY	N	Y	N	N	N	N	Y	N	N	Y	N	N
CR7308	WY	N	N	N	N	N	N	N	N	N	Y	Y	N
CR7309	WY	N	N	Y	N	N	N	N	Y	Y	N	N	N
CR7327	WY	N	N	N	N	N	N	N	N	N	Y	Y	N
CR7447	WY	N	N	N	N	Y	N	N	N	Y	N	N	N
CR763	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR7697	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR773	WY	N	N	N	N	N	N	N	Y	N	N	N	N
CR7745	WY	Y	N	N	N	N	N	N	N	N	N	Y	N
CR7747	WY	Y	N	N	N	N	N	N	N	N	Y	Y	N
CR7914	WY	N	N	N	N	N	N	N	Y	Y	N	N	N
CR8107	WY	N	N	N	N	N	N	N	N	N	Y	Y	N
CR8545	WY	N	N	N	N	Y	N	N	N	Y	N	N	N
CR8818	WY	N	N	N	N	Y	N	N	N	N	N	N	N
CR8875	WY	N	N	N	N	Y	N	N	N	N	N	N	N
CR8895	WY	N	N	N	N	N	N	N	N	N	Y	Y	N
CR9357	WY	N	N	N	N	Y	N	N	N	N	N	N	N
CR9359	WY	N	N	N	N	N	N	N	N	N	N	Y	N
CR9360	WY	N	N	N	N	N	N	Y	N	N	N	Y	N
CR9361	WY	N	N	N	N	Y	N	N	N	Y	N	N	N
CR9363	WY	N	N	N	N	N	N	N	N	N	N	Y	N
CR9501	WY	Y	N	N	N	N	N	N	N	N	Y	N	N

SITE NO	STATE	BISON	DEER	PRHORN	ELK	RABBIT	RODENT	BIRD	UNSPEC	SMMAMM	MDMAMM	LGMAMM	OTHER
CR9601	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR983	WY	Y	N	N	N	N	N	N	N	N	N	N	N
CR986	WY	N	N	Y	N	N	N	N	N	N	Y	Y	N
LA1104	WY	Y	N	N	N	N	N	N	N	N	N	N	N
LA1141	WY	Y	N	N	N	N	N	N	N	N	N	N	N
LA1153	WY	Y	N	N	N	N	N	N	N	N	N	N	N
LA1380	WY	Y	N	N	N	N	N	N	N	N	N	Y	N
LA223	WY	Y	N	Y	N	N	N	N	Y	N	N	N	N
LA3006	WY	N	N	N	N	N	N	N	Y	N	N	Y	N
LA312	WY	N	N	N	N	N	N	N	N	N	N	N	N
LA325	WY	N	N	N	N	N	N	N	Y	N	N	N	N

APPENDIX B

AEON LABORATORIES AMS RADIOCARBON DATING RESULTS

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Radiocarbon Dating Services

Radiocarbon Analysis

2013-12-06

Report for:

Dr. Jason LaBelle
Department of Anthropology
B-219 Andrew G. Clark Building
Colorado State University
Fort Collins, CO 80523

Aeon #	Sample	Material	Pretreat	Yield % C	$\delta^{13}C$ ‰	$F^{14}C$	±	^{14}C age Years BP	±
1632	EN1010	bone	gelatin	24.1	-10.7	0.9753	0.0026	200	20
1633	SPNA1b	bone	gelatin	31.5	-17.9	0.9841	0.0029	130	25
1634	RMOS1	bone	gelatin	33.1	-13.2	0.6570	0.0030	3,375	35
1635	MTA1	bone	gelatin	28.9	-17.5	0.7567	0.0026	2,240	30
1636	5LR1680-241	bone	gelatin	33.6	-11.2	0.9800	0.0026	160	20
1637	48AB130-D1917	bone	gelatin	30.6	-17.3	0.8481	0.0031	1,325	30

Notes

Item	Description
Aeon #	The unique identifier for each radiocarbon analysis performed by Aeon. Use this number for publication: e.g., "Aeon-137"
Sample	The customer-provided sample identifier.
Material	The type of material targeted for analysis. A sub-sample of this type is selected from the total material submitted to Aeon.
Pretreat	The chemical pretreatment protocol applied to the sub-sample. ABA = acid-base-acid; ABOX = acid-base-strong oxidation
Yield	The percentage of carbon in the sub-sample[1].
$\delta^{13}C$	The relative difference between the $^{13}C/^{12}C$ ratio of the test sample[2] and that of the VPDB standard, expressed in per mille.
$F^{14}C$	The ^{14}C activity ratio[3] (corrected for isotopic fractionation and background activity).
^{14}C age	The conventional radiocarbon age, normalized to -25‰, based on a 5568-year half-life.
±	The 1σ uncertainty for the value to the left.

[1] the sub-sample is the pretreated representative selection from the total sample material submitted.
[2] the test sample consists of the carbon extracted from the sub-sample.
[3] relative to "Modern" as defined by the Oxalic Acid I standard.

References

Stuiver, M., Polach, H., 1977. Discussion: Reporting of 14C data. Radiocarbon 19 (3), 355-363.
van der Plicht, J., Hogg, A., 2006. A note on reporting radiocarbon. Quaternary Geochronology 1 (4), 237-240.

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Radiocarbon Dating Services

Supplemental Analysis

for bone samples

2013-12-06

Report for:

Dr. Jason LaBelle
Department of Anthropology
B-219 Andrew G. Clark Building
Colorado State University
Fort Collins, CO 80523

Sample	before pretreatment			RGY	after pretreatment		
	%C	%N	C:N		%C	%N	C:N
EN1010	4.14	0.89	5.42	4.4	40.68	14.84	3.20
SPNA1b	10.49	3.04	4.02	8.6	42.67	15.63	3.18
RMOS1	7.35	1.48	5.79	4.1	38.88	14.18	3.20
MTA1	11.25	3.56	3.69	15.7	38.42	14.06	3.19
5LR1680-241	5.23	0.78	7.82	10.1	38.60	13.92	3.23
48AB130-D1917	7.25	1.84	4.60	7.1	37.87	13.73	3.22

Sample	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
EN1010	--	--
SPNA1b	--	--
RMOS1	--	--
MTA1	--	--
5LR1680-241	--	--
48AB130-D1917	--	--

Notes

$\delta^{13}C$ and $\delta^{15}N$ values are pending supplemental stable isotope analysis.

Item	Description
Sample	The customer-provided sample identifier.
%C	carbon content, % of test sample mass (nominal: 44.0± 4.7% after pretreatment)
%N	nitrogen content, % of test sample mass (nominal: >0.5% before pretreatment, 15.8± 1.9% after pretreatment)
C:N	ratio of carbon atoms to nitrogen atoms (nominal: <11.0 before pretreatment, 3.25± 0.19 after pretreatment)
RGY	residual gelatin yield (nominal: >0.5 %)
$\delta^{13}C$	The $^{13}C/^{12}C$ ratio of the pretreated material. This value may differ from that obtained for the AMS test sample.

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APPENDIX C

CALIBRATED RADIOCARBON DATA

Table C-1. Sigma 1 and Sigma 2 Calibrated Radiocarbon Data Results Used in this Project.[1]

SITENO	STATE	Faunal Pres	Bison Pres	Elevation (m)	RCDATE BP	Sigma 1 (calBP)	PROB (%)	Sigma 2 (calBP)	PROB (%)
AB1	WY	Y	Y	2103	610+/-70	579-651	77	521-674	100
		Y	Y	2103	1190+/-70	1005-1183	81	969-1229	100
		Y	Y	2103	1720+/-40	1568-1629	60	1545-1715	100
		Y	Y	2103	2980+/-60	3061-3242	98	2971-3272	90
		Y	Y	2103	6040+/-130	6734-7026	89	6629-7251	99
AB18	WY	Y	N	2384	1555+/-75	1379-1579	100	1305-1572	98
		Y	N	2384	1930+/-40	1857-1902	58	1809-1988	97
AB4	WY	Y	Y	2256	7900+/-400	8372-9277	100	7931-9692	99
AB130	WY	Y	Y	2335	1325+/-30	1259-1294	0.83	1229-1299	0.8
CR1229	WY	Y	Y	2298	1230+/-90	1068-1193	66	968-1296	100
CR135	WY	Y	N	1957	870+/-110	698-805	58	647-983	98
		Y	N	1957	1680+/-120	1512-1714	76	1346-1835	98
CR1529	WY	Y	N	2076	1940+/-50	1825-1934	99	1774-1996	97
CR1548	WY	Y	N	2039	870+/-50	727-800	68	693-835	72
		Y	N	2039	1010+/-50	904-971	75	794-1000	96
CR1680	WY	Y	N	2085	2990+/-90	3057-3259	82	2925-3380	99
CR1681	WY	Y	Y	2073	940+/-140	797-872	78	767-931	100
CR1790	WY	Y	N	2079	5300+/-60	5996-6126	77	5933-6212	97
		Y	N	2079	6320+/-60	7230-7305	61	7155-7420	98
		Y	N	2079	2490+/-70	2487-2790	100	2377-2739	99
		Y	N	2079	3450+/-60	3638-3732	60	3572-3864	100
		Y	N	2079	1450+/-60	1300-1388	100	1278-1420	89
		Y	N	2079	3910+/-80	4234-4438	94	4138-4532	97
		Y	N	2079	4730+/-70	5507-5581	45	5431-5589	61
CR1880	WY	Y	N	2042	1070+/-60	930-1009	73	905-1151	95
		Y	N	2042	1380+/-60	1262-1352	100	1221-1394	91
		Y	N	2042	1770+/-90	1604-1813	98	1520-1897	98
CR1929	WY	Y	N	2103	3270+/-60	3446-3570	97	3380-3632	100
		Y	N	2103	3600+/-70	3828-3990	90	3702-4090	100
CR1946	WY	Y	N	2042	5130+/-120	5715-6000	99	5642-6182	99
		Y	N	2042	6600+/-110	7422-7584	100	7305-7667	99
		Y	N	2042	5810+/-130	6451-6748	99	6316-6909	100
		Y	N	2042	6150+/-120	6889-7176	96	6741-7306	100
		Y	N	2042	6260+/-280	6849-7429	98	6496-7624	99
		Y	N	2042	6270+/-175	6975-7332	92	6746-7492	100
		Y	N	2042	1020+/-60	1034-1045	72	793-1057	100
CR2200	WY	Y	N	2042	1170+/-60	1050-1178	84	1203-1257	92
CR2300	WY	Y	Y	1975	1420+/-60	1289-1370	100	1255-1416	95
		Y	N	1975	170+/-50	137-223	56	59-234	63

[1] All radiocarbon dates obtained for this research were calibrated using the CALIB 7.0 software and the IntCal13.143 calibration curve and reported in cal BP (Stuiver et al. 2005). Sigma 1 and Sigma 2 calibrated dates listed here for highest probability dates.

SITENO	STATE	Faunal Pres	Bison Pres	Elevation (m)	RCDATE BP	Sigma 1 (calBP)	PROB (%)	Sigma 2 (calBP)	PROB (%)
CR2312	WY	Y	Y	1951	270+/-70	348-457	56	256-501	77
CR2353	WY	Y	N	1981	1130+/-50	964-1080	94	953-1177	99
		Y	N	1981	5160+/-120	5743-6015	91	5649-6209	99
		Y	N	1981	5360+/-80	6015-6081	31	5986-6294	97
CR2371	WY	Y	N	1999	1530+/-70	1354-1423	48	1304-1551	100
CR2392	WY	N	N	1981	1250+/-50	1172-1271	81	1066-1282	100
CR2409	WY	N	N	1951	1670+/-70	1521-1633	72	1395-1733	100
CR2410	WY	N	N	1951	1620+/-60	1474-1564	63	1376-1628	97
CR2411	WY	Y	N	1951	5140+/-70	5873-5947	48	5710-6021	96
		Y	N	1951	1110+/-60	937-1070	100	929-1176	100
		Y	N	1951	1690+/-60	1536-1630	74	1474-1731	93
		Y	N	1951	2040+/-180	1818-2184	87	1555-2384	99
CR2434	WY	Y	N	1951	1120+/-60	956-1083	93	930-1178	100
		Y	N	1951	2310+/-60	2300-2378	60	2149-2490	99
CR2442	WY	N	N	1932	1660+/-60	1520-1624	78	1412-1701	100
CR2464	WY	N	N	1960	1180+/-50	1056-1178	95	973-1186	92
		N	N	1960	1520+/-50	1350-1418	62	1318-1526	100
CR2487	WY	N	N	1972	1240+/-50	1197-1262	50	1060-1282	100
CR2491	WY	Y	Y	2033	820+/-50	688-768	96	669-800	92
CR2550	WY	Y	N	1972	1290+/-60	1180-1287	100	1070-1302	100
CR2583	WY	N	N	1960	1140+/-60	972-1088	80	933-1182	98
CR2588	WY	N	N	1951	1100+/-60	951-1062	93	926-1175	100
		N	N	1951	1050+/-50	925-989	81	901-1067	94
CR2604	WY	N	N	1951	1110+/-50	959-1064	100	932-1096	87
CR2618	WY	Y	N	1957	1080+/-60	933-1011	70	909-1176	99
CR2653	WY	Y	N	1926	1480+/-60	1304-1412	100	1295-1445	80
CR2667	WY	N	N	1957	4880+/-90	5579-5726	81	5449-5765	89
		N	N	1957	7830+/-460	8280-9159	88	7695-9710	99
CR2699	WY	Y	N	1981	870+/-50	727-800	68	693-835	72
CR325 AND 324	WY	Y	Y	2256	1720+/-110	1526-1741	88	1392-1878	100
CR332	WY	Y	Y	1932	3570+/-40	3829-3926	94	3816-3977	84
		Y	N	1932	1240+/-40	1198-1261	55	1069-1271	100
CR341	WY	Y	N	2170	390+/-80	427-509	58	289-542	100
		Y	N	2170	650+/-480	271-1010	92	1-1414	99
CR3473	WY	Y	N	2003	4110/-100	4522-4727	75	4404-4861	99
		Y	N	2003	1660+/-100	1514-1633	55	1358-1745	95
CR3493	WY	Y	Y	2210	1130+/-60	963-1086	88	931-1219	99
CR3498	WY	N	N	1951	1120+/-60	956-1083	93	930-1178	100
CR3502	WY	Y	N	1935	1110+/-90	932-1089	0.84	903-1262	0.96
CR3503	WY	Y	N	1981	1510+/-60	1338-1418	66	1306-1527	100
		Y	N	1981	2590+/-70	2696-2778	57	2457-2852	99
		Y	N	1981	3590+/-90	3820-3990	74	3683-4102	95
CR3814	WY	Y	N	2164	4210+/-130	4528-4871	100	4414-5066	97

SITENO	STATE	Faunal Pres	Bison Pres	Elevation (m)	RCDATE BP	Sigma 1 (calBP)	PROB (%)	Sigma 2 (calBP)	PROB (%)
CR3815	WY	N	N	2161	1170+/-100	977-1181	97	926-1288	100
		N	N	2161	4430+/-270	4809-5334	80	4376-5664	98
		N	N	2161	8210+/-260	8951-9480	86	8447-9692	100
		N	N	2161	8780+/-260	9552-9975	71	9253-10521	99
		N	N	2161	9250+/-810	9468-11630	99	8594-1673	100
CR3961	WY	Y	Y	2089	1320+/-90	1173-1331	94	1053-1394	99
		Y	N	2089	1570+/-110	1347-1563	100	1291-1708	100
CR3962	WY	N	N	2103	4290+/-70	4818-4971	92	4783-5047	79
CR4114	WY	Y	N	1920	1190+/-60	1054-1182	87	977-1194	84
		Y	Y	1920	1440+/-90	1277-1415	93	1225-1535	97
		Y	N	1920	4010+/-160	4285-4652	81	4071-4863	98
CR4139	WY	Y	N	2039	4500+/-80	5046-5296	100	4875-5321	99
CR4278	WY	Y	N	2219	250+/-80	351-436	34	244-494	62
CR4419	WY	Y	Y	2085	1200+/-60	1057-1184	87	1042-1267	87
		Y	N	2085	1340+/-70	1224-1312	76	1171-1374	91
CR4520	WY	Y	Y	2274	9800+/-150	11068-11407	74	10725-11754	100
CR4624	WY	Y	N	2030	3610+/-80	3829-4003	83	3699-4100	97
		Y	N	2030	4850+/-100	5566-5664	49	5438-5756	84
CR4689	WY	Y	N	2036	4140+/-100	4569-4824	98	4417-4866	100
		Y	N	2036	5810+/-80	6499-6678	95	6434-6790	99
CR4891	WY	Y	N	1939	1360+/-50	1260-1326	92	1220-1354	87
CR5188	WY	Y	N	2118	2350+/-70	2310-2491	90	2299-2544	71
CR5511	WY	Y	Y	2146	2220+/-60	2218-2309	59	2056-2343	100
		Y	N	2146	1300+/-60	1220-1290	67	1167-1307	83
CR5699	WY	Y	N	2024	6240+/-50	7155-7252	76	7139-7264	61
		Y	N	2024	5840+/-40	6631-6727	92	6532-6746	100
CR6147	WY	Y	N	2067	2030+/60	1920-2059	93	1868-2146	100
		Y	N	2067	3440+/-60	3631-3731	65	3564-3857	100
CR6203	WY	Y	Y	2054	1400+/-40	1290-1335	100	1272-1377	100
CR6208	WY	Y	N	2042	4490+/-80	5040-5296	100	4872-5318	100
CR6218	WY	N	N	1999	1700+/-50	1551-1629	73	1520-1729	98
		N	N	1999	1360+/-60	1256-1336	85	1176-1386	100
CR6767	WY	Y	N	2219	1170+/-70	1049-1178	78	958-1262	100
CR6798	WY	Y	Y	2207	5460+/-90	6181-6324	81	6000-6409	100
CR6840	WY	Y	Y	2176	960+/-40	822-868	50	786-938	99
CR6841	WY	Y	N	2164	1590+/-40	1415-1464	53	1392-1558	100
CR6892	WY	N	N	2048	3880+/-120	4145-4440	91	3960-4626	98
CR697	WY	Y	Y	2103	250+/-50	273-321	44	261-343	37
CR6979	WY	Y	N	2088	5300+/-40	6039-6118	58	5986-6184	96
CR7035	WY	Y	N	2088	5600+/-40	6318-6374	71	6299-64533	100
		Y	N	2088	7000+/-40	7791-7868	75	7734-7935	100
CR7244	WY	Y	N	2036	4110+/-70	4526-4656	59	4506-4829	92
		Y	N	2036	3810+/-70	4089-4297	94	4068-4415	93

SITENO	STATE	Faunal Pres	Bison Pres	Elevation (m)	RCDATE BP	Sigma 1 (calBP)	PROB (%)	Sigma 2 (calBP)	PROB (%)
CR7309	WY	Y	N	2036	4200+/-40	4699-4759	55	4612-4767	70
		Y	N	2036	1200+/-40	1071-1177	100	1050-1190	82
CR7447	WY	Y	N	2021	1200+/-60	1057-1184	87	1042-1267	87
CR7914	WY	Y	N	2085	1970+/-40	1877-1950	91	1858-1997	94
		Y	N	2085	1600+/-40	1416-1464	51	1394-1566	100
CR8545	WY	Y	N	2030	3680+/-40	3971-4085	97	3897-4096	95
		Y	N	2030	4160+/-40	4641-4762	77	4572-4831	100
		Y	N	2030	3780+/-40	4090-4134	37	4070-4298	92
CR8818	WY	Y	N	2024	3740+/-40	4076-4151	67	3979-4182	92
		Y	N	2024	6620+/-40	7475-7521	58	7440-7570	100
		Y	N	2024	1510+/-40	1343-1416	83	1314-1424	69
		Y	N	2024	5850+/-40	6636-6731	100	6550-6751	99
		Y	N	2024	7050+/-40	7851-7909	71	7818-7958	96
CR8875	WY	Y	N	2073	4670+/-40	5370-5421	49	5312-5475	93
CR8895	WY	Y	N	2073	1430+/-70	1288-1390	100	155-1424	87
CR9357	WY	Y	N	2079	1130+/-40	969-1070	100	960-1151	95
		Y	N	2079	4170+/-40	4688-4762	51	4577-4772	78
CR9359	WY	Y	N	1990	1530+/-40	1369-1419	50	1343-1526	100
CR9360	WY	Y	N	1993	2450+/-40	2378-2504	56	2359-2549	56
CR9361	WY	Y	N	1993	5110+/-40	5758-5822	64	5746-5834	55
		Y	N	1993	6360+/-50	7249-7331	80	7237-7418	89
CR9363	WY	Y	N	1996	1590+/-40	1415-1464	53	1392-1558	100
CR9601	WY	Y	Y	2134	2200+/-100	2112-2337	0.97	1927-2381	0.99
LA1104	WY	Y	Y	1606	2410+/-70	2349-2498	72	2341-2715	100
LA1141	WY	Y	Y	1841	2530+/-80	2491-2603	50	2375-2756	99
LA1153	WY	Y	Y	1835	250+/-50	273-321	44	261-343	37
LA3006	WY	Y	N	1618	5010+/-40	896-1181	81	680-1304	100
LA312	WY	Y	N	1606	4320+/-160	4802-5071	0.62	4508-5321	0.98
		Y	N	1606	1620+/-90	1407-1608	1	1328-1715	1
		Y	N	1606	3680+/-80	3900-4095	0.91	3826-4248	0.99
		Y	N	1606	5360+/-75	6016-6081	0.31	5988-6291	0.98
		Y	N	1606	710+/-110	621-735	0.69	518-803	0.94
LA325	WY	Y	N	1814	1080+/-180	896-1181	0.82	680-1304	1
		Y	N	1814	1130+/-110	953-1177	98	899-1284	95
CR304	WY	Y	Y	2103	4540+/-110	5038-5323	90	4870-540	99
5BL.2712	CO	Y	N	1594	6070+/-190	6719-7169	99	6492-7330	99
		Y	N	1594	650+/-110	542-679	100	484-796	99
		Y	N	1594	970+/-70	795-934	100	731-990	98
		Y	N	1594	850+/-70	689-798	83	678-914	100
		Y	N	1594	780+/-90	652-796	99	632-914	93
5GA.1166	CO	Y	N	2313	7700+/-50	8430-8521	91	8408-8581	100
		Y	N	2313	8400+/-50	9400-9488	88	9302-9518	100
5GA.1208	CO	Y	N	2429	790+/-90	658-796	96	636-918	95
5GA.1219	CO	Y	N	2091	4450+/-70	5162-5281	45	4876-5292	100

SITENO	STATE	Faunal Pres	Bison Pres	Elevation (m)	RCDATE BP	Sigma 1 (calBP)	PROB (%)	Sigma 2 (calBP)	PROB (%)
5GA.1499	CO	Y	N	2341	160+/-60	166-225	34	56-294	83
5GA.1602	CO	Y	N	2292	5180+/-80	5883-6009	70	5743-6129	94
5GA.1609	CO	Y	N	2280	10020+/-90	11326-11650	89	11244-11832	96
		Y	N	2280	7510+/-80	8295-8393	70	8169-8451	100
5GA.195	CO	Y	N	2326	1250+/-50	1172-1271	81	1066-1282	100
		Y	N	2326	9420+/-50	10585-10703	100	10511-10770	100
		Y	N	2326	8510+/-50	9487-9534	100	9449-9547	100
5GA.217	CO	Y	N	2682	810+/-50	684-761	100	666-799	95
		Y	N	2682	2920+/-50	2995-3084	61	2925-3212	99
		Y	N	2682	4170+/-110	4569-4839	100	4419-4965	100
		Y	N	2682	2150+/-90	2038-2184	62	1944-2342	99
		Y	N	2682	4070+/-170	4404-4836	97	4082-4979	99
		Y	N	2682	2410+/-190	2308-2743	98	1988-2879	99
		Y	N	2682	3920+/-160	4141-4572	94	3965-4826	99
		Y	N	2682	900+/-180	669-977	100	544-1181	99
		Y	N	2682	3230+/-50	3385-3483	90	3365-3567	100
		Y	N	2682	890+/-50	738-802	52	725-922	98
		Y	N	2682	4710+/-120	5319-5429	43	5046-5660	100
		Y	N	2682	780+/-50	673-733	100	657-791	100
5GA.660	CO	Y	N	2100	5280+/-50	6039-6119	51	5931-6188	100
		Y	N	2100	5080+/-50	5751-5828	65	5712-5925	99
5JA.1068	CO	Y	N	2643	1530+/-100	1342-1527	100	1278-1625	99
5LR.1683	CO	Y	N	1765	1520 +/- 110	1325-1526	100	1261-1633	97
5LR.42	CO	Y	N	1664	1650+/-90	1476-1624	71	1349-1740	98
		Y	N	1664	1850+/-90	1695-1887	94	1566-1952	98
5LR.9991	CO	Y	N	1588	1160+/-50	1050-1151	70	961-1183	97
		Y	N	1588	2430+/-50	2358-2495	72	2352-2548	63
5PA.1764	CO	Y	N	2633	6400+/-50	7274-7333	0.56	7256-7424	1
		Y	N	2633	800+/-50	678-745	0.96	663-797	0.98
		Y	N	2633	600+/-50	585-646	0.78	533-662	1
5WL.5588	CO	Y	N	1612	6260+/-40	7167-7247	100	7153-7268	85
		Y	N	1612	5880+/-40	6661-6740	100	6626-6794	98
		Y	N	1612	610+/-40	582-611	40	542-659	100
5WL.5597	CO	Y	N	1835	5300+/-40	6039-6118	58	5986-6194	96
5CC.389	CO	Y	Y	2249	1600+/-50	1415-1465	46	1382-1574	96
5GA.1172	CO	Y	Y	2344	560+/-40	599-631	52	583-649	54
		Y	Y	2344	840+/-60	686-796	97	675-833	82
5GA.1513	CO	Y	Y	2536	5230+/-210	5860-6214	80	5584-6442	99
		Y	Y	2536	6015+/-55	6790-6931	100	6720-7002	100
		Y	Y	2536	10240+/-70	11817-12096	100	11705-12240	95
		Y	Y	2536	8090+/-60	8977-9128	91	8772-9144	93
		Y	Y	2536	10470+/-50	12381-12545	88	12361-	67

SITENO	STATE	Faunal Pres	Bison Pres	Elevation (m)	RCDATE BP	Sigma 1 (calBP)	PROB (%)	Sigma 2 (calBP)	PROB (%)
								12561	
5GA.1598	CO	Y	Y	2292	4498+/-50	5212-5286	38	5030-5306	93
		Y	Y	2292	6670+/-50	7504-7584	100	7456-7616	98
		Y	N	2292	820+/-80	673-796	94	659-919	100
5GA.186	CO	Y	Y	2505	2950+/-50	3030-3176	95	2957-3245	99
5GA.2524	CO	Y	Y	2313	1580+/-80	1389-1551	1	1310-1622	0.99
		Y	Y	2313	1700+/-40	1554-1625	81	1535-1703	100
5GA.2526	CO	Y	Y	2316	4150+/-40	4614-4728	68	4568-4828	99
5GA.3222	CO	Y	Y	2393	930+/-50	840-910	64	740-930	100
		Y	Y	2393	1080+/-50	935-1005	74	918-1089	96
		Y	N	2393	7720+/-50	8444-8546	100	8417-8589	100
		Y	N	2393	8290+/-50	9250-9408	0.91	9128-9437	1
5GA.639	CO	Y	Y	2435	3750+/-50	4073-4158	62	3969-4255	99
		Y	Y	2435	9310+/-50	10479-10582	76	10371-10609	88
		Y	Y	2435	8490+/-50	9479-9529	100	9438-9542	100
5GA.869	CO	Y	Y	2414	800+/-50	678-745	95	663-797	98
5GA.9	CO	Y	Y	2246	4700+/-50	5325-5417	64	5318-5486	75
5JA.421	CO	Y	Y	2487	9660-+/-50	11075-11183	65	11061-11203	53
5LR.100	CO	Y	Y	1777	165+/-25	170-217	56	163-225	44
		Y	Y	1777	290+/-20	395-424	62	358-430	65
5LR.104	CO	Y	Y	1820	1005+/-60	900-972	0.62	786-1012	0.94
5LR.13	CO	Y	Y	2039	10780+/-135	12567-12799	100	1419-12996	100
		Y	Y	2039	11200+/-400	12704-13457	100	12099-13966	100
5LR.1370	CO	Y	N	2460	2270+/-50	2180-2241	52	2153-2279	59
		Y	Y	2460	910+/-50	841-910	0.58	732-926	1
		Y	N	2460	820+/-50	688-768	96	669-800	92
5LR.1680	CO	Y	Y	1707	160+/-20	172-218	0.59	167-224	0.47
5LR.263	CO	Y	Y	1893	210+/-95	133-228	39	1-335	82
		Y	Y	1893	250+/-85	350-437	34	243-494	62
		Y	N	1893	1370+/-175	1069-1415	96	929-1622	99
		Y	N	1893	1675+/-85	1521-1701	90	1393-1743	95
		Y	N	1893	420+/-80	429-528	74	301-555	98
5LR.3953	CO	Y	Y	1487	2690+/-60	2755-2844	100	2736-2928	99
		Y	Y	1487	2740+/-40	2783-2864	100	2760-2925	100
5WL.1483	CO	Y	Y	1472	1240+/-80	1171-1264	55	1043-1295	91
		Y	Y	1472	1460+/-50	1307-1384	100	1288-1418	93
		Y	Y	1472	1370+/-60	1260-1344	93	1180-1385	100
		Y	Y	1472	1260+/-70	1172-1281	76	1051-1302	97
5WL.1656	CO	Y	Y	1561	6910+/-50	7685-7788	1	7656-7856	0.99
5WL.1794	CO	Y	Y	1402	2970+/-90	2999-3247	97	2921-3364	98
5WL.1856	CO	Y	Y	1414	1920+/-80	1775-1950	0.92	1692-2058	0.98
5WL.1997	CO	Y	Y	1430	1510+/-70	1334-1419	0.64	1299-1538	1

SITENO	STATE	Faunal Pres	Bison Pres	Elevation (m)	RCDATE BP	Sigma 1 (calBP)	PROB (%)	Sigma 2 (calBP)	PROB (%)
5WL.268	CO	Y	Y	1408	9006+/-130	9902-10282	100	9697-10440	98
		Y	Y	1408	9550+/-130	10706-11100	100	10546-11510	99
5WL.38	CO	Y	Y	1420	880+/-50	732-801	60	702-915	100
5WL.4872	CO	Y	Y	1573	7995+/-80	8755-9000	98	8601-9031	99
5WL.53	CO	Y	Y	1405	9070+/-90	10159-10304	76	10114-10444	82
5WL.32	CO	Y	Y	1423	1210+/-220	922-1333	100	701-1531	100
		Y	Y	1423	1755+/-95	1562-1741	84	1515-1888	95
		Y	Y	1423	1955+/-95	1808-2007	90	1694-2147	99
		Y	Y	1423	2010+/-65	1885-2013	88	1824-2128	100
		Y	Y	1423	2095+/-105	1933-2158	88	1865-2336	100
		Y	Y	1423	2170+/-160	1986-2346	97	1815-2542	95
5WL.27	CO	Y	Y	1423	695+/-150	535-764	100	456-935	99
		Y	Y	1423	735+/-105	632-767	80	536-804	90
		Y	Y	1423	1400+/-90	1256-1403	94	1173-1526	98
5LR.252	CO	Y	Y	1859	3855+/-350	3836-4710	95	3439-5086	96
		Y	Y	1859	3700+/-105	3890-4159	93	3825-4359	96
		Y	N	1859	3095+/-75	3210-3387	100	3104-3456	98
		Y	N	1859	2830+/-175	2765-3167	100	2679-3403	95
		Y	N	1859	2415+/-85	2350-2505	65	2325-2738	100
		Y	N	1859	2340+/-80	2305-2490	80	2289-2545	64
		Y	N	1859	1705+/-70	1545-1701	100	1516-1815	93
		Y	N	1859	1485+/-70	1304-1415	89	1292-1527	100
		Y	N	1859	1315+/-135	1071-1339	100	956-1422	96
		Y	N	1859	1075+/-135	905-1176	93	740-169	100
		Y	N	1859	935+/-140	724-963	92	656-1175	100
		Y	N	1859	880+/-180	663-966	96	656-1175	100
5LR.99	CO	Y	Y	2100	9700+/-250	10652-11398	98	10376-11841	98
BPG	CO	Y	Y	3587	210+/-60	139-222	0.53	58-325	79
SPIP1	CO	Y	Y	3661	2280+/-30	2307-2347	0.82	2301-2351	63
HCIP	CO	Y	Y	3466	2090+/-45	2002-2116	1	1944-2155	97
LLIP1	CO	Y	Y	3621	680+/-15	653-669	1	648-672	80
LLIP2	CO	Y	Y	3621	1095+/-15	966-989	53	960-1011	61
RMIP	CO	Y	Y	3560	2255+/-15	2307-2332	61	2179-2241	52
JPIP	CO	Y	Y	3844	340+/-40	346-396	44	308-488	100
IPG	CO	Y	Y	3639	3270+/-15	3457-3484	52	3453-3514	64
EN1010	CO	Y	Y	1829	200+/-20	150-173	49	146-189	49
SPNA1	CO	Y	Y	1829	130+/-25	68-118	40	57-150	46
RMOS1	CO	Y	Y	1829	3375+/-35	3575-3642	89	3556-3701	97
MTA1	CO	Y	Y	3048	2240+/-30	2179-2242	70	2154-2272	74

APPENDIX D

BONE COLLAGEN EXTRACTION LABORATORY PROCEDURES

LAB PROTOCOL FOR BONE COLLAGEN EXTRACTION (STAFFORD Personal Communication, 2013)

Initial Steps:
Muffle Furnace: Heat glassware to remove contaminants
Mix chemicals:

- Make 0.5 M solution of HCL (Total needed ~ 4 L of solution)
- Make KOH solution (1% stock solution for further dilution)(Total needed ~100 mls of 1 % solution)
- pH2 H20 (0.05 M HCL/deionized H20) for sample rinsing (Total needed – at least 5000 mls of 0.05 M for many rinses)

Equipment:
Student provided Equipment:
20 ml glass test tubes and screw lids
Scintillation vials and lids
Glass filter paper
Syringes
Teflon syringe filters
~40 bison bone samples

Equipment to use in lab facility:
Hood space
Disposable Pipettes
Muffle Furnace
Heat Block
Freeze Dryer
Refrigeration at 4 degrees C
Regular Freezer
Liquid Nitrogen

Ingredients (Solutions to make in lab):
0.5 M HCl solution
KOH – 1% stock solution – make

How to MAKE (10g/1000ml deionized H20) or (*1g/100 ml deionized H20*)
THEN per sample will add 1 ml of 1% KOH into 10 ml deionized H20 (in test tubes)
pH2 water (0.05 HCl solution)

COLLAGEN EXTRACTION STEPS:

STEP 1. HCL Decalcification (0.5 M) solution (ACID) (Gets rid of apatite, calcium)
A. In labeled test tubes - add 1 g samples in small 4-5 mm pieces (easier decanting and better observations of change in quality and pseudomorphs than grinding of samples into powder)

B. Add 10-15 ml of HCl (0.5 M) to test tube or fill the whole thing. It will bubble from geological carbonate and from the apatite. Put in test tube rack and lids cracked a bit. Not tight lids so it can degas.

C. Store at 4 degrees C in fridge, upright. Watch every few hours, tilt and roll test tubes now and then. After 24 hours, decant, recap and *store on side* in fridge, tilting now and then.

D. Repeat decanting and changing of solution as needed.

E. Process takes 1- 4 days until bone is decalcified.
Notes on changes: Will see at the bottom the calcium phosphate dissolving out. May take another day or two or three. Suggestion, change solution each morning, let sit upright for a few hours and look for a density gradient after decant; if I don't see it, then go through process again.
When is it done? Decant and look for a density gradient. When present, decalcification step is done.
Process takes 1-4 days until decalcified, depending on the sample.

F. Wash ALOT in Ph2 water. This helps with reduction of white mucous like debris in bottom. Store in fridge until ready for STEP 2. Ideally, these steps should be done close together.

STEP 2, KOH soak to remove humates (BASE)

Need *maximum* of 0.1% KOH. Any stronger is damaging to the collagen.
Make stock solution of 10 g KOH pellets in 1000 ml deionized H20. This will give a 1% solution. (To make solution 0.1% - **add 1 ml of 1% solution per 10 mls of deionized water in sample test tube. Or just a few drops of 1 % solution to 10 mls of deionized water and if a lot of color is coming out of sample, probably okay. If not, then add a bit more.)**

A. Take my test tube with sample and add no more than 1 ml of 1% solution of KOH and add 10 mls of deionized water. Cap tightly and put on sides in fridge.

B. Store at 4 degrees C for approximately 24 hours, maybe less. Agitate it now and then. Sample may turn white in time, which is fine. Only change out if the solution or bone is dark brown. At an hour or two in, observe, decant, wash with pH2 H20, and add new KOH. Can watch the colors stream out of collagen. If no colors coming out at all, nothing was in there for humates. If the solution starts to break the collagen up, then stop because it is damaging it.

NOTE: Decant CAREFULLY as the KOH solution is slippery. If they float, decant with pipette instead of pouring out. The frags will not adhere, so they could slip right out when decanting. WAY SLIPPERY!

C. Rinse carefully in pH2 H20 again **well.**

(Good samples should look similar and be similar sized to original fragment after HCl and KOH treatments. Variations and changes after that should be noted and may reflect collagen quality and thus eventually the quality of the final isotopes numbers)

D. FREEZE in regular freezer to store until freeze drying. Tap the tubes to make sure they are separate before freezing. They will then freeze in individual fragments.
Put on lid with hole and filter and put on side in regular freezer prior to freeze drying. Filter prevents dust from being pulled out and mixed into other samples under vacuum.

STEP 3. First FREEZE DRY
When ready to freeze dry, pull tubes out of freezer and immediately freeze dry. If collagen gets put in freeze dryer, wet, not frozen, then the collagen is getting aerated (boiled) and broken up. This is damaging to original structure. By regular freezing first, it only freezes the water molecules off frozen surface. The water molecules are sublimating.
So drying it while it is frozen is the best for a protein.
Can't overdo it. Maybe plan on putting in freeze dryer overnight or all day. Won't hurt.

STEP 4. GELATINIZATION
After 1st freeze drying:
A. Use 10 to 50 mg collagen, archive the rest for future use.

B. Just cover with ph2 h20 (0.05M HCL), soak for 5 min, then decant.

C. Do the soak again to be sure that all the calcium (CaCl2) is gone. Test- Add 1-2 ml of pH2 H20. Soak for 2-3 hours. Look at solution, is it clear or cloudy? Clear is good, cloudy is bad and may indicate presence of preservative. Can't do much with it maybe, still has contaminants. May clear up when filtering.

D. Add ph2 H20 again just to cover, (2-3 ml). Tighten the lid down, hard seal lid, not filtered lid.

E. Heat at 90-100 degrees C on **heat block** until dissolved. (*Should take from 15 minutes - 2 hours*). Will boil, and don't want it to boil over, thus the lids sealed. When the collagen dissolves, it's ready to filter. It varies in the amount of time.
OBSERVE, will be a hot liquid that looks like jello, smells like bouillon. Should be a clear solution, slightly yellowish. Any insolubable contaminants will still be present.

F. Let gelatin cool in test tube rack.

G. Pipette gelatin into filter assembly (see filter assembly notes below). Let drip through into scintillation vial or push through slowly with plunger attached to syringe.

H. Wash out test tube with 1 ml ph2 H20, pipette this into filter assembly.

I. Repeat again, and maybe once more watch for frothing. When frothing is done, then this step is done.

J. Rinse syringe with 1 ml ph2. Less liquid the better! (remember the freeze drying). Should have no more than 5-7 mls of liquid.

K. **Shell freeze with liquid nitrogen**, start to freeze and rotate vial so it doesn't crack and the gel will make a parabola shape. When it gets cold and bubbles, slowly rotate in a parabala shape in bottom of vial. This will prevent it from cracking and less surface area to freeze.

L. Put samples in regular freezer with filtered lid until ready to freeze dry.

NOTE: The test tube should ideally be totally empty in the end. There may be rootlets or sand in the bottom or in the filter. Make the observation but it is fine to have because it will be filtered out anyway.
For Filter Assembly Prep: Put the syringe and filter together. Pull off plunger. Fill syringe with ph2 water and run through filter a couple of times. Then put syringe/filter combo over clean scintillation vial. Pipette solution out of test tube, fill syringe with solution with plunger off. Add more ph2 h2o (1ml) with more to make sure we have all of the collagen out. And rinse filter again. Only use 1 cc first, then another wash out with water in tube and pipette into syringe, may do again if needed, then 1 ml to flush through syringe/filter again. Only want 3-4 mls in the vial when done. Each time, you'll see it froths. Less each time its washed out. When done frothing for each rinse, then we are done.

STEP 5. Second Freeze Dry
A. Gelatin Samples stored in freezer until ready to freeze dry.

B. When ready, freeze dry again, probably overnight (5 - 7 ml to freeze dry will take overnight for sure.) Try not to interrupt the freeze drying process.

Make observations. Ideally, the freeze dried gelatin looks silky in the end. It may not, which is probably okay. More concern is in quantity.

Ready to go to the IRMS!

Table D-1. Lab Sample Weights and Notes

Lab Samples	Beginning wt	Wt after trim/Clean	No. of fragments	Extra sample	Notes on Bone Conditions
5LR3953					
F27-13-136	2.76g	1.09g	10	1.67g	relatively clean sample to start, free of sediments, very minor amount of spongy bone to remove
F27-24-258	2.35g	1.04g	6	1.16g	Some clinging dirt to inside surface. Mild amount of spongy bone removed
E27-5-24	7.5g	1.10g	10	6.02g	Large sample, a bit crumbly when cutting
F28-3-215	3.87g	1.08g	9	2.69g	relatively clean sample to start, free of sediments, very minor amount of spongy bone to remove
F27-24-619	5.46g	1.28g	10	3.44g	Has a lot of spongy bone to remove, from near teeth, moderate sediments present. Bone is pretty crumbly, powdery, chalky.
F28-9-328	2.75g	1.07g	19	1.37g	Clean, a bit chalky, moderate amount of spongy to remove
F27-13-298	3.54g	1.15g	9	2.03g	Moderate spongy to remove, very hard bone, moderately dirty
F27-12-276	1.5g	1.12g	18	0	No sample left, will need more if need to run again. Very spongy, sort of chalky
48AB130					
D1981	1.56g	1.11g	13	0.3g	Tiny bit of sample left. Should collect a bit more before sending back to WY
D1917	2.24g	1.06g	9	0.9g	Tiny bit of sample left. Moderate spongy removed
D4417	1.8g	1.05g	15	0.48g	Dirty, rootlets, moderate spongy
D2667	6.93g	1.42g	12	5.29g	A lot of sediments
D4350	1.73g	1.04g	10	0.54g	Dirty, waxy, very little spongy bone
D4568	1.45g	1.21g	19	0	No sample left. Very dirty, moderate spongy
Wire Draw SPNA					
Skull	1.96g	1.25g	13		Sample left for AMS. Sample from skull, delicate, bleached
Skull Canyon RMOS					
Skull	6.08g	1.13g	12	1.79g	Red sediments, a bit chalky, delicate and weathered
Mount Audubon					
MTA1	7.31g	1.5g	26	5.5g	VERY calcined and dense
48CR304					
48	3.32g	1.24g	20	1.8g	Calcined, samples seem heavy
46	4.96g	1.3g	16	3.3g	Hard, clean, slightly calcined

Lab Samples	Beginning wt	Wt after trim/Clean	No. of fragments	Extra sample	Notes on Bone Conditions
45	4.11g	1.11g	19	9g	Very sedimented. No spongy present. A bit brittle ad chalky. May dissolve
49	2.05g	1.06g	21	0.77g	Very hard.
47	4.45g	1.23g	13	3.08g	Slightly calcined, hard but a bit brittle too
5LR1680					
6	1.58g	1.38g	13	0	No sample left. Take more if needed. Moderately spongy, moderately sedimented. Slightly crumbly
274	1.66g	1.24g	12	0	Chalky and spongy. Will use all of sample. Weathered and bleached
124	2.45g	1.11g	10	1.28g	sediments, moderate spongy, hardish
241	6.06g	1.34g	9	4.35g	Weathered and sedimented. Small amounts of spongy. Some chalkiness almost woody in texture
5LR100					
19	2.91g	1.11g	11	1.3g	Spongy, VERY hard, calcined maybe?
22	2.51g	1.36g	22	0.89g	Spongy. VERY hard calcined
18	2.41g	1.18g	16	0.86g	Spongy, dirty
20	1.5g	1.21g	16	0	Spongy, dirty. Used all of sample. Hard, didn’t shatter much.
32	1.6g	1.3g	15	0	Spongy, dirty. No Sample left
25	1.88g	1.33g	10	0	Hard, calcined spongy. NO Sample left
23	2.06g	1.08g	10	0.68g	Spongy, dirty, hard
28	3.23g	1.06g	14	1.98g	Very spongy, dirty, slightly calcined
Eagles Nest					
1010	1.54g	1.13g	17	0.33g	Extra for AMS not weighed.

APPENDIX E

RAW IRMS STABLE ISOTOPES DATA

Nitrogen (^{15}N) Stable Isotopes Raw Data

Identifier 1	Row	Identifier 2	Area All	Ampl 28	d 15N/14N	AT% 15N	offset	Offset Corrected delta 15N
AB130-D1917	41	85	189.058	5887	4.882	0.368255	-0.13614	5.02
AB130-D1981	42	86	195.641	6056	5.305	0.368409	-0.13614	5.44
AB130-D2667	44	88	165.809	5207	5.094	0.368332	-0.13614	5.23
AB130-D4350	46	90	189.527	5887	5.683	0.368547	-0.13614	5.82
AB130-D4417	45	89	207.194	6479	5.122	0.368342	-0.13614	5.26
AB130-D4568	43	87	193.555	6153	5.11	0.368338	-0.13614	5.25
CR304-45	26	70	191.696	5963	5.453	0.368463	-0.13614	5.59
CR304-46	27	71	159.364	4923	6.283	0.368766	-0.13614	6.42
CR304-48	29	73	172.546	5408	6.362	0.368795	-0.13614	6.50
CR304-49	30	74	181.165	5630	7.053	0.369047	-0.13614	7.19
CR305-47	28	72	221.472	6902	6.887	0.368987	-0.13614	7.02
EN1010	50	94	164.227	5116	7.923	0.369365	-0.13614	8.06
RMOS1	47	91	182.038	5696	5.202	0.368371	-0.13614	5.34
SPNA1	48	92	187.085	5842	5.222	0.368379	-0.13614	5.36
LR100-18	18	62	153.206	4800	5.387	0.368439	-0.13614	5.52
LR100-19	14	58	189.874	5888	6.47	0.368834	-0.13614	6.61
LR100-20	20	64	171.474	5331	5.665	0.368541	-0.13614	5.80
LR100-22	15	59	199.248	6154	6.508	0.368848	-0.13614	6.64
LR100-23	17	61	182.142	5626	5.89	0.368623	-0.13614	6.03
LR100-25	13	57	166.338	5042	7.051	0.369047	-0.13614	7.19
LR100-28	16	60	174.47	5468	6.648	0.368899	-0.13614	6.78
LR100-32	19	63	169.4	5312	6.158	0.368721	-0.13614	6.29
LR1680-124	23	67	169.423	5232	6.794	0.368953	-0.13614	6.93
LR1680-241	24	68	183.062	5773	6.824	0.368964	-0.13614	6.96
LR1680-274	25	69	188.601	5948	6.476	0.368837	-0.13614	6.61
LR1680-6	22	66	179.35	5637	6.085	0.368694	-0.13614	6.22

LR3953-136	32	76	145.614	4584	6.517	0.368852	-0.13614	6.65
LR3953-215	33	77	182.878	5778	6.123	0.368708	-0.13614	6.26
LR3953-24	39	83	132.482	4168	6.357	0.368793	-0.13614	6.49
LR3953-258	34	78	150.635	4632	6.205	0.368738	-0.13614	6.34
LR3953-276	35	79	155.165	4824	5.817	0.368596	-0.13614	5.95
LR3953-298	36	80	149.622	4663	4.853	0.368244	-0.13614	4.99
LR3953-328	37	81	167.645	5292	5.618	0.368523	-0.13614	5.75
LR3953-619	38	82	79.979	2460	5.735	0.368566	-0.13614	5.87
MTA1	49	93	194.493	6175	5.766	0.368577	-0.13614	5.90

Carbon (^{13}C) Stable Isotopes Raw Data Results from Carlo Erba NA 1500 elemental analyzer (EcoCore 2013).

Row	Sample Name	Nitrogen TCD Area	pk ht	Carbon TCD Area	pk ht	Major Height	Delta 13C	offset	delta 13C	Offset corrected %C
82	LR100-25 0.131	8.50E-01	3.52E-02	4.61026	2.05E-01	3.79E-09	-11.34	-0.05	-11.29	42.40618
92	LR100-19 0.166	1.02301	4.40E-02	5.97234	2.71E-01	5.07E-09	-13.53	-0.05	-13.49	44.24617
102	LR100-22 0.127	7.76E-01	3.37E-02	4.54514	2.04E-01	3.77E-09	-14.14	-0.05	-14.09	43.06809
112	LR100-28 0.144	9.24E-01	4.04E-02	5.2891	2.38E-01	4.42E-09	-15.28	-0.05	-15.24	44.77185
122	LR100-23 0.138	8.83E-01	3.76E-02	5.07158	2.29E-01	4.24E-09	-15.64	-0.05	-15.59	44.64742
132	LR100-18 0.115	7.43E-01	3.04E-02	3.98501	1.79E-01	3.27E-09	-17.57	-0.05	-17.53	41.16248
142	LR100-32 0.131	8.22E-01	3.58E-02	4.67717	2.09E-01	3.84E-09	-13.66	-0.05	-13.62	43.07728
152	LR100-20 0.211	1.05867	4.72E-02	6.49433	2.97E-01	5.57E-09	-17.23	-0.05	-17.19	38.06026
162	LR1680-6 0.217	1.10571	4.88E-02	6.81153	3.10E-01	5.82E-09	-13.29	-0.05	-13.25	38.92852
172	LR1680-124 0.146	8.61E-01	3.68E-02	4.99707	2.29E-01	4.22E-09	-11.00	-0.05	-10.95	41.53044
182	LR1680-241 0.155	9.73E-01	4.11E-02	5.55097	2.50E-01	4.63E-09	-11.81	-0.05	-11.76	43.81433
192	LR1680-274 0.150	9.18E-01	3.79E-02	5.1762	2.34E-01	4.32E-09	-13.72	-0.05	-13.68	41.99204
212	CR304-45 0.136	9.01E-01	3.75E-02	4.97605	2.26E-01	4.17E-09	-18.61	-0.05	-18.56	44.38107
222	CR304-46 0.142	8.50E-01	3.51E-02	4.71816	2.12E-01	3.89E-09	-14.95	-0.05	-14.91	40.11958
232	CR304-47 0.145	9.19E-01	3.85E-02	4.95573	2.26E-01	4.16E-09	-17.38	-0.05	-17.34	41.44226
242	CR304-48 0.189	1.11143	4.90E-02	6.71685	3.06E-01	5.71E-09	-16.13	-0.05	-16.09	44.0375

252	CR304-49 0.130	8.84E-01	3.63E-02	4.76087	2.15E-01	3.95E-09	-14.48	-0.05	-14.43	44.2546
262	LR3953-136 0.188	9.56E-01	3.95E-02	5.3224	2.43E-01	4.48E-09	-10.25	-0.05	-10.21	34.52606
272	LR3953-215 0.113	7.46E-01	3.18E-02	4.05054	1.79E-01	3.26E-09	-11.56	-0.05	-11.51	42.65297
282	LR3953-258 0.179	1.00569	4.25E-02	5.95914	2.69E-01	4.98E-09	-7.80	-0.05	-7.76	40.93587
292	LR3953-276 0.124	7.23E-01	2.94E-02	3.79937	1.68E-01	3.04E-09	-9.20	-0.05	-9.15	36.20782
302	LR3953-298 0.164	9.38E-01	4.02E-02	5.3459	2.44E-01	4.49E-09	-11.38	-0.05	-11.33	39.76693
312	LR3953-328 0.104	7.60E-01	2.96E-02	3.82928	1.70E-01	3.08E-09	-10.55	-0.05	-10.50	43.54874
322	LR3953-619 0.126	5.36E-01	1.91E-02	2.11709	8.90E-02	1.53E-09	-10.09	-0.05	-10.05	18.09047
332	LR3953-24 0.172	9.21E-01	3.93E-02	5.30729	2.43E-01	4.48E-09	-10.46	-0.05	-10.41	37.62236
352	AB130-D1917 0.150	9.34E-01	3.94E-02	5.36619	2.42E-01	4.48E-09	-17.52	-0.05	-17.48	43.65624
362	AB130-D1981 0.157	1.02187	4.37E-02	5.85097	2.64E-01	4.91E-09	-17.66	-0.05	-17.61	45.76685
372	AB130-D4568 0.116	7.66E-01	3.16E-02	4.00507	1.79E-01	3.26E-09	-14.88	-0.05	-14.83	41.03484
382	AB130-D2667 0.134	8.39E-01	3.59E-02	4.76484	2.16E-01	3.98E-09	-16.29	-0.05	-16.25	42.97249
392	AB130-D4417 0.147	9.97E-01	4.28E-02	5.87102	2.65E-01	4.94E-09	-16.13	-0.05	-16.08	49.05945
402	AB130-D4350 0.134	8.42E-01	3.58E-02	4.68767	2.12E-01	3.90E-09	-16.48	-0.05	-16.43	42.21582
412	RMOS1 0.152	9.19E-01	3.70E-02	5.08474	2.30E-01	4.25E-09	-13.37	-0.05	-13.33	40.64892
422	SPNA1 0.113	7.55E-01	3.11E-02	3.88615	1.73E-01	3.14E-09	-17.92	-0.05	-17.87	40.74152
432	MTA1 0.111	7.00E-01	2.85E-02	3.69398	1.65E-01	3.00E-09	-16.58	-0.05	-16.53	39.20087
442	EN1010 0.113	6.95E-01	2.77E-02	3.86334	1.75E-01	3.18E-09	-11.81	-0.05	-11.77	40.47629

Concentration Calibration

datalogger		Nitrogen		Carbon			
row	Sample Name	TCD Area	pk ht	TCD Area	pk ht	Major Height	Delta 13C
32	sid 0.61	2.05E-01	1.03E-02	1.62806	6.45E-02	1.08E-09	-21.04
42	sid 1.06	3.14E-01	1.20E-02	2.46418	1.05E-01	1.86E-09	-20.77
52	sid 1.41	3.20E-01	1.31E-02	3.1208	1.36E-01	2.47E-09	-20.29
62	sid 1.83	4.12E-01	1.47E-02	3.9432	1.76E-01	3.23E-09	-20.23
72	sid 2.49	4.60E-01	1.66E-02	5.33645	2.43E-01	4.53E-09	-20.01

Sample	Sample ID	Sample Amount	Nitrogen	Carbon
		Mg	Weight	Weight
			[%]	[%]
LR100-25 .499	57	0.499	14.82	41.05
LR100-19 .525	58	0.525	16.06	44.32
LR-100-22 .565	59	0.565	15.69	43.58
LR100-28 .511	60	0.511	15.15	42.23
LR100-23 .508	61	0.508	15.9	44.21
LR100-18 .456	62	0.456	14.96	41.74
LR100-32 .503	63	0.503	14.93	41.74
LR100-20 .544	64	0.544	14.04	39.37
LR1680-6 .569	66	0.569	13.9	39.27
LR1680-124 .496	67	0.496	15.18	41.75
LR1680-241 .545	68	0.545	14.77	42.24
LR1680-274 .546	69	0.546	15.29	42.8
CR304-45 .548	70	0.548	15.53	43.12
CR304-46 .485	71	0.485	14.56	40.21
CR304-47 .620	72	0.62	15.6	43.9
CR304-48 .520	73	0.52	14.72	41.2
CR304-49 .496	74	0.496	16.15	44.74
LR3953-136 .534	76	0.534	12.1	34.38
LR3953-215 .531	77	0.531	15.15	42.02
LR3953-258 .478	78	0.478	14.09	38.36
LR3953-276 .560	79	0.56	12.35	34.15
LR3953-298 .463	80	0.463	14.22	39.28
LR3953-328 .492	81	0.492	15.07	42.29
LR3953-619 .558	82	0.558	6.52	16.6
LR3953-24 .524	83	0.524	11.31	30.59
AB130-D1917 .538	85	0.538	15.5	43.44
AB130-D1981 .541	86	0.541	15.86	44.62
AB130-D4568 .549	87	0.549	15.57	43.66
AB130-D2667 .504	88	0.504	14.59	40.84
AB130-D4417 .593	89	0.593	15.56	44.07
AB130-D4350 .564	90	0.564	14.8	41.45
RMOS1 .565	91	0.565	14.34	40.08
SPNA1 .544	92	0.544	15.24	41.78
MTA1 .574	93	0.574	14.77	41.85
EN1010 .498	94	0.498	14.59	41.56