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CLIMATE CHANGE AT THE PLEISTOCENE-HOLOCENE BOUNDARY IN THE PACIFIC NORTHWEST: A COMPARISON OF PROXY DATASETS AND THE ARCHAEOLOGICAL RECORD

A Thesis

Presented To

The Departments of Anthropology and Geography, History

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Requirements for the Degree

Master of Arts

By

Tiffany J. Fulkerson

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Abstract

The relationship between climate change at the Pleistocene-Holocene Boundary (ca. 12,600-10,200 cal B.P.) and cultural responses to attendant shifts in the environment remains a vexing issue for archaeologists. This study compiles and analyzes glacial, palynological, faunal, and stratigraphic/geomorphological proxy datasets for climate change in the Pacific Northwest of North America and compares them to the coeval archaeological record. The primary purpose of this exercise is to consider the potential ways in which climate change at the Pleistocene-Holocene Boundary affected cultural development for Late Paleoindian-Early Archaic peoples in the Pacific Northwest. Results indicate that climatic and environmental change at this interval was rapid or abrupt, and of a magnitude that likely produced varying adaptational responses by peoples of different cultural traditions who appear across the region at this period. Transformations in tools and technology, shifts in dietary habits, migration and regionalization, and trade intensification are all elements of Late Paleoindian-Early Archaic cultural responses to rapid climate change.

Acknowledgements

The completion of this research would not have been possible without the assistance and support of many people. First and foremost, I would like thank my advisor, Jerry R. Galm, for providing invaluable knowledge, experience, and inspiration throughout the entirety of my graduate career. I would like to extend my gratitude and thanks to members of my committee, Robert R. Sauders and Paul Victor, for offering me insight and feedback on this study. Special thanks go out to Stan Gough, Rebecca Stevens, Dana Komen, and the entire staff of Archaeological and Historical Services for granting me years of guidance, professional support, laboratory facilities, and valuable resources. Thanks are also due to my fellow colleague and former classmate, Jamie M. Litzkow, for editing this research and providing years of advice and novel conversation. I would also like to thank Stephen Westleigh for offering understanding and support in the completion of this study. Finally, I am forever indebted to my parents, Rosa and Steve Jasso, for bestowing on me a lifetime of encouragement, love, patience, and limitless guidance.

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Chapter 1

Introduction

Statement of Problem

Climate change at the Pleistocene-Holocene Boundary (ca. 12,600-10,200 cal B.P.) is considered one of the most significant episodes of paleoclimatic change in the last 20,000 years. It is the time interval when humans begin specific adaptations to new territories and when glacial conditions associated with the Younger Dryas cold reversal transition to a climate regime that, by all indicators, was warmer and drier than today. Significant shifts in the morphology, density, diversity, and distribution of plant and animal communities are associated with this period. Terminal Pleistocene megafauna, including mammoths, mastodons, and ancient bison, become extinct at this interval. High resolution paleoenvironmental proxy records suggest that the shift in climate regimes may have occurred abruptly or rapidly, possibly taking place in a matter of years to decades (Alley 2000; Alley et al. 2003; Penn State 2006). Ecological responses to climate change varied in time, magnitude, and duration based on a multitude of factors.

Human responses to climate change have long concerned archaeologists and paleoecologists (Graf and Bigelow 2011). This is particularly true for the Pleistocene-Holocene Boundary, when significant changes in the material culture of Late Paleoindian peoples occur coevally with a significant shift in climate regimes and associated changes in the environment. Many of the proxy datasets that have been used to interpret the different ecologies encountered by human populations during this period have not been compiled in a single publication for the Pacific Northwest region. In order to understand climate change at the Pleistocene-Holocene Boundary in the Pacific Northwest and to address questions about the relationship between humans and climate change, a comprehensive review of paleoclimatic/paleoenvironmental proxy datasets from primary sources is necessary.

This study addresses the issues stated above by examining datasets generated from four of the most widely reported proxy indicators for climate change at the terminal Pleistocene and Early Holocene in the Pacific Northwest: glacial features, pollen, fauna, and stratigraphy/geomorphology. Proxy datasets are analyzed and compared with one another for the purpose of better understanding the conditions encountered by early human inhabitants of the region. In the concluding chapter, the results are compared with the archaeological record in order to consider the possible responses of Late Paleondian-Early Archaic peoples to major shifts in the environment and attendant resources as a result of climate change.

Three questions framed around the data generated in Chapters 3-6 are addressed in the conclusion: 1) What are the characteristics of climate change at the terminal Pleistocene in the Pacific Northwest?; 2) What is the nature of paleoenvironmental change at the Pleistocene-Holocene Boundary?; and 3) What is the relationship between regionalization of Late Paleoindian-Early Archaic populations and climate change? These questions focus on the potential ways in which climate change and associated changes in ecologies influenced cultural development across the region.

The emerging pattern suggests that as the cool-moist/cool-dry conditions of the Younger Dryas period abruptly or rapidly shifted to the warm-dry Early Holocene, major changes in the landscape occurred in all physiographic regions of the Pacific Northwest. Across the area, the base levels of major rivers and lakes dropped, the frequency and severity of fires increased, previously habitable environments became desiccated, and the availability of certain animals and plant resources was significantly reduced. These changes were of a magnitude that likely produced varying adaptational responses from humans inhabiting the region.

The archaeological record shows distinct changes in the tools, technology, settlement, and subsistence patterns of Late Paleoindian-Early Archaic peoples at the Pleistocene-Holocene Boundary. Characterized by large and rigorously defined fluted points and a spear weapons system, the Paleoindian-Late Paleoindian Clovis tradition is replaced by smaller projectile points presumably used in atlatl/thrusting weapons systems, more expedient and diversified technologies, and generalized subsistence strategies (i.e., an Early Archaic lifestyle). Emphasizing expedient technology and a more generalist subsistence approach, the Windust tradition quickly came to dominate the archaeological record by the Early Holocene. Windust peoples appear to have been able to quickly and successfully adapt to ecological changes associated with climate change.

The contemporary presence of Windust sites, the Haskett site (10PR37), and the Haskett-like tradition at the Sentinel Gap site (45KT1362) suggests that groups of people with different cultural affiliations began moving into the Pacific Northwest at the Pleistocene-Holocene Boundary. Projectile point/biface characteristics and *Olivella* and obsidian trade goods argue for a south-to-north and east-to-west migration of peoples into the Pacific Northwest. While direct lines of evidence cannot be drawn, there is enough paleoclimatic and archaeological data to argue that climate and environmental change at the Pleistocene-Holocene Boundary was significant enough to create pressures on Late Paleoindian-Early Archaic peoples to change the way they utilized and conceptualized their environment. Adaptational responses were manifested in the form of migration, range expansion, shifts in dietary habits and the tools used to obtain subsistence resources, and trade intensification. Climate change at the Pleistocene-Holocene Boundary was of a magnitude that arguably has not since been paralleled, and people inhabiting the region at this interval should be understood within the context of rapidly changing ecologies and transformations in human lifeways.

Methodology

Paleoclimates of the terminal Pleistocene and Early Holocene are interpreted from proxy indicators for climate, which act as indirect measurements of prevailing weather patterns in the absence of instrumental records. Glacial features, pollen, fauna, and stratigraphy/geomorphology are the four proxy types that are used in this study because they are the most widely reported sources for paleoclimate in the Pacific Northwest at the Pleistocene-Holocene Boundary. Further, researchers have determined that these are among the most effective indicators for assessing past climate within defined periods of time (see Gorham et al. 2001 for justifications and limitations). By using multiple proxies, it is possible to gain a much more effective resolution of local and regional conditions. Background information on climates and environments at and around the Late Pleistocene and Early Holocene is provided in Chapter 2. Proxy indicators are analyzed individually by chapter (Chapters 3-6) and discussed by physiographic regions and sub-regions (Figure 1.1).

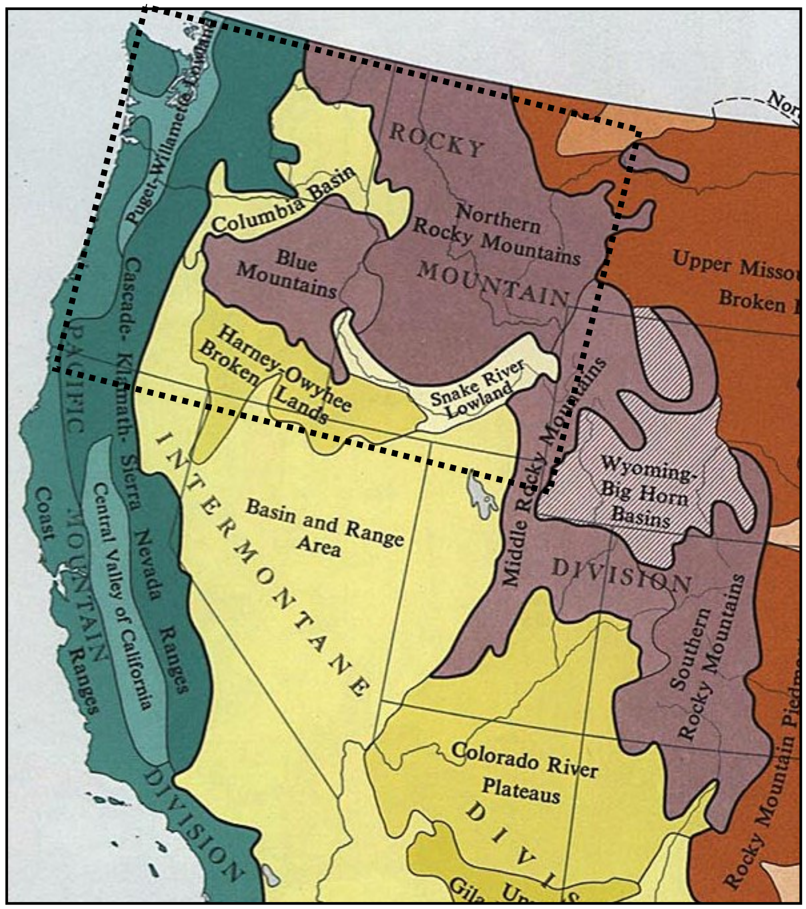

Figure 1.1. *Physiographic regions of the Pacific Northwest (adapted from Hammond 1970 [1965]).*

Data generated from a single proxy type and site is referred to as a "proxy dataset." Proxy datasets are presented as they were interpreted by the original authors and come entirely from primary sources. Secondary sources from qualified authorities are used to assist in the interpretation and summarization of data. In the final chapter (Chapter 7), the results of the preceding chapters are used to assess how climatic and environmental change may have influenced cultural development during the Late Paleoindian to Early Archaic transition.

Dates are presented in calibrated radiocarbon years before present (cal B.P.). In instances where primary and secondary sources provide dates in uncalibrated radiocarbon years before present (rcy ^{14}C) or thousands of years ago (kya), dates were calibrated using the INTCAL09 calibration curve (Reimer et al. 2009). Despite statistical uncertainties that are introduced when calibrating radiocarbon dates (Dehling and van der Plicht 1993), calibrated dates more accurately reflect the actual time of an occurrence or period, and there is a need for consistency in the reporting of radiocarbon dates.

Chapter 2

Climatic and Environmental Background

Introduction

The climatic history of the Pacific Northwest is inferred from a wide variety of biological, geological, physical, and chemical proxy records. These indirect measurements of climate allow researchers to interpret past conditions and document discontinuities and changes in long term prevailing weather conditions. Proxy data taken from an individual location offers evidence for localized paleoclimate. Multiple proxy datasets taken from sites across a large geographic area, however, can provide strong evidence for broad-scale paleoclimatic trends and shifts in regimes that occur on regional, hemispheric, and global scales.

The preponderance of evidence from published primary sources suggests that in the Pacific Northwest, there were significant biotic, atmospheric, geologic, and hydrospheric responses to episodes of Late Quaternary climate change. These changes appear to have occurred rapidly and were of a magnitude that likely produced varying responses from humans inhabiting the region. This chapter provides a general overview of climate change and associated changes in the environment at and around the terminal Pleistocene and Early Holocene. It specifically focuses on the boundary between the two epochs, which is variously referred to as the Pleistocene-Holocene Boundary (PHB), Late Pleistocene-Early Holocene transition, terminal Pleistocene to earliest Holocene transition, and other variations of the above. Accordingly, the information presented in this chapter will provide a context for understanding the individual proxy indicators for climate discussed in the ensuing chapters. It will also provide a framework for the questions outlined in Chapter 1 and discussed in Chapter 7 with regard to the human-climate dynamic.

Paleoclimates and Paleoenvironments of the Pleistocene and Holocene

Early-Late Pleistocene: *2.5 Million Years Ago-ca. 11,400 cal B.P.*

The PHB occurred at the end of a geologic epoch that began 2.5 million years ago. The Pleistocene was dominated by ice age conditions with repeated cycles of glacial advance and retreat. The most recent glacial event in North America, known as the Wisconsin Glacial Episode, occurred ca. 80,000-10,000 years ago (USGS 2003). Between ca. 22,000-16,000 cal B.P., the Cordilleran Ice Sheet, which occupied the northern portions of the Pacific Northwest, advanced into the Idaho Panhandle and created an ice dam that formed the massive Glacial Lake Missoula (IAFI 2011). Geological records indicate that periodic dam failures caused a series of catastrophic floods, known as the Missoula or Bretz Floods. These episodic floods significantly shaped the landscape of Washington, northern Oregon, northern Idaho, and eastern Montana (see Pardee 1910, 1942; Bretz 1927; Smyers and Breckenridge 2003).

The Pleistocene ice age included multiple glacial and interglacial cycles comprised of periods of cold stadials and warm interstadials. The last of the Late Pleistocene interstadials was the Bølling-Allerød warming period (ca. 17,600-13,200 cal B.P.). The Bølling-Allerød was interrupted by the last glacial advance recorded to date, the Younger Dryas.

Pleistocene-Holocene Boundary*: *ca. 12,600-10,200 cal B.P.

The Pleistocene-Holocene transition began during the Younger Dryas (also referred to as the Younger Dryas "chronozone") which occurred at ca. 13,200-11,400 cal B.P. The sudden climatic shift from Bølling-Allerød warming to Younger Dryas cooling is characterized by a rapid return to glacial conditions in latitudes of the Northern Hemisphere, dramatic increases in global ice volume, and a shift in the track of the jet stream over the northwestern United States (Whitlock and Bartlein 1997:58; Grigg and Whitlock 2002:2067; Brunelle et al. 2005; Porter and Swanson 2008). The shift in regimes is evidenced by increases in cold-adapted animal and pollen species, decreases in warm-adapted taxa, and geochemical changes in areas across North America and Europe (Gorham et al. 2001:102).

Coterminous with the last stages of the Younger Dryas are the extinction of many large-bodied animals across North America including mammoths and mastodons (elephants), ancient bison, camelids, horses, and giant ground sloths (Daugherty 1956). A reduction in body sizes of selected Early Holocene fauna including bison and elk appears to occur in concert with this extinction (Lyman 2004, 2010). Terminal Pleistocene megafauna have often been found stratigraphically above a black organic-rich layer of soil in the form of mollic, paleosols, aquolls, diatomites, or algal mats at sites across the United States. These soils are radiocarbon dated to ca. 12,725-11,220 cal B.P. and are interpreted as stratigraphic manifestations of the sudden shift from Bølling-Allerød warming to Younger Dryas cooling (Haynes 2008:6520).

In the Pacific Northwest, Younger Dryas conditions are characterized by cool-moist climatic conditions, although in some localized areas the climate was cool-dry

(Mack et al. 1976, 1978b, 1978d, 1983; Barnosky 1985a, 1985b; Whitlock 1992; Whitlock and Bartlein 1997; Grigg and Whitlock 1998; Whitlock et al. 2000; Mehringer 1996; Heinrichs et al. 2001). This period lasted until ca. 11,400 cal B.P. (Mehringer 1985; Chatters 1995), after which time it was replaced by significantly warmer and drier conditions.

Early Holocene: ca. 11,400-9000 cal B.P.

By ca. 11,400-9,000 cal B.P., paleoenvironmental proxy records from sites across the Pacific Northwest indicate that conditions were likely warmer and drier than today in most areas. Rapid wasting of glaciers, shrinking of vast lakes, significant lowering of river levels, desiccation of land, and final catastrophic floods are characteristics of this period.

Early Holocene vegetation is marked by an expanse of xeric plant communities and increases in sagebrush and grass vegetation in many of the physiographic regions/sub-regions of the Pacific Northwest (Hansen 1947; Mack et al. 1976, 1978a, 1978b, 1978c, 1978d, 1979; Nickmann 1979; Leopold et al. 1982; Mehringer 1985, 1996; Barnosky 1985a, 1985b; Sea and Whitlock 1995; Whitlock and Bartlein 1997; Brunelle and Whitlock 2003; Brunelle et al. 2005; Doerner and Carrara 1999; Heinrichs et al. 2001). Pollen data suggests that xeric, shrub-dominant steppe communities extended as far as the mountains surrounding the Columbia Basin during this interval (Mehringer 1985:174). According to Chatters (1995:381), this suggests that available moisture may have been up to 40 percent less than today. Warmer winters and hot summers with winter dominant precipitation are postulated for the Early Holocene period (Chatters

1991; Chatters and Hoover 1992). Warmer and drier conditions are also recorded in the isotopic record at ca. 10,200 cal B.P. (Davis and Muehlenbachs 2001:3000).

Aggradation and massive eolian deposition associated with a transition to drier, warmer conditions are registered across the Pacific Northwest during the Early Holocene. At the same time, flooding may have occurred as a result of decreased vegetation combined with winter warmth and an increase in rain-on-snow events (Chatters and Hoover 1992:52).

Early Holocene warming in the Pacific Northwest terminated at the beginning of a severe climatic disruption that occurred from ca. 9000-8000 cal B.P. Mayewski and others (2004) refer to the period as the "Glacial Aftermath" rapid climate change (RCC) interval. The climatic episode is characterized by cooling trends over much of the Northern Hemisphere, as indicated by evidence for major ice rafting, greater atmospheric circulation over the North Atlantic and Siberia, increases in polar northwesterly outbreaks over the Aegean Sea, and glacier advances in northwest North America. In lower latitudes there is evidence for widespread aridity, a change to more seasonal and torrential rainfall regimes, decreases in summer monsoons, and widespread drought.

Climate during the Glacial Aftermath RCC interval is characterized by a partial return to glacial conditions preceding an orbitally driven delay in deglaciation of the Northern Hemisphere. Mayewski and others (2004) postulate that bipolar ice sheet dynamics still had the potential for substantial effects on global climate. Climate at this interval is seen as having stronger ties to the glacial world than subsequent periods of Holocene RCC (Mayewski 2004:248-252).

Mid-Holocene Cold Reversal: ca. 8200 cal B.P.

By the beginning of the Mid-Holocene, an abrupt cold reversal at ca. 8200 cal B.P. that is believed to be associated with the Glacial Aftermath RCC interval is recorded in the Pacific Northwest (Alley et al. 1997; Mayewski et al. 2004). The 8200 cal B.P. event is reported to have lasted for less than 100 years and generated abrupt aridification and cooling in North America, the North Atlantic, Africa, and Asia (Alley et al. 1997; Street-Perrot and Perrot 1990; Barber et al. 1999; Weiss 2000:75; Kobashi et al. 2007; NOAA 2008). This period is marked by decreases in snow accumulation rates, lower levels of atmospheric methane, and increases in atmospheric dust and sea-salt loadings which suggest widespread dry conditions (Alley et al. 1997; Blunier et al. 1995). The event is prominently recorded in the Greenland Ice Sheet Project (GISP) and GISP2 data (Alley et al. 1997). Weiss (2000:76) reports that the magnitude of some of the measurable variables associated with the 8200 cal B.P. event is second only to the Younger Dryas. Within two decades of the event, temperatures cooled by ca. 3.3 degrees Celsius in Greenland (Alley et al. 1997; Kobashi et al. 2007). At the terminus of the climate anomaly, temperatures warmed and returned to their previous levels (NOAA 2008).

It is postulated that the forcing factor for the cold event was a perturbation of thermohaline circulation caused by freshwater inputs associated with the decay of the Laurentide Ice Sheet (von Grafenstein et al. 1998; Barber et al 1999). The phenomenon is commonly referred to as a “Heinrich Event” (Heinrich 1988). Although the spatial extent is still debated (NOAA 2008), there is evidence to suggest that climate change possibly associated with the 8200 cal B.P. event occurred in the Pacific Northwest. To date, little research has been conducted to document the event in the Pacific Northwest region. For this reason, evidence supporting the occurrence of the cold reversal is provided whenever possible (see Chapters 3-6), even though the climatic episode occurred at a later interval than the period of interest for this study.

Evidence for Rapid or Abrupt Climate Change at the Pleistocene-Holocene Boundary

There is growing evidence to suggest that climate change can occur much more rapidly or abruptly and with greater frequency than traditionally thought (for selected references see Crowley and North 1988; Manabe and Stouffer 1995; Alley 2000; Alley et al. 1997, 2003; CACC 2002; Mayewski et al. 2004; Broecker 2003). In addition to dramatic shifts in climate associated with glacial and interglacial cycles, it is now apparent that significant changes in climate can occur on millennial to less-than-decadal bases (Hurrell and van Loom 1997; Alley 2000; Alley et al. 1997, 2003; Mayewski et al. 2004; Steffensen et al. 2008).

Using globally distributed high-resolution proxy records, paleoclimatic studies show that there were numerous intervals of hemispheric to global rapid/abrupt climate change throughout the Late Quaternary. One such period occurred during the transition from the Late Pleistocene to Early Holocene (PHB) and may have happened in as little as 50 years or less (Alley 2000; Alley et al. 2003; Penn State 2006). Several periods of RCC have also been documented during the Holocene (ca. 11,400 cal B.P.-present) (Mayewski et al. 2004; Weninger et al. 2009).

Records of Late Quaternary rapid/abrupt climate change indicate that landscapes at the PHB were highly dynamic and unstable. The resulting ecosystem variability undoubtedly had some impact on human access to resources (Newby et al. 2005:141). While debate exists over the degree to which these conditions influenced Late Paleoindian-Early Archaic cultural development, the archaeological record shows a high degree of synchroneity between changes in material culture and climate at this interval. People inhabiting the Pacific Northwest during this dynamic period likely encountered rapidly occurring changes in climate and subsequent changes in the distribution of significant economic and subsistence resources.

Forcing Mechanisms for Climate Change

In the past several decades there has been significant attention on the forcing mechanisms for climate change. Forcing mechanisms are often discussed in terms of “internal forcing” and “external forcing” factors. Internal forcing factors are those that are intrinsic to the earth and its atmosphere, and external forcing factors are those external to earth that are influenced by orbital, galactic, and solar processes. These factors can operate independently or in concert with one another.

Internal forcing factors for Late Quaternary climate change are thought to include retreating ice sheets and changes in the insolation and associated positive feedbacks related to ice sheets (Mayewski et al. 1997:26, 345), shifts in thermohaline circulation possibly associated with deglacial warming and meltwater pulses (i.e., a Heinrich Event) (Stuiver et al. 1995; Alley et al. 1997; Bond et al. 1997; Barber et al. 1999:344), El Niño-Southern Oscillation changes associated with orbital controls (Clement et al. 1999), and increases in the concentration of carbon dioxide (Newby et al. 2005:141) possibly associated with volcanic activity. Volcanic activity has been posited for short and long term changes in climate at localized and regional extents (Bryson and Goodman 1980). It has been suggested that Late Quaternary eruptions of Mount Mazama had a major impact on flora, fauna, and human settlement in surrounding areas (Hansen 1942, 1947; Grayson 1979:427; Matz 1987, 1991).

External forcing factors for climate change are widely believed to be caused by cycles of earth-sun orbital parameters known as the Milankovitch Cycles (Milankovitch 1998 [1941]; Hays et al. 1976) and changes in insolation related both to the earth's orbital variations and to solar variability (Mayewski et al. 2004). It is has also been suggested that external climate change at the terminal Pleistocene was the result of extraterrestrial comet impact at ca. 12,700 cal B.P. (Firestone et al. 2007), although this theory is debated (see Haynes 2008; Holliday and Meltzer 2010).

Discussion

The dramatic changes that are observed in the paleoclimatic and paleoenvironmental record of the Pacific Northwest during the Late Pleistocene-Early Holocene were of a magnitude that has not since been paralleled. There is a vast accumulation of data documenting this variability, yet much of the published primary data used to discuss conditions at the terminal Pleistocene and Early Holocene have not been compiled to provide a more detailed understanding of climatic conditions in the Pacific Northwest. The following chapters (Chapters 3-6) address this problem by undertaking a comprehensive analysis of glacial, palynological, faunal, and stratigraphic/geomorphological proxy records for climate at and proximal to the PHB.

Chapter 3

Glaciological Proxy Datasets for Climate Change

Introduction

The glacial history of the Pacific Northwest provides evidence for glacial readvance during the Younger Dryas chronozone, at various times during the Early Holocene, and possibly during the 8200 cal B.P. event. The Younger Dryas and 8200 cal B.P. events are well documented in GISP and GISP2 ice core data (Alley et al. 1997, 2003; Alley 2000; Dansgaard et al. 1969; Johnsen et al. 1972), as are later periods of hemispheric to global abrupt/rapid climate change. The timing of Late Pleistocene and Early Holocene glaciation throughout the region is variable (Menounos et al. 2009; Hekkers 2010). However, glaciological and geological data obtained from sites across the region (Figure 3.1) shows that numerous glaciers during the Late Pleistocene and Early Holocene expanded due to region-wide changes in climate. These changes are generally marked by a sudden return to cool and/or cool-moist conditions.

Late Pleistocene-Younger Dryas Glaciation

The Younger Dryas occurred during a period of overall deglaciation of the Cordilleran Ice Sheet. The primary causal factors of Pleistocene ice retreat are high summer temperatures, strong insolation, clear skies, and limited precipitation in solid form. The rate of glacial recession is primarily an exponent of the summer quotient of

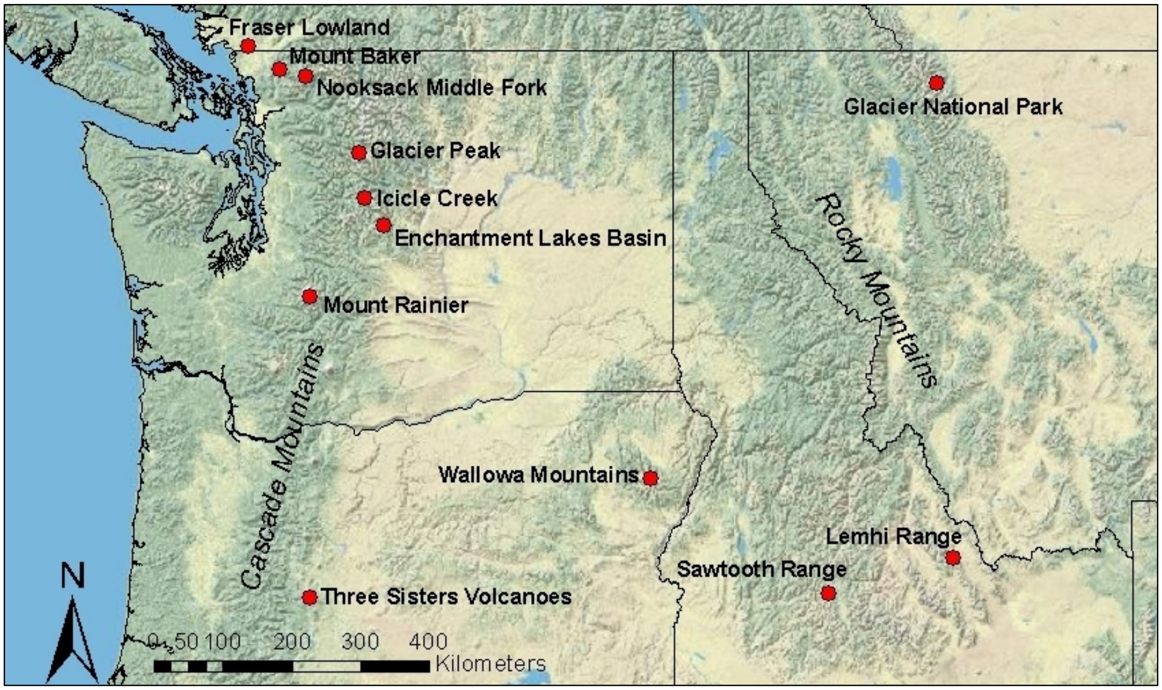

Figure 3.1. *Locations of glaciological sites/areas discussed in this study.*

heat (Antevs 1928:52-53). The Cordilleran Ice Sheet underwent extensive decay beginning at ca. 16,000 cal B.P. in the Pacific Northwest. During the last stages of deglaciation, between ca. 14,730-11,400 cal B.P., the ice sheet began to thin rapidly and retreat northward (Kovanen and Easterbrook 2002). The western periphery of the Cordilleran Ice Sheet began to retreat rapidly after ca. 16,000 cal B.P. due to warming climate and eustatic sea-level rise. Frontal retreat occurred at the same time or shortly thereafter in northernmost Washington, Idaho, and Montana (Menounos et al. 2009:2050). By ca. 14,000 cal B.P., many of the alpine glaciers of the Pacific Northwest were undergoing wastage and retreat.

Although deglaciation is the general trend for the Late Pleistocene, periods of stasis and readvances are known to have occurred and are well documented in the glacial record. During the Younger Dryas chronozone, ca. 13,200-11,400 cal B.P., many alpine areas in the Northern Hemisphere document glacial advances (Davis et al. 2009) associated with a rapid return to cool temperatures. The record for alpine and ice sheet glaciation is less clear in the Southern Hemisphere. Lacustrine sediments provide evidence for a dry Younger Dryas-age climatic event in northern Australia (De Deckker et al. 1991). Evidence for glacial advance and co-existing retreat is registered in the tropical Andes of South America (see Mahaney et al. 2008; Heine and Heine 1996) and New Zealand (see Ivy-Ochs et al. 1999; Denton and Hendy 1994; Kaplan et al. 2010). This suggests the possibility that the Younger Dryas had global effects on climate, but that environmental changes manifested differently across hemispheres and geographic regions.

Glacial readvances associated with the Younger Dryas cold reversal have been reported in western North America (Kovanen and Easterbrook 2002; Reasoner and Jodry 2000), western and eastern Canada (Menounos et al. 2009; Lakeman et al. 2008; Reasoner and Osborn 1994; Stea and Mott 1989), Alaska (Graf and Bigelow 2011); Europe (Grove 2004), European Alps and southern Alps of New Zealand (Ivy-Ochs et al. 1999; Denton and Hendy 1994), Scotland (Sissons, 1979; Ballantyne 2002), the Tibetan Plateau (Tschudi et al. 2003), and Japan (Aoki 2003).

Debate exists over the nature and extent of Younger Dryas glaciation in the Pacific Northwest as well as the timing and length of the cold stadial (see Muscheler et al. 2008). Nevertheless, evidence for Younger Dryas-age glacial advance comes from the Cascade Range of western Washington, Fraser Lowland of western Washington and lower British Columbia, and Northern Rocky Mountains of northwest Montana and central Idaho (Figure 2.1) (MacLeod et al. 2006; Thackray et al. 2004; Easterbrook et al. 2011; Kovanen and Easterbrook 2002; Kovanen and Slaymaker 2005; Waitt et al. 1982;

Waitt 1977; Bilderback 2004; Menounos et al. 2004; Page 1939; Porter 1978; Porter and Swanson 2008; Heine 1998; Hekkers 2010; Armstrong 1975). With the exception of Mount Rainier which appears to have undergone glacial retreat associated with a lack of available moisture (Heine 1998), evidence lends support to a region-wide response to Late Pleistocene, Younger Dryas cooling.

Cascade Range

Middle Fork of Nooksack River, northwestern Washington: Moraines and ice-contact deposits suggest that soon after ca. 13,840 cal B.P., the Nooksack Middle Fork alpine glacier in the North Cascades of Washington, retreated upvalley and built a moraine dating to ca. 12,600-12,470 cal B.P. The formation of the moraine is also evidenced by glacial outwash in the Nooksack North Fork which was dated to ca. 12,570-12,650 cal B.P. by charcoal deposits (Easterbrook et al. 2011:75). This period of moraine building reflects the terminus of Younger Dryas glaciation in the region (Kovanen and Easterbrook 2002; Kovanen and Slaymaker 2005).

Enchantment Lakes Basin, western Washington: In the upper Enchantment Lakes basin of the North Cascade Range, Waitt and others (1982) initially dated the Brisingamen moraine to the Early Holocene based on the position of the geological feature. The moraine underlies Mazama ash (ca. 7700 cal B.P.) and is upvalley from the late glacial Wisconsin Rat Creek Moraine, suggesting that it formed between ca. 15,530-7700 cal B.P. However, Bilderback (2004) later used dates from lake sediments to provided evidence that Brisingamen moraine building ended shortly before ca. 13,190 cal

B.P. This suggests a temporal correspondence with moraine building and the Younger Dryas event (Bilderback 2004; Menounos et al. 2004).

Icicle Creek Range, western Washington: Evidence for multiple Younger Dryas-age glacial advances in the Cascade Range near Leavenworth, Washington, comes from relative and cosmogenic isotope ^{10}Be dates of the Icicle Creek moraine system (Page 1939; Waitt 1977; Porter and Swanson 2008). Boulders from the Eight Mile Creek tributary of Icicle Creek are ^{10}Be dated to ca. 12,600 cal B.P. and 12,300 cal B.P. Moraines from the Rat Creek tributary are dated to ca. 11,300 cal B.P. and 11,900 cal B.P. (Porter and Swanson 2008; Easterbrook et al. 2011:76). Porter and Swanson (2008) place the mean age of the late glacial advance along the Icicle Creek glacial system to ca. 12,500 cal B.P. The dates show that the moraine age and relative extent of the advance is synchronous with the Younger Dryas chronozone. It is also in accord with the Cordilleran Ice Sheet advance in the Fraser Lowland of western Washington and southwest British Columbia, at ca. 12,860-12,030 cal B.P. (Porter 1978:40; Porter and Swanson 2008; Kovanen and Easterbrook 2002).

Mount Rainier, western Washington: Conflicting reports for glacial advance and recession during the Younger Dryas have been documented for Mount Rainier in western Washington. According to Heine (1998), the Younger Dryas climatic reversal did not cause glacial advance on Mount Rainer. However, the reversal may have affected the Mount Rainier area by causing cold, drier conditions. Heine reports that glaciers retreated on Mount Rainier likely as a result of a lack of available moisture. Alternatively, studies of the McNeeley II moraine at Mt. Rainier suggest that the moraine was built during the Younger Dryas, and the absence of sedimentation between ca. 12,885-11,400 cal B.P. is thought to indicate that ice occupied the basin until after ca. 11,400 cal B.P. (Easterbrook et al. 2011:76). Regional data indicates that Late Pleistocene-Early Holocene glacial retreat/advance at Mount Rainier was more synchronous with mountains to the south rather than those to the north (Hekkers 2010:7).

Fraser Lowland

In the Fraser Lowland of western Washington and British Columbia, morphological features of dated moraines provide evidence for multiple glacial readvances synchronous with Younger Dryas cooling (Kovanen and Easterbrook 2002). These advances are associated with oscillations of the remnants of the Cordilleran Ice Sheet and they indicate there were at least three periods of Younger Dryas glaciation in the region. Kovanen and Easterbrook date the advances to ca. 13,420-13,280 cal B.P., ca.12,860-12,030 cal B.P., and ca. 12,030-11,400 cal B.P. (Kovanen and Easterbrook 2002:208, 216). The earliest advance is synchronous with the Sumas readvance of the Cordilleran Ice Sheet in the Fraser Lowland of British Columbia. Armstrong (1975) reports that the Sumas readvance culminated between ca. 13,685-13,280 cal B.P.

Northern Rocky Mountains

Glacier National Park, Northwest Montana: Post glacial moraine deposition and tephra stratigraphy in Otokomi Lake of northwestern Montana offer support for a Younger Dryas-age glacial advance in the region. Lake sedimentary changes created by the onset of the Crowfoot moraine indicate that the emplacement date for the moraine is ca. 12,570 cal B.P. This is coeval with the Younger Dryas interval. The age estimate supports the argument that Crowfoot moraines identified from British Columbia to Colorado represent a regional response to Younger Dryas cooling in western North America (MacLeod et al. 2006:447, 457).

Sawtooth Range, Central Idaho: Thackray and others (2004) present dates on glacial-lacustrine sediments from three valleys in the southeastern Sawtooth Mountains of central Idaho, which cluster around 13,950 cal B.P. The sediments document extensive ice volume coterminous with the onset of the Younger Dryas. The synchronous advance of valley glaciers is thought to indicate a response to reinvigorated moisture transport occurring after the ice-sheet maximum. The responses provide evidence for strong sensitivity to moisture-delivery fluctuations (Thackray et al. 2004:225-227).

Cirque moraines located at multiple elevations in the Sawtooth Range record two Younger Dryas events in the region. ^{10}Be ages of three boulders from a moraine at Fourth Bench Lake and a boulder 100 m lower at Third Bench Lake indicate multiple phases of cirque moraine building between ca. 11,700-11,400 cal B.P. According to Easterbrook and others (2011), multiple successions of moraine building is evidence for multiple phases of Younger Dryas climatic events (Easterbrook et al. 2011:75).

Early Holocene-Mid-Holocene Glaciation

During the Early Holocene, most areas in the Northern Hemisphere experienced maximum glacier recession (Davis et al. 2009). By ca. 11,000 cal B.P. or soon thereafter, glacier cover in the Cordillera was no more extensive than at the end of the 20th century.

Evidence suggests that glaciers reached their minimum extent between ca. 11,000-7000 cal B.P. (Menounos et al. 2009:2049). Even though maximum glacial recession is the general trend for this period, episodes of climatically-induced advances of glaciers are documented in the Pacific Northwest and in many other areas of the Northern Hemisphere. Early Holocene rapid/abrupt climate change is marked by a partial return to glacial conditions after an orbitally driven delay in Northern Hemisphere deglaciation. There was at least one large pulse of glacier meltwater into the North Atlantic at this time (Barber et al. 1999). Freshwater input likely enhanced the production of sea ice and provided an additional feedback contributing to climate cooling (Mayewski et al. 2004:251).

Early Holocene glacial readvances in the Pacific Northwest have been documented in the Cascade Range of western Washington (Beget 1991, 1984; Waitt et al. 1982; Thomas et al. 2000; Menounos et al. 2004; Heine 1998) and central Oregon (Dethier 1980), Wallowa Mountains of northeastern Oregon (Licciardi et al. 2004; Kiver 1974), and Northern Rocky Mountains of central Idaho (Butler 1984, 1986) (Figure 2.1). Glacial advance associated with the early Mid-Holocene 8200 cal B.P. event is postulated for Mount Baker (Menounos et al. 2004), although evidence for a region-wide response to this period of RCC is presently lacking.

Cascade Range

Glacier Peak Vicinity, western Washington: Beget (1981, 1984) reports a period of Early Holocene glacial advance at ca. 9450-9300 cal B.P. in the North Cascade Range. This is based on the presence of moraines and glacial drift that were deposited in cirques near Glacier Peak, Washington. Charcoal collected from till deposits of the White Chuck advance are radiocarbon dated to the Early Holocene. Cooling and/or increased precipitation was sufficient enough to produce glacial advances comparable or equivalent to that of Little Ice Age conditions in the region (Beget 1981:409).

Mount Baker, western Washington: Radiocarbon dates of charred wood obtained below Mazama ash and above moraine till on Mount Baker, Washington, document an Early Holocene glacial advance between ca. 9450-8400 cal B.P. (Thomas et al. 2000:1045). Thomas and others (2000) argue that the advance ended by the time the 8200 cal B.P. event occurred, suggesting that the climatic episode could not be associated with glacial advance on Mount Baker at this interval (Thomas et al. 2000:1045). However, Menounos and others (2004) argue that an advance correlative with the event may have occurred on Mount Baker, but that the moraines were likely destroyed by subsequent Holocene advances (Menounos et al. 2004:1548). Menounos and others (2004) document glacial readvances in multiple locations throughout western Canada that are synchronous with the 8200 cal B.P. event.

Mount Rainier, western Washington: Radiocarbon dated organic sedimentation from cored lakes on Mount Rainier indicate that glaciers in the region expanded during the Early Holocene. Expansion occurred during the McNeeley 2 advance between ca. 10,900-9950 cal B.P. and at a later time between ca. 9450-8400 cal B.P. (Heine 1998:1143, 1146).

Three Sisters Volcanoes, central Oregon: At Three Sisters Wilderness in central Oregon, Dethier (1980) identified a pre-Mazama moraine which is suggested to date to the Early Holocene. Marcott (2005) later used Mazama tephra and geological weathering to place glaciation at the Three Sisters Volcanoes between ca. 12,000-10,000 cal B.P. This supports the assertion that a post Younger Dryas event occurred in the region (Marcott 2005:48).

Wallowa Mountains

Using ^{10}BE exposure ages for moraines in the Wallowa Mountains of northeast Oregon, Licciardi and others (2004) provide evidence for a minor glacial event at ca. 10,200 cal B.P. that formed after the Younger Dryas (Licciardi et al. 2004:83). Kiver (1974) identified an advance of the Glacier Lake moraine which began at ca. 10,200 cal B.P. and ended before the eruption of Mazama O tephra at ca. 7660 cal B.P.

Northern Rocky Mountains

Early Holocene periglacial conditions have been documented by varves and morphological features in sediments reported by Butler (1984, 1986:42) for the period of ca. 11,765-8370 cal B.P. in the Lemhi Range of central Idaho.

Discussion

Late Pleistocene glacial data suggests that following the Late Glacial Maximum and Bølling-Allerød warming, a period of glacial readvance associated with the Younger Dryas cold reversal occurred in the Rocky Mountains, Cascade Range, and Fraser Lowland areas of the Pacific Northwest. The return to glacial conditions began as early as ca. 14,000 cal B.P. and centered around 12,600-11,300 cal B.P. The readvance is synchronous with an episode of rapid cooling that is prominently recorded in GISP and GISP2 data and attributed to the Younger Dryas chronozone (Alley 2000). The response of alpine glaciers to the Younger Dryas was not uniform in all areas, however, as glacial retreat coeval with the Younger Dryas is documented at Mount Rainier in Washington. The retreat is attributed to a period of drier conditions and an associated lack of available moisture in the region (Heine 1998).

Glaciers again readvanced during the Early Holocene, but the timing of advance varied based on the geographic area. Evidence for Early Holocene glaciation indicates there were one or multiple periods of rapid cooling occurring during a general warming trend. In the North Cascade Range of Washington at the vicinity of Glacier Peak and Mount Baker, data suggests that an Early Holocene advance occurred between ca. 9450-8400 cal B.P. Further south at Mount Rainier, glacial readvance occurred between ca. 10,900-10,000 cal B.P. Glaciation occurred even earlier in the Cascade Range of central Oregon, where the Three Sisters Volcanoes document an Early Holocene advance between ca. 11,000-12,000 cal B.P. This suggests that Early Holocene glacial advance in the Cascade Range occurred earlier at lower latitudes. In the Northern Rocky Mountains at the Sawtooth Mountain range of central Idaho, post-Younger Dryas, Early Holocene periglacial conditions did not occur until ca. 8400 cal B.P. Evidence for a minor glacial event beginning by ca. 10,200 cal B.P. is reported at the Wallowa Mountains of northeast Oregon.

Glacial readvance associated with the early Mid-Holocene 8200 cal B.P. cooling event has been suggested at Mount Baker (Menounos et al. 2004). However, evidence for glacial response to the event is at present lacking for the Pacific Northwest of North America, and there is stronger data for a synchronous advance in western Canada (Menounos et al. 2004).

Glacial advance and retreat during the Late Pleistocene and Early Holocene undoubtedly had effects on plant and animal species inhabiting the Pacific Northwest. Palynological and faunal data suggest that glaciers, along with other agents of internal climate change, significantly influenced the composition and distribution of plant and animal species at the terminal Pleistocene.

Chapter 4

Palynological Proxy Datasets for Climate Change

Introduction

Pollen and plant macrofossil records have become one of the principal tools for reconstructing past climate change (Walker and Pellatt 2008:116). They document the vegetation and climatic history of an area with high centennial-to-millennial and annual-to-decadal temporal resolution (Gorham et al. 2001:102; Jiménez-Moreno et al. 2008, 2010). Pollen profiles from sites in the Pacific Northwest (Figure 4.1) show similarities

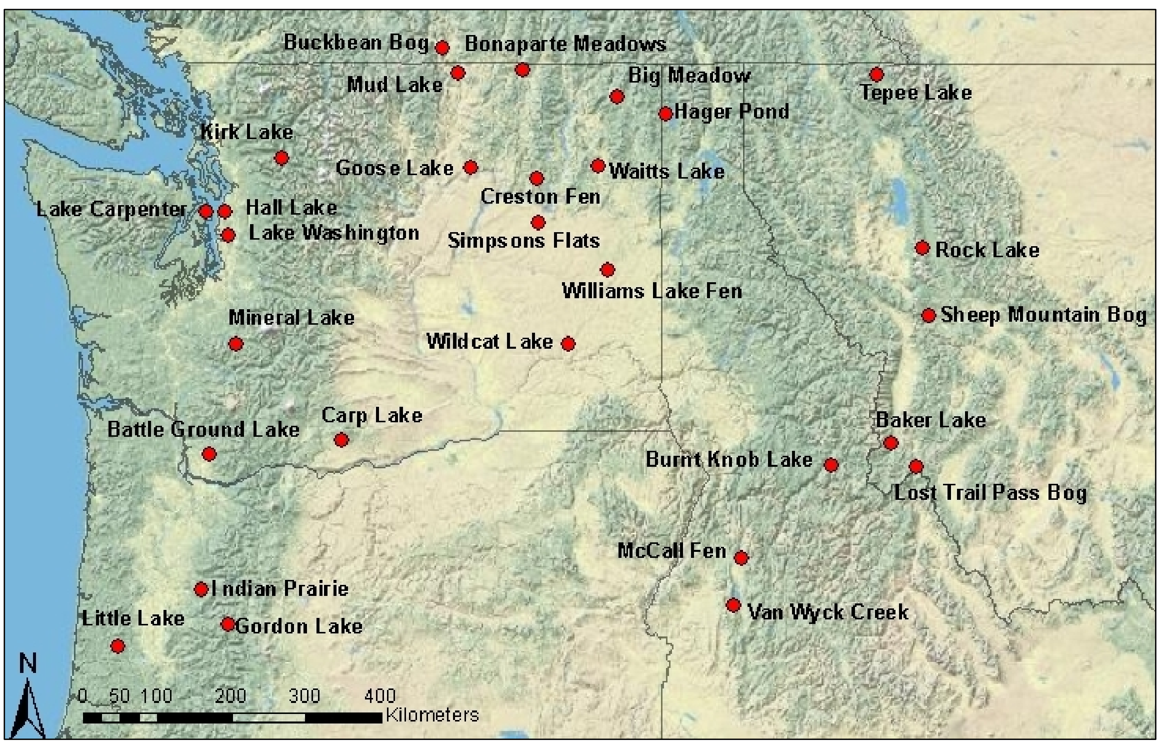

Figure 4.1. *Locations of palynological sites discussed in this study.*

in the direction and timing of vegetation change throughout the Late Quaternary. These similarities provide evidence for region-wide responses to variations in climate during the Late Pleistocene and Holocene (Grigg et al. 2001:19).

The palynological history of the PHB in the Pacific Northwest indicates a shift from generally cool-moist, but in some cases cool-dry, conditions during the terminal Pleistocene to warm-dry conditions beginning by the Early Holocene. The shift in climate regimes is registered in areas of the Puget Lowland, Cascade Range, Okanogan, Columbia Plateau, and Northern Rocky Mountains and river valleys (Table 4.1).

Pollen data acquired to date suggests that the transition from one climate state to another occurred abruptly throughout the region (Gorham et al. 2001; Heusser 2000; Jiménez-Moreno 2010). The relatively high degree of synchroneity between the timing and characteristics of pollen events is perhaps the strongest palynological evidence for rapid or abrupt climate change in the Pacific Northwest.

Pollen Record during the Late Pleistocene: Last Glacial

Pollen data suggests that the species and distribution of plant communities during the last glacial period were strongly influenced by ice sheet and glacier dynamics and large-scale climate controls. Pollen profiles from across northwestern North America indicate changes in forest and steppe communities that are consistent with variations in global ice volume, summer insolation, and the strength and position of the glacial anticyclone and jet stream (Whitlock and Bartlein 1997:58; Grigg and Whitlock 2002:2067; Brunelle et al. 2005; Porter and Swanson 2008).

Table 4.1. Late Pleistocene to Mid-Holocene Pollen Sequences from Sites in the Pacific Northwest.*

Age ^{14}C cal B.P.	**Mineral & Hall Lakes** Puget Lowland, WA 433 m & 104 m amsl (Tsukada et al. 1981)	**Lake Washington** Puget Lowland, WA 0 m amsl (Leopold et al. 1982)	**Kirk Lake** north Puget Lowland, WA 194 m amsl (Cwynar 1987)	**Lake Carpenter** central Puget Lowland, WA 8 m amsl (Anundsen et al. 1994)	Age ^{14}C B.P.
≤ 8000 cal B.P.	*Pseudotsuga menziesii - Thuja plicata - Alnus rubra* woodland with *Pteridium aquilinum* (increased precipitation)	alder, Douglas-fir, grass, Bracken fern, open woodland of Douglas-fir and alder or forest mosaic (warmer-drier than present)	*Alnus rubra - Pteridium* closed forest dominated by *Pseudotsuga, Alnus rubra,* and *Tsuga heterophylla,* increased charcoal accum. rates (warmer and potentially drier)	*Pseudotsuga, Alnus,* ferns, *Fraxinus, Castanopsis* (warm-dry)	≤ 7200 B.P.
9000 cal B.P.					8000 B.P.
10,000 cal B.P.	*Pseudotsuga menziesii - Alnus rubra* woodland with *Pteridium aquilinum,* frequent forest fires (warmer-drier)				8900 B.P.
11,000 cal B.P.					9500 B.P.
12,000 cal B.P.	*Pinus contorta - Picea engelmannii - Tsuga mertensiana,* pine-spruce taiga (cooler than present, moist)	increase in Douglas-fir (*Pseudotsuga*), temp. presence of *Abies*			10,200 B.P.
13,000 cal B.P.			*Picea - Alnus sinuata,* open woodland vegetation	*Abies,* decrease in *Pinus*	11,100 B.P.
14,000 cal B.P.	*Pinus contorta - Picea engelmannii,* parkland vegetation	pine, spruce, alder, Bracken fern (pine pollen overrepresented)	*Pinus - Populus,* open mixture of conifers and deciduous trees	*Pinus, Alnus, Populus,* open canopy woodland (cool)	12,200 B.P.
≥ 15,000 cal B.P.					≥ 12,600 BP

**Younger Dryas interval shaded in blue, transitional boundary from cool to warm conditions marked by double lines.*

Table 4.1. (cont.) Late Pleistocene to Mid-Holocene Pollen Sequences from Sites in the Pacific Northwest.*

Age ^{14}C cal B.P.	**Indian Prairie** west Cascade Range, OR 922 m amsl (Sea and Whitlock 1995)	**Gordon Lake** Tidbits Mountain, OR 1162 m amsl (Grigg and Whitlock 1998)	**Battle Ground Lake** southwest WA 154 m amsl (Barnosky 1985a; Walsh et al. 2008)	**Bonaparte Meadows** Okanagan Valley, WA 1021 m amsl (Mack et al 1979)	Age ^{14}C B.P.
≤ 8000 cal B.P.					≤ 7200 B.P.
9000 cal B.P.	forest of *Pseudotsuga, Abies, Quercus* (warmer-drier than present)	*Pseudotsuga, Alnus sinuata, Pinus, Dryopteris,* increase in *Pteridium, Quercus, Corylus,* montane temperate forest (warm-dry)	*Quercus, Pseudotsuga,* Poaceae dominant Savanna, dramatic increase in fires (warm-dry)	*Artemisia*, Gramineae, diploxylon pines, influx of non-arboreal pollen, steppe (warmer-drier than present)	8000 B.P.
10,000 cal B.P.					8900 B.P.
11,000 cal B.P.					9500 B.P.
12,000 cal B.P.	*Abies* dominant, closed montane forest (cooler-wetter)	*Pinus, Abies, A. sinuata, Tsuga mertensiana,* closed montane forest (cooler winters, drier summers)	*Pseudotsuga* and *Abies* dominated forest		10,200 B.P.
13,000 cal B.P.				haploxylon pine(s), *Artemisia*, Gramineae, Cyperaceae, open vegetation (cooler-moister than present)	11,100 B.P.
14,000 cal B.P.		*Abies, Pinus, A. sinuata, T. mertensiana, Dryopteris,* closed montane forest	open forest or parkland of *Pinus contorta* and *Picea* (cooler than present)		12,200 B.P.
≥ 15,000 cal B.P.	subalpine forest (cooler than present)	subalpine parkland			≥ 12,600 BP

**Younger Dryas interval shaded in blue, transitional boundary from cool to warm conditions marked by double lines.*

Table 4.1. (cont.) Late Pleistocene to Mid-Holocene Pollen Sequences from Sites in the Pacific Northwest.*

Age ^{14}C cal B.P.	**Mud Lake** Okanagan Valley, WA 655 m amsl (Mack et al. 1979)	**Buckbean Bog** Mount Kobau, British Columbia, Canada 1810 m amsl (Heinrichs et al. 2001)	**Carp Lake** south-central WA 755 m amsl (Barnosky 1985b; Whitlock and Bartlein 1997)	**Williams Lake Fen** eastern WA 635 m amsl (Mehringer 1996; Nickmann 1979)	Age ^{14}C B.P.
≤ 8000 cal B.P.		Poaceae, *Artemisia*, Cyperaceae, *Salix*, charcoal increase, moisture increase after 7840 cal BP	*Pinus ponderosa* forest and *Quercus* woodland (warmer-drier than present)		≤ 7200 B.P.
9000 cal B.P.	*Artemisia* and Gramineae, mostly diploxylon pines (warmer-drier than present)	Poaceae, *Artemisia*, Cyperaceae, increase in non-arboreal pollen, grassland (warm-dry)		grass dominant, slight increase in percentages of saltbush, sagebrush, and other composites (warm-dry)	8000 B.P.
10,000 cal B.P.					8900 B.P.
11,000 cal B.P.		grassland steppe (rapid warming)	steppe vegetation with Poaceae and *Chenopodium*-type (warmer-drier than present)		9500 B.P.
12,000 cal B.P.		*Pinus, Picea, Alnus, Artemisia*, Chenopodiinae, *Sarcobatus*, steppe (cool-dry)		largest conifer values, haplox. and diplox. pine peaks (brief cool period)	10,200 B.P.
13,000 cal B.P.	haploxylon pine(s), *Artemisia*, Cyperaceae, Gramineae, *Shepherdia canadensis* (cooler-moister than present)			increase in pine	11,100 B.P.
14,000 cal B.P.			cold steppe with *Artemisia*, *Polygonum bistortoides*-type, alpine/subalpine conditions (coldest-driest)	sagebrush dominant, high amounts of spruce and birch (cool)	12,200 B.P.
≥ 15,000 cal B.P.					≥ 12,600 BP

**Younger Dryas interval shaded in blue, transitional boundary from cool to warm conditions marked by double lines.*

Table 4.1. (cont.) Late Pleistocene to Mid-Holocene Pollen Sequences from Sites in the Pacific Northwest.*

Age ^{14}C cal B.P.	**Goose Lake** north-central WA 373 m amsl (Nickmann and Leopold 1985)	**Wildcat Lake** southeast WA 342 m amsl (Mehringer 1996; Blinman 1978)	**Creston Fen** east-central WA 710 m amsl (Mack et al. 1976; Hansen 1947)	**Van Wyck Creek** central ID 2255 m amsl (Doerner and Carrara 1999)	Age ^{14}C B.P.
				decrease in arboreal pollen, increase in *Artemisia*, Chenopodiaceae/ Amaranthaceae, Polygonaceae, Ranunculaceae, *Alnus*, *Salix* (warmer-drier than present)	
≤ 8000 cal B.P.	diploxylon pine, Gramineae, *Artemisia* (cooler and/or moister)		marked increase in diploxylon pine, decrease in *Artemisia*, *Abies*, and *Picea* (warmer-drier)		≤ 7200 B.P.
9000 cal B.P.		grass dominant steppe vegetation			8000 B.P.
10,000 cal B.P.	Gramineae, diploxylon pine, *Artemisia* (warmer-drier than present)			arboreal pine (mostly *Pinus* and *Picea*) and *Artemisia* dominant, closed spruce-pine forest (cooler-moister than present)	8900 B.P.
11,000 cal B.P.			*Artemisia* and Gramineae dominant in treeless scabland areas; haploxylon pine(s), *Abies*, and *Picea* dominant arboreal stands in loess hills; vegetation mosaic with treeless and prominent forested components (cooler-moister than present)		9500 B.P.
12,000 cal B.P.	diploxylon pine, *Betula*, *Artemisia*	conifer dominant vegetation			10,200 B.P.
13,000 cal B.P.	*Pinus*, *Betula*, *Artemisia*				11,100 B.P.
14,000 cal B.P.	*Pinus*, *Picea*, *Artemisia*, open vegetation with herbs and shrubs (cooler than present)				12,200 B.P.
≥ 15,000 cal B.P.					≥ 12,600 BP

**Younger Dryas interval shaded in blue, transitional boundary from cool to warm conditions marked by double lines.*

Table 4.1. (cont.) Late Pleistocene to Mid-Holocene Pollen Sequences from Sites in the Pacific Northwest.*

Age ^{14}C cal B.P.	**Burnt Knob Lake** Bitterroot Mountains, ID 2258 m amsl (Brunelle and Whitlock 2003; Brunelle 2007)	**Baker Lake** Bitterroot Mountains, MT 2300 m amsl (Brunelle et al. 2005)	**Lost Trail Pass Bog** Bitterroot Mountains, MT 2152 m amsl (Mehringer et al. 1977)	**Rock Lake** Mission Mountains, MT 1888 m amsl (Gerloff et al. 1995)	Age ^{14}C B.P.
≤ 8000 cal B.P.	*Pinus-Pseudotsuga* forest (warm-dry)		Douglas-fir, Lodgepole pine, decline in *Pinus* (warm)		≤ 7200 B.P.
9000 cal B.P.		high percentages of *Pseudotsuga/Larix* -type, *Alnus*, *Abies*, (warmer and/or drier than present)			8000 B.P.
10,000 cal B.P.				increase in *Pinus*, *Picea*, *Abies* (warm-dry)	8900 B.P.
11,000 cal B.P.			*Pinus albicaulis* forest, *Pinus* and *Pediastrum* dominant, sagebrush steppe (slightly cooler than present)		9500 B.P.
12,000 cal B.P.	*Pinus-Abies* forest, increase in whitebark pine, influx of spruce and larch (*Larix*) (slightly warmer-wetter than previous zone)				10,200 B.P.
13,000 cal B.P.		*Picea-Pinus* forest, open forest with alpine meadow (cooler-drier than present)		sage, alder (cool)	11,100 B.P.
14,000 cal B.P.					12,200 B.P.
≥ 15,000 cal B.P.	*Picea* parkland (cooler than present)				≥ 12,600 BP

**Younger Dryas interval shaded in blue, transitional boundary from cool to warm conditions marked by double lines.*

Table 4.1. (cont.) Late Pleistocene to Mid-Holocene Pollen Sequences from Sites in the Pacific Northwest.*

Age ^{14}C cal B.P.	**Sheep Mountain Bog** northwest MT 1920 m amsl (Hemphill 1983; Mehringer 1996)	**Waitts Lake** Colville River Valley, WA 540 m amsl (Mack et al. 1978d)	**Simpsons Flats** Sanpoil River Valley, WA 535 m amsl (Mack et al. 1978c)	**Big Meadow** Pend Oreille River Valley, WA 1040 m amsl (Mack et al. 1978a)	Age ^{14}C B.P.
	charcoal-to-pollen ratios decline for 5000 years beginning ca. 7840 cal B.P.				
≤ 8000 cal B.P.			possible disconformity		≤ 7200 B.P.
9000 cal B.P.					8000 B.P.
10,000 cal B.P.	open forest of *Pseudotsuga menziesii*, lodgepole pine, *Physocarpus*, abundant charcoal (dry)	diploxylon pine, arid *Artemisia* steppe (warmer-drier)		*Pinus*, Gramineae (warmer-drier than present)	8900 B.P.
11,000 cal B.P.			*Pinus*, *Artemisia*, Gramineae (warm-dry)		9500 B.P.
12,000 cal B.P.	Douglas-fir fires increase	abrupt change in frequency and prominence of *S. canadensis*, *Picea* and *Abies* more prominent			10,200 B.P.
13,000 cal B.P.	whitebark pine, spruce, fir, alder (cool-moist)			*Artemisia*, Gramineae, haploxylon pine, tundra-like vegetation	11,100 B.P.
14,000 cal B.P.		*Artemisia*, Gramineae, *Shepherdia canadensis*, haploxylon pine (cooler-moister than present)			12,200 B.P.
≥ 15,000 cal B.P.					≥ 12,600 BP

**Younger Dryas interval shaded in blue, transitional boundary from cool to warm conditions marked by double lines.*

Table 4.1. (cont.) Late Pleistocene to Mid-Holocene Pollen Sequences from Sites in the Pacific Northwest.*

Age ^{14}C cal B.P.	**McCall Fen** Long Valley, ID 1615 m amsl (Doerner and Carrara 2001)	**Tepee Lake** Kootenai River Valley, MT 1270 m amsl (Mack et al. 1983)	**Hager Pond** Priest River Valley, ID 860 m amsl (Mack et al. 1978b)	Age ^{14}C B.P.
≤ 8000 cal B.P.		diploxylon pines, xerophytic forest	*Larix* / *Pseudotsuga*, Diploxylon pine, *Artemisia* (cont. of warmer-drier conditions)	≤ 7200 B.P.
9000 cal B.P.	increase in *Artemisia*, Chenopodiaceae/ Amaranthaceae, *Sarcobatus*, Poaceae, decrease in *Pinus*, open pine forest (warm-dry)		Gramineae and diploxylon pine (warmer-drier than present)	8000 B.P.
10,000 cal B.P.		arboreal communities of pines, *Pseudotsuga* and/or *Larix*; treeless vegetation dominated by *Artemisia* (warm)	haploxylon/diploxylon pine, *Abies*, *Picea* (cooler-moister than present)	8900 B.P.
11,000 cal B.P.				9500 B.P.
12,000 cal B.P.				10,200 B.P.
13,000 cal B.P.	increase in *Pinus* and *Picea*, decrease in *Artemisia*, closed spruce-pine forest (cool-moist)	*Pinus* dominant, *Picea*, *Abies* (cool-moist)		11,100 B.P.
14,000 cal B.P.				12,200 B.P.
≥ 15,000 cal B.P.	*Artemisia* dominant (cold-dry)			≥ 12,600 BP

**Younger Dryas interval shaded in blue, transitional boundary from cool to warm conditions marked by double lines*

The expanse of cold-xeric vegetation and presence of subalpine forest and parkland in many lower elevations between ca. 28,000-14,000 cal B.P., suggest colder and drier conditions than exist today (Barnosky 1985; Mehringer 1984; Worona and Whitlock 1995; Grigg et al. 2001:20). Most basins were covered by vegetation communities most closely resembling periglacial steppe. On many mountains the forest zones were discontinuous (Mehringer 1984). The environment was apparently too dry and cold to support widespread forests except in areas along the Pacific coast (Barnosky et al. 1987:312-313). The expanse of cold-xeric vegetation appears to be associated with Late-Wisconsin glaciation in the region (Mehringer 1984:168).

Temperate taxa associated with deglaciation are registered in pollen profiles by ca. 16,000 cal B.P. Environmental and climatic events occurring during this period caused new plant communities to appear in deglaciated areas and changes in the vegetation of unglaciated areas (Whitlock 1992:14). The trend toward warmer climatic conditions was abruptly interrupted by the Younger Dryas cold reversal between ca. 13,200-11,400 cal B.P (Table 4.1). The Younger Dryas ushered in a brief return to glacial conditions across the Northern Hemisphere, as evidenced in pollen profiles from the Pacific Northwest.

Pollen Record During the Late Pleistocene: Younger Dryas Chronozone

Greenland ice core data suggests that at the Younger Dryas chronozone, the transition from interglacial to glacial conditions was rapid, occurring in less than 50 years (Alley 2000; Alley et al. 2003; Walker and Pellatt 2008:133). The sudden reversal from warmer temperatures to a markedly cooler climate is indicated by an increase in cold-adapted taxa and decrease in warm-adapted taxa in pollen profiles across North America and Europe (Gorham et al. 2001:102). Evidence suggests that the cold reversal ended as abruptly as it began (Alley 2000).

Comparisons of pollen datasets in this study support the presence of predominately cool and/or cool-moist conditions during the Younger Dryas in the Pacific Northwest. Notable exceptions include the pollen sequences from Carp Lake in the Columbia Plateau (Barnosky 1985b; Whitlock and Bartlein 1997), Gordon Lake in the Cascade Range (Grigg and Whitlock 1998), Buckbean Bog in the Okanogan Highlands of British Columbia (Heinrichs et al. 2001), and Burnt Knob Lake and Baker Lake in the Northern Rocky Mountains (Brunelle and Whitlock 2003; Brunelle 2007; Brunelle et al. 2005). With the exception of Burnt Knob Lake, pollen sequences at the aforementioned locations argue for cool-dry conditions during the Younger Dryas. Burnt Knob Lake registers a Younger Dryas-related climatic episode characterized by slightly warmer and wetter conditions (Brunelle 2007) (Table 4.1).

Puget Lowland

Pollen profiles from Mineral Lake, Hall Lake (Tsukada et al. 1981), Lake Washington (Leopold et al. 1982), Kirk Lake (Cwynar 1987), and Lake Carpenter (Anundsen et al. 1994) (Table 4.1) argue for cool and/or cool-moist conditions during the Younger Dryas. This is suggested by the presence of *Pinus contorta* (lodgepole pine), *Picea engelmannii* (Engelmann spruce), *Tsuga mertensiana* (mountain hemlock), *Alnus sinuata* (Sitka alder), and *Populus* (poplar) in pollen profiles by ca. 13,800 cal B.P. Landscapes are characterized as taiga and open woodland. Cool conditions ended at around 12,900 cal B.P. at Kirk Lake and Lake Carpenter, and at ca. 11,400 cal B.P. at Mineral Lake, Hall Lake, and Lake Washington.

Cascade Range

The dominance of *Abies* and *Pseudotsuga* pollen in profiles from Indian Prairie (Sea and Whitlock 1995) and Battle Ground Lake (Barnosky 1985a; Walsh et al. 2008) (Table 4.1) suggests cooler-moister Younger Dryas conditions in the Cascade Range of Washington by ca. 12,800 cal B.P. Conversely, the presence of *Pinus*, *Abies*, *A. sinuata* and *T. mertensiana* in the pollen profile of Gordon Lake (Table 4.1) argues for cooler winters and drier summers between ca. 12,800-11,000 cal B.P. The pollen sequence at Gordon Lake suggests greater seasonality during the Younger Dryas in the region (Grigg and Whitlock 1998:295). Landscapes in the Cascade Ranger were dominated by closed montane forests. Cool-moist and cool-dry conditions associated with the Younger Dryas terminated relatively synchronously between ca. 11,300-10,800 cal B.P.

Okanogan Lowland and Highland

Pollen data from Bonaparte Meadows and Mud Lake (Mack et al. 1979) (Table 4.1) suggest that the climate was cooler and wetter than today in the Okanogan Valley of Washington during the Younger Dryas. Cooler-wetter conditions are evidenced by high percentages of haploxylon pine, Cyperaceae (sedges), *Artemisia* (herbs or shrubs), *Shepherdia canadensis* (Canadian/Russet buffaloberry), and grass pollen.

A contrasting situation is indicated by the pollen sequence from Buckbean Bog (Heinrichs et al. 2001) (Table 4.1), located in Mount Kobau, British Columbia. Pollen profiles from this site suggest that cool-dry conditions existed in the Okanogan Highlands during the Younger Dryas, as evidenced by the presence of Chenopodiinae (goosefoots) and *Sarcobatus* (Greasewood) pollen. These interpretations are reportedly consistent with regional observations from the same period (Heinrichs et al. 2001:2186). However, cool-moist Younger Dryas conditions also have been reported at sites across British Columbia (Hebda 1995).

Pollen data suggests that landscapes in the Okanogan Highland and Lowland were dominated primarily by steppe vegetation. Cool-moist conditions terminated at ca. 11,400 cal B.P. at Bonaparte Meadows and Mud Lake. This is coeval with the waning stages of the Younger Dryas and corresponds with the termination of cool-moist conditions at Mineral Lake, Hall Lake, and Lake Washington in the Puget Lowland. At Buckbean Bog, cool-dry conditions abruptly terminated at ca. 10,740 cal B.P. as evidenced by the rapid onset of warming.

Columbia Plateau

Pollen profiles from Williams Lake Fen (Nickmann 1979; Mehringer 1996), Goose Lake (Nickmann and Leopold 1985), Wildcat Lake (Blinman 1978; Mehringer 1996), and Creston Fen (Hansen 1947; Mack et al. 1976) (Table 4.1) suggest that cooler and/or cooler-moister conditions than present prevailed during the Younger Dryas on the Columbia Plateau. Such conditions are represented by greater values and percentages of conifer, haploxylon and diploxylon pine, *Betula* (birch), grasses, *Abies* (firs), *Picea* (spruce), and *Artemisia* pollen by ca. 12,800 cal B.P.

The exception to the cool-moist trend on the Columbia Plateau comes from Carp Lake (Table 4.1). The pollen sequence at Carp Lake records the coldest and driest period in the site's history during pollen zone CL-3. The zone persists into the early stage of the

Younger Dryas and then transitions to a zone dominated by warm-dry pollen taxa. Cold-dry conditions are inferred from the absence of temperate aquatic taxa and presence of *Polygonum bistortoides* (American bistort)-type pollen (Barnosky 1985b; Whitlock and Bartlein 1997Whitlock et al. 2000:17).

The predominant vegetation on the Columbia Plateau during the Younger Dryas was grassland with herbs and/or shrubs, as indicated by high percentages of Gramineae and *Artemisia* pollen. The landscape in the scablands consisted of cold steppe (Whitlock 1992:15) or possibly tundra-like vegetation (Nickmann 1979). Meanwhile, arboreal stands occupied loess hills (Mack et al. 1976). Vegetation was a mix of high and low elevation forest taxa which have no modern counterparts (Whitlock 1992:15). Younger Dryas-era landscapes evolved into those favoring warmer-drier taxa between ca. 13,200-10,200 cal B.P. and particularly around 11,900 cal B.P.

Northern Rocky Mountains

Pollen profiles suggest that cool and/or cool-moist conditions existed during the Younger Dryas for most locations in the Northern Rocky Mountains of Idaho and northwest Montana. However, cooler-drier and warmer-wetter conditions are also recorded in the region. Cool and/or cool-moist conditions are evidenced by high percentages of pine, spruce, alder, and fir pollen in profiles from Sheep Mountain Bog (Hemphill 1983; Mehringer et al. 1984; Mehringer 1996), Van Wyck Creek (Doerner and Carrara 1999), and Lost Trail Pass Bog (Mehringer et al. 1977) (Table 4.1).

At Baker Lake (Table 4.1), cooler-drier than present conditions are recorded for the Younger Dryas period, as suggested by *Picea-Pinus* dominated pollen indicative of an open forest with alpine meadow (Brunelle et al. 2005). Conversely, at Burnt Knob

Lake (Table 4.1), a change in vegetation potentially associated with the Younger Dryas event occurred between ca. 14,000-12,000 cal B.P. (Brunelle and Whitlock 2003:316; Brunelle 2007). However, the change is characterized by a trend toward slightly warmer and wetter conditions. This is evidenced by a higher percentage of fir and distinct increases in the influx of spruce and larch (Brunelle 2007:1-2).

Landscapes in the Northern Rocky Mountains were dominated by both open and closed pine and spruce forests. The region shows greater variability in the timing of vegetation change at the Late Pleistocene than at any other physiographic area in the Pacific Northwest. Transitions occurred as early as ca. 12,700 cal B.P. at Rock Lake, and as late as ca. 8350 cal B.P. at Lost Trail Pass Bog.

River Valleys of the Northern Rocky Mountains

High percentages of *Pinus*, *Picea*, *Abies*, and *Shepherdia canadensis* from Waitts Lake, Big Meadow, Hager Pond, Tepee Lake (Mack et al. 1978a, 1978b, 1978c, 1978d, 1983, 1984), and McCall Fen (Doerner and Carrara 2001) (Table 4.1) argue for cooler-moister conditions than today around the Younger Dryas for the river valleys of the Northern Rocky Mountains. The change in frequency and prominence of *S. Canadensis* occurred rapidly at Waitts Lake. The pollen sequence at Hager Pond does not begin until ca. 10,740 cal B.P. or slightly earlier, thus it potentially but not necessarily falls within the range of the Younger Dryas. Nevertheless, the initial pollen zone is consistent with other profiles during the Younger Dryas and the delay could represent a local lag in vegetation response to the cold event.

Landscapes in the river valleys are interpreted as tundra-like (Mack et al. 1978a, 1984) and closed spruce-pine forest (Doerner and Carrara 2001). Similar to pollen profiles from the mountain and foothill sites in the Northern Rockies, the transition from Younger Dryas to Early Holocene climatic conditions is more variable than in surrounding regions. The transition to warmer-drier conditions in the river valleys of northeast Washington and west-central Idaho is relatively synchronous, occurring between ca. 11,400-11,200 cal B.P. at Waitts Lake, Big Meadow, Simpsons Flats, and McCall Fen. Simpsons Flats does not have a pre-Early Holocene component (Mack et al. 1978c). The transitional zone is much more variable for river valleys in northern Idaho and northwest Montana. At Tepee Lake, the transition occurs as early as ca. 12,400 cal B.P.; and at Hager Pond, cool-moist conditions persist until ca. 9300 cal B.P.

Pollen Record During the Early Holocene

By the beginning of the Early Holocene or shortly thereafter, pollen profiles from sites in the Pacific Northwest and surrounding regions document increases in warmth and aridity (Table 4.1). The climate regime was likely warmer and drier than today for many areas. Warm-dry conditions are evidenced by a region-wide expanse of warm-xeric plant communities and associated landscapes (Mehringer 1984:168, 1985, 1996). Evidence suggests that the primary forcing mechanism for climate change at the PHB was greater-than-present summer insolation caused by the Milankovitch Cycle. The phenomenon is thought to have triggered increases in summer temperatures, decreases in effective precipitation, intensified drought, and a stronger than present subtropical high (Whitlock and Bartlein 1997:59; 2004:484).

Areas west of the continental divide would have been more susceptible to burning during the Early Holocene than today because of an intensified subtropical high that was brought about by greater summer insolation (Brunelle and Whitlock 2003:316). Evidence for increased burning comes from observations of accelerated charcoal accumulation rates in Early Holocene sediments. Repeated fires left a mosaic of forests in various stages of succession (Cwynar 1987; see also Whitlock 1992:17).

Pollen profiles show that forests expanded toward the north and to higher elevations during the Early Holocene. A relative decline in conifer pollen and increase in grass and sagebrush pollen signals retreat of montane trees and expanding warm steppe (Mehringer 1984:168). Data suggests that shrub-dominant steppe communities extended as far as the mountains surrounding the Columbia Basin (Mehringer 1985:174). The expansion of xeric communities into mountainous areas suggests that available moisture may have been up to 40 percent less than today (Chatters 1995:381).

Increased summer drought in the Early Holocene seems to conflict with evidence for episodes of Early Holocene glaciation. Barnosky and others (1987) and Waitt and others (1982) suggest that the difference resulted from either decreased temperatures or increased precipitation at higher elevations. The paradox may have been caused by a steepening of the temperature lapse rate during a period of aridity (Barnosky et al. 1987:298).

Comparisons of pollen datasets in this study support the presence of warm-dry and/or warmer-drier than present conditions during the Early Holocene in the Pacific Northwest. Pollen and sediment records indicate that these conditions were accompanied by a greater frequency of fires and lake levels that were lower than today. The timing of the transition from cool/cool-moist to warm-dry conditions occurred at various times but appears to have centered around the boundary between the end of the Younger Dryas and beginning of the Early Holocene at ca. 11,400 cal B.P.

Puget Lowland

Warmer and/or warm-drier than present conditions are registered in pollen profiles from the Puget Lowland of northern Washington (Table 4.1) between ca. 12,900-11,400 cal B.P. This is suggested by high percentages of *Pseudotsuga menziesii* (Douglas-fir), *Alnus/A. rubra* (alder/red alder), *Pteridium/P. aquilinum* (fern/bracken fern), and *Castanopsis* (chinquapin) (Tsukada et al. 1981; Leopold et al. 1982; Cwynar 1987; Anundsen et al. 1994).

Forests throughout the Puget Trough and southern Fraser Lowland contained higher percentages of *Pseudotsuga, A. rubra,* and *Pteridium* than today (Whitlock 1992:17). Early Holocene landscapes have been variously described as closed forest (Cwynar 1987), open forest (Heusser 1978), open woodland (Tsukada et al. 1981), and open woodland or forest mosaic (Leopold et al. 1982).

Cwynar (1987) concludes that the landscapes were likely a mix of both closed and open forests. The mosaic is explained by the occurrence of repeated Early Holocene fires which left an irregular distribution of vegetation in various stages of succession (Cwynar 1987:798-799). Frequent Early Holocene forest fires in the Puget Lowland have been inferred from increases in charcoal accumulation rates at Mineral Lake, Hall Lake (Tsukada et al. 1981), and Kirk Lake (Cwynar 1987).

Cascade Range

Pollen profiles from the Cascade Range in Washington and Oregon (Table 4.1) show a transition to warm-dry and/or warmer-drier than present conditions during the Early Holocene by ca. 11,300-10,800 cal B.P. These conditions are inferred from the presence and high percentages of *Quercus* (oak), *Pseudotsuga*, *Dryopteris* (wood ferns), *Pteridium*, and grass pollen.

The landscape is described as *Quercus*-dominant savanna at Battle Ground Lake in southwest Washington (Barnosky 1985a; Walsh et al. 2008). In northwest Oregon the landscape is described as forest or montane temperate forest (Sea and Whitlock 1995; Grigg and Whitlock 1998). Frequent Early Holocene fire episodes of low-to-moderate severity are inferred from pollen cores from Battle Ground Lake. The increase in fires is evidenced by higher charcoal concentrations than previous zones by ca. 10,800 cal B.P. Increased fire activities and changes in vegetation communities of this period are associated with greater summer drought (Walsh et al. 2008:256, 259).

Okanogan Lowland and Highland

Warmer and drier conditions than today are registered in pollen profiles from the Okanogan Valley (Table 4.1) at the beginning of the Early Holocene, ca. 11,400 cal B.P. These conditions are inferred from an influx in nonarboreal pollen such as *Artemisia* and Gramineae as well as higher percentages of diploxylon pine at Bonaparte Meadows and Mud Lake (Mack et al. 1979). Pollen of this type signifies drought (Whitlock 1992:18) and a landscape dominated by steppe vegetation.

In the Okanogan Highland, a brief interval of rapid warming beginning at around 10,700 cal B.P. is suggested by high percentages of *Pinus*, *Picea*, Poaceae (grasses), and

Artemisia pollen at Buckbean Bog (Heinrichs et al. 2001:2189) (Table 4.1). Warm and dry conditions follow this brief zone of initial warming, as suggested by the dominance of Poaceae*, Artemisia,* Cyperaceae*,* and other non-arboreal pollen by ca. 10,200 cal B.P. Charcoal occurs in small quantities at this zone but does not peak until after ca. 8500 cal B.P., which is when increased summer drought is recognized throughout the highland region (Whitlock 1992:18). The landscape was dominated by grassland steppe.

Columbia Plateau

Pollen profiles from the Columbia Plateau (Table 4.1) indicate conditions that were warmer and drier than today by ca. 13,200-10,200 cal B.P., although the transition appears to center around 11,900 cal B.P. Drought is inferred from an increase in the percentages of grass, *Artemisia*, diploxylon pine (either lodgepole or ponderosa), and other xeric taxa at the expense of more mesophytic conifer taxa (Barnosky et al. 1987:299; Mehringer 1985).

Increases in diploxylon pines, like *Pinus contorta* and/or *P. ponderosa* (Ponderosa pine), suggest climatic conditions that are both warmer and drier (Nickmann and Leopold 1985:142). The resemblance of these assemblages with modern pollen spectra from steppe vegetation in the Columbia Basin (Mack and Bryant 1974) demonstrates that the forest/steppe ecotone had shifted northward at least 100 km in the Early Holocene (Barnosky et al. 1987:299).

Maximum aridity occurred at different times throughout the Columbia Plateau. At Goose Lake (Nickmann and Leopold 1985) aridity was greatest between ca. 11,400-7800 cal B.P. At Carp Lake it was over as early as ca. 9500-9000 cal B.P. (Barnosky 1985b; Whitlock and Bartlein 1997). Creston Fen (Mack et al. 1976) and Williams Lake

Fen (Mehringer 1996; Nickmann 1979) did not undergo maximum aridity until after ca. 8350 B.P. (see Barnosky et al. 1987:299) (Table 4.1).

Similar to the pollen record from Big Meadow in the Pend Oreille River Valley, sedimentary and pollen records at Simpsons Flats, Bonaparte Meadows (Mack et al. 1979), and Carp Lake (Whitlock et al. 2000:17) argue for lake levels that were lower than today. Evidence for increased fire activity comes from Williams Lake Fen, where the largest pre-Mazama charcoal values are recorded between ca. 10,200-9600 cal B.P. (Mehringer 1996:22).

Northern Rocky Mountains

Pollen profiles from sites in the Northern Rocky Mountains of Idaho and northwest Montana (Table 4.1) do not show a high degree of synchroneity during the transition from cool to warm-dry conditions in comparison to other areas. The reported timing of this transition ranges from ca. 12,700 to 8350 cal B.P. Nevertheless, the palynological data indicates that warm-dry and/or warmer-drier than present conditions prevailed throughout the region during the Early Holocene.

Warmer-drier conditions are evidenced by increases in *Artemisia*, Chenopodiceae (goosefoot) and/or Amaranthaceae (amaranths), *Pinus contorta* (lodgepole pine), *Pseudotsuga* and/or *Larix* (larch), *Pseudotsuga menziesii*, and *Abies* pollen. Pollen profiles containing these taxa come from Burnt Knob Lake (Brunelle and Whitlock 2003), Lost Trail Pass Bog (Mehringer et al. 1977), Rock Lake (Gerloff et al. 1995), Sheep Mountain Bog (Mehringer et al. 1984; Mehringer 1996), and Van Wyck Creek (Doerner and Carrara 1999) (Table 4.1).

Landscapes are characterized as forest and/or open forest. The vegetation appears to be more open than the previous pollen zone at each site, as evidenced by an increase in more mesophytic nonarboreal taxa. Douglas fir and lodgepole pine are the dominant arboreal taxa. Areas with treeless vegetation are dominated by *Artemisia* and flowering plants. At Sheep Mountain Bog, abundant charcoal between ca. 11,850-11,075 cal B.P. suggests that the number and intensity of fires increased with the change in climate regimes. This period corresponds with decreasing effective moisture and the large charcoal values at Williams Lake Fen (Mehringer 1996:22).

River Valleys of the Northern Rocky Mountain

Warmer and drier than present conditions are recorded in pollen profiles from river valleys in the Northern Rocky Mountains (Table 4.1) between ca. 12,400-9300 cal B.P., but centering around 11,400-11,200 cal B.P. Warm-dry conditions are represented by high percentages of *Artemisia*, Gramineae/Poaceae, pine/diploxylon pine, *Chenopodiaceae/Amaranthaceae*, and *Sarcobatus* (greasewood). Pollen assemblages of this type suggest steppe, grassland, and open forest landscapes.

Sedimentary and pollen records at Big Meadow indicate that lake levels were lower than present at around 11,200 cal B.P. (Mack et al. 1979). Data also suggests that the timing of maximum aridity at Big Meadow and Simpsons Flats occurred between ca. 11,400-7800 cal B.P. Maximum aridity did not commence until after ca. 8400 cal B.P. at Hager Pond (Barnosky et al. 1987:299).

Palynological Events Associated with the 8200 cal B.P. Cooling Event

The majority of pollen profiles analyzed in this study lack noticeable changes in the pollen record that would indicate a response to the 8200 cal B.P. event recorded in GISP and GISP2 data. The rapid climate change episode is thought to have been initiated by a large pulse of glacial meltwater into the Atlantic Ocean (Alley et al. 1997). The result was a return to cool and/or cool-moist conditions in the Northern Hemisphere. Even though most sites do not register such conditions at 8200 cal B.P. in the Pacific Northwest, there are in fact several sites that document a brief interval of cooler and/or cooler-moister conditions at that time.

At Mineral Lake and Hall Lake in the Puget Lowland (Table 4.1), pollen zone PIb (ca. 9500-7800 cal B.P.) is characterized by an increase in moisture. Wetter conditions are inferred from the behavior of the *Thuja plicata* (Western redcedar) curb in addition to the presence of *Pseudotsuga menziesii*, *Alnus rubra*, and *Pteridium aquilinum*. *Thuja* begins to rise exponentially from the PIa (ca. 11,400-9500 cal B.P.)/PIb zonal boundary at Mineral Lake, and begins to appear continuously at Hall Lake. *Thuja* dominated forests indicate greater precipitation (Tsukada et al. 1981:735).

Goose Lake (Table 4.1) in north-central Washington records a brief period of cooler and/or moister conditions between ca. 8600-7600 cal B.P. in pollen zone V (Nickmann and Leopold 1985). The zone is marked by an increase in *Pinus* and decrease in Gramineae. *Picea* increases to over one percent in the bottom half of the zone and *Abies* becomes more consistent. This indicates that the forest surrounding the lake descended to a lower elevation as a result of an increase in available effective moisture (Nickmann and Leopold 1985:144).

A Mid-Holocene increase in moisture beginning around 8500 cal B.P. has been recorded at Buckbean Bog (Table 4.1) in Mount Kobau, British Columbia (Heinrichs et al. 2001). Increased moisture is evidenced by a broad peak of *Salix* and the occurrence of Poaceae, *Artemisia,* and Cyperaceae in the pollen profile. A large charcoal peak is recorded in the early part of the pollen zone, which suggests that at the same time fires burned more frequently (Heinrichs et al. 2001:2190). Conversely, charcoal-to-pollen ratios decline for 5000 years beginning by ca. 8000 cal B.P. at Sheep Mountain Bog in northwest Montana (Mehringer 1996:21).

Discussion

Pollen records from the Pacific Northwest offer evidence for a significant, region-wide shift in climate at the PHB. The shift is characterized by a transition from generally cool-moist, but in some cases cool-dry, conditions during the Younger Dryas (ca. 13,200-11,400 cal B.P.) to warm-dry conditions by the start of Early Holocene (ca. 11,400 cal B.P.). In many areas the pollen sequences indicate that conditions were more extreme than today. The shift is registered in areas of the Puget Lowland, Cascade Range, Okanogan, Columbia Plateau, and Northern Rocky Mountains.

Evidence for another regional shift in climate during the 8200 cal B.P. event comes from multiple sites variously located in the Puget Lowland, Okanogan Highland, Columbia Plateau, and Northern Rocky Mountains. Although the cold event is registered in several pollen profiles from the Pacific Northwest, the signature is much less evident than the transition between climate regimes at the PHB.

There is a relatively high degree of synchroneity in the transition from cool-moist/cool-dry to warm-dry conditions at the PHB. The timing of transition varies from region to region and ranges between ca. 13,000-9000 cal B.P., but tends to center around 11,400 cal B.P. When taking into account the standard deviation of error (at 2-sigma) for calibrated radiocarbon dates using the IntCal09 calibration curve (Reimer et al. 2009), the timing of transition at each site tends to fall within the same statistical range.

Be that as it may, variations in the timing and magnitude of change existed, particularly in the Northern Rocky Mountains. These variations were at least in part caused by coeval glacial and climatic factors that existed on a local and regional level. It is also reasonable to assume that vegetation communities in this timeframe were subject to the same environmental, geologic, and atmospheric factors known to cause variations in plant communities today. Such factors include, but are not limited to, local geomorphology, microclimates, aspect of slope, soil types, and differences in the energy and moisture balance of an area.

Palynological studies have recently been used to support the occurrence of abrupt or rapid climate change in western North America at the PHB (Gorham et al. 2001:102; Heusser 2000; Jiménez-Moreno 2010). The results of this study support the occurrence of rapid or abrupt climate change in the Pacific Northwest at the PHB. This is based on the observation that 1) the characteristics of vegetation communities during the transition in climate regimes are markedly similar from one physiographic region to another; and 2) the timing of the transition from generally cool-moist to warm-dry conditions typically falls within the same statistical range at a 2-sigma standard deviation.

In the future, pollen data combined with fire and plant macrofossil records will allow researchers to gain an even finer resolution of the chronology and dynamics of vegetation and climate change. Greater resolution and understanding of past vegetation events will likely lead to the recognition of new episodes of climate change, and possibly multiple episodes of change within a single climatic chronozone or event.

Significant shifts in the density, diversity, and distribution of plant communities at the Late Pleistocene-Early Holocene documented in this chapter had direct and measurable impacts on fauna inhabiting the region. In the next chapter, faunal proxy datasets for climate change suggest that changes in the size and biogeography of animals, along with the extinction of megafauna, occur synchronously with significant shifts in plant communities.

Chapter 5

Faunal Proxy Datasets for Climate Change

Introduction

Late Pleistocene and Early Holocene faunal datasets from the Pacific Northwest reflect region-wide changes in climate and environments at the PHB. Variations in the size, distribution, and abundance of mammals are linked to large-scale shifts in temperature and precipitation along with associated changes in plant communities. Faunal assemblages from archaeological and paleozoological sites (Figure 5.1) suggest a

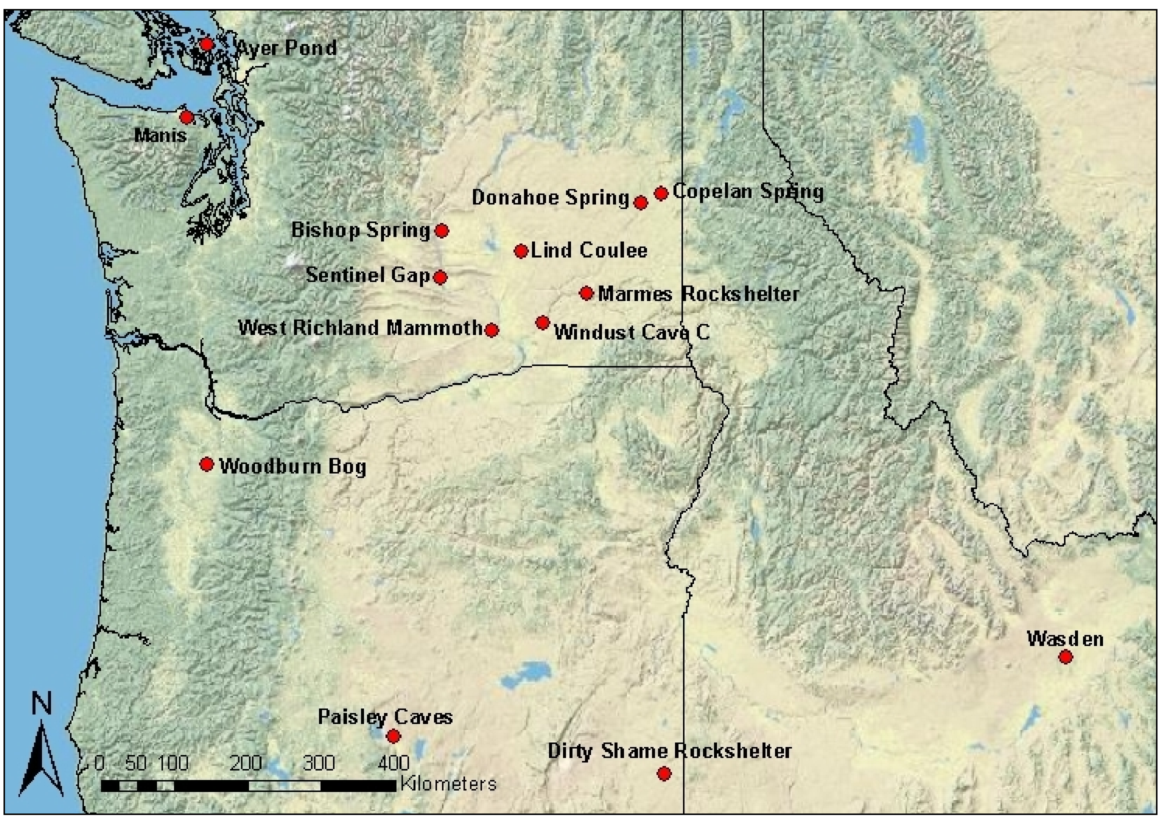

Figure 5.1. *Locations of faunal sites discussed in this study.*

generally cool-moist climate at the Late Pleistocene during the Younger Dryas chronozone, followed by warmer-drier climate by the Early Holocene.

Late Pleistocene-Early Holocene faunal datasets from the Pacific Northwest come from Orcas Island off the coast of Washington (Kenady et al. 2011), the Olympic Peninsula of northwest Washington (Rice 1965; Gustafson et al. 1979; Gilbow 1981; Waters et al. 2011), Columbia Plateau of Washington (Daugherty 1956; Fryxell and Daugherty 1962; Gustafson 1972; Irwin and Moody 1978; Martin et al. 1982; Galm 1983; Galm et al. 2002; Gough and Galm 2003; Luttrell 2001; Huckleberry et al. 2003; Lyman 2004, 2008, 2010, 2011; D.L. Jenkins 2010; S. L. Jenkins 2011) Snake River Plain of southern Idaho (Butler 1965b, 1968, 1969; Plew and Pavesic 1982; Miller 1989), Willamette Valley of northwest Oregon (Stenger 2002; Dunleavy 2003), and in the Harney-Owyhee Broken Lands of southern Oregon (Cressman 1942; Grayson 1977; D.L. Jenkins 2010) (Table 5.1).

Late Pleistocene Fauna

Faunal assemblages dated to the Late Pleistocene demonstrate that now-extinct megafauna inhabited the Northwest Coast, Columbia Plateau, Snake River Plain, and Harney-Owyhee Broken Lands physiographic regions of the Pacific Northwest. From the few megafaunal remains that have been dated (Stenger 2002; Jenkins 2010; Waters et al. 2011; Kenady et al. 2011), it is evident that ancient species inhabited the region beginning before ca. 15,000 cal B.P. and had essentially disappeared by the Early Holocene. *Mammut americanum* (American mastodon), *Mammuthus columbi* (Columbian mammoth), undifferentiated mammoth and mastodon, *Bison antiquus*

Table 5.1. Late Pleistocene-Early Holocene Faunal Assemblages from Sites in the Pacific Northwest.*

Site	Age	Location	Taxa	Source(s)
Ayer Pond site (45SJ454)	LP ca. 13,800 cal BP	Orcas Island	*Bison antiquus* (ancient bison)	Kenady et al. 2011
Manis site (45CA218)	LP ca. 13,800 cal BP	Olympic Peninsula	*Mammut americanum*(American mastodon)	Gustafson et al. 1979; Gilbow 1981; Waters et al. 2011
Coplen Spring (Latah Mammoth) and Donahoe Spring	LP	eastern Washington	*Mammuthus columbi* (Columbian mammoth)	Galm 1983; Luttrell 2001
Bishop Spring site	LP-EH	central Washington	*Bison*(undifferentiated bison), Bovideae (sheep/bison family), sheep, elk, deer, dog, marmot	Schalk 2002 (personal commun.) in Huckleberry et al. 2003
Lind Coulee site (45GR97)	LP-EH ca. 11,600-9645 cal BP	central Washington	*Bison bison* (modern bison), *Cervus elaphus* (big elk), *Cervus canadensis* (wapiti/elk), deer, muskrat, beaver, badger, marmot, skunk, waterfowl, reptiles, birds	Daugherty 1956; Gustafson 1972; Irwin and Moody 1978; Huckleberry et al. 2003; Lyman 2004
Sentinel Gap site (45KT1362)	LP-EH ca. 12,610-11,400 cal BP	south-central Washington	*Bison bison* (modern bison), *Cervus elaphus roosevelti* (Roosevelt elk), *Ovis canadensis* (bighorn sheep), mountain sheep, *Brachylagus idahoensis*(pygmy rabbit), deer, beaver, badger, Chinook salmon	Galm et al. 2002; Gough and Galm 2003; Lyman 2004; Litzkow 2011
Marmes Rockshelter (45FR50)	LP-EH 12,470-10,740 cal BP	southeast Washington	*Cervus elaphus* ("Big elk"), *Alopex lagopus* (Arctic fox), *Ovis canadensis* (Bighorn sheep), *Antilocapra americana* (pronghorn), *Martes americana nobilis* (noble marten), deer, red fox, coyote, rabbits, rodents	Fryxell and Daugherty 1962; Gustafson 1972; Lyman 2008, 2010, 2011
Windust Cave C (45FR46)	EH ca. 11,400-8985 cal BP	southeast Washington	*Bos bison* (bison or American buffalo), *Ovis canadensis* (Bighorn Sheep), *Cervus canadensis* (wapiti/elk) domesticated goat and sheep, deer, bobcat, rabbit, badger, raccoon, Canadian beaver, dog, weasel, other small mammals, rodents, fish	Rice 1965; Jenkins 2011
West Richland Mammoth site	LP > 15,530 cal BP	south-central Washington	*Mammuthus* (mammoth), cloven-hooved mammals, medium-sized carnivores, rodents, rabbits, toad, snake, birds	Martin et al. 1982

*LP=Late Pleistocene, EH=Early Holocene

Table 5.1. (cont.) Late Pleistocene-Early Holocene Faunal Assemblages from Sites in the Pacific Northwest.*

Site	Age	Location	Taxa	Source(s)
Woodburn Bog	LP > 15,150-12,660 cal BP	northwest Oregon	*Mammut* (mastodon), *Mammuthus columbi* (Columbian mammoth), *Bison antiquus* (ancient bison), *Megatherium* (giant sloth), poss. American lion, horse, bear, dire wolf, *Teratanis Woodburnensis* (predator bird)	Campbell and Stenger 2002; Stenger 2002; Dunleavy 2003; Baker 2005, Keefer 2010
Wasden site/Owl Cave (10BV30)	LP-EH 13,840-7840 cal BP	southeast Idaho	*Mammuthus* (mammoth), *Bison antiquus* (ancient bison), *Camelops*(camel), bear, coyote, canine/dog, badger, other small mammals	Butler 1965a, 1965b, 1968, 1969; Plew and Pavesic 1982; Miller 1989
Paisley Caves (35LK3400)	LP ca. 14,290-13,140 cal BP	south-central Oregon	*Bison antiquus* (ancient bison), *Camelops* (camel), horse, artiodactyls, small mammals, waterfowl, fish	Cressman 1942; Jenkins 2010
Dirty Shame Rockshelter (35ML65)	EH 10,740-7425 cal BP	southeast Oregon	*Bison antiquus* (ancient bison), *Lutra canadensis* (river otter), *Ovis canadensis* (mountain/bighorn sheep), pronghorn, deer, bobcat, badger, beaver, fox, mink, dog, coyote, rabbits, rodents	Grayson 1977; Aikens et al. 1977

*LP=Late Pleistocene, EH=Early Holocene

(ancient bison), *Camelops* (camel), *Equus* (horse), *Megatherium* (giant sloth), dire wolf, possibly American lion, and a new species of predatory bird named *Teratanis Woodburnensis* (Campbell and Stenger 2002) are represented in the faunal record (Table 5.1). A bone projectile point imbedded in the bone of the mastodon at the Manis site (site 45CA218) was recently dated to ca. 13,800 cal B.P. (Waters et al. 2011). This is the same reported age as an ancient bison identified at the Ayer Pond site (45SJ454) (Kenady et al. 2011). Species of this period were overwhelmingly cold-adapted (Surovell 2008), thus indicating cooler temperatures, moister conditions, and more mesic adapted vegetation cover during the terminal Pleistocene (Daugherty 1956; Gustafson 1972, Grayson 1977).

The last major pulse of Late Quaternary mammal extinction occurred in the Late Pleistocene during the Younger Dryas chronozone around 12,900 cal B.P. (Grayson and Meltzer 2003:586). The cause of extinction is still debated (for various perspectives see Grayson and Meltzer 2003; Firestone et al. 2007; Barnosky and Kraatz 2007; Haynes 2008). Nevertheless, climatic-extinction models suggest that climate played at least some role in the extinction, speciation, and distribution of Late Pleistocene fauna (Grayson and Meltzer 2003; Barnosky et al. 2004; Barnosky and Kraatz 2007).

Fauana at the Pleistocene-Holocene Boundary

Ancient, larger-than-modern, and modern mammalian taxa are represented in the faunal record of the PHB. At the Wasden site (Owl Cave) (10BV30) and Dirty Shame Rockshelter (35ML65) in southern Oregon, faunal remains indicate that *Bison bison* (modern bison) and other extant species inhabited the region along with now-extinct animals including mammoth, horse, and camel (Butler 1968) (Table 5.1). Larger-than-modern *Bison bison* and *Cervus elaphus roosevelti* (Roosevelt elk) have been identified at the Sentinel Gap site (45KT1362) (Galm and Gough 2001, 2008; Gough and Galm 2003). The elk bone, which dates to ca. 11,975 cal B.P., is reportedly the same size and bone as a larger-than-modern *Cervus elaphus* ("Big Elk") from the Marmes Rockshelter that dates to ca. 11,220 cal B.P. (Lyman 2010).

Terminal Pleistocene bison and elk likely grew to exceptionally large sizes as a result of abundant grasses and forage plants available at the time (Lyman 2010, 2004).

Vegetation began to decrease in abundance as climate shifted to warmer and drier condition towards the Early Holocene. Faunal data suggests that vegetation changes occurring at the PHB were accompanied by a reduction in the size and extent (diminution) of elk, bison, and other mammals. It is likely that diminution and fluctuating abundances of bison and elk at the Early Holocene were caused by climatically driven decreases in the quality and quantity of nutritional forage (Lyman 2004, 2010).

Links between climate change and species distribution are evidenced by changes in the range of species at the PHB climatic shift (Barnosky et al. 2004; Barnosky and Kraatz 2007:527). Most of the species represented in PHB faunal assemblages still occupy the same physiographic regions today. However, bison, elk, *Antilocapra americana* (pronghorn), *Ovis canadensis* (bighorn sheep), *Brachylagus idahoensis* (pygmy rabbit), and *Alopex lagopus* (arctic fox) are found at archaeological sites in locations that today cannot support the habitats needed for their survival. Sites dating to around the PHB that possess no modern faunal analogs include Lind Coulee, Sentinel Gap, Marmes Rockshelter, Bishop Spring, Windust Cave C, Wasden (Owl Cave), Woodburn Bog, and Dirty Shame Rockshelter (Table 5.1). Changes in the spatial distribution of select species at the PHB are linked to a shift from cool-moist conditions at the Younger Dryas chronozone to increasingly warmer and drier conditions by the Early Holocene (Gustafson 1972; Lyman 2004, 2010; Huckleberry and Fadem 2007).

Early Holocene Fauna

Faunal assemblages suggest that by the Early Holocene, the proportion of large bodied mammals decreased, while smaller, xeric taxa grew in abundance. Lyman (2010) suggests that changes in the proportion of animal species were a consequence of decreasing effective moisture and an associated shift to more drought-tolerant plant communities. The relative amount of bison on the landscape decreased as the climate became warmer-drier and grass productivity declined. Bison populations were small if nonexistent by ca. 9000 cal B.P. (Lyman 2004:83). Conversely, xeric-adapted mammals grew in abundance. *Antilocapra americana*, *Ovis canadensis*, and *Brachylagus idahoensis* are among the species that appear with greater frequency in the faunal record (Lyman 1991, 2004, 2008) (Table 5.1). These species have historically occupied the same kinds of xeric habitats that flourished during warmer-drier Early Holocene conditions.

Discussion

Faunal assemblages from Orcas Island, the Olympic Peninsula, Columbia Plateau, Snake River Plain, Willamette Valley, and Harney-Owyhee Broken Lands regions suggest there was a major shift in climate in the Pacific Northwest at the PHB. Climate change at this period was of a magnitude large enough to produce genetic, behavioral and morphological responses in animal species. Significant changes in the composition, size, distribution, and abundance of mammalian taxa suggest that cool-moist conditions at the Late Pleistocene transitioned to warmer-drier conditions by the Early Holocene.

Cold-adapted megafauna inhabited the Pacific Northwest at a time when increased moisture stimulated the expansion of a variety of subsistence resources. The extinction of megafauna at the Late Pleistocene is still debated, but climate-extinction models suggest that climate change played at least some role in the sharp decrease and/or elimination of many megafaunal species.

Climate change played a significant role in changes to the size and distribution of some mammals at the PHB. A reduction in the size and extent of large-bodied mammals, particularly bison and elk, suggests that diminution likely occurred as a result of climatically driven decreases in nutritional forage. Species of this period are found in areas that today cannot support their survival. Shifts in the range of certain mammals are linked to climate-induced changes in plant communities and available habitat.

Faunal assemblages from the Early Holocene argue for a reduction in the number of large-bodied mammals and increases in xeric-adapted taxa across the Pacific Northwest. These changes are associated with a region-wide reduction in available precipitation, increased temperatures, and decreased vegetation in many areas. The disappearance of bison from the faunal record by ca. 9000 cal B.P. is associated with a reduction in precipitation and grass productivity. Xeric taxa, including pronghorn, Bighorn sheep, and pygmy rabbit, became more abundant as shrub-steppe and other drought-tolerant habitats expanded.

Interpretations of Late Pleistocene-Early Holocene climate variability inferred from faunal datasets are generally consistent with interpretations of climate made from other forms of proxy data. Faunal evidence not only reflects shifts in the availability of plant resources, but also evolving landscapes and the distribution/abundance of available moisture.

Chapter 6

Stratigraphic and Geomorphic Proxy Datasets for Climate Change

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Introduction

Stratigraphic and geomorphic proxy data from sites in the Pacific Northwest (Figure 6.1) indicate that the Late Pleistocene to Early Holocene was marked by

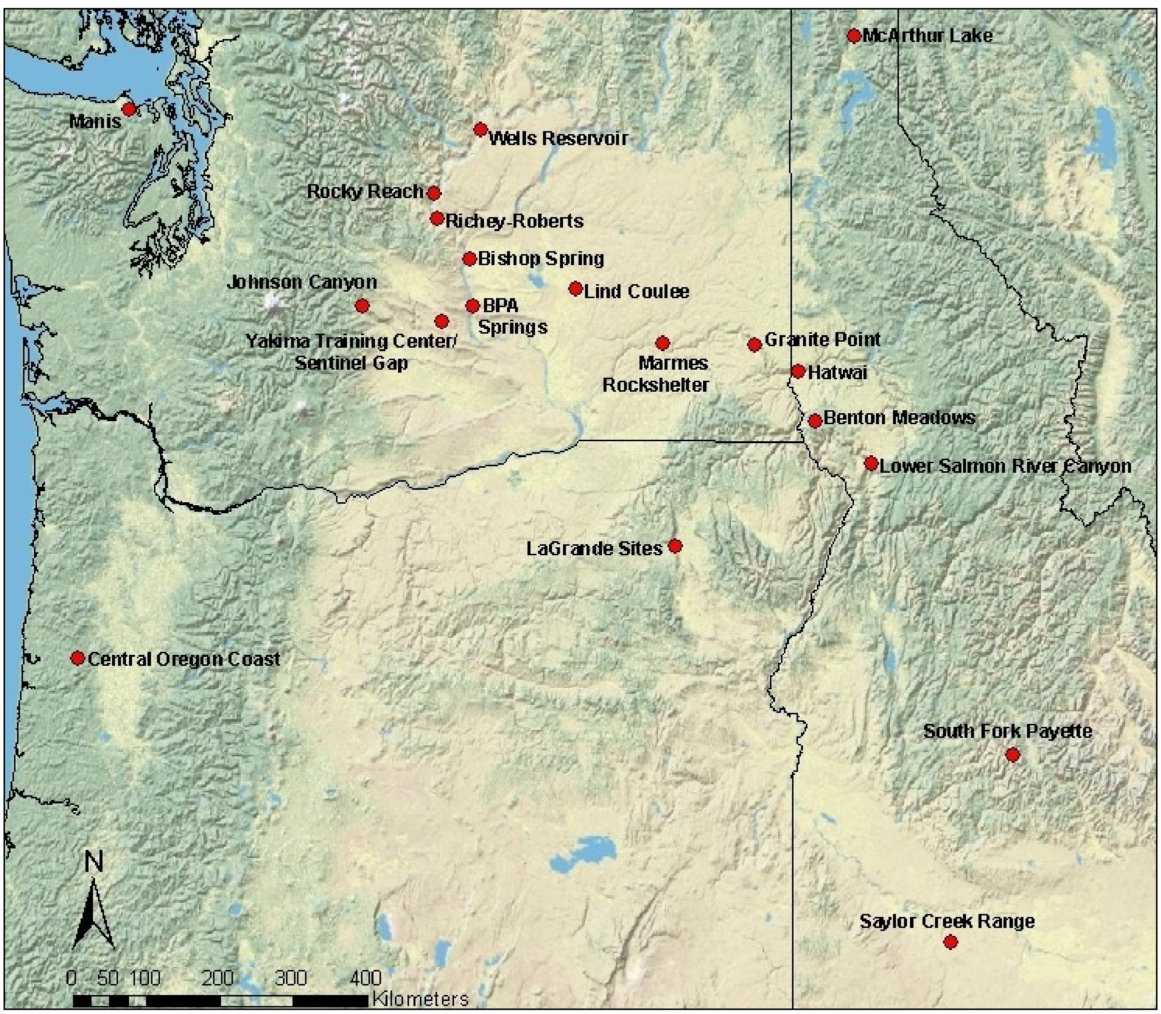

Figure 6.1. *Locations of stratigraphic/geomorphological sites discussed in this study.*

significant changes in landscape processes. Episodes of aggradation and pedogenesis are documented in the Olympic Peninsula (Morgan 1985), Columbia Plateau (Daugherty 1956; Fryxell and Daugherty 1962; Leonhardy 1970; Cochran 1978; Ames et al. 1981; Mierendorf 1983; Chatters and Hoover 1992; Luttrell 1997, 2001; Galm et al. 2000, 2002; Galm and Gough 2003; Gough 1995; Huckleberry et al. 2003; Huckleberry and Fadem 2007; Lenz et al. 2001, 2007; Lenz 2006, 2008); Salmon River Canyon (Davis 2001; Davis and Schweger 2004); Northern Rocky Mountains (Mierendorf and Cochran 1981; Pierce et al. 2011), Snake River Plain (Marler 2004); Grande Ronde Valley (Cochran and Leonhardy 1981), and in the central coast of Oregon (Personius et al. 1993) (Table 6.1).

Major changes in the erosion-sedimentation regime during the Late Pleistocene and Early Holocene occurred in response to changes in climate and related changes in the regional agents of sediment transport (Hay 1994:15). Geological research discussed in this chapter suggests that after the last episode of catastrophic flooding (Missoula Floods), the Late Pleistocene was characterized by landscape stability under the cool-moist climatic conditions of the Younger Dryas. These conditions are evidenced by the presence of paleosols in Late Pleistocene sediments. Paleosols often represent periods of increased moisture availability and landscape stabilization from vegetation (Wolfe et al. 2000:61).

The transition from the Late Pleistocene to the Early Holocene (PHB) is marked by fluctuating water tables and landscape instability. The transitional boundary appears to vary based on the physiographic region and local conditions, but it is generally synchronous across the Pacific Northwest, occurring between ca. 12,700-10,200 cal B.P.

Table 6.1. Late Pleistocene-Early Holocene Geological History of Sites in the Pacific Northwest.*

Site/Area	Age	Location	Geological History	Source(s)
Manis site (45CA218)	LP ca. 13,840-10,740 cal BP	Olympic Peninsula	aggradation, soil development, marsh-like landscape	Morgan 1985
	LP-EH ca. 10,740-10,200 cal BP		fluctuating water table, changes in mode of deposition	
	EH <10,200 cal BP		highly vegetated marshy or peaty landscape	
Wells Reservoir region	EH ca. 10,200-9000 cal BP	north-central Washington	rapid floodplain aggradation	Chatters and Hoover 1992
	EH-MH ca. 8600-7425 cal BP		channel downcutting, slow floodplain accretion	
Rocky Reach of Columbia River Valley	LP-EH > 12,880- > 7840 cal BP	central Washington	alluvial fan aggradation	Gough 1995
	EH > 9130 cal BP		episode of aggradation and entrenchment	Mierendorf 1983
Richey Roberts site (45DO482)	LP ca. 15,525-12,880 cal PB	central Washington	soil development	Lenz 2006
	LP-EH ca. 12,880-10,200 cal BP		rapid loess accumulation, fluctuating water table	
	EH ca. 10,200 cal BP		soil development	
Johnson Canyon region	LP ca. 15,525-13,140 cal BP	central Washington	fluvial sand deposition	Cochran 1978
	LP ca. 13,140-12,430 cal BP		fluvial sand deposition	
	LP-EH ca. 12,430-7840 cal BP		soil development, alluviation, erosion, downcutting	
Bishop Spring site	LP-EH	central Washington	soil development, changes in mode of deposition	Huckleberry et al. 2003

**LP=Late Pleistocene, EH=Early Holocene*

Table 6.1. (cont.) Late Pleistocene-Early Holocene Geological History of Sites in the Pacific Northwest.*

Site/Area	Age	Location	Geological History	Source(s)
Lind Coulee site (45GR97)	LP ca. 12,880 cal BP	central Washington	Touchet Bed deposition	Daugherty 1956
	LP < 12,880 cal BP		alluviation in stream or lake	
	EH		rapid loess accumulation	
BPA Springs site	LP-EH	central Washington	fluctuating water table, landscape instability	Huckleberry et al. 2003
Yakima Training Center	LP-EH 12,620-11,320 cal BP	south-central Washington	soil development formed on alluvium	Galm et al. 2000
	EH < 11,245- > 9000 cal BP		soil formation aggraded above older buried soil	
	EH < 9000 cal BP		significant erosion	Galm et al. 2002
Sentinel Gap site (45KT1362)	LP > ca. 11,860 cal BP	south-central Washington	soil development, landscape stability, marsh-like	Galm et al. 2000, 2002; Galm and Gough 2003; Huckleberry et al. 2003
	PHB		fluctuating water table, landscape instability	
	EH ≤ ca. 11,860 cal BP		rapid eolian deposition	
Marmes Rockshelter (45FR50)	LP-EH ca. 12,570-11,175 cal BP	southeast Washington	eboulis production, δ13C and δ18O signatures in soil organic matter	Huckleberry and Fadem 2007; Fryxell and Daugherty 1962
	EH ≤ 10,200 cal BP		salt accumulation in hillslope soils, increased eolian deposition in rockshelter	

**LP=Late Pleistocene, EH=Early Holocene*

Table 6.1. (cont.) Late Pleistocene-Early Holocene Geological History of Sites in the Pacific Northwest.*

Site/Area	Age	Location	Geological History	Source(s)
Granite Point site (45WT41)	EH < 11,400- ca. 9000 cal BP	southeast Washington	floodplain development, eolian deposition	Leonhardy 1970
	EH ca. 9000- > 7575 cal BP		moderate soil development overlain by eolian deposition	
Hatwai site (10NP143)	LP ca. 11,740 cal BP	northeast Idaho	dune bar aggradation	Ames et al. 1981
	PHB-EH ca. 11,075-9545 cal BP		reduced alluviation, sandy braided system	
	EH ca. 9545-8610 cal BP		aggradation	
	MH ca. 8160-7425 cal BP		deltaic-fan and modified alluvial fan deposition	
Benton Meadows site (10NP315)	EH	northeast Idaho	eolian deposition	Luttrell 1997
lower Salmon River Canyon	LP > 13,215 cal BP	western Idaho	eolian loess deposition	Davis 2001; Davis and Schweger 2004
	LP ca. 13,215-12,630 cal BP		soil development	
	EH		increased erosion, transport of slope sediments, significant landscape and geomorphic changes	
McArthur Lake vicinity	LP	northern Idaho	fluvial deposition, terrace formation	Mierendorf and Cochran 1981
	LP-EH		dune and sheet sand deposition	
	EH		eolian aggradation and dune formation	

**LP=Late Pleistocene, EH=Early Holocene*

Table 6.1. (cont.) Late Pleistocene-Early Holocene Geological History of Sites in the Pacific Northwest.*

Site/Area	Age	Location	Geological History	Source(s)
South Fork Payette River	PHB	central Idaho	aggradation and incision	Pierce et al. 2011
	MH ca. 7840-6845 cal BP		substantial aggradation	
Saylor Creek Range	LP ca. ≤ 15,150- ≥ 13,110 cal BP	southern Idaho	Bishop Geosol (Lenz et al. 2001, 2007; Lenz 2008) indicating soil development	Marler 2004
	EH < 13,110- > 7575 cal BP		Badger Mountain Geosol (Lenz et al. 2001, 2007; Lenz 2008) indicating soil development	
La Grande sites (35UN52, 35UN95, 35UN74)	LP-EH ca. 12,610- ≤ 8425 cal BP	northeast Oregon	aggradation, soil development, landscape stability	Cochran and Leonhardy 1981
	EH		erosion, downcutting and/or wind deflation	
Central Oregon Coast	LP-EH ca. 12,880-10,200 cal BP	west-central Oregon	region-wide aggradation, continuous terrace formation	Personius et al. 1993

**LP=Late Pleistocene, EH=Early Holocene*

Fluctuating water tables are represented by redoximorphic features in stratigraphic profiles (Table 6.1). Redox mottling is associated with oxidation and reduction of minerals caused by water saturation and desaturation (O'Leary 2012). Fluctuating water tables may represent a response to unstable climatic conditions at the PHB (Davis et al. 2002).

Accelerated eolian deposition and aggradation in major river systems mark an abrupt transition to warmer-drier conditions at the Early Holocene. Eolian activity indicates a periods of regional drought (Wolfe et al. 2000:61). Stratigraphic records suggest that sometime after this warm-dry episode, another period of increased moisture occurred across the region, as evidenced by the presence of paleosols that formed in Early Holocene sediments. At several locations an episode of Mid-Holocene aggradation is recorded which may be associated with the 8200 cal B.P. cooling event (Table 6.1).

Olympic Peninsula

Manis Site

Stratigraphic studies from the Manis site (45CA218) (Table 6.1) in the northern foothills of the Olympic Mountains suggest a marsh-like environment, aggradation, and soil development during the Late Pleistocene-Early Holocene between ca. 13,840-10,740 cal B.P. Sometime between ca. 10,740-10,200 cal B.P., fluctuations in the water table and variations in deposition occurred whereby silt accumulated in an open water pond. After ca. 10,200 cal B.P., stratigraphic records show a complete change in the environment marked by a transition from an open pond to a highly vegetated marshy or peaty landscape. Morgan suggests that the cause in environmental change is attributed to the Early Holocene warming trend which allowed trees to expand into lower elevations, thus adding organic debris to the site (Morgan 1985:18, 28-31).

Columbia Plateau

Wells Reservoir Region

Stratigraphic records from the Wells Reservoir region (Table 6.1) reveal a dated sequence of floodplain development characterized by cycles of alluvial deposition and landform stability during the Holocene. Aggradation episodes began shortly after Late Pleistocene catastrophic floods dated to ca. 15,150 cal B.P. Four episodes of rapid floodplain aggradation were identified, the oldest occurring between ca. 10,200-9000 cal B.P. Chatters and Hoover posit that decreases in vegetation exposed soil for transport during this period, while winter warmth enhanced flooding as a result of more frequent rain-on-snow events.

Paleoenvironmental records register a cool-moist interval in the region between ca. 7840-7425 cal B.P. that is represented in the stratigraphic record by channel downcutting and slow floodplain accretion (Chatters and Hoover 1992:42, 45, 52). The aggradational event is synchronous with episodes of rapid aggradation in river systems recorded throughout Europe. The aggradation events in Europe are linked to the 8200 cal B.P. cooling event (see Nesje & Dahl 2001; Bonsall et al. 2002), thus it is possible that the second episode of aggradation recorded by Chatters and Hoover is similarly associated with the 8200 cal B.P. cooling event.

Rocky Reach of Columbia River Valley

Sedimentological studies by Gough (1995) suggest that alluvial fan aggradation occurred in the Rocky Reach of the Columbia River Valley (Table 6.1) during the Late Pleistocene and Early Holocene. Deposition at the Chelan Falls and Orondo localities began before ca. 12,880 cal B.P. and ceased shortly before the fall of Mazama tephra at ca. 7840 cal B.P. Sediments were deposited in a manner consistent with arid and semi-arid climate alluvial fan processes (Gough 1995:65, 90). Mierendorf (1983:640) reports four possible episodes of aggradation and entrenchment during the Holocene at Rocky Reach, the first occurring before ca. 9130 cal B.P.

Richey-Roberts Site

Recent geoarchaeological research conducted at the Richey-Roberts site (Table 6.1) by Lenz (2006) identified terminal Pleistocene buried soil dating to ca. 15,525-12,880 cal B.P. The paleosol was buried by rapid loess accumulation and the formation of Early Holocene soils at ca. 10,200 cal B.P. This phenomenon is described as sequenced pedogenic/geologic coupling. Also noted are redoximorphic features that terminate in Early Holocene loess. According to Lenz, known Paleoindian sites exhibit features similar to the Richey-Roberts site, including alluvial terrace formation which occurred as a result of post-flood dewatering followed by upper Pleistocene alluviation (Lenz 2006:104).

Johnson Canyon

Stratigraphic investigations in Johnson Canyon (Table 6.1) show cyclic episodes of erosion, deposition, and soil formation during the Late Pleistocene and Early Holocene. A major period of erosion and eolian deposition is documented between ca. 15,525-13,140 cal B.P. Fluvial sand deposition occurred between ca. 13,140-12,430 cal B.P. after Glacier Peak ash fall. A period of soil formation, alluviation, and erosion and downcutting is recorded from ca. 12,430-7840 cal B.P. (Cochran 1978:v-vi, 50).

Bishop Spring Site

Preliminary stratigraphic investigations at the Bishop Spring site (Table 6.1) in the western Columbia Plateau suggest that soil formation during the Late Pleistocene and Early Holocene was interrupted by a change in the mode of deposition. The change in deposition is evidenced by the presence of paleosols that were formed and buried in eolian, fluvial, and colluvially redeposited silt beds. Paleosols are marked by buried A horizons with abundant plant macrofossils. St. Helens Set S (ca. 15,150 cal B.P.) Glacier Peak (ca. 13,110 cal B.P.), and Mazama (ca. 7575 cal B.P.) tephra bracket the silt beds (Huckleberry et al. 2003:242-243).

Lind Coulee Site

Stratigraphic and paleoenvironmental investigations at the Lind Coulee site (45GR97) (Table 6.1) in Central Washington provide evidence for a cool-moist Late Pleistocene environment that is followed by warm-dry Early Holocene conditions (Daugherty 1956). The site occupation surface is found above Missoula Flood sediments known as Touchet Beds (“Bed E”) that were formed during a proglacial period at ca. 12,880 cal B.P. Proglacial conditions were replaced by cool-moist Anathermal conditions after ca. 12,880 cal B.P., as evidenced by stratigraphic “Bed D” characteristics which indicate deposition in a sluggish stream or lake. Culture-bearing sands are capped by a thick layer of loessial material thought to have formed under a warm-dry Altithermal climate (Daugherty 1956:233-234, 256).

BPA Springs Site

The stratigraphic record at the BPA Springs site (Table 6.1) in central Washington suggests that water table fluctuations and possible landscape instability occurred at the PHB in the area. Prominent fine-grained flood sediments possessing redoximorphic features provide evidence of this. Redox mottling indicates fluctuating water tables which may represent a response to unstable climatic conditions at the PHB (see Davis et al. 2002). Pleistocene-Holocene Boundary redoximorphic features at BPA Springs are similar to those found at the Sentinel Gap site (Huckleberry et al. 2003:244).

Yakima Training Center

Stratigraphic and geomorphic investigations of drainage basins in the Yakima Training Center (Table 6.1) of south central Washington provide evidence for four major cycles of alluviation spanning the Late Pleistocene and Holocene (Galm et al. 2000). Alluvial Cycle 1 is dated to the Late Pleistocene-Early Holocene and includes younger Dryas- and Early Holocene-age soil formation. Younger Dryas-age soil formation includes A horizons of buried soils that formed on Late Pleistocene-Early Holocene alluvium between ca. 12,620-11,320 cal B.P. The second period of soil development occurred during the Early Holocene sometime after ca. 11,245 and before 9000 cal B.P. Early Holocene soil development may represent a regional pattern of landscape stability (Galm et al. 2000:7.3). The younger paleosol predates a strong erosion episode that is observable in many channel cross sections and alluvial fans in the region. Early Holocene erosion occurred sometime after ca. 9000 cal B.P. (Galm et al. 2000:6.3-6.4).

Sentinel Gap Site

Paleoenvironmental investigations at the Sentinel Gap site (45KT1362) (Table 6.1) in the Yakima Training Center provide a record of abrupt climate change marked by a shift from cool-moist to warm-dry conditions at the PHB (Galm et al. 2002; Galm and Gough 2003; Huckleberry et al. 2003). The Younger Dryas interval is characterized by a buried, organic matter-rich soil A horizon and long redox structures which suggest the growth of phreatophytic plants (Figure 6.2). The stratigraphy suggests a moist riparian environment and landscape stability sometime before ca. 11,860 cal B.P. Soil

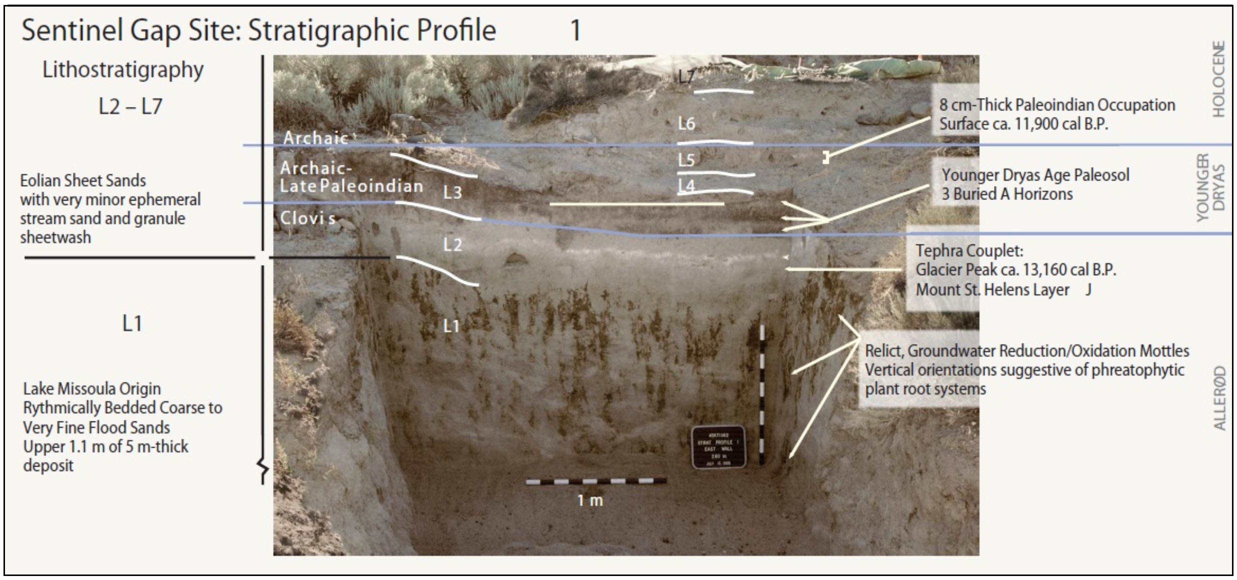

Figure 6.2. *Stratigraphic profile from the Sentinel Gap site (45KT1362) (image courtesy of Archaeological and Historical Services, Eastern Washington University).*

formation is further indication of moister environmental conditions during the Younger Dryas.

Accelerated eolian deposition and fluctuating water tables mark the transition into the Early Holocene (Galm and Gough 2003). Rapid capping of the occupation surface by eolian sand aggradation at or after ca. 11,860 cal B.P. contributes to the interpretation of an abrupt change toward warmer-drier conditions (Galm et al. 2002; Galm and Gough 2003). The degree of bone preservation and nearly vertical flake orientations further suggests rapid eolian sedimentation (Galm et al. 2002). Similar eolian aggradation events have been reported at Marmes Rockshelter, Granite Point, and elsewhere on the lower Snake River region (Huckleberry et al. 2003:40).

Marmes Rockshelter

Physical, chemical, and isotopic analyses of archived sediments from the Marmes Rockshelter (45FR50) (Table 6.1) in southeastern Washington document a transition from cool-moist conditions at the Late Pleistocene to warm-dry conditions by the Early Holocene (Fryxell and Daugherty 1962; Huckleberry and Fadem 2007). Initial stratigraphic excavations were conducted by Fryxell and others in the 1960s and recently analyzed in detail by Huckleberry and Fadem (2007). Cool-moist climatic conditions from ca. 12,570-11,175 cal B.P. are suggested by eboulis production and $\delta^{13}C$ and $\delta^{18}O$ signatures in soil organic matter. A shift to a warmer-drier climate occurring as early as ca. 10,200 cal B.P. is suggested by salt accumulation in hillslope soils and increased eolian deposition in the rockshelter (Huckleberry and Fadem 2007:21, 30-31).

Granite Point Site

The stratigraphic record at the Granite Point site (45WT41) (Table 6.1) in southeastern Washington provides evidence for floodplain development followed by eolian sand deposition at the Early Holocene. Floodplain development is dated to sometime after ca. 11,400 cal B.P. and before ca. 9000 cal B.P. Moderately developed soil is deposited sometime around 9000 cal B.P. and is overlain by pre-Mazama (ca. 7575 cal B.P.) eolian sands (Leonhardy 1970:72-73).

Hatwai Site

Multiple phases of aggradation during the Late Pleistocene and Holocene are documented at the Hatwai site (10NP143) (Table 6.1) in northeast Idaho (Ames et al. 1981). The earliest episode of aggradation is documented in the mid-gravel-sand dune bar at the Hatwai narrows. It is attributed to the Late Pleistocene and dates to ca. 11,740 cal B.P. A period of reduced flow characteristic of a sandy braided system is recorded between ca. 11,075-9545 cal B.P. and attributed to the PHB. Stream competence increased after ca. 9545 cal B.P. and was followed by a period of erosion and reduction in deposition beginning by ca. 8610 cal B.P. A Mid-Holocene episode of deltaic-fan and modified alluvial fan deposition is documented between ca. 8160-7425 cal B.P. (Ames et al. 1981:44-48). This is contemporaneous with the 8200 cal B.P. cooling event.

Benton Meadows

Cultural resource testing at site 10NP315 in Benton Meadows (Table 6.1) of western Idaho identified a projectile point/knife attributed to the Windust Phase (ca. 11,400-9000 cal B.P.). The projectile point/knife was buried above a dry, oxidized fine silt surface (Luttrell 1997:11, 14).

Lower Salmon River Canyon

Pedostratigraphic, geomorphic, and lithostratigraphic data from the Cooper's Ferry site (10IH73) and elsewhere in the lower Salmon River Canyon (Table 6.1) contribute to the interpretation of an evolving riparian ecosystem at the Late Pleistocene-Early Holocene in the region (Davis 2001; Davis and Schweger 2004). Records present evidence for cycles of Late Pleistocene eolian loess deposition followed by Younger

Dryas-age pedogenesis. Soil development at the terminal Pleistocene is replaced by a period of Early Holocene erosion and aggradation.

The Late Pleistocene is marked by the accumulation of eolian loess across the landscape (Davis 2001). Loess accumulations are commonly linked to arid and windy glacial conditions with sparse vegetation in source areas (Sweeney et al. 2005:261). Paleosol horizons within loess deposits show that soil development was occurring under moist conditions during the Late Pleistocene. Paleosol horizons in the Rock Creek Soil pedofacie (ca.15,530-12,630 cal B.P.) are dated to ca. 13,215 B.P. and 12,630 cal B.P. (Davis and Schweger 2004:691, 699, 701).

A shift from eolian deposition to alluvial fan and floodplain aggradation at alluvial lithofacie Qa14 (>13,200-ca. 1915 cal B.P.) indicates a shift in geomorphic and landscape evolution at the Early Holocene. The depositional sequence suggests changes in the geomorphic systems and landscape evolution associated with increased erosion and transport of slope sediments. Occasional dewatering structures are seen at the boundaries of the unit (Davis 2001; Davis and Schweger 2004:700, 689).

Northern Rocky Mountains

McArthur Lake Vicinity

Geomorphic and stratigraphic investigations of archaeological sites in the McArthur Lake vicinity (Table 6.1) of northern Idaho (Mierendorf and Cochran 1981) present a record of fluvial deposition at the Late Pleistocene followed by a period eolian aggradation at the Early Holocene. The geomorphic context suggests the occurrence of Late Pleistocene proglacial terrace formation followed by Late Pleistocene to Holocene dune and sheet sand deposition. The immediate postglacial stratigraphic sequence is represented by eolian activity that resulted in the formation of the dunes. Within these dunes is a buried, weakly developed soil horizon which is interpreted to represent a brief warming episode, a period of non-deposition, or both.

South Fork Payette River

Geomorphologic data from the South Fork Payette River (Table 6.1) in central Idaho (Pierce et al. 2011) indicates that a period of aggradation and incision occurred at the PHB in the area. This is based on extrapolations of soil development, Early Holocene incision rates, and deposit characteristics. Terraces with treads ca. 10, 13, and 21 m above bank fill (T0-T2) are dated between the last glacial age and Early Holocene. The T0 terrace is interpreted to be a glacial fill terrace based on lithology and depositional features. A substantial interval of aggradation is also recorded for the middle Holocene between ca. 7840-6845 cal B.P. (T3 terrace) (Pierce et al. 2011:4, 16). The middle Holocene aggradation event is contemporaneous with the 8200 cal B.P. cooling event.

Snake River Plain

Stratigraphic records from the Saylor Creek Range (Table 6.1) in southern Idaho (Marler 2004) document two periods of Late Pleistocene-Early Holocene soil development. This is evidenced by the presence of two paleosol horizons in terminal Pleistocene and Early Holocene sediments. The paleosol sequence at the Saylor Creek Range is consistent with the model of geosol development proposed by Lenz and others (2001, 2007) (Marler 2004:64). According to the model, Late Pleistocene and Early Holocene soil development is represented in the stratigraphic record by distinct geosol or paleosol strata that are referred to as Bishop and Badger Mountain geosols. These pedostratigraphic units are found in a wide variety of depositional environments in the Pacific Northwest.

Bishop Geosol, dating to the Late Pleistocene, is characterized by a well-developed A horizon and thin Cambic (Bw) or Argillic (Bt) horizons. The horizons are positioned between Mount St. Helens Set S (ca. 15,150 cal B.P.) and Glacier Peak (ca. 13,110 cal B.P.) tephras. Badger Mountain Geosol is Early Holocene in age, post-dating Glacier Peak tephra and pre-dating Mazama (ca. 8500 cal B.P.) tephra. It is similar to the Bishop Geosol and characterized by multiple buried A (Ab) horizons, Cambic horizons, and well-developed argillic horizons (Lenz et al. 2001, 2007; Lenz 2008; see also Marler 2004:65).

Grande Ronde Valley

Geologic investigations from the Stockhoff (35UN52), Marshmeadow (35UN95), and Ladd Canyon (35UN74) archaeological sites (“La Grande” sites) (Table 6.1) indicate region-wide episodes of floodplain aggradation, landscape stability, and erosion at the Late Pleistocene-Early Holocene. Aggradation began at ca. 12,610 cal B.P. and persisted until at least ca. 8425 cal B.P. Aggradation deposits are capped by paleosols that contain argillic and cambic horizons, indicating a period of landscape stability. The deposits are truncated, suggesting that landscape stability transitioned to a period of erosion in which sediments were degraded by downcutting and/or wind deflation. Comparisons with other contemporaneous sites in the Pacific Northwest suggest alluvial deposition was synchronous throughout the Pacific Northwest (Cochran and Leonhardy 1981:26, 35).

Central Oregon Coast

A regional aggradation episode is documented in the drainage basins of the central Oregon Coast Range (Table 6.1) at the Late Pleistocene-Early Holocene. Region-wide aggradation is evidenced by radiocarbon ages of nearly continuous terraces that are present along streams in drainage basins throughout the region. According to Peresonius and others (1993), the aggradation may be related to climate-induced changes in the frequency of colluvium evacuation from hollows common in all drainage basins in the region. Terraces are clustered at ca. 12,880-10,200 cal B.P. (Personius et al. 1993:297).

Discussion

Stratigraphic and geomorphic studies of major river systems in the Pacific Northwest suggest that there was an abrupt transition in climate regimes at the PHB. Climate change is represented by episodes of aggradation and pedogenesis in physiographic areas across the region. Characteristics of region-wide geological events argue for a moist and/or cool-moist climate during the Late Pleistocene, followed by a warmer-drier climate by the beginning of the Early Holocene.

Soil development at the terminal Pleistocene occurred during a period of landscape stability associated with the cool-moist conditions of the Younger Dryas. An abrupt change in the mode of deposition and sedimentation rates is recorded in the pedogenic sequences at the PHB (Lenz et al. 2007:82). The presence of redoximorphic features in Late Pleistocene-Early Holocene sediments suggests fluctuating water tables and landscape instability at this time (Galm et al. 2000; Davis et al. 2002; Huckleberry et al. 2003). By ca. 12,700-10,200 cal B.P., the onset of warmer-drier conditions is evidenced by eolian deposition and aggradation in the drainage basins of the Pacific Northwest (Galm et al. 2000:7.12; Lenz 2008:354). Wind took the place of water as the primary agent of aggradation after ca. 10,200 cal B.P., and soil transport was accelerated by decreases in vegetation (Chatters and Hoover 1992;vChatters 1998:44). A second period of soil development dating to the Early Holocene is documented in most areas.

The geological events observed in this and other studies are consistent with the model of aggradation and pedogenesis proposed by Lenz and others (2001, 2007) and Lenz (2008). According to the model, region-wide, climate-controlled aggradation began by around 13,840 cal B.P. Episodes of aggradation are recorded by Late Pleistocene-Early Holocene alluvial chronologies along the major drainage ways in the Pacific Northwest. Aggradation formed terraces in major river systems and their tributaries.

Regional soil formation during the Late Pleistocene is suggested by the presence of Bishop Geosol in the stratigraphic record. A second episode of soil formation is indicated by the presence of Badger Mountain Geosol in Early Holocene sediments. The Bishop and Badger Mountain geosols/paleosols are observed in a wide variety of depositional environments (Lenz et al. 2007:82; Lenz 2008:354).

A Mid-Holocene-age episode of aggradation is observed in the Wells Reservoir region in north-central Washington (Chatters and Hoover 1992), at the Hatwai site (10NP143) in northeast Idaho (Ames et al. 1981), and the South Fork Payette River in central Idaho (Pierce et al. 2002). The 8200 cal B.P. cooling event is associated with sea level rises, increases in the frequency and magnitude of floods, and substantial aggradation in river systems throughout Europe and in areas of North America. Environmental events associated with the cooling period lasted for a duration of around

330 years, from ca. 8290–7960 cal B.P. (see Nesje & Dahl 2001; Bonsall et al. 2002). Significant episodes of Mid-Holocene aggradation documented in the Pacific Northwest are dated to around the same time, thus it possible that these episodes of aggradation are similarly associated with the 8200 cal B.P. cooling event.

Climatic conditions inferred from stratigraphic and geomorphological data are consistent with conditions interpreted from glacial, palynological, and faunal data. The similarity and synchroneity of geological events from one physiographic area to another adds to growing evidence for large-scale climate change in the Pacific Northwest. The apparent rapidity and abruptness of change from moist and/or cool-moist to warm-dry conditions supports the occurrence of rapid or abrupt climate change at the PHB.

Information accumulated in this and the preceding chapters has provided the framework necessary for understanding the micro- and macro-scale effects of climate change. In the following and final chapter, this knowledge is applied to the archaeological record in order to consider the ways in which climate change influenced cultural adaptations and development for Late Paleoindian-Early Archaic peoples of the Pacific Northwest.

Chapter 7

Conclusion

Introduction

This chapter examines the questions outlined in Chapter 1 as part of the Statement of Problem: 1) What are the characteristics of climate change at the terminal Pleistocene in the Pacific Northwest?; 2) What is the nature of paleoenvironmental change at the Pleistocene-Holocene Boundary?; and 3) What is the relationship between regionalization of Late Paleoindian-Early Archaic populations and climate change?

These questions address the potential ways in which climate change and associated changes in the environment influenced human adaptive strategies and altered the way that people conceptualized their surrounding landscapes. The data accumulated in Chapters 3-6 provide the foundation for considering these relationships. The discussions that follow each question are not intended to solve the vexing problem of how climate change influenced human behavior during the Late Quaternary. Rather, they provide insights which may help archaeologists and paleoecologists to better understand the connection between the earliest human inhabitants, the archaeological signature left by these people, rapid/abrupt climate change, and evolving ecologies at the terminal Pleistocene and Early Holocene in the Pacific Northwest.

1. What are the Characteristics of Climate Change at the Terminal Pleistocene in the Pacific Northwest?

Climatic and Environmental Conditions at the Younger Dryas Chronozone

Proxy records examined in this study suggest that the Younger Dryas chronozone in the Pacific Northwest was marked by a shift from the warming conditions of the Bølling-Allerød chronozone to cool-moist, but in some cases cool-dry, climatic conditions. Although this is the general trend, it is becoming more apparent that the cool-moist/cool-dry models that are typically used to describe conditions of this interval are an oversimplification of a more dynamic and variable climatic system. For example, research (Denton et al. 2005; Meltzer and Holliday 2010) suggests that seasonality may have been amplified at the Younger Dryas interval. This is inferred from increased CO_2, insolation and seasonality highs, and other proxy records which indicate that a majority of temperature lowering occurred during the winter rather than summer seasons.

There is a higher degree of variability between environmental responses to climate change of this period than was once recognized. Responses were different depending on a large number of factors, including elevation and proximity to the Pacific Ocean. In some areas it is believed that conditions were not extreme enough to produce a significant shift in vegetation (Grigg and Whitlock 1998; Meltzer and Holliday 2010). Nevertheless, a review of the most widely reported proxy indicators for climate in the Pacific Northwest—glacial features, pollen, fauna, and stratigraphy/geomorphology—consistently point to a shift to an overall cool-moist climate.

Northwest Coast and Puget-Willamette Trough: Cool Younger Dryas conditions are inferred from faunal assemblages at the Woodburn Bog site in northwest Oregon

(Dunleavy 2003; Stenger 2002), Ayer Pond site (45SJ454) in Orcas Island (Kenady et al. 2011), and Manis site (45CA218) in the Olympic Peninsula (Gustafson et al. 1979; Gilbow 1981; Waters et al. 2011). Taxa identified at these sites demonstrate that a diversity of cold-adapted, now-extinct megafauna occupied the coastal and lowland areas of western Washington and Oregon beginning sometime before ca. 15,000 cal B.P. and ending at the transition to the Early Holocene (ca. 11,400 cal B.P.). Mammals inhabiting the region at this period include *Mammut americanum* (American mastodon), *Mammuthus columbi* (Columbian mammoth), *Bison antiquus* (ancient bison), *Megatherium* (giant sloth), horse, dire wolf, and possibly American lion. More recently, a new species of predator bird, *Teratanis Woodburnensis*, was identified at the Woodburn Bog site in northwest Oregon (Baker 2005, Keefer 2010), adding to the list of extinct Pleistocene fauna from this region.

Episodes of Younger Dryas-age aggradation and pedogenesis associated with increases in available moisture are recognized at numerous sites along coastal Washington and Oregon. In the central Oregon coast (Personius et al. 1993), an episode of region-wide, climatically induced aggradation is evidenced by nearly continuous terrace formations along streams. The terraces cluster at around 12,900-10,200 cal B.P. Similarly, an aggradational event beginning by ca. 13,800 cal B.P. is recorded at the Manis site in the Olympic Peninsula (Morgan 1985).

Palynological data from the Puget Lowland demonstrates that cooler and moister than present climatic conditions began by ca. 13,800 cal B.P. and terminated at around 11,400 cal B.P. (Tsukada et al. 1981; Leopold et al. 1982; Cwynar 1987; Anundsen et al. 1994). Landscapes in the region were dominated by taiga and/or open woodland vegetation. Pollen profiles from the Puget Lowland are noticeably similar to those in the Okanogan Valley, where pollen data suggests that cooler-moister than present conditions also terminate at ca. 11,400 cal B.P. Although pollen data from the Northwest Coast was not examined in detail for this study, evidence for cool-dry Younger Dryas conditions comes from Little Lake in west-central Oregon (Grigg and Whitlock 1998) (Table 4.1).

Cascade Range: Relative and cosmogenic isotope ^{10}Be dates of moraine and ice-contact deposits suggest that glaciers in the Cascade Range of Washington began to advance at ca. 13,800 cal B.P. Evidence for multiple Younger Dryas-age climatic events comes from the Icicle Creek glacier near Leavenworth, Washington, where a dated moraine system suggests multiple episodes of glacial advance (Page 1939; Waitt 1977; Porter and Swanson 2008). Pollen data from the Battle Ground Lake site in southwest Washington (Barnosky 1985a; Walsh et al. 2008) and Indian Prairie site in northwest Oregon (Sea and Whitlock 1995) argue for cool-moist conditions by ca. 12,800 cal B.P. The pollen sequence at Gordon Lake (Grigg and Whitlock 1998), located ca. 26 miles southeast of Indian Prairie, suggests greater seasonality with cooler winters and drier summers between ca. 12,800-11,000 cal B.P. (Grigg and Whitlock 1998). Although it is located in the Okanogan Highlands area just east of the Cascades, similar cool-dry conditions are reported at Buckbean Bog in Mount Kobau, British Columbia (Heinrichs et al. 2001). Vegetation at sites interpreted to be cool-moist consisted of fir-dominant forests. A forest mosaic of pine, fir, mountain hemlock, alder, shrubs and/or herbs, and flowering plants are inferred at both Gordon Lake and Buckbean Bog.

Columbia Plateau: The vast majority of proxy datasets from the Columbia Plateau physiographic region suggest a transition to cool-moist climatic conditions by ca. 12,800 cal B.P. The exception is at Carp Lake in south-central Washington (Barnosky 1985b; Whitlock and Bartlein 1997), where cold-dry conditions are inferred from the absence of temperate aquatic taxa and presence of *Polygonum bistortoides* (American bistort)-type pollen (Whitlock et al. 2000:17). Interpretations of pollen spectra indicate that the scablands region was occupied by cold steppe (Whitlock 1992:15) or possibly tundra-like vegetation (Nickmann 1979), while trees occupied Palouse hills (Mack et al. 1976).

Stratigraphic and geomorphic studies in the major river systems of the Columbia Plateau indicate that soil development and aggradation occurred during a period of landscape stability at the terminal Pleistocene. The Younger Dryas event is associated with terrace formation, episodic alluviation, paleosol development, and other forms of aggradation beginning at around 13,200 cal B.P. In the lower Salmon River Canyon, multiple paleosol horizons identified in Rock Creek Soil indicate at least two episodes of soil development occurred under moist conditions at ca. 13,200 and 12,600 cal B.P. (Davis and Schweger 2004). These geological observations are consistent with the model of aggradation and pedogenesis proposed by Lenz and others (2001, 2007; see also Lenz 2008). This model suggests that a region-wide episode of climate-controlled aggradation and pedogenesis began around 13,800 cal B.P. in the Pacific Northwest. Soil development is represented by a distinct geosol horizon in the stratigraphic record in certain geographic locations of the Plateau around this time. The geosol horizon may immediately post-date the last cataclysmic Missoula Flood event.

Faunal assemblages from multiple archaeological and paleozoological sites support the interpretation of a cool-moist climate. Columbian and undifferentiated mammoth remains identified in southeast and east-central Washington (Martin et al. 1982; Galm 1983; Luttrell 2001) indicate that mesic vegetation dominated the region, and that the regional community of now-extinct megafauna can be characterized as cold-adapted species (see Daugherty 1956; Gustafson 1972; Grayson 1977).

Northern Rocky Mountains: In the Northern Rocky Mountains physiographic area, glacial advance associated with an abrupt return to cool temperatures is documented by moraine and glacial-lacustrine sediments deposited between ca. 14,000-11,400 cal B.P. (MacLeod et al. 2006; Thackray et al. 2004; Easterbrook et al. 2011). Multiple successions of moraine building in the Sawtooth Mountain range of northwest Montana are interpreted as an indicator of multiple climatic events during the Younger Dryas (Easterbrook et al. 2011:75). Evidence for increased moisture comes from Younger Dryas-age proglacial terrace formations in the McArthur Lake and South Fork Payette River vicinities (Mierendorf and Cochran 1981; Pierce et al. 2011).

Palynological data support glacial and geomorphologic evidence for generally cooler and moister conditions, but also suggests greater climatic and environmental variability and less extreme conditions than in surrounding regions (see Meltzer and Holliday 2010; Chapter 4 of this study). Taxa that are adapted to cool and/or cool-moist conditions dominate the pollen profiles of most sites. However, the pollen profile from Baker Lake in the Bitterroot Mountains argues for conditions that were cooler and drier than today (Brunelle et al. 2005); and pollen data from Burnt Knob Lake in the far western Bitterroot suggests that conditions were slightly warmer and wetter than during the Bølling-Allerød. In the mountains and foothills, vegetation cover is interpreted as open and closed pine-spruce forest. In the river valleys, tundra-like vegetation and closed pine-spruce forest are suggested.

Blue Mountains: Paleoenvironmental proxy data is largely lacking in the Blue Mountains physiographic region, but there is evidence to suggest that glacial advance occurred in the Wallowa Mountains of northeast Oregon shortly after the Younger Dryas at ca. 10,200 cal B.P. (Licciardi et al. 2004; Kiver 1974). Stratigraphic investigations at three sites (35UN52, 35UN95, 35UN74) in the Grande Ronde Valley of northeast Oregon suggest that aggradation, soil development, and landscape stability began at ca. 12,600 cal B.P. and ended during the Early Holocene (Cochran and Leonhardy 1981).

Snake River Plain and Harney-Owyhee Broken Lands: Faunal assemblages from the Wasden Site (10BV30) (Butler 1965a, 1965b, 1968, 1969; Plew and Pavesic 1982; Miller 1989) and Paisley Caves (35LK3400) (Cressman 1942; Jenkins 2010) suggest the presence of mammoth, ancient bison, camel, horse, and other extinct genera in the Snake River Plain and Harney-Owyhee Broken Lands physiographic regions during the terminal Pleistocene. Similar to the stratigraphic record of sites in the Columbia Plateau, Olympic Peninsula, and Grande Ronde Valley, stratigraphic investigations at the Saylor Creek Range in southern Idaho (Marler 2004) reflect a period of landscape stability and soil development during the terminal Pleistocene. Soil development is represented the presence of Bishop Geosol first identified by Lenz and others (2001, 2007). Soil development is dated from ≤ 15,150 to ≥ 13,110 cal B.P., thus it terminated by the beginning of the Younger Dryas chronozone.

Human Record at the Terminal Pleistocene

The evidence for Paleoindian habitation in the Pacific Northwest at the terminal Pleistocene remains extremely thin (Galm 1994; Meatte 2012). The earliest archaeological materials typically occur as surface finds. In rare instances when archaeological materials of this age are found in a depositional context, they are observed above Late Pleistocene flood sediments. If there was an archaeological record prior to the last episode of catastrophic Missoula Floods (ca. 15,500-14,000 cal B.P.; Atwater 1984), it was more than likely destroyed or possibly deeply buried. Until recently, what little was known about Paleoindian populations suggested that the first inhabitants of the region were people of the Clovis tradition. Research published in the last several years (Waters et al. 2011; Kenady et al. 2011; Jenkins et al. 2012), however, is challenging this notion by presenting evidence to suggest that humans may have occupied the region before or at the same time as Clovis.

At the Manis site (45CA218) in the Olympic Peninsula, AMS radiocarbon dates from a bone projectile point imbedded in the rib of a mastodon, and the rib and ivory tusk of the mastodon, have produced the oldest ages to date for a human presence in the Pacific Northwest with an average age of ca. 13,800 cal B.P. (Waters et al. 2011; see also Gustafson et al. 1979). Waters and others (2011) argue that the Manis site provides evidence that people were hunting probiscideans some two-to-eight millennia before Clovis (Waters et al. 2011). Across the Strait of Juan de Fuca at the Ayer Pond site (45SJ454) in Orcas Island, an ancient bison (*Bison antiquus*) showing signs of human butchering was similarly radiocarbon dated to ca. 13,800 cal B.P. (Kenady et al. 2011).

Research recently published on radiocarbon dates from Paisley Caves (35LK3400) in southern Idaho argues for pre-Clovis, or at least coeval, human occupation in the southern Pacific Northwest/Northern Great Basin region. This is based on the upper limiting radiocarbon dates of deposits containing human coprolites and artifacts, which suggest that humans occupied the area as early as ca. 14,500 cal B.P. (Jenkins et al. 2012).

Deposits containing possible Western Stemmed Tradition points from Paisley Caves are dated to ca. 13,240-12,950 cal B.P. (Jenkins et al. 2012). Similar dates of ca. 13,285 and 13,265 cal B.P. have been reported at the Cooper's Ferry site in the Lower Salmon River Canyon of west-central Idaho (Davis and Sisson 1998; Davis 2004). The cultural tradition associated with Cooper's Ferry and the vast majority of early Archaic (ca. 11,400-9000 cal B.P.) sites in the Pacific Northwest is a variant of Western Stemmed known as Windust. The Windust tradition is represented by Windust Phase/Complex material culture (Leonhardy and Rice 1970; Rice 1972) (Figure 7.1). If the dates from

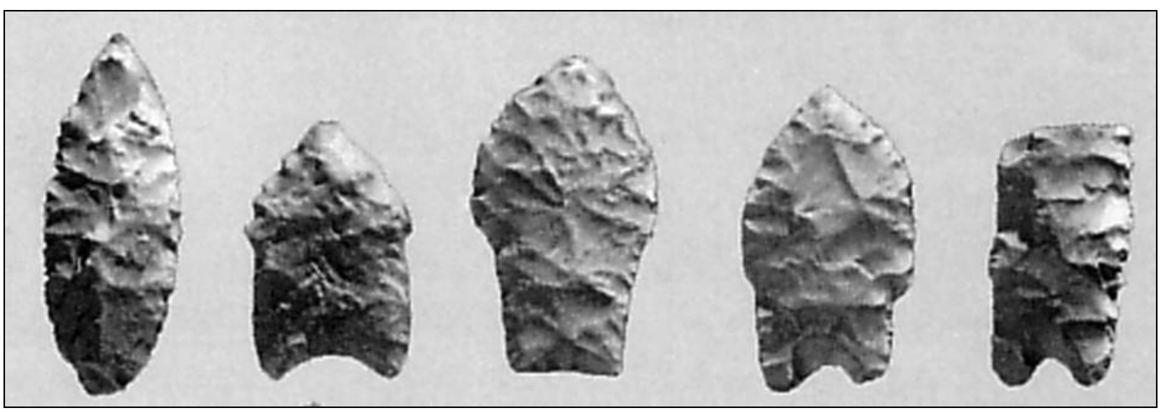

Figure 7.1. *Windust points showing the range of variation in style (photo courtesy of Idaho State University).*

Paisley Caves and/or Cooper's Ferry are correct, then the argument could be made that the Windust/Western Stemmed Tradition represents an earlier migration into the New

World, or at least one that is coeval with Clovis. Jenkins and others (2012) argue that Windust and Clovis are two distinct technologies with parallel developments and are not part of a unilinear technological evolution.

Despite these new early contenders, Clovis is still considered the first well-established culture in the Pacific Northwest. Surface finds of fluted points and one stratified Clovis site suggest that Clovis people occupied a number of physiographic regions in the Pacific Northwest at the terminal Pleistocene. The Clovis signature is ephemeral and the disproportionately large number of surface finds in comparison to buried sites suggests very short-term occupancy.

Currently the only well-defined site in the region is Richey-Roberts (Mehringer 1988; Gramly 1993) and it is clearly another "cache" or specialized site as opposed to a long- or short-term camp. Similar caches have been identified at the Simon site in south-central Idaho, Anzick site in south-central Montana, Colby site in north-central Wyoming, and Fenn cache in the general area of northeast Utah (Kilby 2008). Kilby (2008) argues that the Richey-Roberts, Simon, and Anzick caches are ceremonial or "afterlife" caches which represent a geographically restricted behavior that is not characteristic of Clovis culture as a whole. Kilby suggests that the majority of Clovis caches were created as a solution to resource incongruity, whereby their function was to ensure that lithic raw material was available along the way to an important subsistence resource area (Kilby 2008:222).

Very little is known about how Clovis utilized their environment. What is clear is that plant and animal subsistence resources were available to them and their diet more than likely included large-bodied mammals. A lack of archaeological data, however, has made it difficult to meaningfully discuss their settlement and overwintering patterns, details about their hunting and land use strategies, and if and how they fit into the generalist/specialist models of foraging (for various perspectives on the "Clovis as Generalist" and "Clovis as Specialist" debate see Meltzer and Smith 1986; Meltzer 1993; Haynes 2002; Waguespack and Surovell 2003).

Clovis surface finds and sites in the Pacific Northwest suggest an orientation to coastal regions and the Puget Lowland, and to a lesser extent the Columbia Plateau and Snake River Plain. Whether the orientation of Clovis finds to the costal west is a product of differential site preservation, environmental preferences and/or restrictions, human migration and/or entry into the New World, cultural preferences, or some other factor(s) is largely unknown.

Based on our limited knowledge of Clovis site locations and Younger Dryas environments, the most desirable places for human habitation at the terminal Pleistocene were probably in environments suitable for hunting large mammals and accessing other resources needed to fulfill their dietary, fuel, and construction requirements. Proximity to large bodies of water would have been equally as important. Palynological and faunal data presented in Chapters 4 and 5 of this study suggests that the plant and animal communities available to people at this period were very different from those before the Younger Dryas or after the transition to the Early Holocene. At many sites the pollen spectra suggest that there are no modern analogs for vegetation compositions before the Holocene Epoch.

The Northern Rocky Mountains and Northern Cascades were probably the least suitable areas for Paleoindian habitation in the Pacific Northwest. Even though there is evidence to suggest that conditions were less extreme in the Northern Rocky Mountains at the Younger Dryas (Meltzer and Holliday 2010; this study), glacial, palynological, and faunal data suggest that environments in these regions were highly unstable and variable, and there were fewer available subsistence resources. Cool-moist, cool-dry, and warmer-wetter climatic conditions have all been registered in higher elevations, and evidence for multiple glacial advances in both mountain ranges may indicate multiple episodes of Younger Dryas climate change (Easterbrook et al. 2011; Porter and Swanson 2008). Glaciers at the Younger Dryas occupied the northern tiers of the Columbia Plateau, which would also have made habitation very difficult.

By the terminus of the Pleistocene, material culture associated with the Clovis tradition rapidly fades from the archaeological record. In the Pacific Northwest, Windust/Western Stemmed, and to lesser extent Haskett traditions, begin to appear with greater frequency. These traditions represent the first clear evidence of regionalization in the Pacific Northwest. Just as with the Clovis tradition, their appearance coincides with an episode of major climatic change.

2. What is the Nature of Paleoenvironmental Change at the Pleistocene-Holocene Boundary?

Climatic and Environmental Conditions at the Pleistocene-Holocene Boundary

The vast majority of paleoenvironmental proxy records suggest that there was a significant shift in climate regimes at the Pleistocene-Holocene Boundary in the Pacific Northwest. Climate change at this interval is characterized by a transition from Younger Dryas glacial conditions to a markedly warmer and drier climate by the beginning of the Holocene (ca. 11,400 cal B.P.). This change is most prominently evidenced in the

Greenland ice cores, where Greenland Ice Sheet Project (GISP and GISP2) data (Alley 2000; Alley et al. 2003) suggest that the change occurred rapidly, possibly within a matter of years to decades (Alley 2000, Alley et al. 2003; Penn State 2006).

Climate change is associated with maximum glacial recession (Davis et al. 2009), rising temperatures, significant reduction in effective precipitation, drops in the base levels of rivers and lakes, wide-spread drought, megafaunal extinction, changes in the composition and distribution of plant and animal species, and aggradation and erosion in major river systems.

Palynological data suggests that the transition from Younger Dryas cooling to Early Holocene warmth and aridity occurred anywhere between ca. 13,000-9000 cal B.P. depending on the location, but tended to center around ca. 11,400 cal B.P (Table 4.1). With the exception of mountainous regions where forests expanded north as land became available following glacial recession, pollen data indicates that xeric shrub-steppe communities dominated many of the lower elevation landscapes. There is evidence to suggest that these communities expanded as far as the mountains surrounding the Columbia Basin (Mehringer 1985), leading Chatters (1995) to conclude that available moisture may have been much as 40 percent less than it is today.

An abundance of charcoal in Early Holocene sediments reflects greater frequency and severity of fires. Frequent fires may have left an irregular distribution of vegetation on the landscape (Cwynar 1987). Pollen proxies arguably offer the best evidence for rapid climate change at Pleistocene-Holocene Boundary in the Pacific Northwest. Proxy datasets provide a chronology for climate change, and the chronologies show a high degree of synchroneity in the transition from Younger Dryas to Early Holocene conditions. This is particularly true when considering the timing of transition at a 2-sigma calibrated age range.

Stratigraphic and geomorphological data point to a highly dynamic and unstable landscape at the Pleistocene-Holocene Boundary, which may represent a response to unstable climatic conditions (Davis et al. 2002). The presence of redoximorphic features in the stratigraphic record at numerous sites suggests fluctuating water tables and rapid dewatering. Geomorphological features and pollen profiles indicate that the base levels of many lakes, rivers, and streams dropped dramatically at this interval.

Episodes of rapid aggradation and erosion, channel incision and downcutting, terrace formation, and dune and sandsheet aggradation have all been recorded in watersheds and major river systems (Cochran 1978; Morgan 1985; Mierendorf 1983; Gough 1995; Chatters and Hoover 1992; Huckleberry et al. 2003; Galm et al. 2000, 2002; Galm and Gough 2003; Huckleberry and Fadem 2007; Davis 2001; Davis and Schweger 2004; Pierce et al. 2011). Sediments reflect a change in the mode of deposition at the PHB interval, where wind began to act as the primary agent of transport as opposed to water (Chatters and Hoover 1992; Morgan 1985; Huckleberry et al. 2003). Most Early Holocene sites are marked by rapid eolian/loess deposition and significant erosion after ca. 11,000 cal B.P. Eolian activity is further evidence of regional drought (Wolfe et al. 2000).

Faunal assemblages indicate that the last major pulse of Late Quaternary megafaunal extinction began around 12,900 cal B.P. during the Younger Dryas chronozone (Grayson and Meltzer 2003:586) and ended by the beginning of the Early

Holocene. At some sites evidence suggests that both extinct and extant species occupied the region at the same time, which is the case at the Wasden site (10BV30) in southeast Idaho (Butler 1965a, 1965b, 1968, 1969; Plew and Pavesic 1982; Miller 1989) and Woodburn Bog in northwest Oregon (Stenger 2002; Dunleavy 2003; Campbell and Stenger 2002; Baker 2005, Keefer 2010). Faunal assemblages from these sites show that now-extinct megafauna such as mammoth, mastodon, ancient bison, giant sloth, camel, and possibly American lion inhabited the Willamette Valley and Snake River Plain along with modern genera known to occupy the regions today.

At some sites faunal data suggests that modern species were present in areas that today cannot support the habitat required for their survival. For example, at the Marmes Rockshelter (45FR50) in southeast Washington, the remains of Arctic fox and pronghorn antelope are represented in the faunal assemblages (Fryxell and Daugherty 1962; Gustafson 1972; Lyman 2008, 2010, 2011). At the Sentinel Gap site (45KT1362) (Galm et al. 2002; Gough and Galm 2003; Lyman 2004; Litzkow 2011), Lind Coulee site (45GR97) (Daugherty 1956; Gustafson 1972; Irwin and Moody 1978; Huckleberry et al. 2003; Lyman 2004), and Windust Cave C (45FR46) (Rice 1965; Jenkins 2011), modern bison are among the represented species.

The Sentinel Gap site and Marmes Rockshelter also provide evidence to suggest that larger-than-modern mammals were present at the PHB. Larger-than-modern bison and Roosevelt elk are included in the Sentinel Gap faunal assemblage (Galm and Gough 2001, 2008; Gough and Galm 2003). The elk bone is radiocarbon dated to ca. 12,000 cal B.P., and is reportedly the same size and bone as a "Big Elk" species identified at the Marmes Rockshelter that is dated to ca. 11,200 cal B.P. (Lyman 2010). It is possible that these larger-than-modern species grew to their exceptional size as a result of an abundance of available grass during the waning stages of the Younger Dryas (Lyman 2004, 2010). Grasses diminished along with these large modern taxa when conditions began to become significantly warmer and drier.

Paradoxically, the warm-dry Early Holocene climate model that is seemingly ubiquitous in pollen, fauna, and stratigraphic/geomorphic records is not supported by glaciological data which argues for the contrary. Glacial records indicate that there were one or multiple episodes of climate cooling during the Early Holocene. Glacial readvances have been reported in the Northern Rocky Mountains of Idaho (Butler 1984, 1986), Cascade Range of Washington and Oregon (Beget 1981, 1984; Waitt et al. 1982; Thomas et al. 2000; Menounos et al. 2004; Heine 1998; Dethier 1980), and Wallowa Mountains of Oregon (Licciardi et al. 2004, Kiver 1974). Barnosky and others (1987) and Waitt and others (1982) posit that advances of this period were either the result of decreased temperatures or increased precipitation at higher elevations. The paradox may have been caused by a steepening of the temperature lapse rate during a period of aridity (Barnosky et al. 1987:298)

Changes in Human Adaptation at the Pleistocene-Holocene Boundary

Climate change at the PHB coincides with a significant transition in Late Paleoindian-Early Archaic weapons systems, technologies (Figure 7.2), and adaptive strategies. This interval is marked by an overall reduction in the size of points and bifaces, shifts in inferred point functionality (Beck and Jones 1993; Beck 1995), changes in the lithic reduction trajectory, and a movement toward more expedient flake technology (Galm et al. 2011). The large and highly specialized fluted points that

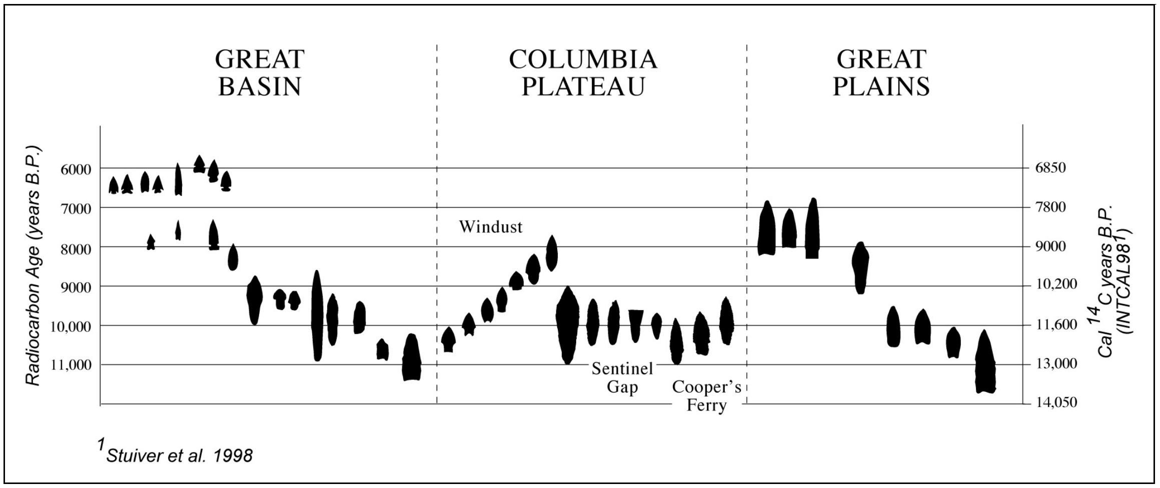

Figure 7.2. *Late Pleistocene-Early Holocene projectile point/knife sequences from the Great Basin, Columbia Plateau, and Great Plains (Galm and Gough 2008:219).*

are characteristic of Clovis tradition are replaced by smaller point complexes presumably used in thrusting and atlatl weapons systems. Researchers (Davis 2001; Huckleberry et al. 2003) have suggested a probable relationship between the changes observed in the archaeological record and shifts in climate and the environment.

Clovis culture virtually disappears at the PHB and is immediately followed by the appearance of regional cultures (Rice 1972; Davis 2001, 2004; Galm et al. 2011). The most prevalent and widely recognized post-Clovis tradition in the Pacific Northwest is the Windust tradition. The Windust point complex (Phase) was first defined at sites in the Lower Snake River region (Leonhardy and Rice 1972; D. Rice 1972; Daugherty 1956), but is now recognized over much of the inland and intermontane regions of the Pacific Northwest. Four forms dominate Windust complex point assemblages: a stemmed variant, small lanceolate variant, concave/notched base variety, and a shouldered lanceolate form (D. Rice 1972) (Figure 7.1). Points in this complex share stylistic similarities with Western Stemmed forms from the Northern Great Basin (Beck and Jones 1997; Ames et al. 1998; Davis 2001). Windust tradition is typically characterized by a more generalist subsistence model and expedient technological system (Ames et al. 1998).

Although Windust is the most prevalent tradition in Pacific Northwest, there is growing evidence for forays into the region by people with different adaptive strategies. Dated to ca. 11,975 cal B.P. (Galm and Gough 2001), the Sentinel Gap site in south-central Washington suggests the presence of a tradition that is arguably quite different from its Windust neighbors. Points and bifaces from the Sentinel Gap site (Figure 7.3)

Figure 7.3. *Late stage biface and projectile points from the Sentinel Gap site (45KT1362) (photo courtesy of Archaeological and Historical Services, Eastern Washington University).*

Figure 7.4. *Three Haskett points from the Haskett site (10PR37) in southern Idaho (photo courtesy of Idaho State Museum).*

Strongly resemble Haskett (Figure 7.4) and related (i.e., Hell Gap and Agate Basin) forms typical of the Great Plains to the east (Figure 7.2); and Cougar Mountain Cave and Lake Mohave styles associated with the Great Basin to the south (Galm et al. 2011). These points are typically large and lanceolate in style. There is an emphasis on the production of large bifaces. Final forms are produced through broad collateral flake removal. A prominent feature common to Sentinel Gap, Haskett, and related forms is a distinct broad shoulder on points and bifaces, where the greatest width dimension is characteristically above (distal) the point/biface midline (Galm and Gough 2002, 2008; Galm et al. 2011; Butler 1965b) (Figure 7.3).

Other factors separating the Sentinel Gap site from Windust complexes include the apparent single occupancy of the site, well radiocarbon dated occupation surface, highly regularized technological approach, and poor representation of expedient technology. The magnitude of the distinctions between Sentinel Gap and Windust complexes makes a strong argument for different cultural affiliations (Galm et al. 2011).

There are no ways to directly measure how climatic and environmental change influenced human behavior and technology, but several lines of reasoning can be explored. Proxy records reviewed in this study suggest a high degree of environmental variability at the PHB, marked by dramatic decreases in precipitation and water levels, increases in temperatures, redistribution of plant and animal species, desiccation of land, and the extinction or reduction in size of large-bodied mammals. If conditions changed rapidly and there was enough variability or disruption in the established subsistence/settlement system to affect productivity, it may have created enough pressure on humans to change the way they utilized and conceptualized their landscape.

For instance, it has been suggested (Beck and Jones 2009; Galm et al. 2011) that diminution in the overall size of projectile points at the PHB, and the corresponding shift from spear to atlatl/thrusting weapons systems, represent shifts in adaptation strategies associated with changes in animal communities. If there are fewer large-bodied mammals on the landscape, then it would seem less effective in terms of energy expenditure to maintain a subsistence strategy that focuses on the hunting of large-bodied mammals (i.e., the "Specialist" foraging model). Instead, strategies may change to focus on a wider diversity of animals and plants in order to fulfill the necessary dietary requirements of the group (i.e., the "Generalist" foraging model).

A diversified toolkit with projectile points that are more appropriate for hunting medium and small bodied mammals would probably be more effective with a generalist foraging model, which is exactly what is seen in Windust and other Early Holocene assemblages. The apparent explosion of convenience tools and expedient tool manufacturing techniques in Windust and other Early Archaic complexes is a possible indication of a movement away from the more rigorously defined and stylized lithic industries of the Paleoindian-Late Paleoindian periods. It may also coincide with a movement away from specialization in adaptive strategies to more generalized approaches (e.g., "catch as catch can").

There is also a basis for arguing that changes in the distribution of Late Paleoindian-Early Archaic sites might reflect shifts in settlement strategies associated with the redistribution of plant and animal species and available water. Stratigraphic, geomorphic, and palynological data point to a period of rapid dewatering and unstable landscapes at the PHB. The presence of Windust sites in the major riverine valleys of the Snake, Columbia, and Clearwater rivers indicate that water levels in these areas had reached approximations of modern base levels at this time. While Clovis may be present in lower elevations of at least portions of the Snake and Clearwater river systems, this is not the case for the mainstem of the Columbia due to the proximity and effect of the retreating continental ice sheet. This is reflected at the Richey-Roberts site which is located on a flood chute high above the modern base level of the Columbia. The fact that

Windust sites are found in the new riparian zones of the Columbia River at a relatively early date (i.e., ca. 12,600 cal B.P.; Sheppard et al. 1987) indicates they were capable of adapting quickly to changes in environmental conditions.

There are many unanswered questions when it comes to Late Paleoindian-Early Archaic traditions and their relationship with the environment. What does seem to be clear is that Windust peoples rapidly and successfully adapted to Early Holocene conditions. Shifts in the form, style, and function of point complexes; transition to a more generalist foraging approach; and a movement away from rigorously defined manufacturing techniques to more expedient technologies are all characteristics of Windust and other Early Archaic traditions. The prevalence of these technological approaches by the beginning of the Early Holocene suggests that populations inhabiting the Pacific Northwest were quickly changing their adaptive strategies at the PHB in response to climate change and associated changes in attendant resources. This model proved very successful for people of the Windust tradition, who in a short amount of time spread across the Pacific Northwest and dominated the Early Holocene archaeological record.

3. What Is the Relationship Between Regionalization of Paleoindian/Late Paleoindian-Early Archaic Populations and Climate Change?

Regionalization at the Terminal Pleistocene

The earliest evidence for human occupation in the Pacific Northwest suggests that small groups of highly mobile Paleoindian-Late Paleondian people moved into the region at the terminal Pleistocene during the Younger Dryas chronozone, and possibly earlier during the waning stages of the Bølling-Allerød warming period. The prevailing model for human entry into North America argues that the earliest Paleoindian populations crossed from Asia to Alaska through the Bering Strait land bridge that was exposed during the Wisconsin glaciation period (Figure 7.4). This model was first proposed in the 16th Century (de Acosta 1590) and was later supported by the discovery of geological evidence for an ice free corridor in Beringia during the Late Pleistocene (Johnston 1933).

The Bering Strait model of human entry is also supported by genetic data indicating that modern Native American populations descended from Asia. A recently published (2012) study on human genomes by Reich and others (2012) argues that there were three streams of Asian gene flow into North America during the Late Pleistocene. This three-wave model suggests that the earliest humans migrated into the Americas through Beringia, rapidly traveling southward on the West Coast of North America. The first population eventually diverged into three genetic groups that followed independent migratory trajectories.

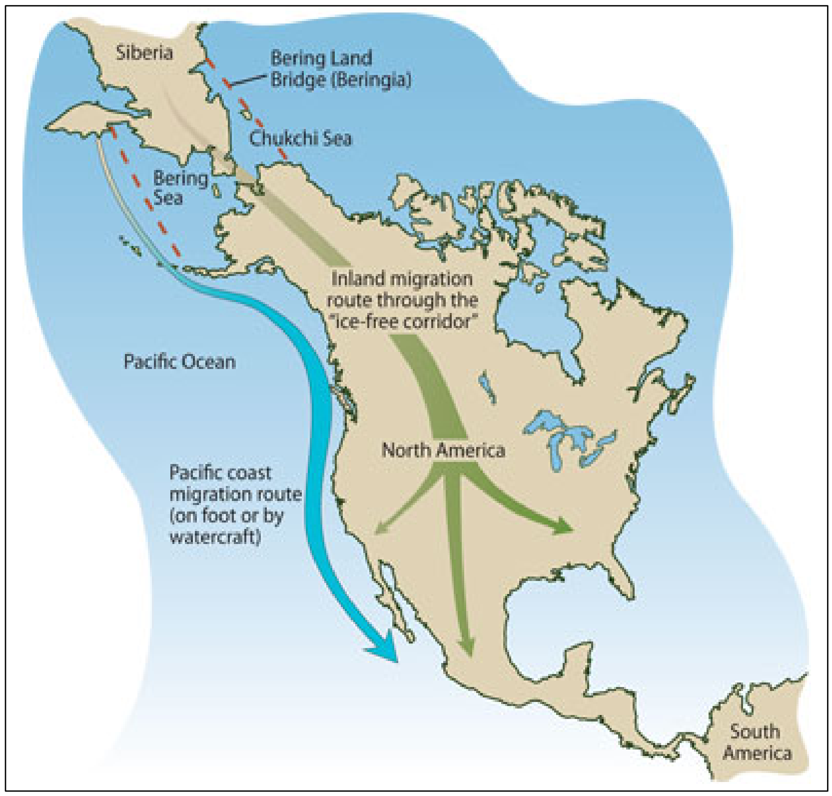

Figure 7.5. *Diagram of proposed migratory routes into North America (Crow Canyon Archaeological Center 2011).*

Reconstructing human history from genetic data is problematic, however, because there is a lack of archaeological evidence to support the Bering Strait model of migration

(Stanford and Bradley, eds. 2012). Since archaeologists generally agree that Clovis was the first tradition to regionalize North America, early Clovis sites are often used as a proxy for gauging the potential migratory patterns of the earliest people. If we accept the Bering Strait model of human entry, then one would expect the earliest Clovis sites to be found along the inferred migratory route. This includes areas in Alaska where the Bering Strait land bridge connected Siberia to North America, in the Alberta Plains of Canada where it is believed that an ice free corridor existed, and in the Northern Great Plains where the corridor provided entry into North America. It is also expected that a north-to-south trajectory would be reflected somewhere in the archaeological record. Currently there is no strong archaeological evidence in support of either a Bering Strait migration out of Siberia to Alaska much before ca. 12,000 cal B.P., or of a north-to-south trajectory (see Stanford and Bradley, eds. 2012).

Over the past several decades, alternative models for human entry into the New World have been gaining support. In the American West, there is growing evidence to suggest a coastal entry into the Americas (Figure 7.4). Radiocarbon dates from the Manis site (Waters et al. 2011), Ayer Pond site (Kenady et al. 2010; Lepper 2011), and in the Channel Islands of California (Erlandson et al. 2011) argue for the presence of Paleoindian peoples before Clovis in the coastal lowlands and islands off the Pacific Ocean. The density of early Paleoindian sites on the east coast similarly suggests a coastal entry, but by people of the Clovis tradition. Stanford and Bradley (eds. 2012:91) argue that Clovis technology originated along and expanded out from the eastern seaboard, and that Clovis tradition then spread westward through exploration and adaptation.

Clovis sites are most abundant in mid-Atlantic and southeastern states, and they represent a wide diversity of activities as opposed to sites to the west and north. Sites in the west are less diverse and tend to represent kill sites (Stanford and Bradley, eds. 2012:33) and/or cache sites (Kilby 2008; Meltzer and Holliday 2010). Stanford and Bradley (eds. 2012) argue that the density and diversity of fluted points in the southeastern states imply that Clovis originated somewhere in the southeast rather than in the north and/or west. This is argued using the Age-Area Hypothesis, which states that the greatest number and variants of a tradition will be found at the point of origin and diffuse outward (Mason 1962; Stanford and Bradley, eds. 2012:34). In light of evidence for other migration routes into the Pacific Northwest and eastern seaboard, it is possible that there were multiple migratory strategies and routes occurring at different periods during the Late Pleistocene.

In addition to the problem of *how* people regionalized North America, there is also the issue of *who* the first humans to regionalize North America were. In the Pacific Northwest, new data is arguing for the presence of pre-Clovis and/or contemporary Clovis cultures in the region. The Manis and Ayer Pond sites are argued to be pre-Clovis because of their early dates (ca. 13,800 cal B.P.) and the absence of diagnostic material associated with the Clovis tradition. If the earliest dates of Windust/Western Stemmed complexes at Cooper’s Ferry (Davis and Sisson 1998, Davis 2004) and Paisley Caves (Jensen et al. 2012) are correct, then the people of the Windust/Western Stemmed tradition may have been in the Pacific Northwest at the same time or even before Clovis (see Davis and Sisson 1998; Davis 2004; Jenkins et al. 2012). These sites argue for different traditions in the region by the terminal Pleistocene.

Pleistocene-Holocene Boundary and Early Holocene Regionalization

The archaeological record at the Pleistocene-Holocene Boundary and Early Holocene is largely dominated by the Windust tradition in the Pacific Northwest. Similar to the record of Paleoindian migration at the Late Pleistocene, regionalization of Windust peoples is poorly understood. While a directional trend from north-to-south (Columbia Plateau to northern Great Basin) and west-to-east (Great Basin to Great Plain) cannot be ruled out, there are multiple lines of evidence arguing for a southern and eastern migration into the Pacific Northwest.

Obsidian and *Olivella* shell, two of the only indicators of social networks, and potentially, movements of groups at the PHB, arrive in the Columbia Plateau from locations in the Northern Great Basin to the south (Galm 1994; Beck and Jones 2010; D. Rice 1972; Galm and Gough 2001; Connolly 1999). This connection to the Northern Great Basin, presumably through an existing trade and exchange network, not only points to the early development of this economic link but also, corresponds to apparent cultural connections between Windust components and the adjoining Western Stemmed Complex to the south.

Evidence for an east-to-west migration into the Pacific Northwest comes from the Sentinel Gap site (45KT1362) (Galm et al. 2011) and Haskett site (10PR37) (Butler 1965a, 1965b; Frison and Stanford, eds. 1982; Marler 2004). As was previously discussed in Question 2, these sites show clear affinities with complexes in the Great Plains. Late Paleoindian point complexes distributed from the northern Great Plains to the western reaches of the Northern Great Basin and Columbia Plateau reflect a progression of stylistic forms. This progression and movement of point forms presumably marks the movement of peoples into essentially unoccupied geographic regions/subregions. The argument can be made that climate change played a significant role in regionalization, creating pressures to explore and map out new settlement and subsistence strategies along with new lithic technological strategies (Galm et al. 2011).

The Haskett tradition fades from the archaeological record of the Pacific Northwest after the abandonment of the Sentinel Gap site at ca. 11,975 cal B.P. (Galm and Gough 2001). According to Galm and others (2011), The Sentinel Gap site supports the interpretation of Windust as the first appearance of human regionalization in areas throughout the Pacific Northwest, and the first clear sign of adaptive strategies linked to changes in climate, regional ecologies, and attendant resource options.

Role of Climate Change and Regionalization

Historic and prehistoric data shows that human migratory patterns can be influenced by changes in climatic conditions. Whether these migration events are responses to short-term variability of weather/climate or to manifestations of longer periods of climatic change is a matter of conjecture (Stanford and Bradley, eds. 2012:33). Weninger and others (2009) argue that environmental deterioration associated with rapid climate change (i.e., change occurring in a matter of years to decades) is a major factor underlying social change. There is growing evidence in support of rapid or abrupt climate change at the PHB in the Pacific Northwest. Thus, it is possible that changes observed in the archaeological record at this interval may reflect social changes, such as the decision to map out new and more productive territories, in association with a rapid or abrupt shift in climate regimes. As Weninger and others (2009) point out, however, these changes are typically at work within a wide spectrum of other factors including society, culture, economics, and religion.

The archaeological record of the Pacific Northwest points to large-scale changes in the adaptation and migration strategies of Late Paleoindian and Early Archaic peoples during the Late Pleistocene and Early Holocene. Coeval with these changes are shifts in the biogeographic density and distribution of plant and animal species, the extinction of megafauna and reduction in the size of select large-bodied mammals, a dramatic drop in the base levels of rivers and lakes, and the desiccation of many environments. It is possible that the apparent changes in adaptive and migratory strategies of people at the PHB are a reflection of range expansion associated with ecological shifts at this interval. Range expansion is a well-known adaptive response to risks associated with climate change (McLeman and Smit 2006). The decision to map out new territories stems, in large part, from a need to reorganize human populations in order to manage scarce resources in restricted areas (Brown 2008:21).

There is also a correlation between climate change and intensification of trade (Jenkins et al. 2004). In the Northern Great Basin, trade is believed to have played an important part in the redistribution of “patchy” resources between intra- and inter-basin populations (Jenkins et al. 2004). Lack of available resources or access restrictions in the Pacific Northwest at the PHB interval may have created an increase in the need for trade for specific commodities. Evidence of this demand may be represented in the archaeological record by the appearance of *Olivella* shell and obsidian trade goods, both derived from sources to the south, at the PHB. Whether trade/trade intensification occurred through human migration or developed through the establishment of social networks is a matter of debate.

The archaeological record of the Pacific Northwest indicates that migration, range expansion, and the development and/or intensification of trade networks may well have occurred in response to significant changes in climate at the PHB. This is evidence in the paleoenvironmental record by shifts in the density, diversity, and distribution of economic and subsistence resources in virtually every physiographic region of the Pacific Northwest.

Discussion

Comparisons of glacial features, pollen, fauna, and stratigraphic/geomorphic proxy datasets for climate change suggest that significant shifts in climate and associated changes in the environment occurred at the Younger Dryas chronozone and during the PHB in the Pacific Northwest. These changes are represented by a rapid or abrupt return to glacial conditions at the Younger Dryas, followed by an equally if not more rapid/abrupt shift to warm-dry conditions by the Early Holocene.

Although researchers are uncertain about the relationship between climate change and contemporary changes in the archaeological record, it is clear that significant transformations in the tools, technologies, settlement patterns, and subsistence strategies of people occupying the Pacific Northwest at the terminal Pleistocene-Early Holocene occurred coevally with climate change. Rapid dewatering, increases in the frequency and intensity of fires, extinction of megafauna and a reduction in the size of select large-bodied mammals, restrictions in access to attendant resources, and desiccation of previously habitable environments are all consequences of climate change at this interval.

It is not possible to directly measure the effects of climate change on cultural development, but the available data suggests that abrupt/rapid climate change at the PHB may have significantly influenced the way that humans strategized and coped with unstable and rapidly evolving conditions around them. Technological transformations, including a reduction in the size of projectile points/bifaces, a more expedient and diversified toolkit, greater economizing of lithic materials, a movement away from rigorously defined manufacturing techniques, and a movement from spear to atlatl/thrusting weapons systems may all reflect subsistence and economic adaptations to climate change. Transformations in technology and weapons systems may have allowed people to focus on a wider diversity of animals and plants (i.e., a "generalist" subsistence strategy) as climate change restricted the access, availability, and abundance of natural resources.

Along with subsistence and economic adaptations, there is also evidence to argue that climate change influenced the migratory and settlement patterns of peoples at the PHB. The contemporary presence of the Haskett site and Haskett-like tradition at the Sentinel Gap site along with the more widely represented Windust sites suggests that multiple cultural manifestations were present in the region by this interval. The progression of projectile point/biface styles and forms, along with the presence of *Olivella* shell and obsidian trade goods that originating from the south, indicate that Windust and Haskett traditions in the Pacific Northwest shared cultural affinities with groups in the Northern Great Basin and Great Plains. They also argue for a south-to-north and east-to-west migration into the Pacific Northwest. Human migration and trade can be understood within the context of a need to manage scarce resources in restricted environments.

With its expedient and diversified technologies and more generalized subsistence strategy, the Windust tradition appears to have been the first to adapt successfully to warm-dry Early Holocene conditions across the Pacific Northwest. It could be argued that Windust peoples were well suited for a wide array of ecological settings and the unstable environmental conditions forced by climate. By the beginning of the Early Holocene, Windust sites dominate the archaeological record while the Haskett tradition disappears from the region with the abandonment of the Sentinel Gap site at ca. 11,975 cal B.P.

Climate change at the PHB is considered one of the most significant shifts in climate regimes in the last 20,000 years. Throughout the historic and prehistoric record, human responses to large-scale changes in their environment caused by climate change bears some resemblance to one another. They tend to include technological and strategic adjustments to changes in subsistence and economic resources, migration and range expansion, and trade intensification. Therefore, the narrative of rapid/abrupt climate change and corresponding coping mechanisms of Late Paleoindian-Early Archaic peoples addressed in this study likewise have direct applications for discussions of past, present, and future climate change.

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