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A HUMAN BEHAVIORAL ECOLOGICAL ASSESSMENT OF THE YELLOWSTONE LAKE BASIN, YELLOWSTONE NATIONAL PARK, WYOMING

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A HUMAN BEHAVIORAL ECOLOGICAL ASSESSMENT OF THE YELLOWSTONE LAKE BASIN, YELLOWSTONE NATIONAL PARK, WYOMING

BY

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Abstract: A Human Behavioral Ecological Assessment of the Yellowstone Lake Basin, Yellowstone National Park, Wyoming

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The Yellowstone Lake Basin has been an important region for hunter-gatherers since the close of the Late Pleistocene that has provided an abundance and well diverse suite of subsistence resources (i.e prey animals and edible plants). Due the diversity found within this ecosystem, the primary objective of this thesis is to demonstrate that through the tenants of human behavioral ecology, it can be argued that the subsistence and settlement strategies of mobile foragers were heavily influenced by the abundance and availability of subsistence resources. This is based on the premise that resource patches comprising of riparian and grassland habitats obtain high productions of subsistence resources which would have encouraged mobile foragers to occupy these areas.

Furthermore, these tenants can be applied on a macro-evolutionary scale to demonstrate how shifts in climate over the past 12,000 years affected the subsistence and settlement strategies of hunter-gatherers. Like all ecosystems, the Yellowstone Lake Basin is constantly undergoing ecological transformations in response to disturbances in the climate. Shifts in climate may have had significant impacts on the distribution and compositions of vegetative zones that in turn affected the quality and production of resource patches. It is suspected that when poor patch conditions existed, mobile foragers responded by dispersing to new resource patches that were more productive. Conversely, when patch conditions became favorable, mobile foragers occupied these areas more frequently and over longer periods of time.

The final objective of this thesis was to determine if the spatial distribution of prehistoric sites could be associated to paleo-shorelines that reflected past lake levels. This objective was carried out by applying the principle tenants used in the geosciences. Using Nicolaus Steno's principle of superposition, it will be demonstrated that archaeological sites with intact and undisturbed contexts will only be associated with paleo-shoreline features that were exposed prior to any drops in lake levels. This is based on the geologic principle that younger layers of strata will overlie older deposits, which can be applied here by arguing that older archaeological deposits should be associated with lake levels reflecting similar ages while younger deposits should correspond to lake levels reflecting younger ages.

Acknowledgements

I would like to first and foremost thank my committee chair and supervisor, Dr. Douglas H. MacDonald for all his hard work in helping me realize my aspirations. He has been a tremendous influence on my academic growth to become a professional archaeologist. I owe a great deal gratitude for his mentorship and extreme patience.

I also want to thank Dr. Marc S. Hendrix and Dr. Michael H. Hoffman who taught me a lot about how Gilbert-stlye deltas are formed in the Yellowstone Lake Basin. All their hard work and expertise in interpreting the complex morphologies of shoreline terraces was greatly appreciated.

A great deal of thanks goes out towards Dr. Anna M. Prentiss for all her interesting classes that taught me to think critically and rationally. It was Dr. Prentiss that got me very interested in the subject of Human Behavioral Ecology which is the very subject matter of this thesis.

Finally I would like to thank my dear wife, Natalia for being the most patient person in the world. She has given up countless opportunities to go on nature walks and go exploring through Missoula, to allow me the much needed time to accomplish my objective in writing this thesis.

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Chapter I

Introduction

1.1 Introduction

For over 10,000 years humans have been settling in the Yellowstone Lake Basin to take advantage of the abundance of subsistence resources it has to offer. These include both animal and plant resources which range from camas, biscuit root, an assortment of wild berries, bison, deer, elk and waterfowl. Since hunter-gatherers relied upon these resources as main staples of their diets it is postulated that their settlements are situated within or in proximity to the habitats that support these types of resources. This is based upon the tenants of human behavioral ecology in which hunter-gatherers were selecting these habitats (i.e. patches) based upon the availability and access to subsistence resources. Settling near patches that supported a diverse suite of resources would have enabled hunter-gatherers to efficiently and effectively allocate the necessary calories to meet their daily caloric intakes. Patch types that primarily supported both riparian and grassland habitats would have been sought after most since they can support large abundances of edible plants and prey species.

However, the abundance and availability of these resources are under the direct influence of climatic controls which may either inhibit or encourage their production rates. It is most certain that climate fluctuations had occurred over the last 12,000 years since the retreat of the last glaciers and with that so did the diverseness and abundance of subsistence resources. Any significant shifts in climate would have had tumultuous implications on the ecosystem. Foraging areas for ungulates and habitats suitable for edible plants would have either expanded, contracted or have been redistributed throughout the region. As a consequence, hunter-gatherers had to be very cognizant of alternating environmental conditions in order to plan accordingly and intercept resources where they were most abundant and predictable.

Aside from environmental changes occurring over the millennia, profound geologic forces have been reshaping the Yellowstone Plateau over 2.1 million years with cataclysmic volcanism. The most recent eruption occurred 640,000 years ago with the Lava Creek Tuff eruption and formed the Yellowstone Caldera. Today the northwestern half of Yellowstone Lake falls within the southern portions of the caldera with two active resurgent domes residing directly to the west and northeast of the lake. Due to the geographic position of these resurgent domes and the placement of the lake's main outlet, lake levels have fluctuated as a direct result of caldera breathing. The cyclical nature of uplift and subsidence associated with this phenomenon has also caused paleo-shorelines in the northern reaches of the lake to become more tilted and deformed compared to paleo-shorelines in the south. One of the objectives of this thesis is to determine if the spatial distribution of prehistoric sites could be associated to paleo-shorelines that reflected past lake levels despite the deformational processes occurring with caldera breathing.

In summary, the primary objectives of this thesis are to first understand the subsistence and settlement strategies of hunter-gatherers. The second objective is to examine how fluctuations in climate over the past 12,000 years may have impacted these strategies. This of course is dependent upon the premise that hunter-gatherers were selecting vegetative zones that supported an abundance of subsistence resources. Lastly, the final objective is to determine if the spatial locations of prehistoric occupations could be correlated to ancient lake levels.

1.2 Study Area and Environmental Settings

Yellowstone Lake is positioned atop the highly elevated Yellowstone Plateau in northwestern Wyoming at an elevation of 2,356 meters above sea level (see figure 1.1 and 1.2). The lake comprises of approximately 225 km of shoreline and covers an area of 211 km^2. With a maximum depth of 119 meters, Yellowstone Lake is the largest body of water in North America above 2,134 m in elevation. The lake formed as a result of the collapse of a magma chamber roof during the Lava Creek eruption 640,000 years. The northwest half of the lake falls within the caldera while the southwest portion resides just outside the caldera rim (Christiansen 2000).

To the northeast and western regions beyond the lake, are two resurgent domes, (Sour Creek Dome and Mallard Lake Dome) which are remnant magma chambers left from the last eruption. In concert, the domes expand and contract as magma beneath them cause the ground surfaces above them to swell and bulge from the confidence of extreme pressures (Christiansen, 2000; Pierce et al. 2007). Since the close of Late Pleistocene lake levels of Yellowstone Lake have been directly impacted by caldera breathing since the lake's outlet traverses directly over the axis between the two resurgent domes at Le Hardys Rapids (Pierce et al. 2007; Locke and Meyer 1994; Meyer and Locke 1986). Today, ancient terraces of remnant shorelines are still visible and clear reminders of ancient vestiges from forgotten times.

To the east, the lake is flanked by steep sloping peaks of the Absaroka Mountain ranges with peaks reaching elevations greater than 3,000 meters. To the southwest lies the Red Mountains with peaks reaching heights of up to 3,140 meters above sea level. Flanking the western shores of the lake, lie gentle slopes that comprise primarily of the Central Plateau and are relics of ancient rhyolitic flows. In the northern portions of Yellowstone Lake resides the Elephant Back fault system which connects between the Mallard Lake and Sour Creek resurgent domes. Together, the surrounding topography forms the Yellowstone Lake Basin, which creates a diverse ecological environment.

Considered as part of the Intermountain Zone, the Yellowstone Lake Basin supports a vast array of flora and fauna inhabiting a diverse suite of habitats. Although, dominated today by stands of lodge pole pine, the basin offers a myriad of vegetative zones comprised of mesic subalpine fir, forested riparian, graminoid riparian, sage brush steppe, and finally shrub and grass habitats, (Livers and MacDonald 2011; MacDonald and Livers 2011). The presence of these vegetative zones help support habitats suitable for many types of fauna that comprise of, big horn sheep, bison, antelope, deer, elk, bear, moose, coyotes, mountain lions and wolves (Livers and MacDonald 2011 a, b; MacDonald and Livers 2011).

On a regional scale, the lake basin and plateau has offered an attractive environment for hunter-gatherers to occupy. This is primarily influenced by the availability and access to both subsistence and lithic raw-material resources. The dynamic nature of the ecology on the plateau would have allowed for mobile foraging groups to not only hunt after a wide range of fauna as just described, but also forage and collect a myriad of edible plant resources. In addition, the volcogenic nature of the plateau is rich with outcroppings of lithic raw-material sources most suitable for the production of stone tool technology. Combined, these two factors would have served all the necessary needs for human survival.

Edible plants such as camas, tiger lily, biscuit root, dandelion, bitterroot, nodding onion, and an assortment of wild berries would have served as a small sample set of the types of plant

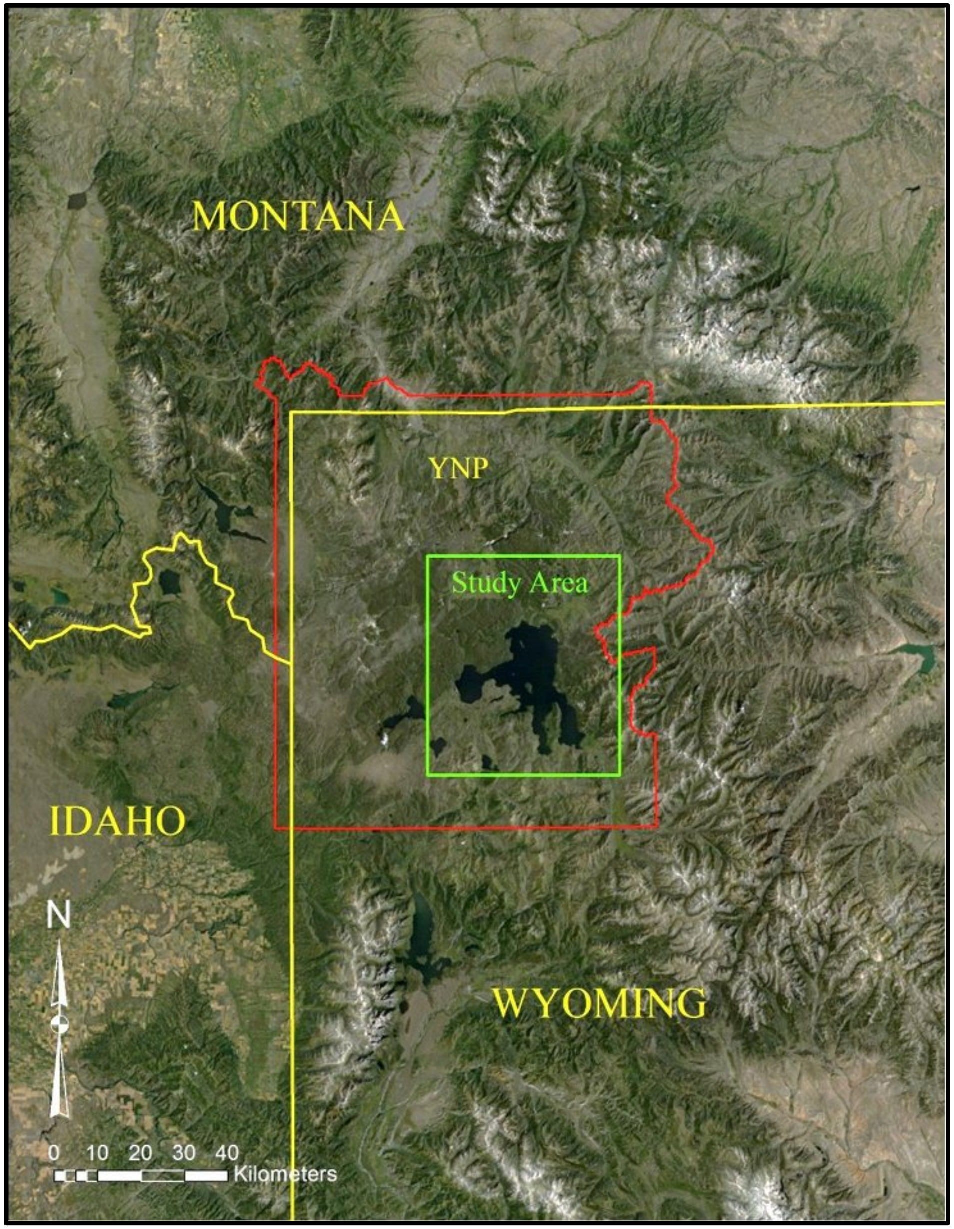


Figure 1.1 Satellite Imagery of the Study Area

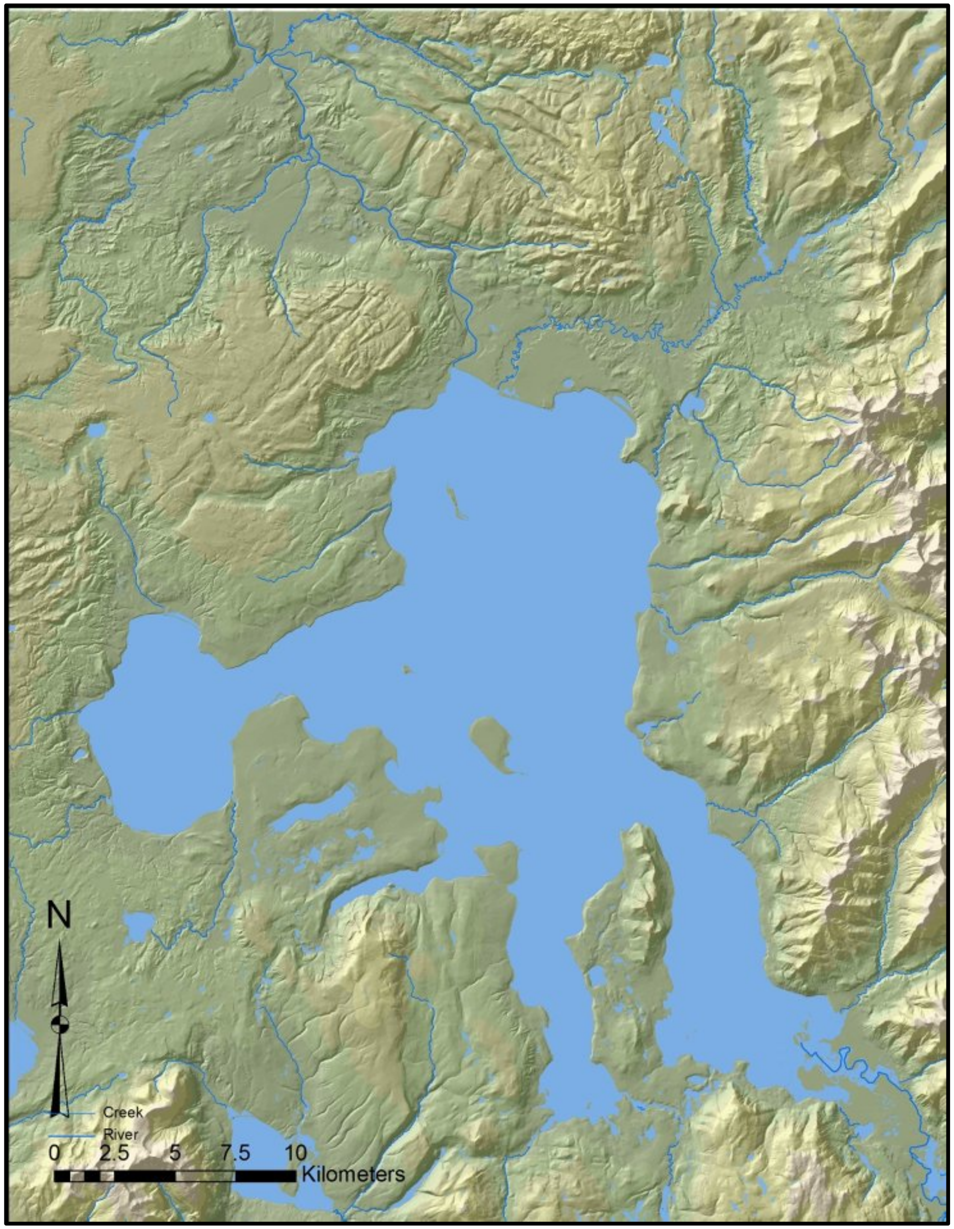


Figure 1.2 Digital Elevation Model of the Study Region encompassing the Yellowstone Lake Basin

resources that were available to hunter-gatherers at varying periods of the growing season (Thoms 2008). Camas for example was utilized for its carbohydrate rich bulbs. Native Americans processed the plant by roasting the bulbs in order to convert the complex carbohydrates and break it down into simple sugars (Livers and MacDonald 2011a, b; Thoms 2008). Camas is primarily found in well drained and moist meadows associated with mesic or riparian zones and were normally harvested in the autumn after the flowers had bloomed.

On the contrary, bitterroot is commonly found in the drier vegetative zones and is often associated with drier and more gravelly soils. Processing bitterroot requires the steaming, roasting, boiling or drying of the root stalk, which renders the tap root less noxious and more palatable for human consumption (Livers and MacDonald 2011 a, b; Thoms 2008). Bitterroot would have been normally harvested during the spring when mobile bands began their spring seasonal rounds. However, because bitterroot occurs more infrequently than camas, it would have primarily been utilized as a delicacy rather than a staple by Native Americans.

Dandelions, wild onions, and an assortment of wild berries would have also served important dietary staples. Dandelions are found on open meadows and every aspect of the plant would have provided nourishment to hunter-gatherers throughout the growing season (Livers and MacDonald 2011 a, b). Wild onions are normally distributed in open meadows or in forest clearings. The whole plant is edible with the main core of carbohydrates found in the bulb (Livers and MacDonald 2011 b). Wild berries are well distributed in the lake basin and vary from wild strawberries, raspberries, huckleberries, chokecherries and service berries. Berries would have been favorable to harvesting during the late summer and early autumn months when they fully ripen during those periods.

Harvesting edible plant resources would have provided the most important facet to the diet of hunter-gatherers since they provided the bulk of their carbohydrates. However, the dispatching of wild game also played an integral role in supplementing their dietary needs. While it has been documented from blood residue analyses, hunter-gatherers hunted a wide range of species. This has comprised of, bear, cat, dog, rabbit, deer, elk and bison (MacDonald and Livers 2011 a, b). The most common occurring species observed on the plateau today are primarily ungulates, including of bison, deer and elk. More elusive fauna comprise of bears, wolves, coyotes, and other predatory species.

In the Yellowstone Lake Basin and immediate surrounding areas, the vegetative zones are quite suitable to bison, deer, and elk. Bison prefer to forage in open grasslands while deer and elk prefer eco-tones that transition between forest and grassland/ meadows (Coughenour 2005; Davis 2007; Fullbright and Ortega 2006; Plumb and Dodd 1993). Consequently, these areas are also suitable to most predatory species since they are susceptible to preying off of ungulates. The Hayden Valley situated approximately four miles north of Yellowstone Lake, is comprised almost entirely of open grasslands, making it a very appealing habitat for bison, as well as for deer and elk along the peripheral edges. In areas immediately surrounding the lake, occur pockets or clearings of vegetative zones ranging from subalpine alpine mesic meadows, riparian, and subalpine grasslands. These types of vegetative zones are primarily suitable for deer and elk, but it may not be uncommon for a single bison to stray away and wander into these types of habitats.

Cumulatively, the diverse range of vegetative zones that comprise the Yellowstone Plateau and Yellowstone Lake Basin ecosystem provide important needs for hunter-gatherers. Not only does the ecosystem provide sustenance in form of edible plants, but it offers a diverse suite of wild prey to hunt for subsistence needs. However, the availability of subsistence resources is not the only factor responsible for attracting hunter-gatherers to the region. The availability of lithic raw-materials is another guiding force in attracting hunter-gatherers to this region. With large quantities of lithic raw-materials available throughout the park, hunter-gatherers had an almost endless supply of material to produce stone tools.

Due to the volcanic nature of the Yellowstone Volcanic Field, major out-crops of rich lithic raw-material can be found throughout the park and surrounding regions. These sources primarily occur in the form of obsidians, cherts, quartzites, chalcedony or other quartz bearing materials. These types of raw-materials were sought after by hunter-gatherers due to their unique properties to induce conchoidal fractures. These unique properties allow hunter-gatherers to manipulate and control where fractures occur in the stone while reducing stones into useable tools used for everyday activities.

Obsidian, an isotropic material, forms from the rapid cooling of silicic-rich rhyolitic magma flows or from the rapid cooling margins of pyroclastic flows (Gifkins et al. 2005; Watkins et al. 2008). Obsidian Cliff, positioned in the northern portion of Yellowstone National Park is characteristic of obsidian formed from extrusions of rhyolitic magma rapidly cooling along contacts between air and ground surfaces. Conversely, in the northeastern edge of Yellowstone Lake, Park Point obsidian is eroding out as nodular cobbles of an exposed section of the Lava Creek tuff. The formation of Park Point obsidian stems from the rapid cooling of vitriferic glass condensing against cooler air and ground surfaces within a silicic rich matrix of highly dense volcanic ash during pyroclastic events (Boyd 1961; Gifkins et al. 2005; Watkins et al. 2008).

Cherts, chalcedonies and quartzites form from the digenesis of a silicic rich parent material. This is primarily associated with the bimodal nature of the Yellowstone Volcanic field which is comprised of both rhyolitic and felsic-rich materials (Christiansen, 2000). Over time the chemistry of the parent materials begins to breakdown causing silica to leach out and concentrate into thin lenses of microcrystalline cherts. In other instances, silica will begin to precipitate out and concentrate within the voids in pumice and recrystallize to form chalcedonies and are commonly referred to as 'thunder eggs' (Kile 2002). Another process by which cherts form stems from the precipitation of silicic rich material being precipitated out from felsic rich hydrothermal fluids under heat and pressure and concentrate into thin pools or in between natural occurring voids or along fractures in the felsic-rich parent material. These types of cherts have been identified in the northern portion of Yellowstone National Park at the Crescent Hill Chert Quarry (Adams 2011).

The largest source of obsidian found within park boundaries is Obsidian Cliff in the northern portion of the park while other sources occur from Cougar Creek, Warm Springs and Park Point. Other sources of obsidian that originate outside the park boundaries include Teton Pass, Lava Creek, Huckleberry Ridge, Pack Saddle Creek, Bear Gulch, Conant Creek and Cashman Dacite. Likewise, the primary concentration of chert found in the park originates from the Crescent Hill Chert quarry. Other types of cherts or silicic-rich materials occur sporadically across the region but are generally associated with major geologic formations like the Madison and Green River formations. Overall, the distribution of these geologic features would have allowed mobile foragers more liberties in planning their seasonal rounds without having to be reliant on any one raw-material source.

In summary, the Yellowstone Plateau and Yellowstone Lake Basin has been continuously used by hunter-gatherers for the acquisition of both subsistence and raw-material resources for over 10,000 years. The distribution and availability of obsidian, chert and other siliceous raw-materials, allowed groups of hunter-gatherers to replenish their tool kits and stock up on extra material during their seasonal rounds. However, the placement of these resources in or near the Yellowstone Plateau was a much added benefit due to their closeness to an abundance of subsistence resources. This allowed mobile groups to occupy the plateau for most of the growing season without having to travel great distances to acquire raw material resources. Only when colder winter conditions set in, were groups enticed to seek lower elevations where subsistence resources were more plentiful.

1.3 Cultural Chronology of the Yellowstone Lake Basin

Currently there exists 285 site locations spatially dispersed around the shores of Yellowstone Lake (see figure1.3). Of these site locations, 180 sites cannot be assigned to any specific time period while the remaining 105 site locations can be attributed to one or more time periods spanning from the Paleoindian period to the Late Prehistoric Period (figure 1.4). Considering that a number of site locations have been reoccupied across multiple cultural periods, it would be accurate to suggest that these site locations are made up of a composite of sites relative to the number of cultural periods that could be associated with them. Taking this consideration into account, the true number of sites that can be dated to a specific cultural period would be 175 that encompass Yellowstone Lake.

The frequency at which sites occur within each respective cultural period is based upon absolute and relative dating of either diagnostic artifacts or radio-carbon dating of hearth features. The Paleoindian period spans from 12,000-8,000 B.P. and is comprised of 25 site locations representing multiple cultural traditions belonging to Goshen, Hell Gap, Agate Basin and Cody Complexes (MacDonald 2012; Frison 1991; Vivian et al. 2007) (see figure 1.5). Sites dating to this period occur mostly in the northern and western portions of the lake, with fewer sites distributed in the southern arms of Yellowstone Lake and a complete absence of sites on the entire stretch of the eastern shores. The main concentrations of Paleoindian era sites are primarily distributed at Fishing Bridge and Bridge Bay in the North, the southernmost regions of the West Thumb and a tight cluster occurring at Wolf Bay (Johnson et al. 2004)

Following the Paleoindian period the Early Archaic period spans from 8,000 to 5,000 B.P. and is characterized by a shift in technology from the large lancelet projectiles observed during the Paleoindian period to side-notched projectile points primarily associated with atlatl technology (MacDonald 2012). Several side notched points recovered in the southern portions of the lake have been identified by Vivian et al. (2007) as Salmon River Side-notched points which are associated with the Corwin Springs Sub phase or the Mummy Cave Complex dating between 7,750 and 4,500 B.P. During this period the frequency of site counts slightly drop to just 22 site locations but the degree of sites clustering together increases (see figure 1.6). The main concentrations of sites occur in the north near Fishing Bridge, the West Thumb and the Flat Mountain Arm of Yellowstone Lake. Other Early Archaic sites are also identified in the southern portions of the lake with the earliest presence of human occupation occurring on the eastern shoreline between Cub Creek and Clear Creek (MacDonald and Livers 2011; MacDonald et al. 2012).

It is only after the Early Archaic Period, that there is a significant rise in the frequency of site locations in the Yellowstone Lake basin increasing from 22 to 39 sites (see figure 1.7). The spatial distribution of sites appears to be a continuation of territorial use, as observed in the Early Archaic Period, with the exception of increased frequency of site counts and a dramatic increase in the degree of sites clustering together. The Middle Archaic period spans from 5,000 to 3,000 years ago and is associated with the McKean, Duncan and Hana complexes found in the lake basin. However, MacDonald (2012) points out that, projectile points from this period are diagnostically similar to each other and that there is little evidence to support that they are all independent cultural variants to one another. Vivian et al. (2007), following Reeves (2003) attribute these diagnostic point types to be intrusive to the Rocky Mountain and Northern Great Plains regions, originating from the northeast portions of the Great Basin and southern portions of the Columbia Plateau.

Following afterwards, the Late Archaic Period reflects another rise in the frequency of sites, and represents the apex at which sites occur during the whole prehistoric record. Spanning from 3,000 to 1,500 B.P. the Late Archaic Period represents a region wide population growth not only in the Rocky Mountains but also in the Northern Great Plains. The Late Archaic Period is attributable to the Pelican Lake complex and is believed to be descendant from McKean complex. Other cultural variants also include the Besant (MacDonald 2012) and the Quilomene Bar corner notched point types (Vivian et al. 2007).

The number of occurrences of sites increases from 39 observed during the Middle Archaic to 53 site locations around Yellowstone Lake (see figure 1.8). The spatial distribution of Late Archaic sites indicates that territorial use still resembled the patterns observed during the Early and Middle Archaic Periods. However, the distribution also indicates that the degree of sites clustering together decreases. This is suggests, that hunter-gatherers were expanding and exploiting more of their territory compared to the Middle Archaic Period.

The transition into the Late Prehistoric period reflects dramatic changes technological innovations. The transition into the Late Prehistoric Period begins at 1,500 B.P. and ends in 300 B.P. This period is attributable to the widespread adoption of the Bow and Arrow over Atlatl technology (MacDonald 2012; Frison 1991; Vivian et al. 2007). Adoption of this technology resulted in projectiles dramatically reduced in size and weight. Projectile points identified from this period are attributable to three cultural traditions within Yellowstone Park; Black Canyon, Tower Junction, and First Blood (Vivian et al. 2007). Vivian et al. (2007) have associated these point types as variants of Avonlea, Unita and Numic complexes. They have also identified a few projectile points in the southern regions of Yellowstone Lake as Rose Springs corner-notched points which are also variants to the Numic tradition (Vivian et al. 2007).

The Late Prehistoric period also reflects significant changes in settlement patterns. The accumulative number of sites decreases from 53 site locations identified during the Late Archaic Period to just 36 sites (see figure 1.9). This is an overall 32 % decrease in site occurrences. This period also reflects a dramatic reduction in territorial use and increased aggregation per unit area. Site concentrations are primarily situated near Fishing Bridge, Steam Boat Point Arnica Creek, Big Thumb Creek, Clear Creek and in the vicinity of Eagle Bay.

Overall the occupational history of the Yellowstone Lake indicates fluctuating changes in population and site distribution. There appears to be a slight decrease in site counts between the Paleoindian and Early Archaic Periods followed by sharp increases during the Middle and Late Archaic Periods. The spatial distribution of sites during the Paleoindian and Early Archaic Periods are less concentrated together and is probably the result low population levels. In contrast, the spatial distribution of site locations during the Middle and Late Archaic Periods suggests that the concentration of sites becomes less pronounced during the Late Archaic Periods and indicates a greater exploitation of territory. Following the Late Archaic Period the site counts during the Late Prehistoric Period indicate a significant reduction in frequency and contracted territorial use. However, MacDonald (2012) identifies similar overall counts of Late Archaic (n=33) and Late Prehistoric (n=33) projectile points in University of Montana's studies at the lake. Also he cites similar feature frequencies between the |Late Archaic (n=12) to Late Prehistoric (n=9); this recent data suggests a less severe reduction in human use between the Late Archaic and Late Prehistoric periods (MacDonald et al. 2012).

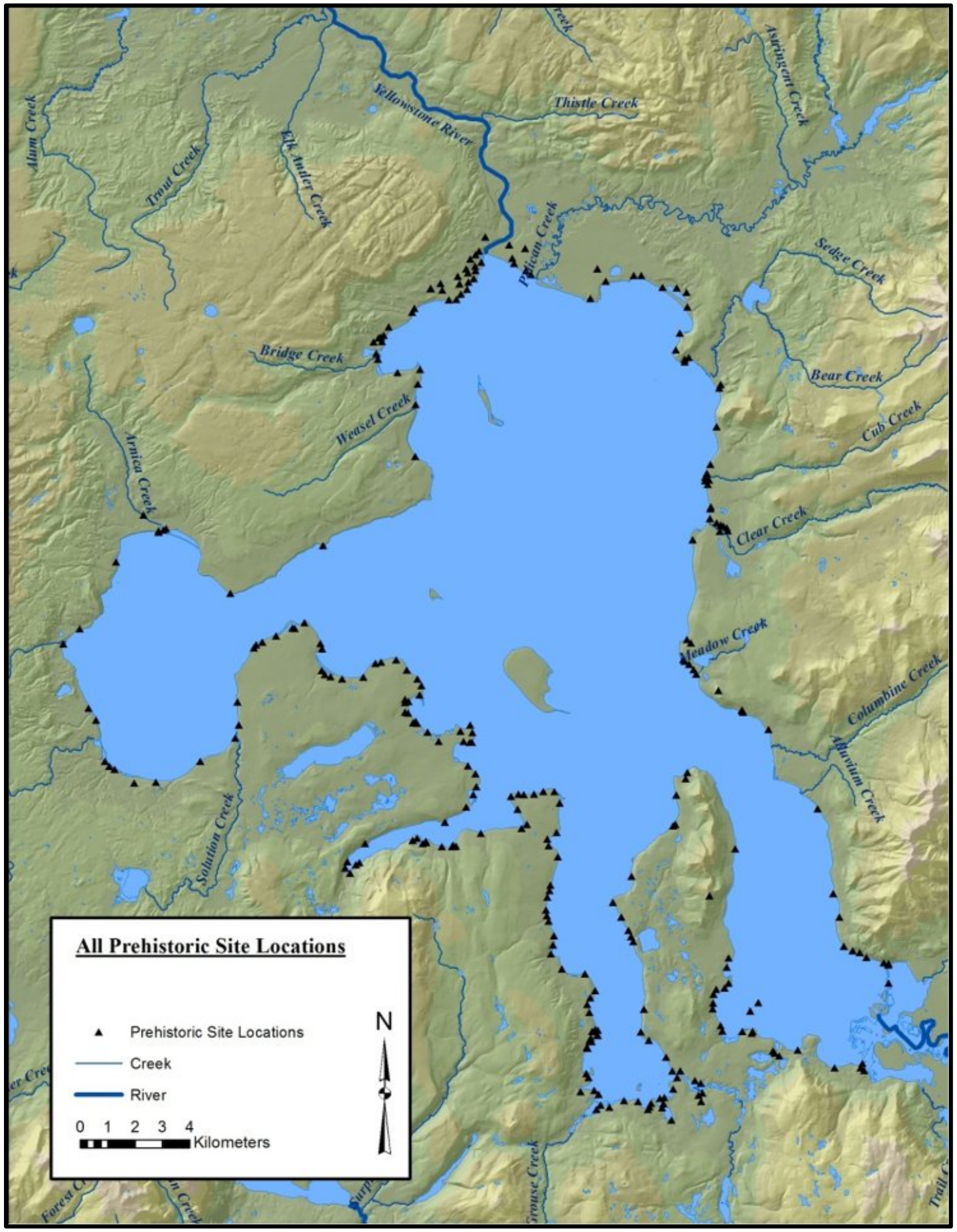


Figure 1.3 Map depicting the spatial distribution of all prehistoric sites.

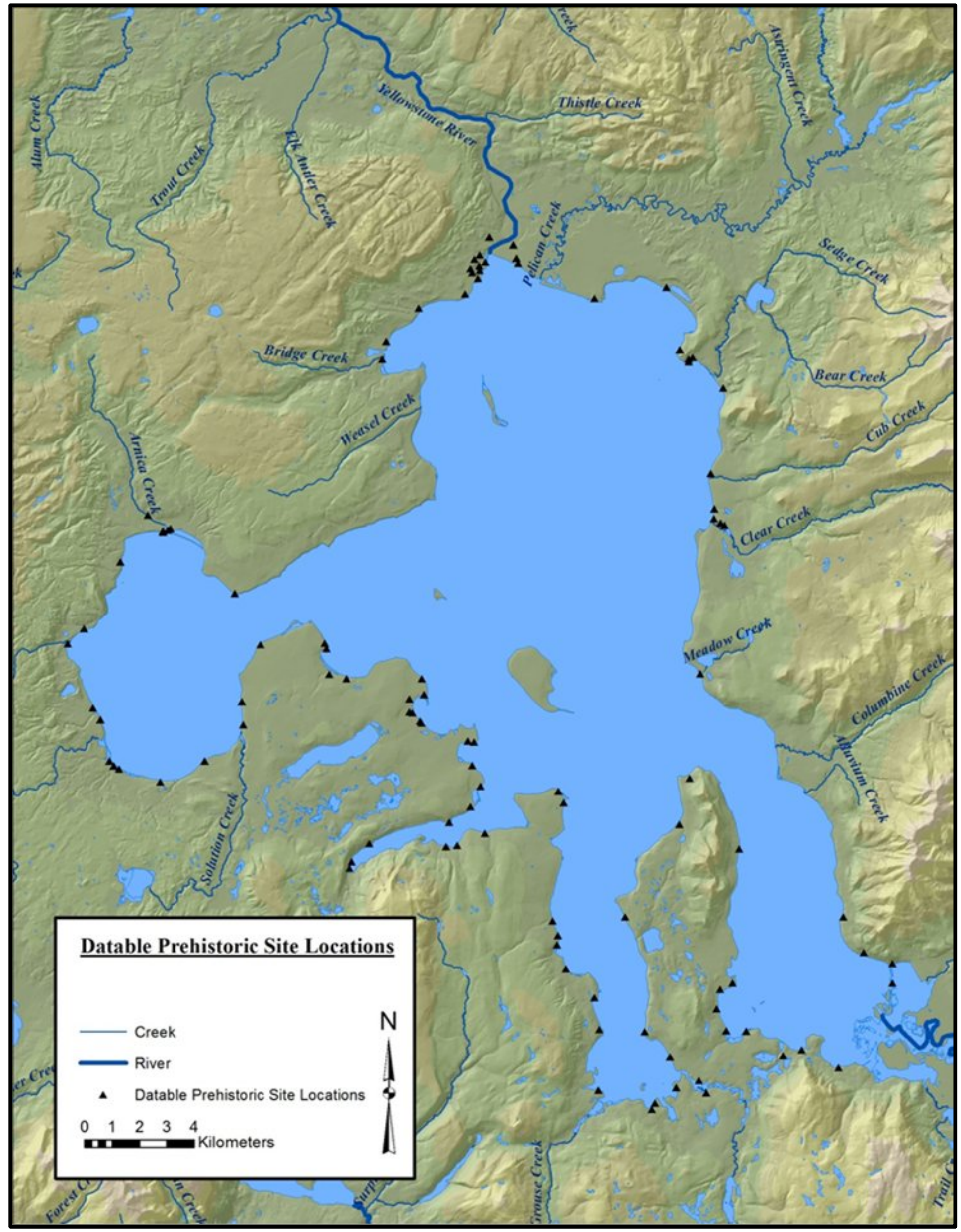


Figure 1.4 Map depicting the spatial distribution of only dated prehistoric sites.

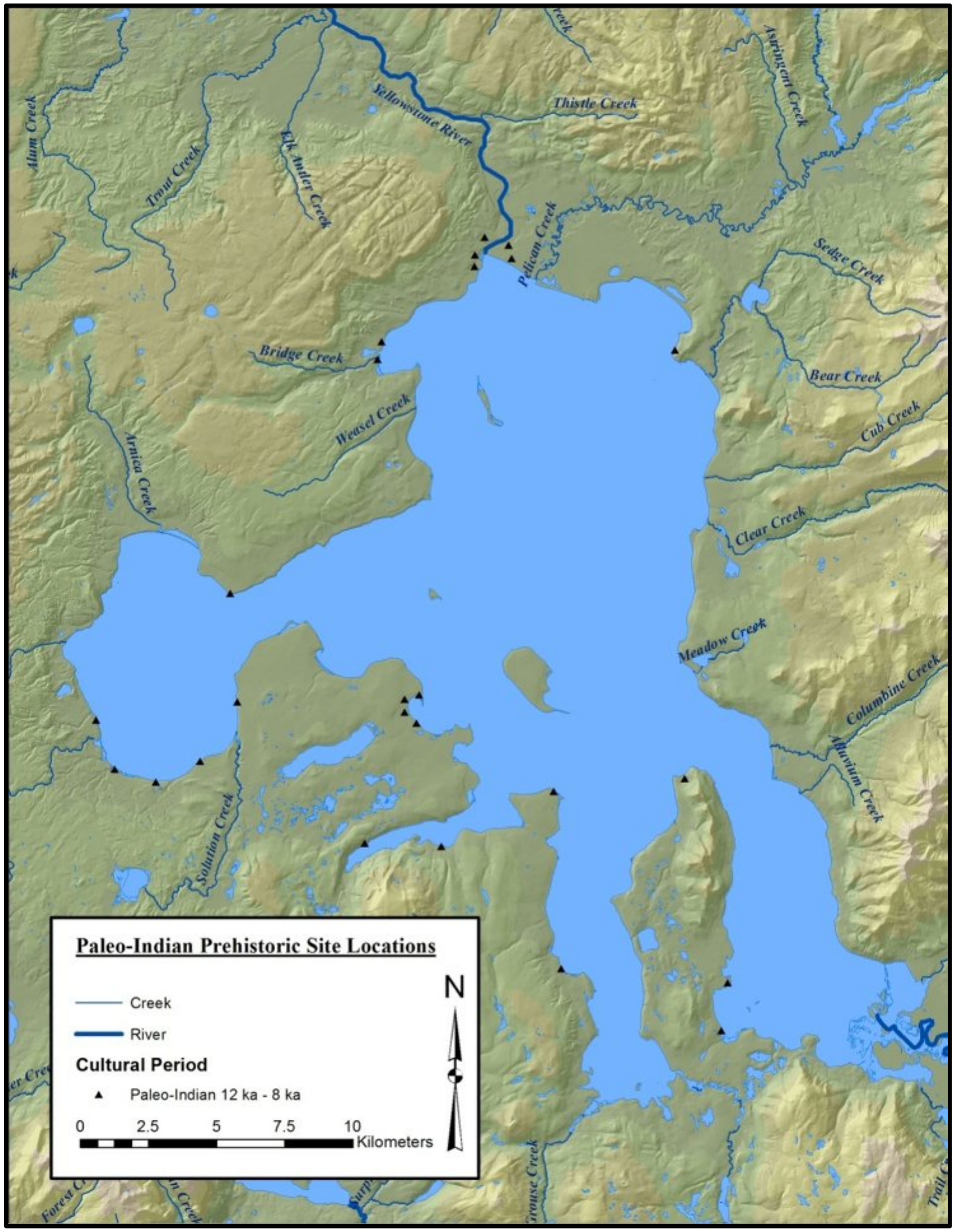


Figure 1.5 Map depicting the spatial distribution of all Paleoindian sites.

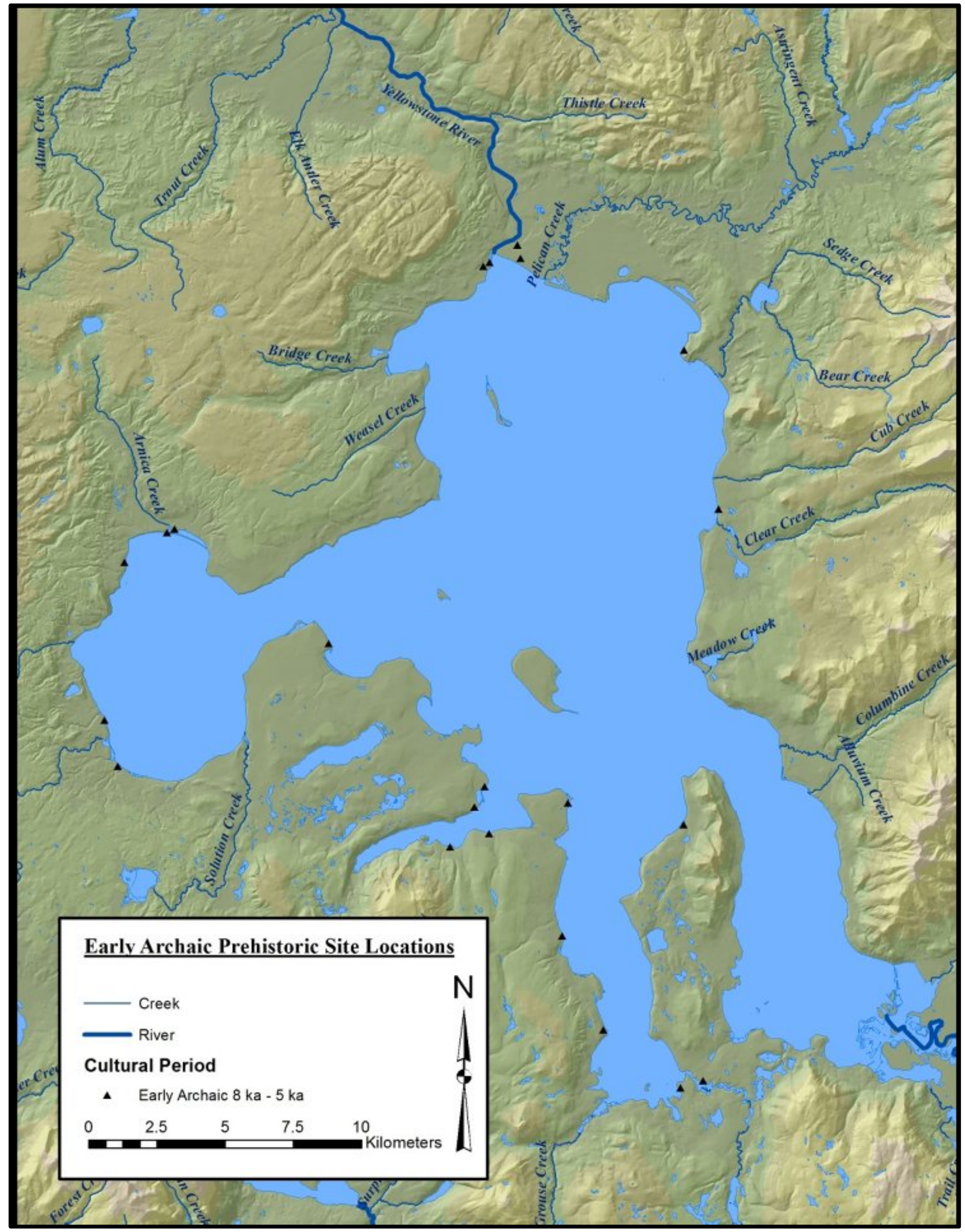


Figure 1.6 Map depicting the spatial distribution of all Early Archaic sites.

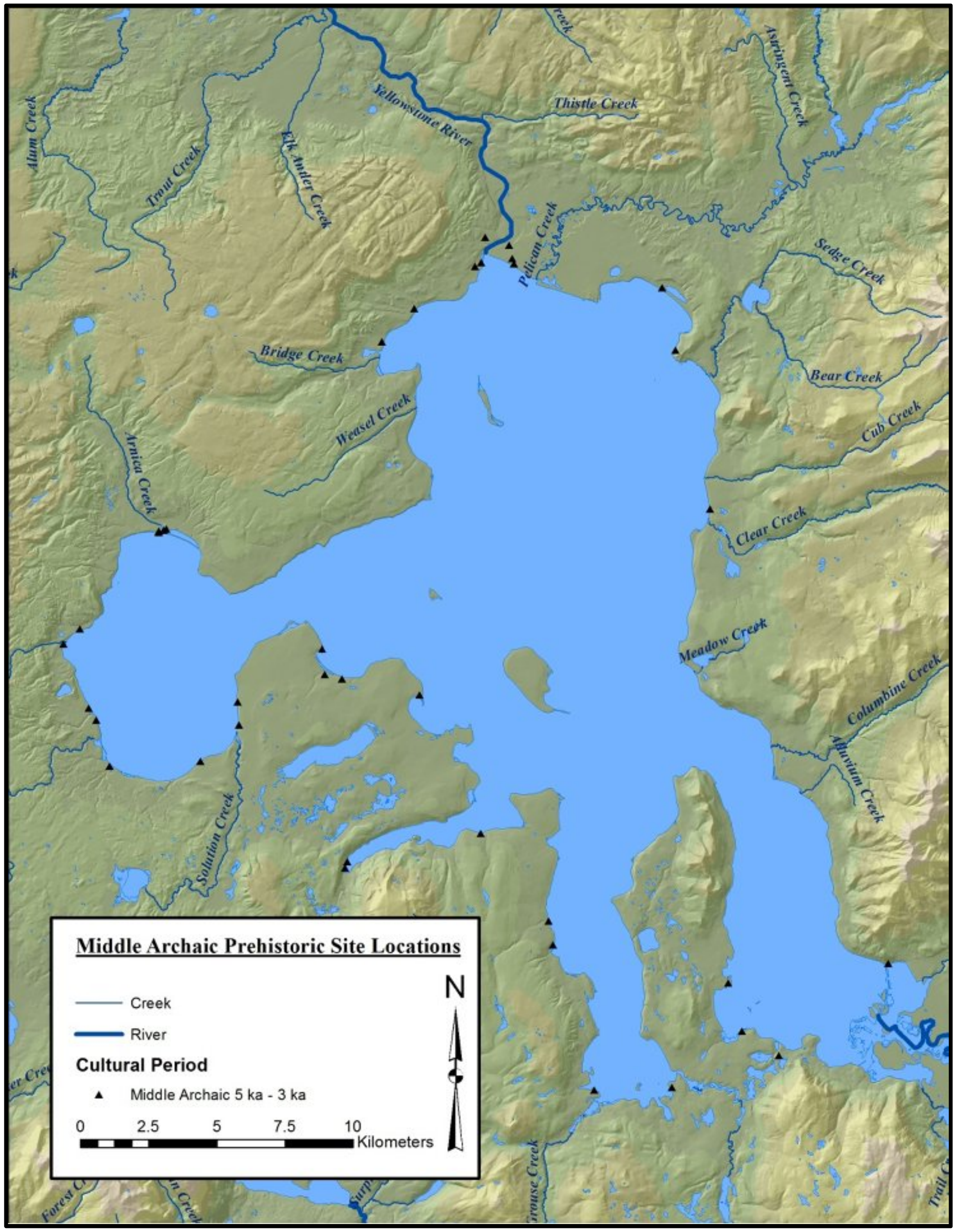


Figure 1.7 Map depicting the spatial distribution of all Middle Archaic Sites

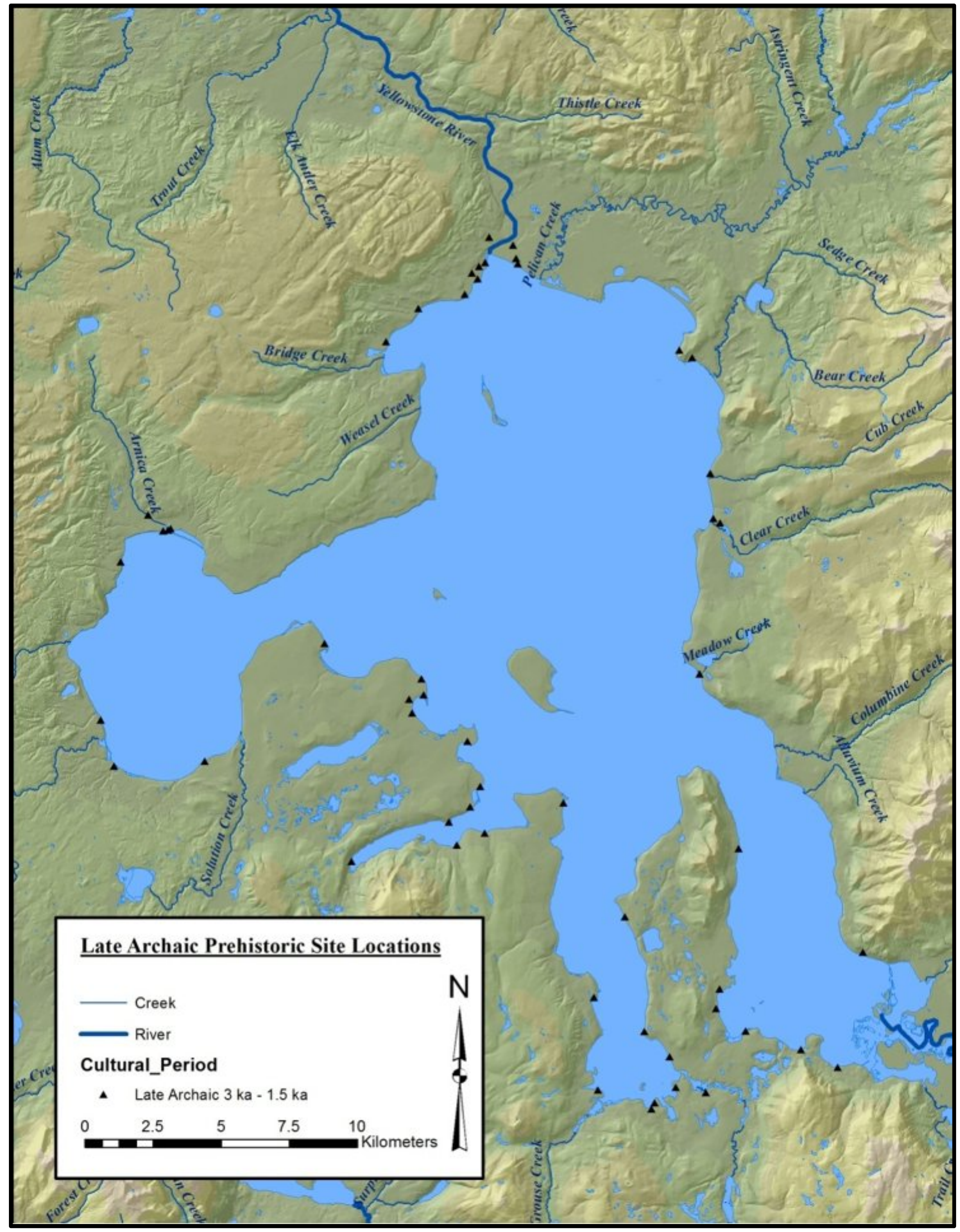


Figure 1.8 Map depicting the spatial distribution of all Late Archaic sites.

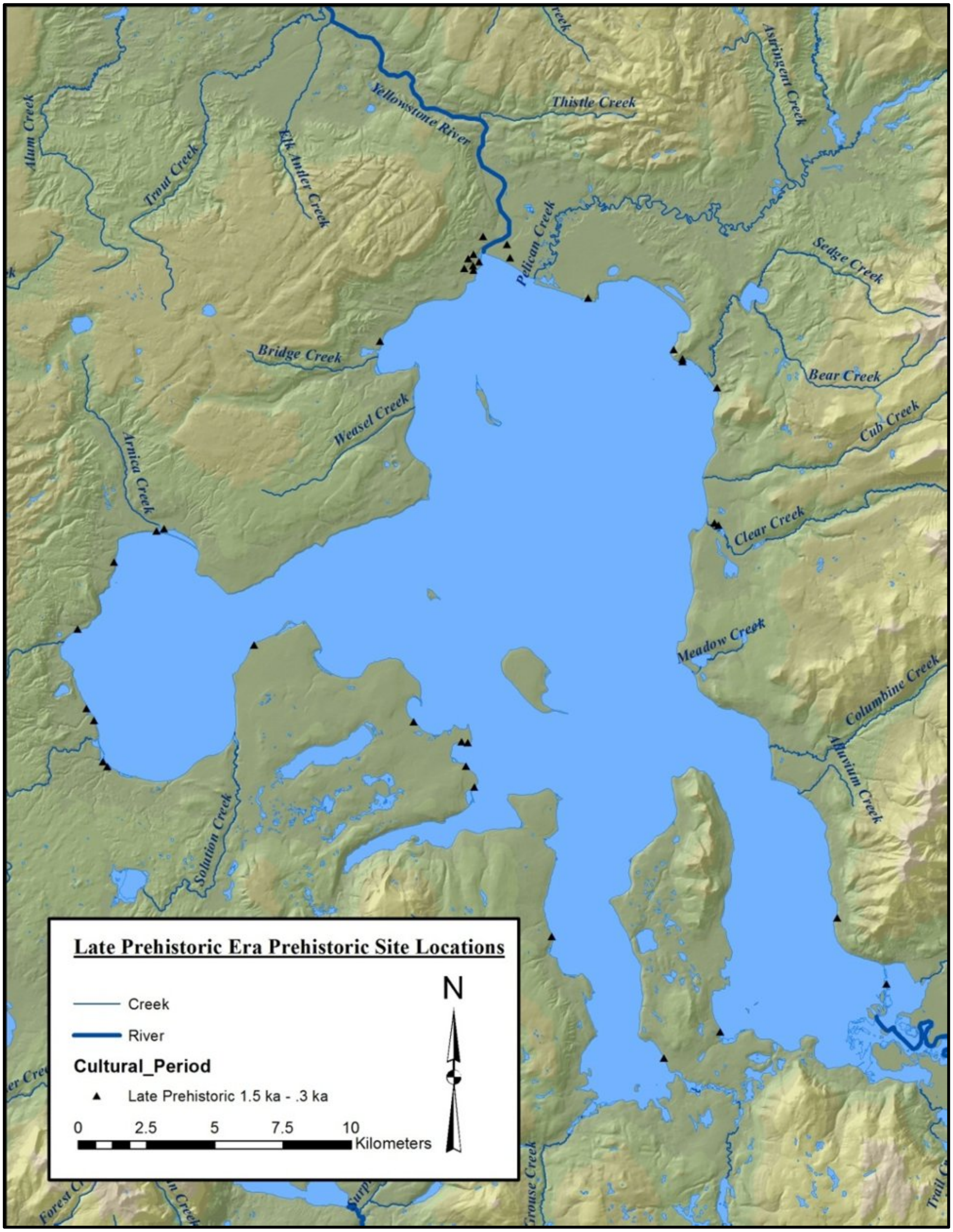


Figure 1.9 Map depicting the spatial distribution of all Late Prehistoric sites.

1.4 Climate History Overview

Prior to 13,000 years ago the Yellowstone Plateau was covered by an enormous ice cap up to 1 km thick in its thickest section (Thackray et al. 2004; Pierce et al. 2007). Near the end of the Late Pleistocene the ice cap receded, giving way to alpine glaciers and the filling of the Yellowstone Lake Basin where lake stands were 20 meters above modern lake (Pierce et al., 2007; Locke and Meyer, 1994). The vegetative communities at this time consisted of tundra steppe, which were primarily dominated by grasses that persisted until 11.5 ka (Huerta 2008; Millspaugh et al. 2000; Millspaugh and Whitlock 2002; Thackray et al. 2004). Conditions then moistened, allowing for cold climate acclimated spruce to take root and expand in the higher elevations on andesitic and non-volcanic soil substrates (Thackray et al. 2004; Millspaugh and Whitlock 2002). During this time the rhyolitic substrate of the plateau provided insufficient soil conditions to foster the growth of trees until after 10 ka (Thackray et al. 2004).

The period leading after this was marked by warmer and drier conditions and peak summer radiations, which are representative of the Altithermal climatic episode between 9-5 ka (Huerta 2008; Millspaugh et al. 2000; Millspaugh and Whitlock 2002; Thackray et al. 2004). This period is characterized by continual expansion of mixed conifers into higher elevations replacing forests dominated by spruce. The frequency of wild fires had also increased during this period and is believed to have increased available forage areas for ungulates (Thackray et al. 2004; Millspaugh and Whitlock 2002). However, it is also speculated that the production of overall biomass was at its lowest due to a lack of moisture, which may have hindered ungulate populations (Thackray et al 2004, Gish, 2010).

Succeeding this period of maximum warmth, the Yellowstone Plateau became cooler and moister marking the transition into the Neo-Glacial period. Not much is understood about this period in the park, but it has been commonly accepted that the climate stabilized with two distinct climate regimes (Huerta, 2008; Millspaugh et al. 2000; Millspaugh and Whitlock 2002; Thackray et al. 2004). The northern region of Yellowstone Park is characterized by a summer wet/ winter dry regime while the central and southern regions are characterized by summer dry/ winter wet regimes. The northern regime is influenced by the onshore flow of moisture deriving from the Gulf of California and the Gulf of Mexico and up into the southwestern United States, southern Rockies and Great Plains. While the southern regime is influenced by the east Pacific subtropical high-pressure system, whereby individual mountain ranges intercept winter storms. It is understood today, that the drier conditions preceding the Neo-Glacial period was a result of a strengthened east Pacific subtropical high-pressure system (Huerta, 2008; Millspaugh et al. 2000; Millspaugh and Whitlock 2002; Thackray et al. 2004).

Present climatic conditions are believed to have appeared around 1,500 BP. During this this transition the continual expansion of conifer forests had reached their apex and adversely affected the production and distributions of vegetative habitats conducive to support ungulates and other fauna that were dependent upon them (Thackray et al. 2004; Millspaugh et al. 2000). However, despite these adverse effects, there are still large regions of grasslands that have yet to be consumed by forestation. To name few these areas include the Hayden Valley just north of Yellowstone Lake, the Lamar Valley in the northeastern section of the park and the Pelican Valley that meets up with Yellowstone Lake just east of Fishing Bridge.

1.5 Theoretical Focus and Objectives

Despite fluctuating lake levels caused by inflation and deflation cycles, the archaeological record suggests that mobile foraging groups have continuously occupied the Yellowstone Lake basin since the close of the Late Pleistocene well over ten thousand years ago. However, it is not fully understood what attracted people to the lake in the first place. In modern times the primary use of the lake is strictly recreational while in prehistoric periods the use was likely driven by the availability of subsistence resources. The primary objective of this thesis is to understand settlement patterns and ascertain what environmental factors influenced the decisions of hunter-gatherers over the course of 11,000 years. Determining what these factors are will help us all understand the behavioral aspects of human decisions and their interactions with their environment (MacDonald et al. 2012).

This thesis asks three important research questions in order to fully understand the full scope of human behavior. The first question examines whether or not hunter-gatherers were selecting the locations of their settlements based upon the availability of subsistence resources. The second question examines how changes in climate affected both the spatial variability of site locations and the frequency at which they occur. Finally, the last question examines how the spatial locations of sites along the z-axis (elevation) can be used as good indicators to past lake levels.

The premise of this research is primarily focused on the tenants of behavioral ecology. Behavioral ecology employs several models such as the patch choice model, diet breadth model, central foraging theorem and others, but most revolve around the central theme of risk management. These models seek to explain the behavioral decisions hunter-gatherers will make in response to environmental contingencies. In productive environments risk management strategies are employed less because there is an abundance of subsistence resources. Only when the environment becomes less productive do the risk management strategies become more heightened. In situations where resources become unevenly distributed across the landscape hunter-gatherers may employ various strategies involving expanding their territorial base, developing specialized tools, increase their logistical or residential mobility or further distancing their residential bases in attempts to acquire subsistence resources (Binford 1980; Bettinger 1991; Bleed 1986; Kelly 2007; McCall 2006; Surovell 2009).

Since hunter-gatherers are primarily dependent upon the productiveness of their environment the precepts of the Marginal Value Theorem (MVT) will be used to examine how environmental conditions factored into their decisions in settlement placement and their frequencies. The theorem explains that hunter-gatherers will exploit resources from a patch as long as the energy costs involved in collecting and processing those resources do not exceed the amount of potential energy that could be gained from the patch (Bettinger 1991; Kelly 2007). A patch can be best explained as an ecological zone or habitat that supports various types of species of plants and animals that are exploited by humans for subsistence needs (Kelly 2007). When environmental conditions are conducive enough to support large populations of animals the patch is regarded as productive. Nonproductive patches are therefore associated with poor environmental conditions.

While fluctuating lakes levels have been primarily associated with caldera breathing cycles (Locke and Meyer 1994; Pierce et al. 2007), another theoretical approach will be used to determine how this phenomenon affected settlement placement patterns. The law of superposition taken from the geosciences will be applied to identify patterns of site locations in relation to paleo-shorelines. The law states that in an undisturbed chronological sequence of stratified deposits the youngest deposits are found closer to the surface while older layer deposits increase sequentially with age the deeper they become (Stanley 2005). This would suggest that archaeological material from any time period should be associated at or above lake levels of its respective time period, only unless they become secondary deposits.

In summary, the paradigms previously mentioned will help determine, first, how humans adapted to the natural environment and secondly, how their archaeological deposits reflect the heights of past lake levels of Yellowstone Lake. In the chapters ahead it will be first ascertained whether or not hunter-gatherers selected patch-types based on the availability of subsistence resources. Then a thorough examination will be conducted to determine how shifts in climate may have affected the productions of patches that in turn would have influenced the subsistence and settlement strategies of hunter-gatherers. Lastly, it will be determined if archaeological deposits can be associated with past lake level heights.

1.6 Incorporation of GIS and Remote Sensing Techniques

The primary means of analysis in this research will be facilitated through the spatial analysis utilizing both Geographical Information System (GIS) and Remote Sensing Techniques. A GIS allows the graphical and visual representation of georeferenced data through the use of specialized software programs. It also allows the user to manipulate and statistically seek out patterns relating to georeferenced data and come to meaningful interpretations. This enables researchers to test hypotheses and gain a more clear understanding on any recognizable patterns observed in the data.

Similarly, remote sensing involves the interpretation and analysis of satellite imagery. This is done through the classification of pixel values that are assigned to landcover type based upon their range of values. Each land cover type (i.e. forest, water, urban ect,…) has a unique range of values pertaining to the values of the electromagnetic spectrum (Lillisand et al. 2008).

For instance, a grid cell may have the assigned values of B=30, G=50 and R=23, which is representative of the blue, green and red spectral bands of the visible portions of the electromagnetic spectrum. Together, these values make up a spectral signature, and belong to a range of values that are characteristic of standing water (Lillisand et al. 2008). Classifying grid cells in this manner enables researchers to conduct meaningful analyses by examining the conditions and boundaries of different vegetative zones, changes over time, or assessing the negative effects of drought and burned portions of forests.

In summary, remote sensing will be used to classify land cover types of Yellowstone Lake and the surrounding regions using satellite imagery taken from archived images from the Landsat V mission. GIS techniques will then be utilized to perform comparative analyses between the spatial location of prehistoric sites and their proximity to land cover types. GIS analyses will also be conducted in comparing the spatial locations of prehistoric sites with paleo-shoreline models. These analyses will allow for the acquisition of data that can be used to test the hypotheses and come to meaningful conclusions concerning the research questions.

1.7 Organization

The organization of this thesis will next offer a literature review of the geologic history of Yellowstone National Park followed by an overview of the inception and use of GIS as an emergent field of study in archaeology. Following this, will be a brief chapter outlining the specific questions and hypotheses and expected results. Next, individual chapters will be assigned to each research question discussing the procedures/methodology, analyses and results. Lastly, final conclusions will be made concerning the findings from the research analyses.

Chapter II

The Geology of the Yellowstone Plateau

2.1 Origins of Yellowstone Hotspot

Over the course of two million years, active tectonic stretching and violent volcanism has completely reshaped the topographic relief of Yellowstone National Park. Prior to this, the Yellowstone Plateau and adjacent regions were non-existent and the topography resembled contemporary relief of the Madison, Gallatin, Teton and Absaroka Ranges (Christiansen 2000). Approximately 1.8 to 2.0 million years ago a violent volcanic eruption of unimaginable force displaced approximately 2,500 km^3 of magma and ejected enough pumice and ash to bury 15,500 km^2. The eruption was so massive that it is believed that the magna chamber emptied in only a matter of days or perhaps just hours forming a caldera 75 to 95 km across (Christiansen 2000).

The Huckleberry Ridge eruption was the first of a series of three eruption events to occur in the Yellowstone Plateau. Transpiring over the next 1.5 million years, the Yellowstone Plateau would be struck again by two later catastrophic eruptions that would form the modern relief of the park, we see today. The Mesa Falls eruption characterizes the second and smallest eruption event and formed a caldera 6 km across and occurred approximately 1.3 million years ago. The last of these cataclysmic eruptions was the Lava Creek eruption that had occurred 640,000 year ago. This eruption alone formed the modern Yellowstone Caldera, measuring 85 km in length and 45 km in width. The culmination of all three eruption events is impressive to say the least, but the geologic history of these volcanoes has a much darker and turbulent past that spans more than 16 million years ago into the Tertiary (Christiansen 2000; Pierce and Morgan 1992; Perkins and Nash 2002; Smith and Siegel 2000).

Recently, two seismic tomography studies identified a low-velocity mantle body inclined to the northwest of Yellowstone at 20° from vertical and extending 500 km below the Earth's surface (Saunders et al. 2007). Referenced in popular culture as the Yellowstone Hot-Spot, the anomaly it is not entirely a true, 'hot-spot', but rather a shallow upwelling of magma resulting from a tectonic flaw in the plates (Christiansen et al. 2002; Christiansen 2000). Hot-spots describe the effects of a convective plume that has upwelled from the base of the mantle to the upper mantle causing excessive heat to erupt onto the surface and form volcanoes (Christiansen et al. 2002; Christiansen 2000; (Smith 2004). The term, 'hot-spot', was defined by Tuzo Wilson in 1963 to describe the cause and effect of linear chains of oceanic volcanoes that record the progression of overlying plates. These types of volcanoes are generally characterized by low viscosity basalt flows comprised of high concentrations of iron due to the extreme depths from which the magma originates from. The Hawaiian volcanic islands are a case example of this.

In contrast, the Yellowstone volcanic field does not share all these characteristics but rather resembles the qualities associated with deep-mantle plumes and volcanic arcs. This is observed with the bimodal composition of the rhyolite-basalt flows found throughout the region. These flows are generally comprised of mostly of rhyolites at 76% with the remainder made up of iron rich basalts (Christiansen 2000). This unique composition indicates that the source of the magma is fairly shallow and not deep within the Earth's mantle as are the sources associated with hot-spots. The rhyolitic composition suggests the magmatic anomaly is shallow enough to liquefy the upper portions of the Earth's crust while the basalt indicates that the source extends down into the upper mantle regions where basalt is more prominent due to its density. Due to these conditions it is thus difficult to classify the Yellowstone volcanic field as the resulting effect of a deep-mantle plume.

However, because the source of the magmatic anomaly appears to be stuck in limbo between the upper-mantle and crust, it does share some characteristics associated with hot-spots. This is attributable to the linear progression of volcanism pot-marking the Snake River Plane. Pierce and Morgan (1992) accept a model that illustrates that the silicic magmatism along the Yellowstone hot-spot track results from the partial melting of the upper continental lithosphere by basaltic upwelling from the mantle. Additionally, the track trends at the same rate and inclination as the North American Plate (Christiansen et al. 2002; Pierce and Morgan 1992; Saunders et al. 2007).

While there is still yet to be any agreement regarding the classification of this type of volcanism amongst the scientific community, the volcanism resembles more so the characteristics of hot-spots despite the bimodal compositions of magma. For whatever reason being the precise nature of the magmatic anomaly, this chapter will recognize it as a 'hot-spot' for simplistic reasons. Eventually, with the progress of society and learned knowledge, the issue with the "hot-spot' debate will eventually be resolved.

Volcanism in the Yellowstone Plateau is a fairly recent development when considering the 16 million year record of the Yellowstone hot-spot track. Extending back 16 million years ago the mantle plume was first positioned in the central Basin and Range near the Nevada-Oregon-Idaho border. The Yellowstone hotspot is thought to be associated with Late Cenozoic rhyolitic volcanism in both central and southern regions of the Basin and Range as well as basaltic volcanism related to the Columbia River basalt fields and others situated in Oregon and California (Christiansen et al. 2002; Pierce and Morgan 1992; Saunders et al. 2007).

Pierce and Morgan (1992) believe that the Yellowstone hot-spot developed in this region based on the premise that some mantle plumes have been associated with extensive rift zones, as observed with the 1,100 km Nevada-Oregon rift zone. They also cite that, hot-spot tracks are normally preceded by continental basalt floods and list the; Deccan Plateau and the Reunion track; the Parana basalts and the Tristan track; the Columbia River basalts and the Yellowstone track as case examples. They further point out that volcanism of this nature occurs only after major basalt flooding events. The 15-16 million year old ignimbrites in northern Nevada-southwest Oregon postdate and overlie the middle Miocene Oregon flood basalts by about one to two million years. This establishes a timeline between the genesis of the Yellowstone hot-spot and the later stabilization of a shallow mantle plume in the upper continental lithosphere (Pierce and Morgan 1992).

Gradually, over the last 16 million years the Yellowstone plume head has traversed across the North American continent at a rate of 29 km\m.y. (Pierce and Morgan 1992). In its trek it has formed several volcanic fields and sculpted out the Snake River Plane. The Snake River Plain, (SRP) is comprised of two structurally contrasting segments, the Western Snake River Plain, (WSRP) and the Eastern Snake River Plain, (ESRP). The Western Snake River Plain, (WSRP) trends westward and northwestward from Twin Falls, ID and extending past Boise, ID to close proximity to the Oregon border. The Eastern Snake River Plain, (ESRP) trends northeastward from Twin Falls, ID up toward the Yellowstone Plateau (Christiansen et al. 2002; Smith and Siegel 2000).

It is not fully understood what role the Yellowstone hot-spot had on the SRP province, but the WSRP has been identified as a graben bound by north-northwest trending normal faults that formed after the passage of the Yellowstone hot-spot (Andrews et al. 2008; Pierce and Morgan 1992; Shervais et al. 2002). Shervais et at. (2002) have proposed that the WSRP formed as a result of thermal tumescence from the Yellowstone plume head rising underneath eastern

Oregon and Washington. As this graben deepened, basaltic magma was then ejected as a resulting factor from pressure-release mechanisms (Christiansen et al. 2002; Shervais et at. 2002). Shervais et al. (2002) interpret that these expulsions of basalt represent remnant plume material left over from the development of the Yellowstone plume head. Further to the east, the ESRP is characterized by extensional faulting very similar to the Basin and Range provinces and is being stretched in a northeast to southwest direction, (Christiansen et al. 2002; Pierce and Morgan 1992; Smith 2004). Ancient volcanic fields are visible throughout this region as evidence to the volcanic history and the active forces of plate tectonics as the North American plate traverses over the mantle plume.

Over the course of 10 million years the ESRP has seen a regular cyclical pattern of volcanism arising from the Yellowstone hot-spot. These patterns would begin with the rise of basaltic magma from the plume head into the shallower depths of the crust, where it would begin pool between 8 to 20 km below the Earth's surface (Smith 2004). The immense heat would eventually cause the earth's crust to liquefy into magma chambers forming a mixture comprised of both basaltic and silicic material. Over time pressure would eventually build up and succumb to a massive release of energy in the form of a volcanic eruption (Smith 2004).

Each cycle of volcanism would last about three million years, while simultaneously the North American plate traversed to the southwest over the plume head. At the end of each cycle, the regions that were once affected by the plume began to dramatically subside as the plume head was driven further to the northeast. These waning stages of volcanic cycles were also accompanied by expulsions of basaltic magma. Smith (2004) believes that regional subsidence played a crucial role in the formation of the ESRP during the waning stages of volcanic cycles.

He interprets this phenomenon as partial melting from remnant mantle material associated with the Yellowstone plume head. Primarily comprised of basalt, the remnant material is eventually released to the surface where it flows directly into the subsiding basin region filling them in. Christiansen (2000) along with Pierce and Morgan (1992) collaborate with Smith (2004) and point out several ancient volcanic fields associated with post departure basalt flows extending up the ESRP trending northeast into Island Park and into the Yellowstone Plateau volcanic field. Christiansen (2000) attributes these basalt flows as the final stage of a four stage process (referenced as the Cauldron Cycle) by which the volcanic fields of the ESRP undergo throughout their life span. The first three stages of the cauldron cycle may repeat multiple times before the fourth stage takes into effect resulting in regional subsidence.

The first of these volcanic stages occurs with major uplifting in an area causing circumferential radial fractures in the Earth's crust to occur forming a ring fracture zone (Christiansen 1984; 2000). Minor eruptions of magma then erupt through these weak fracture zones as pressure increases. During the second stage the sub-aerial pressure will become so great that a massive eruption will occur along the weakened ring-fracture zone releasing voluminous amounts of rhyolitic ash and debris. The sudden release of gas pressure during this second stage causes the magma chamber to collapse in a matter of hours or days after initial eruption. During the third stage additional eruptions of rhyolitic and basaltic lavas may occur over many thousands of years after the initial eruption. These usually occur near the proximity to weakened faults along the ring fracture zone. In some cases resurgent doming of the ring fracture zone may also occur, but does not necessarily happen (Christiansen 1984; 2000). Christiansen (1984; 2000), explains that these first three stages may repeat multiple times creating a well stratified volcanic field comprising of two or more calderas.

The fourth and final stage is attributable to region wide subsidence and the release of basaltic magma through vast arrays of basalt dikes (Smith 2004). This occurs when the mantle plume head has moved sufficiently far away from the older calderas allowing the magma chambers to cool. As cooling initiates, the rhyolitic magma inside the chamber begins to solidify and becomes increasingly denser allowing for subsidence to occur in the area. Since rhyolitic magma also solidifies at a higher temperature than basaltic magma, basalt is pushed out as the rhyolite forms into an expanding pluton (Christiansen, 1984; 2000; Smith 2004). Eventually Basalt is driven towards the surface and erupts. Christiansen (2000) explains that this phenomenon occurs when an overbearing amount of pressure forces the highly viscous basalt to seep through weak faults leading up to the Earth's surface to erupt.

It is apparent that these cyclical patterns of volcanism have occurred in the Snake River Plain and played a crucial role in the plain's formation. For over two million years the Yellowstone Plume head has moved away from the ESRP to its current location under the Yellowstone Plateau. It is unclear if basaltic volcanism will continue to occur in the areas immediately southwest of the plume's current location under the Yellowstone Plateau since these areas may still be experiencing the effects of the fourth stage of cyclical volcanism (Christiansen 1984; 2000). However, Christiansen (2000) mentions the possibility that even perhaps the Yellowstone Volcanic Field may be in its waning stages of volcanic activity due to the presence of basalt flows along the peripheral margins of the volcanic field. Though, there is not enough viable data to really confirm this and only time will tell whether or not the next eruption will primarily consist of basalt flows. Currently the hotspot has shown no signs of dissipating anytime soon and volcanism is likely to occur for millions of years to come.

2.2 Yellowstone Volcanism

Prior to 2.2 million years ago the Yellowstone province comprised primarily of mountainous terrain formed by regional uplifting and normal faulting. Today it is now an active volcano field that has since been through three major volcanic eruptions that have transfigured the region into a highly elevated plateau, covering an area of 17,000 km^2, (Christiansen, 1984; 2000; Christiansen et al. 2002). Christiansen (2001) describes the igneous composition of the Yellowstone Plateau to be 76 percent rhyolites and 24 percent basalts. The plateau comprises of three stratigraphic deposits of welded ash-flows from three major rhyolitic eruptions and numerous flows of both rhyolites and basalts.

The welded ash-flow formations represent three major volcanic eruptions of the Yellowstone volcanic Field. These comprise of the Huckleberry Ridge Tuff (2.1 m.a), Mesa Falls tuff (1.3 ma) and the Lava Creek tuff (640 kya). Large calderas formed soon after the emptying of the magma chambers that are believed to have transpired over a course of several hours or days (Christiansen 2000). The Huckleberry Ridge eruption formed a caldera 75 to 95 km across, while the Mesa Falls eruption formed a caldera 16 km wide. The final Lava Creek eruption formed the Yellowstone Caldera, an elliptical caldera basin 85 km long and 45 km wide (Christiansen 1984; 2000).

The Huckleberry Ridge Tuff represents the climax of the first volcanic cycle in the Yellowstone province 2.1 million years ago. Much of the material ejected from this eruption is buried and deeply stratified below the younger rocks from the succeeding eruptions. (Christiansen 1984; 2000). The caldera is thought to extend from Big Band Ridge west of Island Park and into the central plateau, but much of it underlies younger rocks making it difficult to map its margins (Christiansen 2000). Rhyolitic lava flows are thought to have ensued soon after this eruption, which filled in the caldera basin as well as regions along the margins of a ring fracture zone (Christiansen 2000). Due to the deeply stratified region, identifying the first cycle's ring fracture zone has been near impossible since much of it is concealed by younger deposits. However, it is thought to extend from Island Park area to the younger Yellowstone Plateau area, (Christiansen 2000)

The basalt floods from this eruption are identified as the Junction Butte Basalt. Much of the flows from this sequence are attributed to pooling into low valleys forming thicknesses as great as 60 m in depth (Christiansen 2000). Christiansen (2000) identifies two areas where the Junction Butte Basalt is exposed. The first of these exposures is situated at the junction of Tower Creek and the Yellowstone River and the second at Mt. Everts east of Mammoth Hot Springs. However, the most accessible of these is the Overhanging Cliff flow, an outcrop found along the road north of Tower Falls on the west side of the Narrows of the Grand Canyon (Christiansen 2000).

Christiansen (2000) noted that there were two sequences of ash events during this first volcanic cycle. The first being the initial fallout of ash and debris ejected into the atmosphere and then later by ignimbritic ash-flows. The initial fallout formed an even layer of very fine ash blanketing ground surfaces as far east as southwest Kansas. Ash deposits were even found in the Gulf of Mexico suggesting that they were carried there by major streams and rivers that fed into the Mississippi River (Christiansen, 2000). In some regions, Christiansen (2000) notes that the temperatures from the ash-fall were so high that sediments directly underlying these deposits were reddened to depths of up to10 meters.

The second stage of ash-flows occurred only shortly after the initial eruption of the first stage and were vented from ignimbrites or volcano vents along the ring fracture zone, (Christiansen 1984; 2000).The ash flows from these vents were so dense and so hot that the fine particles welded together to form welded tuff. In areas within close proximity to the volcanic vents, the ash-flow began to fuse and weld with the top 15 cm of the initial fallout ash (Christiansen 2000). Christiansen (2000) estimates that the maximum radius of the second ash-flow eruption covers a distance of 90 to 100 km from Island Park, Idaho. He further points out that this eruption alone displaced approximately 2,500 km^3 of magma and ejected enough pumice and ash to bury an area of 15,500 km^2 (Christiansen 1984, 2000).

The second volcanic cycle climaxed about 1.3 million years ago with a smaller eruption that formed the Mesa Falls Tuff. The second eruption was the smallest of the three eruptions and formed the Henrys Fork Caldera measuring 19 km across. Christiansen (2000) posits that the extent of the ash-flow was primarily limited to the southern wall of the caldera due to its shared boundary with the north wall of the first cycle caldera. The thickest section of ash-flow from this eruption occurs on Thurman Ridge and measures up to 150 meters in depth (Christiansen 2000). Deposits of this ash have been identified in both the southern Rockies and Great Plains based upon petrologic composition found in deposits of these areas. In addition, deposits of this ash have also been discovered in the Gulf of Mexico, suggesting again that stream transport played a functional role in depositing these sediments (Christiansen 2000).

The post-collapse history of this eruption is quite interesting. Within and or close proximity to Henrys Fork Caldera five rhyolite domes formed not long after the formation of the Mesa Falls tuff. These features are described by Christiansen as steep sided domes having a flow structure that forms a shell-like structure that runs parallel to their sides (Christiansen 2000). These rhyolitic features form a 30 km belt trending linearly northwest across Island Park and are approximately 7 km in width. The rhyolites associated with the Henrys Fork caldera are believed to have formed as a byproduct of all three volcanic episodes of the Yellowstone volcanic field (Christiansen 2000).

After the formation of the caldera, basalt flows enveloped the region and formed the Narrows of the Grand Canyon. These basalt flows are interlayered with gravely sediments and glacial till associated with glacier activity in the past. The thicknesses of these flows are as much as 70 m thick and are a major feature to this section of the park (Christiansen 2000). Christiansen (2000) remarks how this flow once constituted an ancient paleo-valley that was later incised and cut down to expose earlier deposits from the Huckleberry Ridge Tuff as well as the Junction Butte basalt formation.

The third volcanic cycle began 1.2 million years ago that climaxed to an eruption 640,000 years ago. This cycle of volcanism is very important to geologists because it lends insight into the formational processes involved with the stages of the cauldron cycle model discussed in the previous section. This first stage occurs with the development of ring fracture zone where by magma is released through weak fault lines. The second stage involves the eruption of rhyolitic ash-flows and degassing of the magma chambers. This is followed suit by periodic post-collapse rhyolitic and in some case basaltic lava eruptions that may ensue for thousands of years after the initial eruption. The final stage of this cycle occurs only after the cooling of the rhyolitic magma chambers where remnant basalt it pushed towards the surface and erupted pluton (Christiansen 1984, 2000; Smith 2004). This last stage is also attributed with increased regional subsidence.

Evidence for the first stage of the cauldron cycle comes from numerous rhyolite flows associated with the Mount Jackson rhyolite. The Mount Jackson rhyolite represents a fissure system that began to develop 1.2 million years ago and caused several major rhyolite flows along the outer margins of the modern day Yellowstone Caldera. These flows are attributed to a system of fissures that formed the boundary of the ring fracture zone (Christiansen, 1984, 2000).

The rhyolitic flows that make up the Mount Jackson Rhyolite are the; Wapiti, Flat Mountain, Moose Creek Butte, Big Bear Lake, Harlequin Lake, and Mount Haynes flows. The Mount Haynes, Harlequin Lake and Big Bear Lake flows form the lower walls of Madison Canyon near the west entrance of Yellowstone National Park. Mount Haynes flow dates to 610,000 ka and underlies the Lava Creek Tuff. The close proximity in age of the Mount Haynes rhyolite with the estimated date of Lava Creek Tuff may represent a margin of error (Christiansen, 2000). However, the Mount Haynes does predate the Lava Creek Tuff based on stratigraphy of the two deposits. The Harlequin Lake Flow which underlies Mount Haynes flow dates to 840,000 ka but Christiansen (2000) does not give a calibrated date for the Big Bear Lake flow but only implies that it is older than the Lava Creek Tuff.

Northeast of the Yellowstone Caldera situated in proximity to the Grand Canyon of the Yellowstone and Broad Creek lies another Mount Jackson rhyolite flow. The flow in this region is identified as the Wapiti Lake flow and has a calibrated age of 1.2 ma. Situated on top of an elevated position of the Yellowstone Caldera just southwest of Yellowstone Lake, lies another flow identified as the Flat Mountain Arm flow with a calibrated age of 930,000 ka. (Christiansen, 2000). Collectively, these flows represent a long and very active volcanic history leading up to the full eruption of the third volcanic cycle (Christiansen 1984, 2000).

In addition, there were also minor basalt flows occurring in the southwest and north of the plateau. The Udine Falls basalt flow located in the northern section of Yellowstone followed along the same stream courses as the Gardner and Yellowstone Rivers including Obsidian, Lava and Blacktail Creeks (Christiansen 2000). This flow’s calibrated age is just slightly older than the 640,000 ka Lava Creek Tuff. Other basalt flows, Warm River and Shotgun Valley basalt flows are located southwest of the Yellowstone Plateau. The Warm River basalt flow dates to roughly 760,000 Ka while the Shotgun Valley flow is contemporaneous with the age bracket of the third volcanic cycle (Christiansen 2000).

In light of these numerous flows that embodied the nature of the cauldron cycle the third eruption still had a devastating impact across much of North America and is characteristic to the second stage of the cauldron cycle. The fallout ash was deposited as far east as the Great Plains, Kansas and Nebraska and depositing sediments as deep as nine meters. Ash deposits have also been identified in Iowa, California and north into Canada as well as sediments in the Gulf of Mexico deposited by the Mississippi River and other tributaries. It is estimated that this eruption ejected enough ash to cover 7,500 km^2 and fill a volume of 1,000 km^3 (Christiansen, 1984, 2000). Christiansen postulates that it was only a matter of a few hours after the eruption when the magma chamber collapsed to form the Yellowstone Caldera.

Nevertheless, despite this last climactic eruption 640,000 years ago, continued volcanism is still prevalent today as it is in its third stage of the cauldron cycle. Since the formation of the Yellowstone Caldera, two resurgent domes residing in the ring fracture zone have been periodically releasing and venting rhyolitic magma flows over the past 600,000 years. Christiansen (2000) cites Smith and Bailey’s analysis that resurgent calderas will exhibit a cauldron block bounded by a ring-fracture zone that remains intact after the collapse of the magma chamber roof. Christiansen explains that the Mallard Lake and Sour Creek Domes may have formed by the inward collapse of the magma chamber roof from its highest position which caused the topography to slump toward a central axis from its outer rim (Christiansen, 2000).

The Sour Creek Dome is the eastern most structure and is believed to have become resurgent soon after the collapse of the Lava Creek magma chamber roof. Its dimensions measure 13 by 21 km across with an axis that trends northwestward towards an area of faults outside the caldera (Christiansen 2000). The Mallard Lake Dome lies directly southwest of the Sour Creek Dome and forms an elliptical dome 11 km by 19 km across. It too, has a system of faults trending to the northwest along its main axis (Christiansen 2000). Christiansen (2000) explains that the unique fault pattern of complex grabens and spreading fault zones demonstrates their origins to be of domical uplift associated with a ring-fracture zone.

Christiansen (1984, 2000) goes on further to recognize that there are two ash-flow sheets associated with these structures and both show dissimilarities in their chemical compositions (Christiansen 2000). He infers that the irregularities associated with these two ash-flows are attributed to different bodies of magma positioned very shallowly beneath the Earth's upper crust. He suggests that the two magmatic intrusions rose separately to the upper crust but both probably originated from a single magmatic body from greater depths, (Christiansen 2000). He points out further, that the rise of these bodies occurred simultaneously, based upon stratigraphic evidence from the ash-flow tuffs which reveal no apparent lapse in time for erosion to occur between these two ash-flow bodies (Christiansen 2000).

Since the resurgence of these two domes, the Yellowstone Plateau has continuously been filling in with sediments alongside with periodic episodes of rhyolitic flows representative of the third stage of the cauldron cycle. These flows are mainly concentrated along the ring-fracture zone that bound the resurgent domes. Beginning 150,000 years ago, these flows have released enough magma to cover the Mallard Lake Dome and flood the western segment of the

Yellowstone Caldera and ultimately bury its western rim (Christiansen 1984). These rhyolitic flows were released in three episodes dating to 150,000, 110,000 and 70,000 ka.

The flows were released along fissure vents spreading from regional trending fault systems that span across the entire caldera complex. Christiansen (2000) believes that these flows represent the crystallization or cooling of the magma chamber. This is based on the fact that the flows occurred along regional faults. He suggests that as the crust becomes increasingly more rigid, the regional faults that intersect the ring fracture zone become broken up. This then allows deeper magma to rise and penetrate through the weakened fault zones and erupt (Christiansen 1984). At the moment it is unclear whether or not continued eruptions will occur as a result of these weakened faults but the relative young age of these flows suggest other eruptions may occur.

To summarize all that has been discussed, all three volcanic cycles have all culminated to climatic eruptions resulting in the major ash-flow formations present in the Yellowstone Volcanic field. The Huckleberry Ridge tuff was formed approximately 2.1 Ma followed by the Mesa Falls tuff 1.3 Ma and later succeeded by the Lava Creek tuff 640,000 years ago. Each of these eruptions was catastrophic in which enormous amounts of ash were deposited as far east as Nebraska and Kansas and even enveloping parts of California and Oregon. The eruptions expelled ash with such immense temperatures that the glass and crystalline rock particulates welded together, forming a welded tuff along the margins of a ring fracture zone.

Christiansen (1984, 2000) explains that each of these climatic eruptions may have transpired within only a matter of a few hours or up to a few weeks for degassing to occur. This is based on stratigraphic evidence, which has shown that no apparent lapse in time had occurred for erosional forces to take place. The stratigraphic record of all three eruptions reveals that the main ash-flow eruption only occurred during the settling of the finer ash from the initial eruption. Christiansen (1984, 2001) notes that the rapid release of these ash-flows caused the magma chamber to empty rapidly causing the roof to collapse under its own weight, forming a basin caldera.

Usually, the caldera rim represents the margins of a ring fracture zone. These are complex concentric fault systems formed when mounting pressure from a magmatic body below the Earth's surface is forcing magma into a magma chamber. The buildup of pressure causes the surface of the Earth to bulge and form fissure systems at weak points (Christiansen 2000; Pierce and Morgan 1992; Smith and Siegel 2000). These networks of weakened faults form a ring fracture zone and are the focal point in which eruptions of rhyolitic magma are released. As further pressure builds, a critical threshold is reached and voluminous amounts of hot gasses and ash are released from this weakened fracture zone. The last two eruptions show clear signs of the formation of a ring fracture zone. It is quite probable that the first eruption resulted from the failure of a ring-fracture zone as well but any evidence for it is mostly buried deep under younger rocks and sediments associated with the younger eruptions (Christiansen 2000, Christiansen et al. 2002).

Rhyolitic and basaltic flows have also been a common issue since the existence of the Yellowstone Volcanic Field. Rhyolitic flows are expelled during the development of the ring fracture zone and precede the main climatic eruption (Christiansen 1984, 2000). They are also associated with the ring fracture zone even after post-collapse since the faults bounding this zone are still structurally weak. Eruptions of basalt have also occurred in Yellowstone and may be linked to the apparent cooling of the aging magma chambers. These basaltic eruptions are a characteristic feature associated with the Yellowstone hotspot and is seen all throughout the eastern Snake River Plain (Andrews et al. 2008; Christiansen 1984, 2000; Christiansen et al. 2002; Pierce and Morgan 1992; Smith and Siegel 2000). It occurs when the magma-chamber is cutoff from the hotspot and begins to solidify over millions of years causing the basalt to be pushed out through weakness in the Earth's crust.

In summary, it is uncertain if Yellowstone is in its final stages of volcanism. Given the fact that the Mallard Creek Dome has only been uplifted not more than 160,000 years ago is enough reason to postulate that the region may expect more volcanism. Additionally, episodes of rhyolitic flows are directly linked to this uplift all of which lasted up to 70,000 years ago. Christiansen (2000) attributes this activity to be associated with cooling in the magma chamber and its interactions with regional Basin Range faulting that intersect through the fault system of the ring-fracture zone. In any case, there is no reason to believe that another rhyolitic eruption could occur in the near or distant future. Additionally there is no clear evidence if Yellowstone Volcanism will repeat the cauldron cycle or transition into the waning stages of volcanism as Christensen (2000) speculates.

2.3 Lakeshore Deformation Processes.

During the last 640,000 thousand years since the last major eruption, the Yellowstone Plateau has never since rested from volcanic activity. This activity ranged from major rhyolitic flows venting from weak points in the Earth's crust along the ring-fracture zone to hydrothermal explosions like the Mary Bay explosion approximately 13 kya and an active hydrothermal system. Just in recent decades it has been verified that the entire Yellowstone Plateau near the vicinity of the Mallard Lake and Sour Creek resurgent domes has been experiencing oscillations in overall elevation. These variations in elevation were first observed by Bob Smith in 1973 when he noticed drastic lake level changes had occurred since he had last worked in the region in 1956 (National Geographic, 2009)

Between 1975 and 1977, Smith coordinated a resurvey of level lines along the Yellowstone Road system and discovered that regional uplift had been occurring within the caldera region. The results from this survey revealed that the maximum uplift had occurred at Le Hardys Rapids (LHR) with a total uplift of 80 cm since 1923. Between 1976 and 1985 results from further resurveys yielded an additional uplift of 15 centimeters at LHR. This is a total uplift of 95 centimeters since the emplacement of line levels in 1923. Pierce et al. (2007) point out that this was an uplift rate of about 15mm/yr over an extent of 62 years. In 1985 there was no apparent change in uplift, but between 1986 and 1996 the surveys revealed a drop in elevation by 20 centimeters, attributed to subsidence (Pierce et al. 2007)

The historical record of uplift and subsidence has led numerous researchers to document and compile a data record to monitor and further study the intracaldera region of the Yellowstone Plateau. The Yellowstone Lake basin has been the focus of attention in understanding long-term effects of intracaldera uplift and subsidence. Over the course of 15,000 years deformation in lake shore development has been directly affected by these cycles of inflation and deflation. Scanning the Yellowstone Lake Basin with the visual eye, one may notice the many prominent terraces situated at varying elevations with respect to the modern lakeshore. These terraces represent past beach terraces that have since been abandoned with receding lake-stand heights (Locke and Meyer 1994; Meyer and Locke 1986; Pierce et al. 2007).

The mechanism behind the long history of fluctuating lake-stands, resides 5 km downstream from the outlet of Yellowstone Lake at Le Hardys Rapids. Le Hardys Rapids (LHR) is a section of the Yellowstone River that is positioned near the southwest base of Sour Creek

Dome and traverses across the northwest trending axis of the Mallard and Sour Creek domes. At present, the drop in elevation from the lake outlet to LHR is only .25m over a 5 km stretch making for a very slow and lethargic river current (Pierce et al. 2007). Because Le Hardys Rapids is positioned over this axis point, any changes in uplift and subsidence will directly affect the river's gradient. Any change in elevation due to inflation or deflation will directly control the discharge rate of water flow as well as overall lake-stand height.

Since the 1980s an increased effort has been made to better understand the formational processes involved with the Yellowstone Lake terraces with regards to Le Hardys Rapids.

Grant Meyer and William Locke began a thorough survey between 1984 and 1988 that encompassed the entire perimeter of Yellowstone Lake. Using automatic levels, rods and tapes with centimeter scale resolution of topography they surveyed 230 profiles and identified 11 recognizable terraces. Out of these 11 terraces, five were continuous around the lake basin and used to identify deformation patterns. Pierce et al. (2007) performed a similar study just prior to 2002 and identified six prominent terraces. Both studies of Meyer and Locke and Pierce et al. used radiocarbon-isotopic analysis to date shoreline features. However, Pierce et al. incorporated archaeological evidence to have a better age control in shoreline chronology.

Locke and Meyer attributed the formation of these terraces with fluctuations in lake-stand heights that are controlled by the lake outlet. Terraces are formed when erosion occurs from a wave-cut platform and cliff which meet at the shoreline angle (Locke and Meyer 1994). Cliffs will develop when wave action undercuts the base of the cliff and thus removes massive amounts soil. These cliffs will form terrace risers when lake levels have subsided to cease further undercutting by wave movements. Terrace treads form as undercut sediments accumulates at the base of the platform, forming a, 'ramp', like structure up towards the top of the terrace (Locke and Meyer 1994). Locke and Meyer, further explain that the deposition and construction of beach ridges and barriers will also form into terraces as well.

Both, studies reported that there were major tilts and deformation processes occurring along the caldera side of the lake which comprises the northwestern half of Yellowstone Lake. These deformations are caused by numerous factors such as regional uplift or subsidence, faults and or regional extension. However, Locke and Meyer (1994) and Pierce et al. (2007) agree that the tilting observed was trending towards the caldera rim. Due to this phenomena Locke and Meyer used the southeastern arm as a means to interpret elevation and deformation processes occurring in the northern section of the lake.

As noted earlier, Locke and Meyer (1994) identified five prominent shorelines (S3, S4, S5, S7, and S9) that were continuous around the lake basin. Due to the complex shoreline line deformations, the elevations for each of these shorelines vary depending on geographical location within the lake basin. For example, gauging from a line profile view of the north to southeastern reaches of the lake, (see Locke and Meyer 1994 figure 4), all shorelines incline steeply toward the caldera rim with major drops beginning near Mary Bay. Outside the caldera margin these slopes plateau and gradually rise again as they meet toward the easternmost edge of the Southeast Arm. These changes in elevation clearly indicate that deformation and stretching is occurring in the eastern half of the lake and is likely occurring elsewhere around the basin.

Shoreline 3 exceeds 7 m above datum between Sand Point and Pumice Point and also in the West Thumb area of Yellowstone Lake. However, along the north and northeastern shore and outlet area, S3 shoreline elevation drops to an average of 4.5 m above datum. Shoreline 4 has a similar pattern to S3 but Locke and Meyer note that there is also a marked depression along the mouth of the arms and an increase in elevation of 5 m above datum in the Southeast Arm (Locke and Meyer 1994). Shore line S5 also has common characteristics with S3 as seen with depressions occurring near the mouth of the arms and also in the West Thumb area. Locke and Meyer's shorelines S7 and S9 are the highest and share similar deformation as the lower shorelines but they note that there may be some extra-caldera deformation associated with local complexities observed in the southeastern section of the lake basin (Locke and Meyer 1994).

Locke and Meyer assign the following calibrated ages to their shorelines that post-date the Pinedale glaciation sometime after 15 kya. S1 represents the modern shoreline, S2 1.0 kya; S3 2.0 kya; S4 3.0 kya; S5 4.5 kya; S6 5.5 kya; S7 9.0kya; S8 10.7 kya; S9 11.5 kya; S10.0, n/a and S11, 14.0kya. Locke and Meyer note that the calibrated age from S8 comes from the analysis of diatoms taken from stratigraphic depths of a barrier bar that had formed Alder Lake that had once been a bay of Yellowstone Lake. They also noted that there was the presence of submerged shorelines located in the northern section of the lake but they restricted their study to only shorelines above the current water line (Locke and Meyer 1994). Pierce et al. (2007) investigated these submerged shorelines further and estimated their age to bracket within the last 3.0 ka to 4.0 ka years.

In a research study conducted by Pierce et al. (2007), he found substantial evidence that indicated the presence of drowned stream valleys that entered Yellowstone Lake. He noted that areas north and south of the West Thumb Geyser Basin had stream valleys drowned by pro-grading water levels that protracted into alluvial wetlands near their confluences to the Yellowstone Lake (Pierce et al. 2007). A core sample taken from a drowned valley of Little Thumb Creek North revealed the region was once a shallow wetland. This evidence comes from insect fauna analysis and wood and charcoal samples taken from a depth of 4.3 meters below datum with an age of 3.0 ka. Another boring taken from Bridge Bay yielded a wood sample at a depth of 3.45 m below datum that yielded an age of 3.8 ka.

Pierce et al. noted that Pelican Creek and Sedge Creek are representative of drowned stream valleys as well. The high stream cut scarps flanking both sides of the Pelican Creek flood plain are indicative of a stream undercutting the flanks of the higher relief terrain. Boring samples revealed that gravelly sands extended down to a depth of 5m below datum and overlaid finer lake sediments dating to 13.8 ka. Pierce et al. (2007) interpret these gravely sands to have once been a channel of Pelican Creek that had eroded its self into the older lake sediments. Unfortunately there was no carbon samples obtained from this matrix of sandy gravel to correlate its age to bracket within the late Holocene.

Sedge Creek has a gravely sand matrix that extends down to a depth of 18m below datum and overlies 6 meters of fine grained lake sediments. These sandy gravel sediments carried by Sedge Creek were noted by Pierce to extend well within the caldera margin to its central region.

Both, lake bottom beds at the vicinity of Sedge Creek and Pelican Creek overlie a gravelly matrix believed to be remnants from the Pinedale Glaciation composed of glacial till and or outwash (Pierce et al. 2007). These deposits suggest that lake levels were well below modern levels in order for these sandy gravels to be transported and deposited over older sediments.

Multi-beam bathymetric and seismic reflection studies, have however, confirmed Pierce's argument for the existence of lower lake stands. Several of these former shorelines form benches up to 15-20 m below current datum and are positioned in the northern and West Thumb areas of Yellowstone Lake (Morgan et al 2002). The existence of these submerged benches lends support that Sedge Creek deposits of upto18 m below datum were indicative of a much lower lake stand

and well within the findings of bathymetric and seismic reflection studies. It will be interesting to see if future studies will be able to properly date these deposits to a specific time period.

After 3.0 ka, lake levels began to rise and drown these lower lying stream valleys and shorelines to present day level. Evidence to substantiate this comes from a slough that is a remnant outer meander of an older Yellowstone channel outlet that became isolated after the formation of a sand bar structure (Pierce et al. 2007). Pierce notes that the slough is comprised of 3.5 meters of fine sediment overlying a half meter of river gravel taken from a depth of 4m. Wood and charcoal samples date the upper portion of this gravel to 2.8 ka. The accumulation of fine sediments indicates that the transport carry load had diminished dramatically which resulted in a slower current. Pierce attributes this reduction in velocity to be directly linked to the uplifting and reduction in gradient of LHR, 3 km further downstream (Pierce et al. 2007).

Pierce (2007) also identifies six shoreline features that are reminiscent to Locke and Meyer's study. The modern shoreline is representative of S1 and is characterized by active wave-cuts that are undercutting cliffs up to 18m in height as observed at Rock Point (Pierce et al. 2007). Shoreline angles are established up to 1.8 m on average above datum, while bar crests usually form 15 cm higher. It is perceived by Locke and Meyer (1994) that bar crest represents wave setup during storm events at relatively high seasonal lake stands.

S2 is estimated to be 8.0ka. This is based upon radiocarbon-isotopic analysis from wood and charcoal samples retrieved from the northern outlet area and a paleo-delta that once fed waters into the southeastern end of the lake basin. Two charcoal samples taken from lagoonal sediments of an abandoned S2 shoreline and its barrier beach located in front of the Lake Lodge yielded ages of 8.0 ka. Another sample retrieved from a 2m thick eolian sand mantling on the Fishing Bridge Peninsula yielded an age of 7.7-7.6 ka (MacDonald and Livers 2011, Pierce et al.

2007). In the southeastern arm of Yellowstone Lake, Pierce identified a paleo-distributary channel 4 km upstream from the confluence of Yellowstone River and the lake. This channel had graded 7 to 8 m above datum and yielded an age of 7.8 ka (Pierce et al. 2007). Pierce notes that there is a .06/km tilt towards the caldera over a 34 km stretch from the southern distributary channel to the northern section of the lake at Fishing Bridge. The average height of S2 in the northern outlet area ranges between 4-5m above datum.

The formation process of S3 indicates a short lived existence. This is evident in the lack well-formed shorelines and beach terraces in the northern outlet area. This may have resulted when changes in lake elevation abruptly shifted and prematurely halted erosional processes (Pierce et al. 2007). If lake levels sustained themselves longer, then erosional processes may have developed more prominent and distinct shoreline features. Pierce comments how the S3 is referred to as the S2/S3 and believes that they are very closely linked. Features relating to this shoreline have been identified at Lake Lodge and east of Pelican Creek. Deposits of S3 are apparent in a S4 lagoon at a depth of 1 m and rests 4.75m above datum. Charcoal retrieved from this lagoon yielded an age of 8.5-8.2 ka (Pierce et al. 2007). In addition, two projectile points were recovered from this location, one of which was diagnostic of the Backwater type-style seen from Mummy Cave (Pierce et al. 2007). This type-style has been bracketed to between 9.0 and 8.0 ka which correlates well with the charcoal sample dates.

The development of S4 occurred sometime in the early Holocene and is well represented by shoreline cuts and barrier beaches along Fishing Bridge peninsula and forms a crest in the same locality as the General Store. Two Scottsbluff and one Cody knife associated with the Cody cultural complex have been recovered near the vicinity of the General store at Fishing Bridge (Pierce et al. 2007). The Cody complex is estimated to have existed from about 10.6 ka to 9.7 ka and represents the Late Paleoindian period 10,000 to 8,000 years ago. Pierce points out that an additional six projectile points resembling the Mountain Foothill Tradition found along the Fishing Bridge peninsula also correspond to the Paleoindian period (Pierce et al. 2007). In the West Thumb area east of Grant Village, the earliest component of the Osprey Beach site belongs to the Cody Complex. The Cody complex horizon is situated within a basal part of mixed non-bedded material overlying beach gravels at 6.8 m above datum while shoreline elevations in the northern outlet reside at 8 meters. Pierce infers that the age of S4 is approximately 10.7 ka based upon extensive archaeological evidence recovered (Pierce et al. 2007)

Shoreline 5 is identified along the northern outlet area and extends east of Pelican Creek and may correlate with Locke and Meyer's S6. Pierce believes that Locke and Meyer's S7 shoreline situated in the southeast arm of the lake is an extension of this same shoreline (Pierce et al. 2007). Major tilting of S5 towards the caldera axis suggests that deflation accompanied with faulting and extensional processes has occurred since its formation. This tilting begins at Mary Bay where elevation datum is 16 to 17m, and then declines 13m at Fishing Bridge and continues to decline to 9 m across Fishing Bridge peninsula (Pierce et al. 2007). Locke and Meyer also noticed this trend in their study as well.

Pierce determined a rough estimate of 12.6 ka for S5 based upon stratigraphic profiles and charcoal samples retrieved from lake sediments at Mary Bay (Pierce et al. 2007). Charcoal samples taken from lake sediments date to between 13.4 to 11.3 ka and overlie sediments intermixed with Glacier Peak Ash which date to between 14.1- 13.4 ka. Overlying these lake sediments are deposits from the Mary Bay hydrothermal explosion. Pierce infers that the Mary Bay deposits are roughly 13 ka based upon the ages and stratigraphic positions of the Glacier

Peak ash and the charcoal samples (Pierce et al. 2007). The formation of S5 occurred after this event because the water-line began eroding into the crater walls.

Pierce recognizes S 5.5 to be comprised of a double crested barrier beach extending from Mary Bay to Pelican Creek with an overall 17 m above datum taken at Mary Bay. This shoreline is best distinguishable 1 km east of Pelican Creek where deposits of the Mary Bay explosion lie up to a meter thick over S5.5 (Pierce et al. 2007). Certain localities of this shoreline may have been eroded away or buried by deposits from Pelican Creek that lie along a gravel bench extending up the Fishing Bridge peninsula (Pierce et al. 2007). Since there is no presence of wave-cut erosion other than S5 into the crater walls of Mary Bay, it suggests that S5.5 formed prior to this hydrothermal explosion. Pierces gives this shoreline an age estimate of 13.6 ka based upon stratigraphic sequence and carbon dating retrieved from insect parts.

Directly east of Pelican Creek, S6 is recognized by its distinct 3 m high wave-cut scarp and sits approximately 20 m above lake datum (Pierce et al. 2007). The formation of S6 is believed to have occurred after deglaciation and the disappearance of the Yellowstone ice-cap. Pierce estimates that S6 formed sometime between 14.5-14 ka based on Mary Bay deposits which mantle this shoreline and suggests that it formed prior to the Mary Bay explosion (13 ka) and prior to S5.5 (13.6 ka) (Pierce et al. 2007).

Pierce separates the post-glacial history into two periods of oscillating episodes to explain the chronology of Yellowstone Lake. He attributes erosional processes at LHR and the cycles of inflation and deflation to cause oscillations in lake levels to drop 10 meters between the time of S6 (14.4 ka) to S4 (10.7 ka). Currently, Le Hardys Rapids has eroded down to a an erosionally resistant bedrock composed of interlocking microsperulites 1-3 m in thickness that make up the base of the Lava Creek Tuff (Pierce et al. 2007). Pierce calculates the rate of erosion to be

5m/k.y. during the first episode of oscillations. A second episode of oscillations began after S4 time and is believed to be associated with the historic uplift record. These oscillations as Pierce describes have no clear trend like the first episode of oscillations (Pierce et al. 2007). Currently any rise or drop in elevation is entirely dependent upon an erosionally resistant bed rock of LHR which may take millennia before reaching a less resistant zone.

There are two favored models for which to help explain these oscillating episodes of inflation-deflation cycles. The first model recognizes that inflation is caused by magmatic intrusions while subsidence results from tectonic extensions. Locke and Meyer (1994) point out that magma intrusion alone, does not account for the rapid subsidence occurring after 1984. Pierce corroborates with Locke and Meyer, and explains that magma intrusion only accounts for a fraction of total observed uplift observed during the historic uplift between 1923 and 1984 (Pierce et al. 2007). Despite the complexities involved with magma intrusions, Locke and Meyer agree that much of the long-term subsidence results from ductile thinning and regional faulting and extensions.

The processes involved with regional subsidence are complicated but Pierce along with Locke and Meyer argue that tectonic extension does play a role in subsidence. Outside the park boundaries, lie extensional Basin and Range faults that include the Hebgen earth quake faults, Teton fault, and the east Sheridan fault. The southeast to northwest extension of these faults cause tectonic stretching in the local region of Yellowstone Lake (Pierce et al. 2007). Pierce attributes the sagging of shorelines in certain areas around the lake basin are a result from these processes. The Elephant Back fault system that runs along the caldera axis also shows this Basin and Range extension trend but also may be attributed to localized doming as well (Pierce et al. 2007).

Faults residing within the caldera complex also show similar trends. The Lake Hotel fault forms a 1 km wide graben 0.5 km southeast of Lake Hotel and strikes northwestwardly toward Lake Village and possibly continues to fault further inland (Pierce et al. 2007; Morgan et al. 2003). However, this fault has had no apparent impact on any of the shorelines. In contrast, extensional deformation is occurring along the shoreline at Lodge Bay in the form vertical fractures just in front of the General Store.

Pierce also identified that a fault has offset S2 and S4 barrier beach across the western tip of Fishing Bridge peninsula. The offset leaves the S2 and S4 barrier beach on the eastern side of the peninsula higher than the western end and submerges the S4 wave-cut shoreline (Pierce et al. 2007). The Fishing Bridge fault has also caused displacement of 1.8 m observed at a sand spit formed during construction of S2. Pierce notes that shorelines older than 9.7 ka are generally offset by no more than two meters. Locke and Meyer (1994) reason that the subsidence observed at the mouth of the arms is related to the subsidence of the hanging wall of the Eagle Bay fault (Locke and Meyer 1994). Warping and uplifting of this foot wall may have also caused Rock Point to uplift as well.

Although subsidence does appear to occur due to general faults and tectonic extensions, but yet, faulting in and around the lake basin appear to have only regional impacts. In addition, much of the faults in the northern outlet area of Yellowstone Lake only offset shorelines by a few meters at most. Lastly, these regional faults have shown no sign of activity since the construction of S2 approximately 8,000 year ago. This indicates that normal faulting and Basin and Range tectonic extension do not measure up to the 20 m or more of post-glacial lake oscillations if considering the submerged benches as well.

On the contrary, Pierce et al. (2007) propose a second model that suggests that uplift and subsidence may occur from hydrothermal inflation and deflation. In this model, uplift and subsidence are mainly driven by the release of trapped hydrothermal fluids via a ruptured seal in a hydrostatically pressured hydrothermal system (Pierce et al. 2007; Fournier, 1989). Pierce argues that the processes involved with inflation-deflation cycles are principally driven by hydrothermal activity occurring at shallow depths beneath the surface. Hydrothermal systems develop from the cooling and crystallization of a rhyolitic magmatic body, in which evolved magmatic fluids are leached and precipitated out (Pierce et al. 2007; Fournier 1989; Locke and Meyer 1994). These minerals begin to accumulate and form a self-sealing seal or cap overlying these magmatic fluids and thus become trapped. The mineral composition of this seal is such that it becomes impermeable and the magmatic fluids permeating beneath it accumulate to lithostatic pressures causing uplift (Pierce et al. 2007; Fournier, 1989; Locke and Meyer, 1994).

Release of this pressure occurs either by exceedance of confining pressure or by the rupturing of the seal releasing pressure and fluids to the surface (Locke and Meyer 1994; Fournier 1989; Pierce et al. 2007). Once released, the uplifted region will subside to its original state. Pierce considers that if net inflation is equal to net deflation, it may explain the lack of deformation seen with the latest Pleistocene shorelines (Pierce et al. 2007). Fournier calculated that at a depth of 4-5km a total net volume increase of .026 $km^3\ yr^{-1}$ is reached before the rupture and release of magmatic fluids trapped during the crystallization of $0.2km^3\ yr^{-1}$ of rhyolitic magma (Fournier 1989.) He further explains that this increase in volume is more than enough to explain the 1923-1984 historic uplift.

The Mary Bay hydrothermal explosion that occurred 13,000 years ago resulted from a ruptured seal in the hydrothermal system (Pierce et al. 2007). Indian Pond, Duck Pond, Fern

Lake, subaqueous Elliot's crater and more geothermal formations all formed by similar geophysical processes. It is speculated that the Mary Bay explosion is linked to glacial-isotactic rebound. After the over bearing weight of the Yellowstone ice-cap was removed, the confining pressure of the hydrothermal system became disproportionate to the reduction of weight pressure from above and resulted in a seal rupture, (Pierce et al. 2007).

Currently, major tilting of shorelines (S2, S1.8 and S1.6) as much as 6m/km is occurring just west of the Storm Point hydrothermal center (Pierce et al. 2007). East of Pelican Creek, Pierce identified a local dome that is causing shorelines near it to tilt as well. No faults or thermal vents were identified but south of the dome Pierce noted that the beach sands were considerably hot which implies that thermal release is occurring. If these localized thermal processes were extrapolated to a grander regional scale, then hydrothermal inflation may account for most of the uplift observed at Le Hardys Rapids and elsewhere in the area.

In conclusion, the observances seen with oscillating lakeshore stand, involves a combination of the following: inflation-deflation of a hydrothermal system; transferring of magmatic bodies followed by subsidence from extensional faults; and erosion (Locke and Meyer 1994; Meyer and Locke 1986; Pierce et al. 2007). Approximately 4 km downstream from the mouth of Yellowstone Lake the Yellowstone River traverses across the caldera axis which is the focal point for maximum uplift and subsidence rates seen during the historic uplift between 1923 and 1984. When in motion these forces control the amount of flux between uplift and subsidence located at Le Hardys Rapids. Erosion at LHR has been occurring since postglacial times with the most occurring during the first half of the existence of Yellowstone Lake. Currently the river has cut down to erosionally resistant bedrock laid down by the Lava Creek tuff flow 640,000 years ago. It is speculated that erosion has been at a minimum for about the past 8,000 years or so (Pierce et al. 2007).

Discussed earlier, regional uplift may result from magma intrusion and the transferring of magmatic fluids between the Sour Creek and Mallard domes. The transferring of magmatic fluids between domes will cause one region to uplift and the other region to subside. However, this active transferring of magmatic fluids only accounts for a small percentage of total uplift and subsidence observed during the historic uplift (Pierce et al. 2007). Hydrothermal inflation is perceived to be the driving force that causes expedient rates of uplift and subsidence. Hydrothermal systems develop from evolved magmatic fluids that precipitate above a crystalizing body of rhyolitic magma (Locke and Meyer 1994; Fournier 1989; Pierce et al. 2007). Minerals accumulate and form an impermeable seal that acts like the lid of a pressure cooker. This hydrostatic pressure builds up and causes uplift of the region. Only when the seal b fractures and ruptures the built up pressure releases causing a rapid rate of subsidence to occur.

Active Basin and Range extensional faulting adjacent to the Yellowstone Plateau is also causing subsidence of this region to occur as well. However, tectonic extension does not account for the rapid rates of subsidence and is presumed to cause minimum subsidence to occur over large durations of time spanning thousands of years. Within the Yellowstone Plateau, faulting is occurring due to the ductile nature of the crust. These faults are generally shallow occurring at depths of about 3 km and are characterized as normal faults, small grabens and fissure like structures (Pierce et.al 2007). The faults observed around Yellowstone Lake only impact the latest Pleistocene shorelines and only offset them by a few meters at most.

Since the last glaciers retreated from the Yellowstone Plateau about 14.5 ka, lake levels ranged from at least 20 m above datum to at least 4 +/- 1 meters sub-datum, (Pierce et.al 2007)

Bathymetric and sonar reflection studies confirm that there are submerged benches that once reflected past lake level heights to depths not more than 15 to 20 m sub-datum. More research is needed to date and correlate these submerged shoreline-benches in order to corroborate them with the current lake-shore chronology. Between 3.0 to 4.0 ka, lake levels have risen 4m to current elevation due to the uplift of Le Hardys Rapids. This illustrates the very sensitive nature in lake levels, directly influenced by regional uplift and subsidence.

From the post-glacial period to 10.7 ka, lake levels were controlled by erosional wear at LHR and oscillations involved with inflation-deflation cycles. Since then, lake levels have been oscillating in height due to inflation-deflation cycles. It is unclear if the current lake levels will rise in the years to come, but current data suggests caldera wide subsidence is occurring at 20/mm yr (Pierce et al. 2007). The Yellowstone Lake Basin has experienced caldera breathing for millennia and is likely to experience more centuries of continued caldera breathing. In the years to come Yellowstone Lake will continue to alter in form to meet the changes in the rise and fall of these breathing cycles.

Chapter III

The Inception of GIS in Archaeology

3.1 Introduction

With the rapid advancement of computer technology beginning in the early 1980’s cultural resource management (CRM) has benefitted tremendously through this period of technological revolution. Computer technology has allowed for the development of a geographical information system (GIS) which has allowed researchers to store and retrieve vast amounts of data that can be referenced to geographic locations. GIS also has the capabilities to manipulate, analyze and display data sets pertaining to topographic, geophysical, socio-economic, and environmental factors (Kvamme 1999). Over the Past 35 years GIS has primarily been used by cultural resource managers for its predictive modeling and data management capabilities.

Predictive modeling has been used by managers to identify and assess what areas pertaining to an area of potential affects (APE) will be affected least by a proposed federal undertaking by predicting high and low probability areas of site locations (Kvamme 1989, 1995). Predictive models are developed through two methods; inductive and deductive reasoning. Inductive reasoning is the simplest method and operates by correlating environmental variables, (i.e. distance to water, slope, aspect, ect,…) with pre-existing site locations and then applying those correlations to areas where no surveys have been administered (Church et al. 2000; Duncan and Beckman 2000; Kvamme 2006, 1995). Predictive models based on deductive reasoning are harder to construct but they offer inferences about human behavior. They are developed based upon the principles out of landscape theory and behavioral ecology and require numerous datasets that are often difficult to obtain.

A geographical information system has also played an integral role in database management. This is to say that cultural resource managers have utilized GIS programs to store geospatial data pertaining to known archaeological sites, surveys, historic landmarks, ect,…(Green et al. 1995; Naunapper 2006; Trimble Mapping & GIS Division 2010; NPS(a)(b), 2010). Managers have realized that database management has greatly improved the efficiency, and expediency of the section 106 process by allowing managers to quickly retrieve the necessary data to assess any possible effects of a proposed federal undertaking (Naunapper 2006; Richards 1998). Since 1989 the Department of Interior (DOI) has developed and maintained a nationwide cultural resource database. The Cultural Resources Geographical Information System Facility (CRGIS) stores geospatial data and other pertinent information on all known cultural resources which are made available to all agencies. Today database management is becoming more widely accepted amongst agencies as a tool to save time and resources in managing cultural resources.

A part from predictive modeling and database management, GIS technology has come a long way from its humble beginnings as a technological curiosity. The history of GIS in CRM can be separated into three periods; early (1975-1989), middle,(1990-2005) and late (2006-current time). The early period represents an increased need by land managers to manage cultural resources as development projects began to expand during the 1970s (Duncan et al. 2000; Kvamme 1996, 2006; Lock and Harris 2006). This period is marked by innovations of technology and the widespread use of predictive models relying on inductive methods. The middle period represents a transition away from inductive reasoning towards more deductive or explanatory methods in constructing predictive models. This period also represents the creation of detailed geospatial databases that enable land managers to maintain a vast inventory of historic and prehistoric site locations. The current period spans the last five years and represents increased efforts to incorporate archaeological theories. It also represents widespread use of GIS programs not only in CRM but among private institutions and universities.

3.2 The Early Period 1975-1989

GIS arose from the need for land managers to protect, maintain and manage cultural resources as the rate of development increased during the 1970s. However, geographical information systems were limited in their capabilities due to the limits of technology and the availability of data (Kvamme 1995). Oftentimes archaeologists had to write their own computer code just to create a program that would manipulate data from a geographical information system data base. Kenneth L. Kvamme, Sandra Scholtz and Bob Hasenstab were among the first archaeologists to pioneer the use of GIS in modeling cultural resources. In doing so they had to first go out into the field and collect data pertaining to elevation, available water sources, soil types , slope and other environmental variables that could be later entered into a database (Kvamme 1995). Once the data was established they could then manipulate the data to produce predictive models.

For example Kvamme (1995, 2006) utilized inductive methods to draw correlations between known archaeological site locations and their immediate environmental surroundings, such as water sources, slope, elevation, aspect, soil type ect,... From these statistical associations he could then predict the location of sites based upon weighted environmental factors that would suggest high, medium or low probabilities (i.e. p-value) of site presence. For example, if 90% of known sites are situated near water sources, fertile soils and slopes of less than 5% then one would expect to find archaeological sites in regions exhibiting similar environmental factors. If a region has less fertile soil but has access to water sources and shallow slopes, the probability of sites existing may be significantly less.

Kvamme (2006) applied this method to create a predictive model of a region that had been recently surveyed and where three sites had been identified. His objective was to determine if his model would correlate with the sites that were identified. He later input all environmental variables pertaining to each 50 x 50m grid cell covering an $800m^2$ area that he had collected data from and computed a p-value for all 256 grid cells. The results revealed that Kvamme's model was very proficient. It accurately portrayed high probability scores to the areas in which the archaeological sites were previously identified.

The early period for Geographical Information Systems was truly a punctuated equilibrium because it offered new approaches for land managers to protect, maintain and manage their cultural resources. The use of predictive modeling was of particular interest to land managers because it allowed them to develop probability maps that depicted areas where sites were likely or unlikely to occur (Kvamme1989, 2006; Lock et al. 2006). This enabled cultural resource managers to effectively plan which areas were best for development and which areas to avoid (Church et al. 2000). If high probability areas could not be avoided, cultural resource managers at least had an inclination that more time and resources may be required to mitigate the adverse effects of sites if they happened to be identified.

However, despite these advantages the use of GIS was very limited in its capacity to serve as a useful tool for cultural resource land managers. These disadvantages stem from the widespread use of correlative or inductive reasoning methods in developing predictive models (Church et al 2000; Duncan et al. 2000; Lock 2006; Kvamme 2006). Church et al. (2000) argued that inductive methods merely correlated residential site types to obvious environmental variables such as distance to water, slope and other terrain variables, but they failed to explain the behaviors and motivations of hunter-gatherers (Lock 2006; Kvamme 2006). Inductive methods also failed to predict specialized sites pertaining to lithic reduction sites, quarrying sites, rock art localities and other specialized site types (Church et al. 2000; Duncan et al. 2000). This inability to reconstruct or explain hunter-gatherer behaviors through the use of deductive or explanatory theoretical methods posed a mild setback for the emergent field of GIS. As result cultural resource managers along with the rest of the archaeological community were hesitant in adopting this software technology for their management purposes.

Church et al. (2000) also brings to light that predictive models have to be met with a critical eye because often the incompleteness or inaccuracy of data will compromise the integrity of the model (Duncan et al. 2000). This was especially true in the early period when data was not readily assessable and data that did exist were scaled so largely that they presented major issues with accuracy. For example, modern data relating to digital elevation models (DEM) have a scale of range between 1 arc second to 1/3 arc second. This means that each pixel or grid cell represented in a digitized topographic map represents $30m^2$ to $10m^2$. This presents very accurate and detailed representations of the landscape. However, when the scale of resolution increases and covers greater areas the accuracy in environmental representation decreases as a function. In the early period, the issue of scale was of major concern for archaeologist in developing predictive models.

Aside from these issues, the adoption of GIS technology in the 1980s was further delayed by the lack of funding, staff and technology (Kvamme 1995; Naunapper 2006). During the late 1970s' and early 1980s'computer technology was just emerging and only highly funded institutions could afford the technology and staff to operate it. Even when the technology was available during this very early period, only a minute population of land managers knew of the capabilities that GIS could offer toward the management of cultural resources. Even still, there existed just a handful of people nationwide that had the computer programming skills necessary to write the programs that could carry out the functions of a GIS system (Kvamme 1995). Furthermore access to data was nonexistent (Kvamme 1995) and required intensive surveys that required further funding from government agencies.

It wasn't until the mid-1980s' that GIS gained a foothold in the cultural resource management field and became a resourceful commodity. This was aided by the availability of personal computers and commercial grade software (Kvamme 1995). With increased exposure to the technology and software, it allowed for a florescence of new ideas and methods to incorporate GIS technology in the CRM industry. It was not until the late 1980s' that land managers became aware of the technology's capabilities to store and manage vast amounts of data that could be quickly retrieved and viewed from a digital database. Cultural resource managers realized that the quick access to stored information and data improved the efficiency and expedited the section 106 process of the National Historic Preservation Act (NHPA) Kvamme 1999; Naunapper 2006). Support soon gained momentum for this capability and ushered in the middle period of GIS where database management became the central focus for cultural resource managers and their agencies.

3.3 Middle Period 1990-2005

The middle period of GIS represents a period marked with increased utilization and development of databases to aid in the management and protection of cultural resources. Data bases allowed federal and state agencies to store vast amounts of data and information which could be readily accessed and shared between multiple agencies via the internet (Green et al. 1995; Naunapper 2006; Kvamme 1995, 1999; NPS(b) 2010). It also enabled State Historical Preservation Officers (SHPO) and other agency departments to have access to a complete inventory of all archaeological sites, survey inventories and other cultural resources which could be visually displayed and geographically referenced. This tremendously facilitated quick review and information gathering for proposed undertakings. The process alleviated time spent pulling records for the review process of section 106 and informed both the agency and the SHPO whether an area has already been surveyed or should require further survey (Green et al. 1995; Naunapper 2006).

In the late 1980s and early 1990s' Fred Limp of the Arkansas Archaeological Survey spear headed the movement to create a fully integrated GIS database system for the Arkansas Department of Heritage using the Geographical Resources Analysis Support System program (Green et al. 1995; Kvamme 1995). Arkansas became the leading example for incorporating GIS databases into their cultural resource management programs and achieved the most comprehensive and thorough database (Kvamme 1995). In 1993 the Arkansas Archaeological Survey went further to incorporate all known surveys into the state's database to include areas where sites were not identified. The addition of this information quickly proved to be a valuable asset to the department because it allowed the SHPO and other agencies to quickly identify the geographical locations of identified sites and previously surveyed locations where sites were not identified (Green et al. 1995; Kvamme 1995; Naunapper 2006; Wheatley 2000). Ultimately, the process of retrieving information quickly, effectively improved the efficiency of the section 106 process.

However, the period also saw some improvements with predictive modeling methods. Prior to the 1990s' predictive modeling was limited to inaccurate data and was confined to a narrow window of theoretical application (Church et al. 2000; Kvamme 2006; Lock et al. 2006). Since then, software innovations and the availability of accurate datasets have markedly improved the accuracy of predictive modeling. Researchers now have the capabilities to incorporate more sophisticated and complex quantitative methods in building models (Duncan et al. 2000; Kvamme 1999). Some of these capabilities have allowed researchers to construct cost friction surfaces which can model the caloric energy expended through foot travel by accounting for the changes in elevation across the landscape (Carlisle 2007).

During the 1980s predictive modeling was focused on inductive methods by simply correlating site locations with environmental variables. These methods created a lot of controversy because they failed to explain the human behaviors involved with settlement and mobility strategies (Church et al. 2000; Duncan et al. 2000; Lock et al. 2006; Kvamme 2006; Richards 1998). During the 1990s' archaeologists began to incorporate the concepts from landscape theory by applying ranked values to known terrain or manmade features that influenced human behavior (Church et al. 2000). Church (2000) explains that humans assign value to resources that coexist in their territorial range which in turn influences behavior. For instance, if humans had a known settlement strategy to establish their base residence near the base of granite cliffs then we could expect to discover residential sites near these terrain features.

The inception of landscape theory in predictive modeling soon became a popular trend during the 1990s' and early 2000s' but little else was afforded to other theories. It was not until the mid-2000s that the concepts from behavioral ecology became of significant use in predictive modeling (Kvamme 2006). What is more interesting is that as of yet there has been no mention or use afforded toward the concepts from lithic technological organization.

Despite the minor improvements made towards theoretical applications, the role GIS was most notably recognized for its capabilities in database management during the middle period. Cultural resource managers immediately recognized that this capability allowed them to expedite the section 106 process by having immediate access to records (Green et al. 1995; Kvamme 1989,1999; Naunapper 2006). The ability to spatially display the locations of all cultural properties to include areas previously surveyed proved to be an invaluable function of GIS that aided in the identification of historic properties in pursuant to 36CFR800.4 (Green et al. 1995; Kvamme 1995; Naunapper 2006). By the end of 2005 GIS primarily functioned as a database management tool more so than as a predictive modeling tool. Following the transition into what is now the current period, the role of GIS marks an era that is finally stepping beyond the narrow theoretical focuses that stalled the improvement of predictive modeling (Church et al. 2000) and moving towards more complex and dynamic models.

3.4 Late Period 2006 – 2011

Over the past five years the role of GIS has remained much the same in the domain of cultural resource management. It has been accepted by federal and state agencies to serve as a proficient means to manage and protect cultural resources (Green et al. 1995; Naunapper 2006; Kvamme 1995; NPS(b) 2010; Wheatley 2000). However, there are many issues that have arisen over the past couple decades dealing with the organization of databases that have caused GIS to become counter-productive (NPS(a) 2010). The most debilitating factor that is causing this inefficiency is the lack of continuity in databases between federal, state and local department agencies. Among each of these agencies the organization of databases is constructed under different systems of classifications and schemes that meet the specific needs of the agency. The unconformity that results delays the process of retrieving records for review in the section 106 process with particular attention to 36CFR800.4.

Complicating this matter further is the issue involving quality control of data. Some agency departments will have very thorough records of site information while other agencies will be lacking considerably. In order for GIS to serve as an efficient management tool the information used for inputting data must be meaningful and accurate so that other users could retrieve records that are of value to their objectives and needs. Otherwise, the database will serve as a functionless tool to manage and protect cultural resources. One must remember that the most favored function of a GIS is its capability to immediately retrieve and display spatial data concerning cultural resources in addition to information regarding their age, cultural affiliation, functionality, ect,… The more in depth a database could be will substantially increase its overall effectiveness, functionality and purpose for all users alike.

Another matter that has arisen concerns the employment of GIS databases on a national level. Not all SHPO offices nationwide obtain a fully functioning GIS database. Similarly, those that do obtain a database may not have a complete listing of all their cultural resources. Montana for example is just now developing their GIS database in coordination with the Montana Bureau of Land Management office (Mark Baumler per com. 2011). In comparison, the Wyoming SHPO office obtains a functioning GIS database but is incomplete and is still in the process of adding data. In contrast, Arkansas has one of the most up to date and comprehensive GIS databases and has been a leading figure in database management since the early 1990s (Kvamme 1995).

Despite the current issues of database management there has been marked improvements with the modeling aspects of GIS. This has been afforded by the expanding use of the technology by private institutions for research purposes. In recent years GIS has emerged out of academic contexts promoting the use of evolutionary ecological concepts to model human behavior. In the earliest period models were based largely off of correlative factors linking site location with terrain features, but were inadequate at explaining human behaviors (Church et al. 2000; Duncan et al. 2000; Lock et al. 2006; Kvamme 2006). During the 1990s and still in use today is the modeling approaches developed out of landscape theory. However, these approaches are most applicable towards hierarchical contexts where socio-economic variables could be used to model human behavior (Lock et al. 2006). The modeling approaches now emerging from evolutionary ecology are presenting new ways in which researchers could examine the behaviors of less complex hunter-gatherer societies.

Zeanah (2010) has used GIS to construct a model entirely based on the precepts of central place foraging to model the subsistence and settlement strategies of hunter-gatherers in the Carson Desert of the Great Basin. He calculated the biomass of various species of flora based on the soil types they thrived in and mapped their distribution. He then calculated the carrying capacity of 14 species of prey animals based upon the production of biomass material. Once the distributions of both animal and plant productions were mapped Zeanah then ranked these areas in relation to proximity to water sources and shallow slopes to predict probable areas for residential sites.

One of his objectives was to determine if foragers were positioning their residential camps near areas that were suitable for large game or near areas where plants could be harvested and processed. His model revealed that foragers of the Carson desert were more likely to position their settlements closer to areas where there were higher abundances of harvestable plants. This is because these areas provided hunter-gatherers the highest caloric return rates compared to the payoff rates from hunting activities. Zeanah suggests that residential camps should be situated near these areas to accommodate women's activities while men were more logistically mobile in their hunting activities (Zeanah 2010).

This example reflects a new direction of GIS modeling that offers a fresh perspective at explaining human behavior and offers new employable methods in the CRM arena. As more studies become available and the methods more concrete the CRM industry could soon apply similar methods to construct predictive models for site location studies. Additionally, CRM agencies could use the models developed from private research as a source if a federal under taking happens to occur where the original research took place. However, the most important aspect from this innovation is that it offers the CRM industry different means of developing predictive models. Not all regional contexts are the same and while the employment of one type of model may be adequate for one regional context it may not be applicable towards another region (Kvamme 2006). The flexibility to choose between different modeling techniques allows the researcher to achieve optimal results in producing predictive modeling sets.

3.5 Conclusion

In summary, the current period presents new hopes for applying predictive models to help aid CRM managers in determining which areas of a landscape may be impacted most by a federal undertaking. However, it is unlikely that predictive models will ever become the corner stone of CRM as they were during the 1970s' and 1980s'. This is because predictive models do not really expedite the CRM process. Regardless of how accurate a model may be, a phase I survey still has to be conducted to identify sites within an area of potential effects. Predictive models primarily serve to guide developers in selecting areas that present the lowest labor costs associated with the identification and mitigation aspects of NHPA. Predictive modeling will more than likely play a more dominant role in academic contexts simply because the objectives are focused differently. CRM is seeking to avoid sites while academia is seeking to identify them.

In contrast, database management seems to be the most dominant use of a geographical information system within the arena of CRM. It has enabled agencies to quickly retrieve records that display where sites have been identified as well as the locations of archaeological surveys (Green et al. 1995; Kvamme 1989, 1995, 1999; Naunapper 2006). Ultimately this has expedited the identification phase of 36CFR800.4 pertaining to the section 106 process of the National Historic Preservation Act. This was particularly true with FEMA's recovery process after Hurricane Katrina in 2005 where GIS made it capable for the agency to respond quickly and efficiently.

The current issue adversely affecting the management of GIS databases is the lack of continuity in record organization between interagency database holdings. This has been further conditioned by the type of information being stored. Unless this issue is resolved through a national effort to develop specific guidelines and standards, the efficiency of sharing information between agencies will be affected. Left unattended, the matter will result in the incompatibility to share data between agencies and or result in the inadequacy of the information relating to the data which serves to expedite the section 106 process. As GIS databases become more prominent in their use amongst agencies both federal and state, these issues will have to be addressed (NPS(a) 2010) soon if not now.

In closing the use of GIS will continue to be an integral component in cultural resource management. It has proved to be a valuable tool for agencies to manage their resources as well as for predictive modeling purposes. With more advances in technology the abilities of GIS become more effective in serving the operational needs cultural resource managers. As more of these needs are being met the more enticing it becomes for agencies to adopt a GIS on a national scale. Currently, not all states or federal agencies have adopted or completed a functioning GIS but it could be expected that perhaps within the next decade this will not be the case.

Chapter IV

Research Questions Hypotheses and Expected Results

The objective of this chapter is to briefly introduce the research questions, hypotheses and expected results. As stated earlier in the introduction, the primary premise of these questions is to examine the behavioral aspect of human decisions regarding their settlement patterns along the shores of Yellowstone Lake. The intent is to recognize patterns that may be associated with environmental factors such as access to subsistence resources (i.e. riparian/grassland zones) or fluctuations in the availability of subsistence resources influenced by changes in climate. Other examinations consider the effects of fluctuating lake levels of Yellowstone Lake and how they can be related to settlement patterning around the lake basin.

Question 1

Were hunter-gatherers actively selecting settlement positions based upon the availability and access to subsistence resources?

Hypothesis 1

If hunter-gatherers were selecting areas based upon the availability and access to subsistence resources, I would expect there would be greater densities of sites occurring in or within close proximity to riparian and or grassland habitats.

Question 2

If hunter-gatherers were selecting site placement based upon the availability and access to subsistence resources then how did fluctuations in climate affect these settlement patterns?

Hypothesis 2

If hunter-gatherers were selecting riparian/grassland habitats I expect that the distribution and frequency at which sites occur over time to be dependent upon the conditions of the climate which influences the distribution and productivity of subsistence resources.

Question 3

Do the spatial locations of sites along the z-axis (elevation) reflect the fluctuations of lake levels over time caused by the inflation and deflation cycles of the Sour Creek and Mallard Lake resurgent domes?

Hypothesis 3

Since paleo-shorelines have been directly attributed to fluctuations of lake levels I expect the elevations of site locations to reflect past lake levels.

The first question examines the spatial locations of sites and their proximity to subsistence resources to determine if the availability to such resources influenced the settlement strategies of hunter-gatherers. Subsistence resources would have high occurrences within habitats that would not only support a diverse suite of fauna, but also a broad spectrum of edible plant resources. These types of habitats would primarily occur within the grassland and riparian wetland vegetative zones. Conversely, forest (coniferous) vegetative zones offer the least amount subsistence resources because vegetation important for ungulates or for humans are either outcompeted by the forest canopy or ill-adapted to the acidic soil conditions of the forest floor.

In a Darwinian sense riparian/grassland vegetative zones obtain a greater selective factor compared to forested regions because they offer the most in caloric return rates compared to the unsubstantial resources found within forested zones. Since obtaining subsistence resources is an integral aspect for all human life and without the emplacement of agricultural practices, targeting riparian/grassland vegetative zones would have been a key factor in ensuring survival and enhancing one's own personal fitness. Therefore, it is postulated that hunter-gatherers were positioned their settlements within close proximity to riparian/grassland vegetative zones in efforts to acquire a fairly predictable and ample supply of subsistence resources. Acquiring subsistence resources away from these areas would require increases in energy expenditure and invested search times, thus decreasing one's overall fitness.

The second question examines how fluctuations in climate regimes may have affected hunter-gatherer settlement patterns. Any change in climate pattern would have a direct impact on vegetation communities by influencing the quantities and types of vegetation found within each. Any changes within these plant communities in turn affect the biodiversity of fauna and availability of edible plant resources that are utilized for human consumption. Disruptions in biodiversity ultimately affect where humans must settle to obtain subsistence resources in addition to controlling the carrying capacity of population sizes.

Presupposing that hunter-gatherers targeted riparian/grassland zones, it is postulated that disruptions in vegetative communities following shifts in climate patterns affected hunter-gatherer settlement strategies. This is to suggest that the frequency at which sites occur within each cultural period should correspond with any changes in the pollen compositions relating to riparian/grassland vegetative zones. Increases in riparian/grassland pollen counts should reflect increases in site counts, since there is an increased availability of subsistence resources. Conversely, any decrease in riparian/grassland pollen counts should signal a decrease in sites due a loss of available subsistence resources and degradation of the habitat.

The final question examines if oscillating lake stand heights in response to inflation and deflation cycles occurring with the Mallard Lake and Sour Creek resurgent Domes are reflected in the archaeological record. The objective is to determine if the elevation of sites across time reflect the various elevational changes of lake stand heights occurring at Yellowstone Lake. It is expected that archaeological material pertaining to any one particular cultural period should not be associated with paleo-shorelines that reflect younger lake stand heights. The exception to this rule would be any archaeological material transported either through natural erosional processes or human interception and reuse.

In summary, the intent of this research is to first determine the behaviors associated with settlement strategies in relation to the proximity to subsistence resources. The purpose of this is to understand if the availability to subsistence resources were an important consideration for hunter-gatherers in choosing the locations of their camps. The second intent is to determine if shifting patterns in climate regimes affected settlement strategies of hunter-gatherers.

Determining if and how climate patterns affected settlement strategies will help us understand how hunter-gatherers adapted to either improving or deteriorating environmental conditions. Finally the last objective, is to determine if the spatial location of archaeological sites along the z- axis (i.e. elevation) reflect the elevational changes in oscillating lake stand heights over time. The purpose of this is to ascertain if the elevation of sites can be used as identifying markers of past lake stand heights and vise versus.

Chapter V

A Behavioral Ecological Model of the Yellowstone Lake Basin

Question 1

Were hunter-gatherers actively selecting settlement positions based upon the availability and access to subsistence resources?

Hypothesis 1

If hunter-gatherers were selecting areas based upon the availability and access to subsistence resources, I would expect there would be greater densities of prehistoric sites occurring in or within close proximity to riparian and or grassland habitats.

5.1 Introduction

As noted previously it is postulated that hunter-gatherers were positioning their settlements within close proximity to riparian/grassland vegetative zones. This would have enabled mobile foragers to have immediate access to a substantial resource base where sufficient and predictable quantities of subsistence resources could be allocated. Riparian/grassland vegetative zones are noted for their high rates of biomass production which would allow for healthy populations of deer, elk, bison and other types of fauna to thrive. Additionally, edible plant resources, such as camas, wild onions, and various types of berries would also thrive within these vegetative zones. Having direct access to these resource patches would have certainly been a primary selective factor in settlement strategies as hunter-gatherers were in need of subsistence resources (Elliot and Hektner 2000).

Conversely, forested (coniferous) vegetative zones offer the least amount of subsistence resources which require high energy costs in extracting the necessary resources to meet daily caloric needs. This primarily results from the lack of biomass production due to insufficient amounts of sunlight penetrating through the forest canopy and the acidic qualities of the forest floor. The lack of biomass production would substantially inhibit ungulate populations from foraging within these areas and encourage them to seek more productive areas. Without ungulate populations, predatory species are left with a diminished resource base that may not meet their caloric demands and force them to seek more productive patches. Whatever animal life would be present in forested patches would be limited to small creatures that could survive off of meager amounts of available subsistence resources that were available. Edible plant resources may occur but appear more sporadically or not at all depending upon the availability of sunlight and soil acidities. Ultimately, forested vegetative zones would be a negative selective factor for hunter-gatherers due to the insufficient and sporadically occurring subsistence resources available to them.

Considering that riparian/grassland vegetative zones incur greater amounts of subsistence resources, the encounter rate of seeking these resources is considerably higher. This benefits the hunter-gatherer tremendously for four reasons. First it reduces the search costs or the amount of caloric exertion needed to seek out subsistence resources, whether it involves hunting prey or foraging for wild edible plants. Secondly, it reduces the search time of acquiring resources since the encounter rates are higher than forested zones. Thirdly, the reduction of search costs and search time then enables hunter-gathers to allocate their time more towards processing times and the costs involved with food preparation tasks. Lastly and most importantly, the added benefit of more down time enables the hunter-gatherer to engage in more social activities and also allows for more time devoted towards reproductive opportunities and child rearing.

Clearly, the benefits of targeting riparian/grassland zones undoubtedly enhance both social and reproductive fitness levels, thus making these patch zones highly desirable. To determine if hunter-gatherers are targeting these areas we must first understand what defines a 'patch', (as it will be commonly be used throughout this thesis). A patch represents an ecological zone or habitat (i.e. riparian, grassland, forest, ect,..) that supports various types of species of plants and animals that are exploited by humans for subsistence needs (Bettinger, 1991;Kelly, 2007). Essentially it is a shorter term giving reference to a type of vegetative zone or other type of land cover classification type. Secondly, we must define the boundaries of these patch types based upon the composition of the dominant vegetation. Lastly we must compare the spatial locations of archaeological sites and their proximity to either riparian/grassland patches and forest patches.

5.2 Procedures and Methods

To begin testing the hypothesis, several procedures were carried out to organize and obtain the necessary data to begin analyses. This first involved the digitization of all archaeological sites within an 800 meter distance from the perimeter of Yellowstone Lake. Succeeding this was the construction of a vegetative model illustrating the different vegetative communities and land cover types encompassing the regions around Yellowstone Lake. Finally, spatial analysis techniques were applied between site localities and their spatial relationship with the vegetative model. Much of these procedures were performed using the software program, ArcGIS which allows the user to manipulate and analyze spatially referenced data sets into meaningful interpretations.

ArcGIS was first utilized to spatially reconstruct the spatial locations of archaeological sites around the perimeter of Yellowstone Lake and to visually conceptualize their boundaries. This was accomplished by retrieving pertinent information relating to a site's northing and easting coordinate position and its boundary borders from archaeological and cultural resource inventory reports as well data retrieved from Wyoming's, State Historic Preservation Office online database. Additional data was used from previous field work conducted by the Montana Yellowstone Archaeological Project (MYAP) under the direction of University of Montana's Associate Professor, Dr. Douglas H. MacDonald. After this information was collected it was digitized and stored into a ArcGIS geodatabase where information regarding each prehistoric site's cardinal position and total area was stored.

This database was further enhanced to store information relating to a site's relative or absolute age indicating which cultural period(s) if any it represented. These were classified into five cultural periods; Paleoindian (12,000 to 8,000 B.P.), Early Archaic (8,000 to 5,000 B.P.), Middle Archaic (5,000 to 3,000 B.P.), Late Archaic (3,000 to 1,500 B.P.) and Late Prehistoric (1,500 to 300 B.P.). Information used to assign sites to a cultural period(s) was based upon typology of projectile points and radio-isotopic dating of hearth features. Prehistoric sites that could not be assigned to a specific cultural period were classified as 'unknown prehistoric'. If a site locality obtained multiple components representing more than one cultural period, new records were created to represent each cultural period pertaining to the multi-component site. This was done to ensure that each component of a multicomponent site was treated as an independent site belonging to a specific cultural period.

The table below (see table 5.1) reflects all prehistoric sites that are within 800 meters of Yellowstone Lake (see figures 5.1-5.7 for the breakdown site locations). The table depicts the occurrences of sites falling within each cultural period leading from the Paleoindian Period up to the Late Prehistoric Period. It also portrays the total number of sites that can or cannot be relatively dated. Finally, the table reflects the sum total of sites. Keep in mind, that, while the total number of sites list at 357, this figure is taking into account site locations exhibiting multiple components representing two or more cultural periods. If just considering a site location and not accounting for multiple components the total number of sites is 285.

Cultural Period	Time Range	Number of Sites
Paleoindian	12,000 - 8,000 B.P.	25
Early Archaic	8000 - 5,000 B.P.	22
Middle Archaic	5,000 - 3,000 B.P.	38
Late Archaic	3,000 - 1,500B.P.	54
Late Prehistoric	1,500 - 300 B.P.	36
Dated Sites	12,000 - 300 B.P.	175
Unknown Sites	12,000 - 300 B.P.	182
All Prehistoric Sites	12,000 - 300 B.P.	357
Site Localities		285

Table 5.1 Breakdown of all prehistoric sites that occur within 800 meters from the perimeter of Yellowstone Lake.

After the careful digitization of all prehistoric sites and assigning them to a specific cultural period or to an undetermined status, the next procedure was to construct a vegetative model. This model was constructed to illustrate the differentiating boundaries between riparian/grassland vegetative communities and those of forested communities. The techniques used to construct this model encompassed the use of remote sensing techniques and the utilization of a geographic information system (GIS). Together these techniques were used to analyze and manipulate satellite imagery to derive all the aspects of the model used to test the hypothesis outlined in the beginning of this chapter.

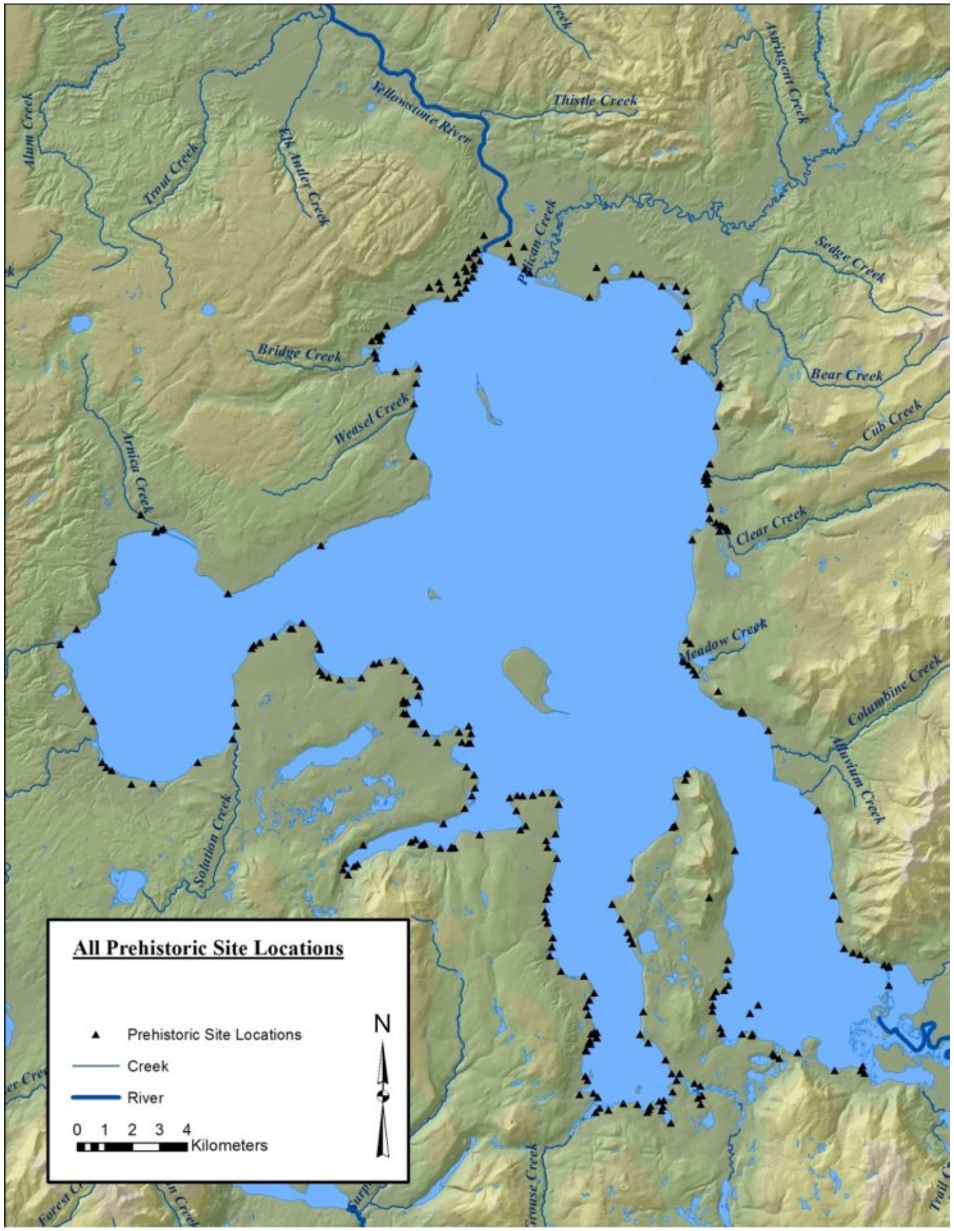


Figure 5.1 Map depicting the spatial distribution of all prehistoric sites.

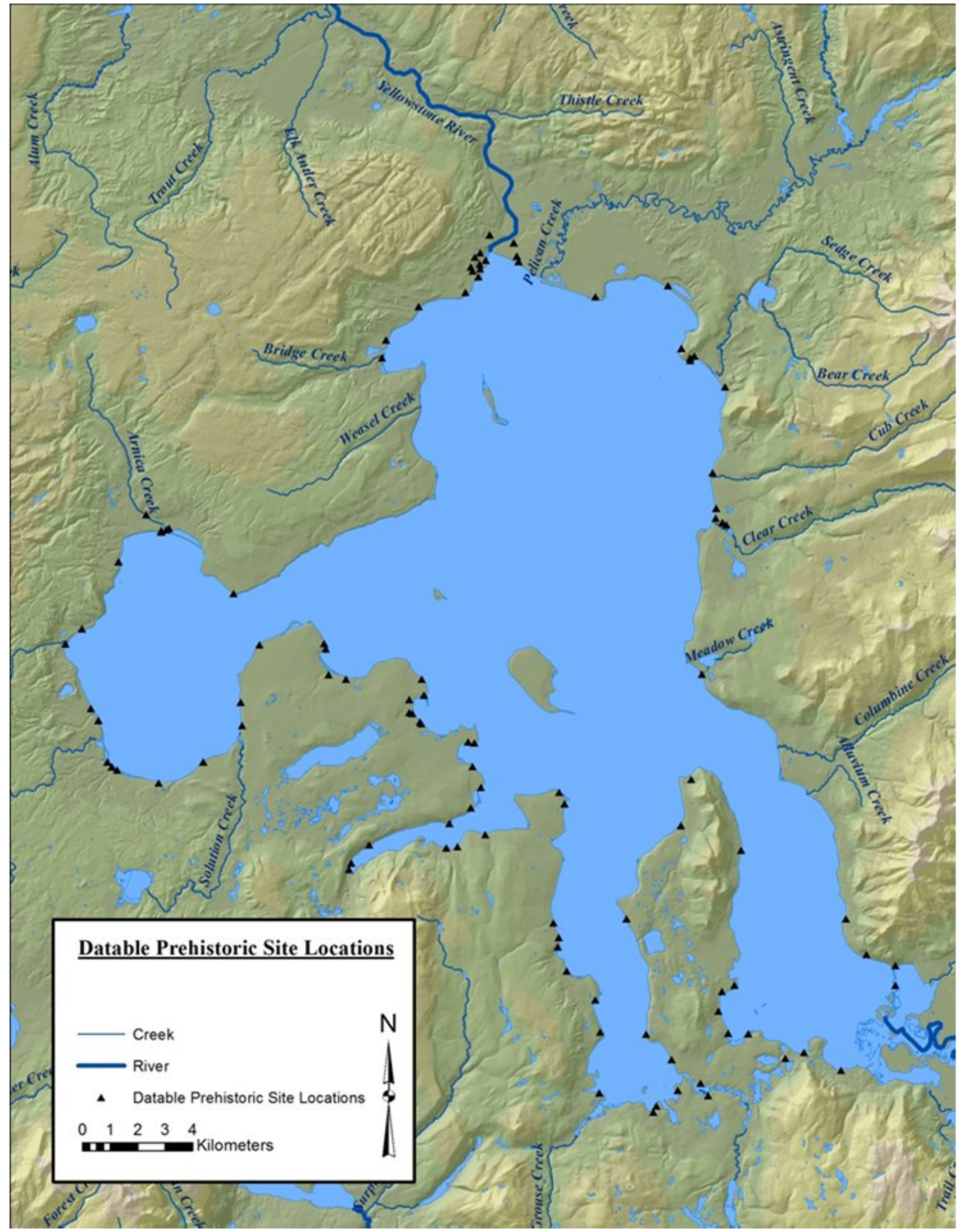


Figure 5.2 Map depicting the spatial distribution of only dated prehistoric sites.

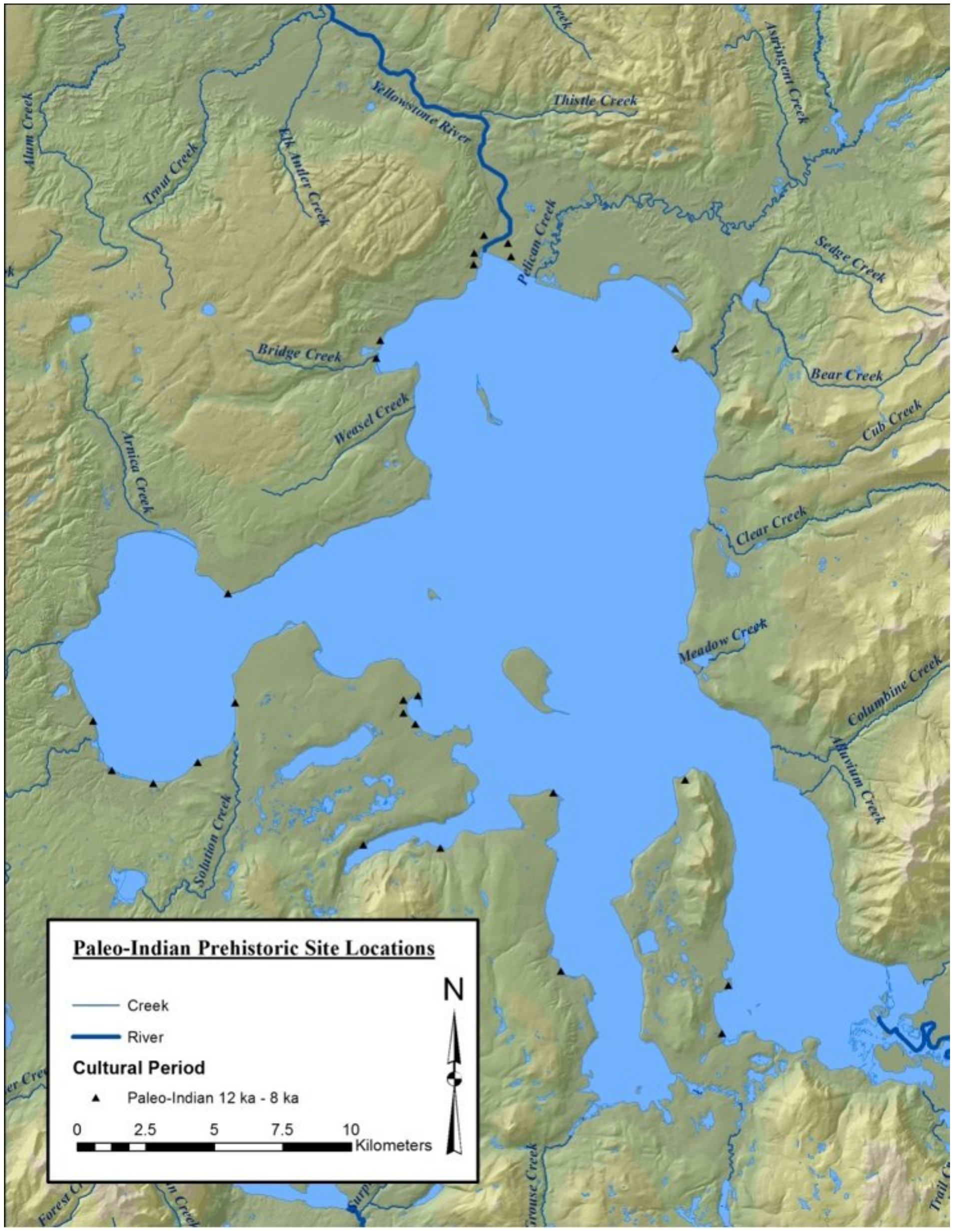


Figure 5.3 Map depicting the spatial distribution of all Paleoindian sites.

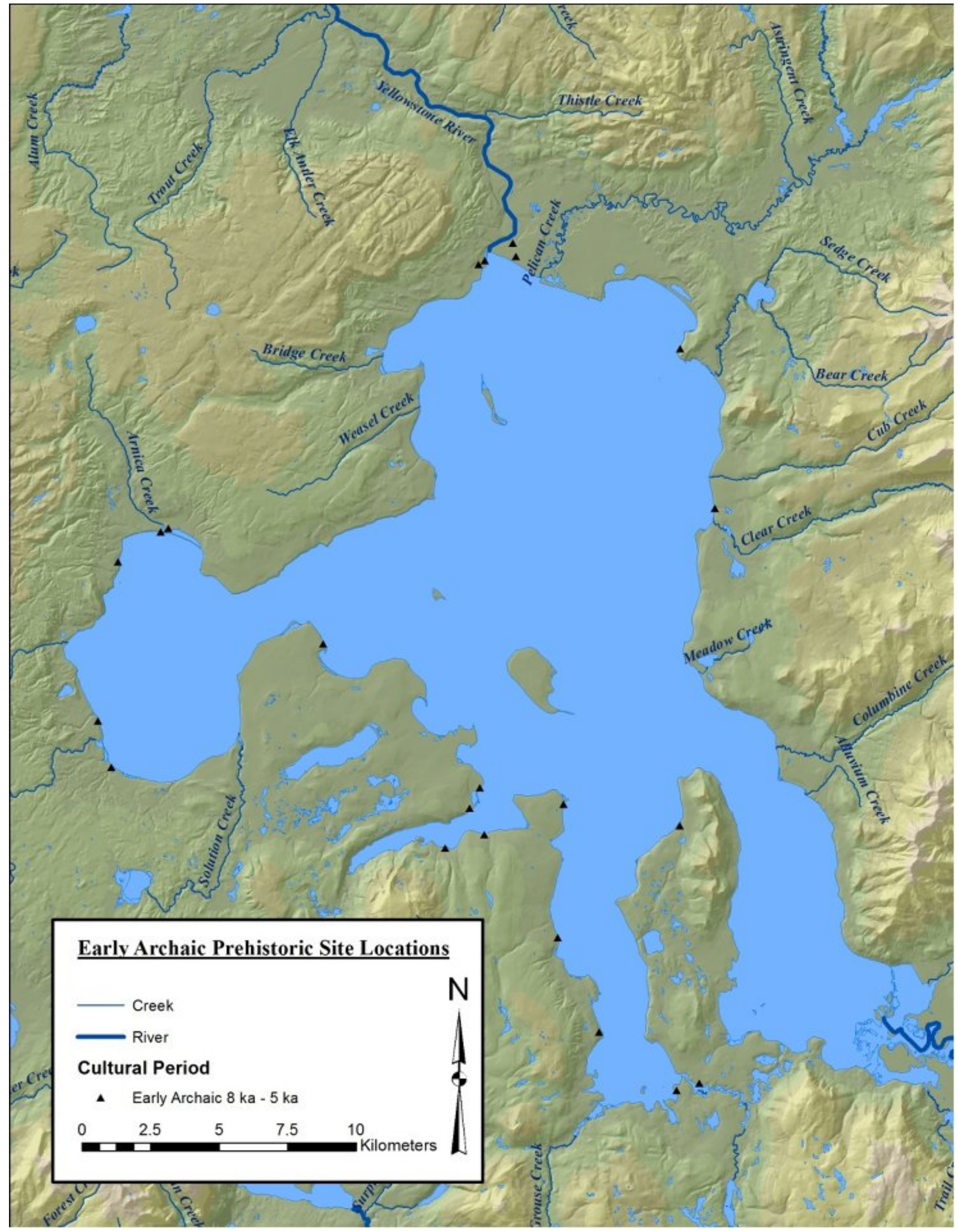


Figure 5.4 Map depicting the spatial distribution of all Early Archaic sites.

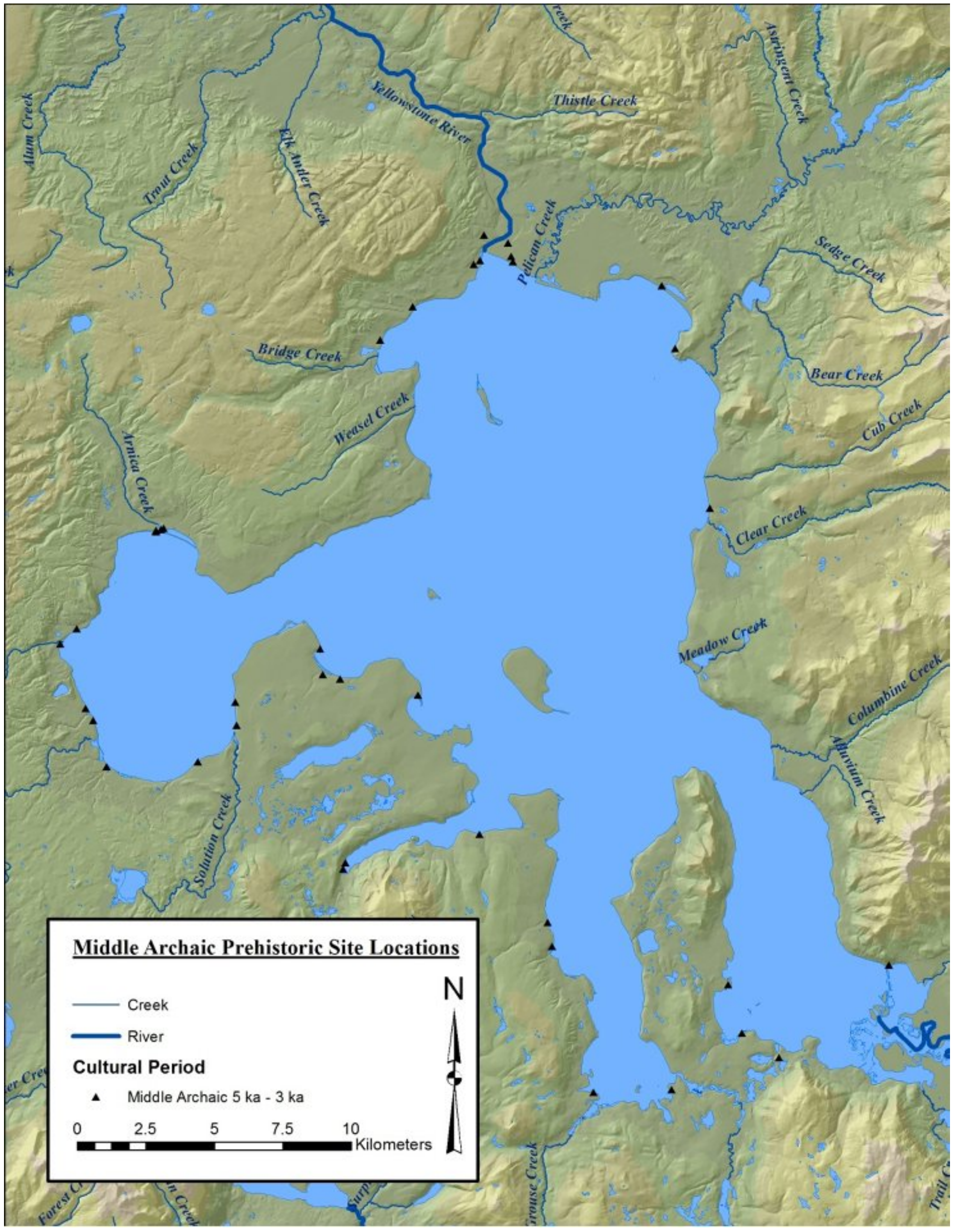


Figure 5.5 Map depicting the spatial distribution of all Middle Archaic Sites

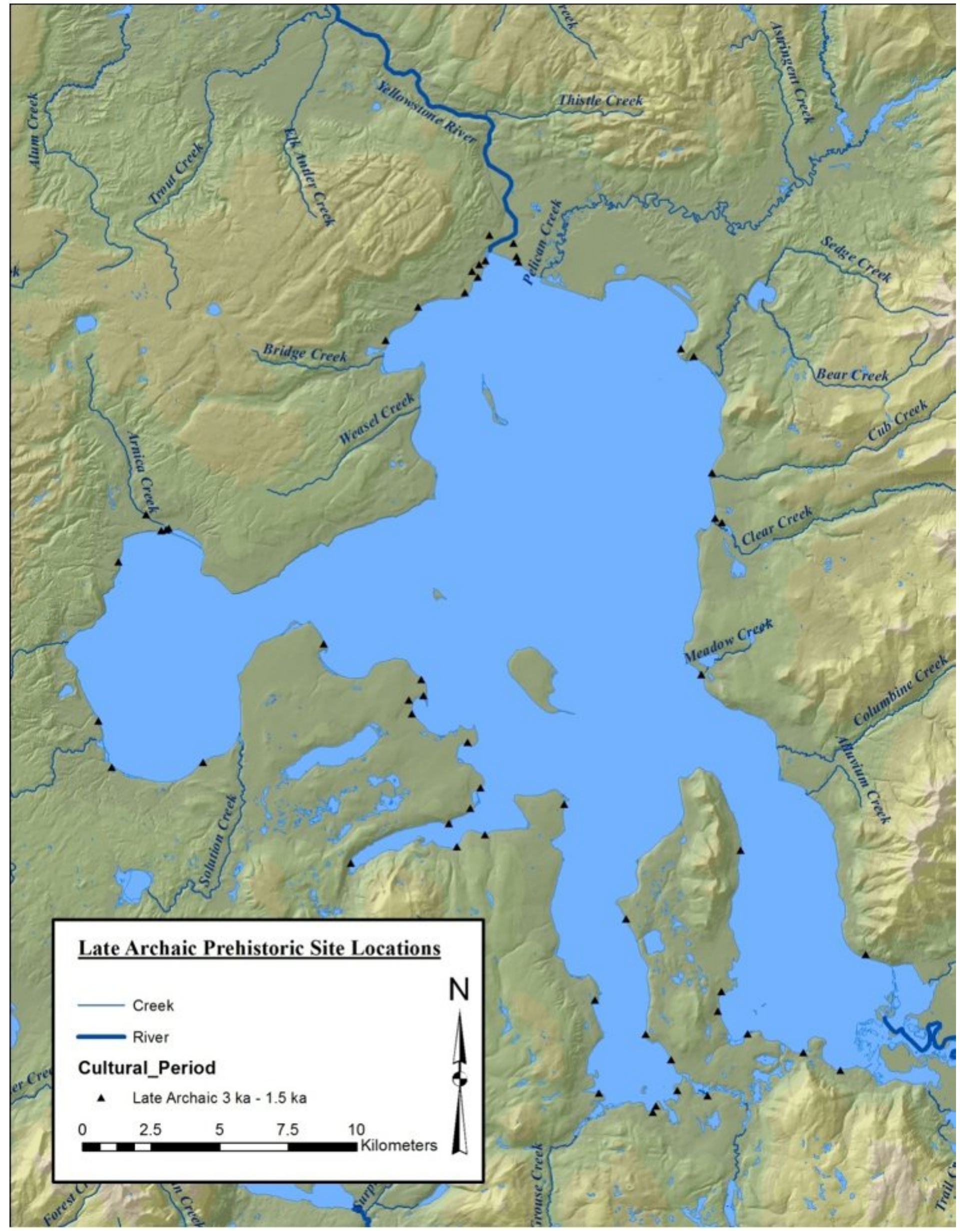


Figure 5.6 Map depicting the spatial distribution of all Late Archaic sites.

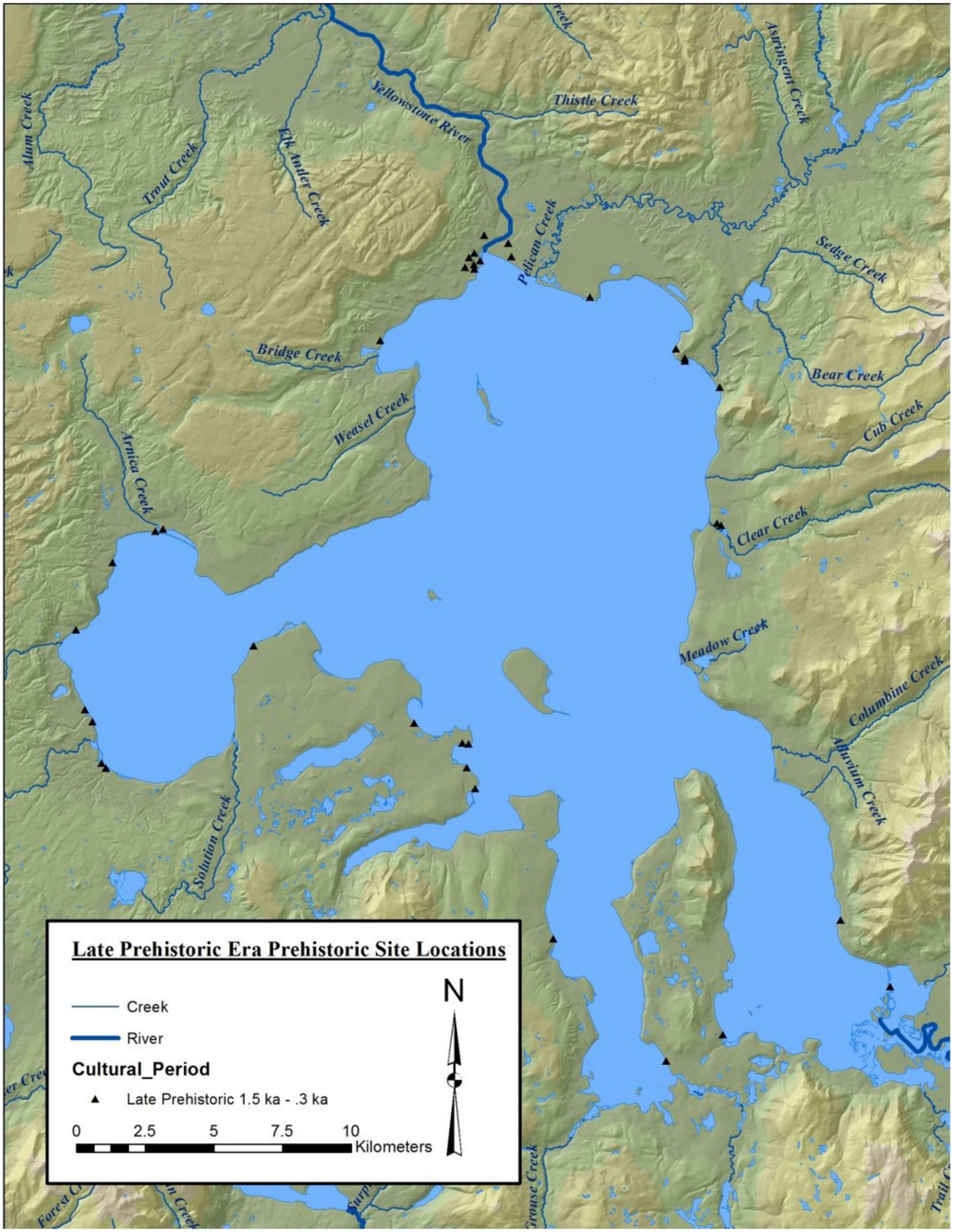


Figure 5.7 Map depicting the spatial distribution of all Late Prehistoric sites.

First, remote sensing techniques were used to classify vegetation and other land cover types from satellite imagery based upon the spectral signatures of pixel values within the image. This was done by first acquiring satellite imagery downloaded from the, Earth Resources Observation and Science (EROS) Center's website, http://eros.usgs.gov. Satellite imagery was obtained from archived images taken from the Landsat V satellite during July of 1986. Imagery was utilized from this period to reflect closed forest conditions and prevent biased misinterpretations of any satellite imagery taken after the 1988 wild fires. The 1998 wildfires drastically transformed vegetative communities along the western and southern flanks of Yellowstone Lake. Using satellite imagery post 1988 wildfires will only result in misinterpretations concerning the boundaries of different patch-types.

Next a false color composite of the satellite imagery was created using the spectral bands 2, 3, and 4 (i.e. green, red and infrared) utilizing ArcGIS software (see figure 5.8 and 5.9). The infrared band was used in this analysis due it is high reflectance off of vegetation. This allowed for more accurate classifications in vegetation types and other land cover types such as snow, water and urban areas. This image was then resampled so that each individual pixel obtained the same cell dimensions as the elevation data set utilized in this study. The original pixel dimensions of the satellite imagery reflected an area of 30x30 meters and were resampled to 10 x 10 meters. Resampling the image pixels did not affect the analysis but rather enhanced it by depicting more clear and precise boundaries between land cover types.

Following this, ArcGIS was used to perform an unsupervised classification analysis on all pixel values within the false color composite image. This process automatically classified all pixels values into groups using the, 'Iso-Cluster' and 'Maximum Likelihood Classification' tools. This resulted in six major groupings; water, snow, urban development, riparian,

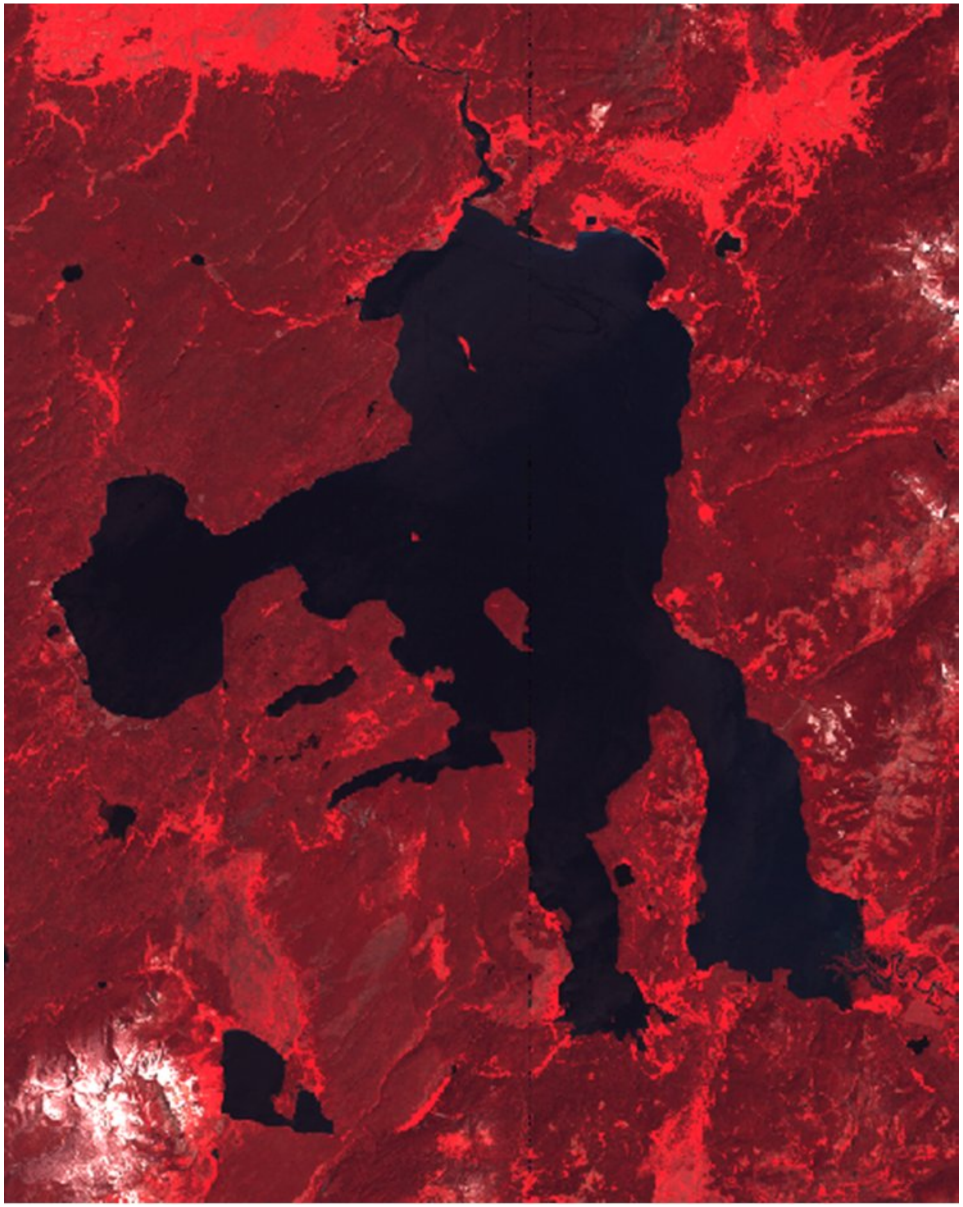


Figure 5.8 False color composite of the Yellowstone Lake region. Lighter shades of red are indicative of riparian/grassland vegetative zones while the darker shades reflect closed forest canopy.

Figure 5.9 An enhanced image from the left that allows the pixels reflecting riparian/grassland vegetative zones to appear more prominent.

grassland/meadows, and forests. From these groupings further processing was required to correct for misclassifications of pixel values and to clean up the image. This was accomplished by comparing the image of classified land cover types against satellite imagery and reclassifying the misidentified pixel values into the proper landcover classifications.

After the corrections were made on the land cover classifications, the next process involved finishing up the final vegetative model. Since urban development has occurred over the last 130 years in the lake region, it is unknown whether or not the pixel values representing these areas were once lush grasslands or dense forests. Since it is unknown, all urban areas were assumed to have been forested prior to their development and reclassified as forest patches. This was to ensure that the model was not biased towards proving the hypothesis correct. Next, the pixels representing riparian and grassland/meadows were combined and reclassified into one class type named 'riparian/grassland'. A streams layer with a 100 meter buffer was added to this classification since these areas also constitute riparian zones.

In addition to the riparian/grassland patch area, a 150m buffer around this area was created to act as an intermediary zone between forest and riparian/grassland zones. The importance of this buffer area is to take into consideration that hunter-gatherers are perhaps choosing the peripheral margins of these zones for cover and concealment purposes. Forest cover along these edges would offer protection from inclement weather while also providing concealment to avoid frightening wild game away. Prehistoric sites that may occur within this buffer zone should still be considered with the same regard as riparian/grassland patches since they are in very close proximity to each other.

The final step in finishing the vegetation model was simplifying it and removing the cell values that corresponded with the land cover types; water (i.e. lakes, ponds, ect…,) and snow.

These were removed from the model because they served no functionary role in the model. Next, all remaining patch types were carefully evaluated for any mistakes to ensure the model was prepared for analysis. The final model comprised of four patch types representing the various vegetative communities in the region. This included a forest patch, riparian stream patch, riparian/grassland patch, and the riparian/grassland intermediary patch (see figure 5.10). The only remaining procedure left to conduct after the completion of the model was to overlay the digitized site locations and begin analysis.

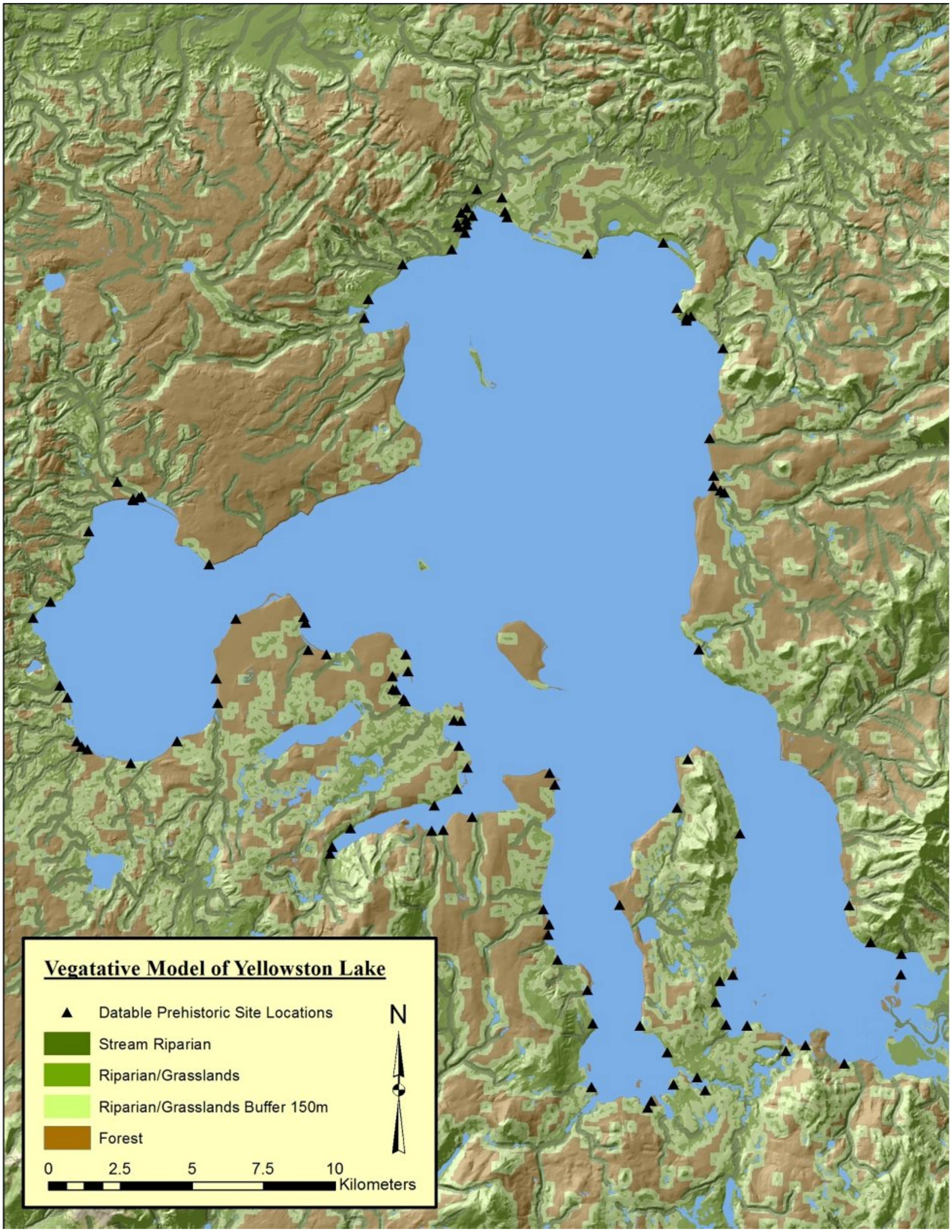


Figure 5.10 Finished vegetative model of the Yellowstone Lake Basin with dated prehistoric sites overlaid.

5.3 Analysis and Results

To begin testing the hypothesis, three analyses were performed to properly interpret the data. This first involved an analysis on the accuracy of the vegetative model to determine what percentages of prehistoric sites fell within areas that were either favorable or unfavorable to hunter-gatherers. The second analysis examined the significance of the vegetative model to determine if the model is viable or not. Finally, an analysis was performed to determine the statistical significance between the densities of prehistoric sites associated with riparian and grassland type patches and those reflecting forested patches.

To determine the accuracy of the model, the digitized site locations were overlaid the vegetative model in ArcGIS. Using the conversion tool in ArcGIS, the vegetative model was converted from a vector shape file into a raster file. This enabled the utilization of the 'extract by attributes', tool to extract cell values directly from the rasterized model that corresponded with any overlying point features (i.e. digitized site locations). These values were then automatically recorded into the geodatabase that obtained the records for prehistoric sites that were previously digitized. Each site record within this geodatabase was now assigned an attribute from the model indicating which patch-type it is associated with (i.e. riparian/grassland, forest, ect…,). Following this, the records were consolidated into data tables that reflected information regarding a site's relative age and association with a particular patch-type (see table 5.2)

Determining the accuracy of model next required summing up the distribution of sites that were directly associated with non-forested patches (i.e. riparian/grassland patches, stream riparian patches and the intermediary patch) and dividing that sum by the total number of sites (see table 5.3). The sum total of prehistoric sites is considered to be the expected value since it is required that all sites must fall within the non-forested patch-types in order for the model to achieve 100% accuracy. Prehistoric sites that are observed falling within these non-forested patch-types are considered the observed value. Therefore, dividing the observed values by the expected values will result in the overall accuracy of the model. This analysis was carried on each cultural period to include the cumulative sum from all cultural periods and the sum total of all prehistoric sites with the inclusion of sites with no known ages.

Patch-Type	Paleoindian	Early Archaic	Middle Archaic	Late Archaic	Late Prehistoric	Dated Sites	Unknown Age	All Sites
Forest	4	3	6	9	2	24	55	79
Riparian/Grassland	8	8	10	17	19	62	40	102
Riparian/Grassland Intermediary Zone	8	7	14	21	9	59	49	108
Riparian Stream	5	4	8	7	6	30	38	68
Sum of Patch-types	25	22	38	54	36	175	182	357
All Non-Forested Patches Combined	21	19	32	45	34	151	128	278

Table 5.2 This table reflects the distribution of prehistoric sites amongst the various patch-types.

	Paleoindian	Early Archaic	Middle Archaic	Late Archaic	Late Prehistoric	Dated Sites	All Sites
Observed	21	19	32	45	34	151	278
Expected	25	22	38	54	36	175	357
Accuracy in Percent	**84**	**86**	**84**	**83**	**94**	**86**	**78**

Table 5.3 This table illustrates the accuracy of the vegetative model. The, 'observed', row represents the distribution of sites that fall within the vegetative communities; riparian stream patch, riparian/grassland patch, and the riparian/grassland intermediary patch. The 'Expected' row represents the expected total number of site occurrences supposing a 100 % accuracy rate of the model.

Compiling together the distribution of sites associated with all riparian and grassland-type patches was to reflect the true range of subsistence resources available to mobile foragers. Between the riparian/grassland patches, riparian stream patches and the intermediary patches, all offer a diverse suite of subsistence resources amongst them. This aspect would enable foragers to move freely between these productive patch zones to allocate subsistence resources whenever needed. Quantifying these patch-types together will result in a more accurate assessment in the analysis of the model.

Table 5.3 reflects the results in the accuracy of the vegetative model. The results pertaining to the each cultural period reflect accuracy ratings above 80 percent. The highest accuracy rating was observed in the Late Prehistoric Period at 94 percent. Comparing the sum total of all cultural periods in the, 'Dated Sites' column, the accuracy is rated at 86 percent. However, the accuracy drops slightly below 80 % when the model is tested against all prehistoric sites which include sites of unknown prehistoric contexts or ages.

The model's reduced accuracy when tested against all prehistoric sites (including sites of unknown prehistoric context) may be the result of differential site use. Sites that are assigned to a cultural period generally reflect occupations occurring over longer periods of time compared to sites that cannot be assigned to any particular period in time. This is often times reflected in archaeological assemblages. Sites locations exhibiting longer occupational use have a tendency to accrue higher rates of discarded tools compared to temporary occupations where little if any artifacts are discarded and accumulate over time (Andrefsky 1994; Chatters 1987; Surovell, 2009). This would suggest that sites that can be relatively dated, characterize direct use of riparian-type patches while sites of unknown ages may reflect temporary occupations, perhaps reflecting in-transit camps between patch-types.

A Chi-square test was performed to determine if the spatial distribution between dated and unknown aged sites reflected differences in patch-type distribution. The results reflect a Pearson Chi-Square significance value of 0.00, suggesting that sites that can be relatively dated indicate more direct use of riparian-type patches compared to sites of unknown ages (see table 5.4). This would suggest that the vegetative model is more accurate in predicting site locations that exhibit longer durational occupations than those reflecting short term or temporary occupations.

Since the accuracy of the vegetative model sheds encouraging results, the model was next tested for its statistical significance. Two statistical tests were performed to measure the kappa value or the measure of agreement (see table 5.5). The first test examined sites that could only be relatively dated while the second test examined all prehistoric sites (i.e. dated and unknown ages). The results indicate that when the model only considers dated prehistoric sites, the kappa value (.831) is in high level agreement with the model's prediction. However, this value slightly drops to .714 when considering all prehistoric sites. This suggests that the kappa value is in substantial agreement with the model's prediction. Landis and Koch (1977) suggest that kappa values that range from .40 to.59 are reflected as moderate, .60 to .79 as substantial and values over .80 are considered outstanding.

These results clearly indicate that the model's predictions are significant enough to strongly suggest that it should not be rejected. In particular, the model is more accurate and reliable in predicting sites that can be relatively dated than those of unknown ages. This falls back on the notion, discussed earlier, that sites unassigned to a specific time period may reflect differential site use. In either case the vegetative model strongly suggests that hunter-gatherers are actively targeting patch-types that comprise of riparian/grassland, riparian stream, and the riparian/grassland intermediary patches.

Following these results, the next analysis was to determine the statistical significance between the densities of sites associated with forest patches and the combined areas associated with; riparian/grassland; riparian stream; and the riparian/grassland intermediary patches. Examining the densities of prehistoric sites between patch-types will determine where hunter-gatherers are concentrating their settlements. If the densities of sites are higher within the riparian and grassland patch-types (i.e. non-forested) than they are with forested patches, it

Count		Patch-Type		Total
		All Riparian Patches	Forest Patch	
Site Type	Dated Sites	151	24	175
	Unknown Aged Sites	128	55	183
Total		279	79	358

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	13.889[a]	1	.000		
Continuity Correction[b]	12.955	1	.000		
Likelihood Ratio	14.217	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	358				

Table 5.4 These tables reflect the Chi-Square test results to determine if the spatial distribution between dated and unknown aged sites reflected differences in patch-type distribution.

Analysis of Dated Prehistoric Sites

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	.831	.031	23.679	.000
N of Valid Cases		175			

Observed vs. Expected Cross Tabulation

		Expected					Total
		Paleo Indian	Early Archaic	Middle Archaic	Late Archaic	Late Prehistoric	
Observed	Paleoindian	21	0	0	0	0	21
	Early Archaic	0	19	0	0	0	19
	Middle Archaic	0	0	32	0	0	32
	Late Archaic	0	0	0	45	0	45
	Late Prehistoric	0	0	0	0	34	34
	Out of Bounds	4	3	6	9	2	24
Total		25	22	38	54	36	175

Analysis of all Prehistoric Sites (including sites with unknown ages)

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	.714	.027	31.211	.000
N of Valid Cases		357			

Observed vs. Expected Cross Tabulation

		Expected						Total
		Paleoindian	Early Archaic	Middle Archaic	Late Archaic	Late Prehistoric	Unknown Prehistoric	
Observed	Pale-Indian	21	0	0	0	0	0	21
	Early Archaic	0	19	0	0	0	0	19
	Middle Archaic	0	0	32	0	0	0	32
	Late Archaic	0	0	0	45	0	0	45
	Late Prehistoric	0	0	0	0	34	0	34
	Unknown Prehistoric	0	0	0	0	0	127	127
	Out of Bounds	4	3	6	9	2	55	79
Total		25	22	38	54	36	182	357

Table 5.5 Depicts the results from two statistical tests to measure the kappa value or the level of agreement the value has with the model's predictions. The top most tables reflect the results and error matrix from the first analysis which only considered prehistoric sites of know ages. The bottom tables reflect the results and error matrix from the second analysis which only considered prehistoric sites of both known and unknown ages.

would strongly suggest an attraction towards patch-types that are more productive with regards to subsistence resources. If this is not the case, then mobile foragers were uninterested in these areas regardless of the available resources.

The densities were achieved by first determining the total area that radiated away from prehistoric sites with a max radius of 1,000 meters. This was accomplished by utilizing ArcGIS to create ring buffers around prehistoric sites and then dissolving any buffers where areas had overlapped each other (see figure 5.11). The process of dissolving the buffers was to achieve a single uniform surface area around clustering prehistoric sites. For example, if two sites were spaced 500 meters apart and both had buffers that overlapped each other, there would be a shared area between the two. The dissolve tool in ArcGIS would essentially erase these overlapping regions and then combine the two remaining buffers areas together to form a single buffer around two site locations.

If portions of these buffers extended over Yellowstone Lake, their areas were subtracted from the total area since these areas do not constitute likely settlement placements. Afterwards, the areas within the enhanced buffers were subdivided further to account for differences in patch-types as observed in the vegetative model. Immediately following, prehistoric sites were then divided by the total area of their associated patch-type to ascertain their density (see table 5.6). Finally, the densities were multiplied by 100 to reflect densities covering an area of 100 km^2. This was done to adequately perform statistical operations with IBM's statistical software, 'SPSS'.

The results from this analysis indicate that higher densities of prehistoric sites occur within the patch-types that are comprised of riparian and grassland vegetative communities (see table 5.7 and figure 5.12). Results reflect that the rates of sites occurring within riparian and

Period	Forest Patch Site Counts	Forest Patch Area Km^2	Forest Patch Density per 100 km^2	All Riparian-Type Patches Combined Site Counts	All Riparian-Type Patches Combined Area km^2	All Riparian-Type Patches Combined Density per 100 km^2
Paleoindian	4	8.8	45	21	25.6	82
Early Archaic	3	7.8	38	19	22.4	85
Middle Archaic	4	12.4	32	35	36.2	97
Late Archaic	9	15.3	52	45	49.4	91
Late Prehistoric	2	7.2	28	34	31.0	110
Dated Prehistoric Sites	23	25.9	89	152	73.8	206
All Sites	79	41.7	189	278.0	105.7	263.0

Table 5.6 Depicts the number of sites that fall within each patch-type, the total area of the patch-type that's within in a fixed 1000 m radius from the sites and the density of those sites occurring within each respective patch-type; forest or all combined riparian and grassland patch-types.

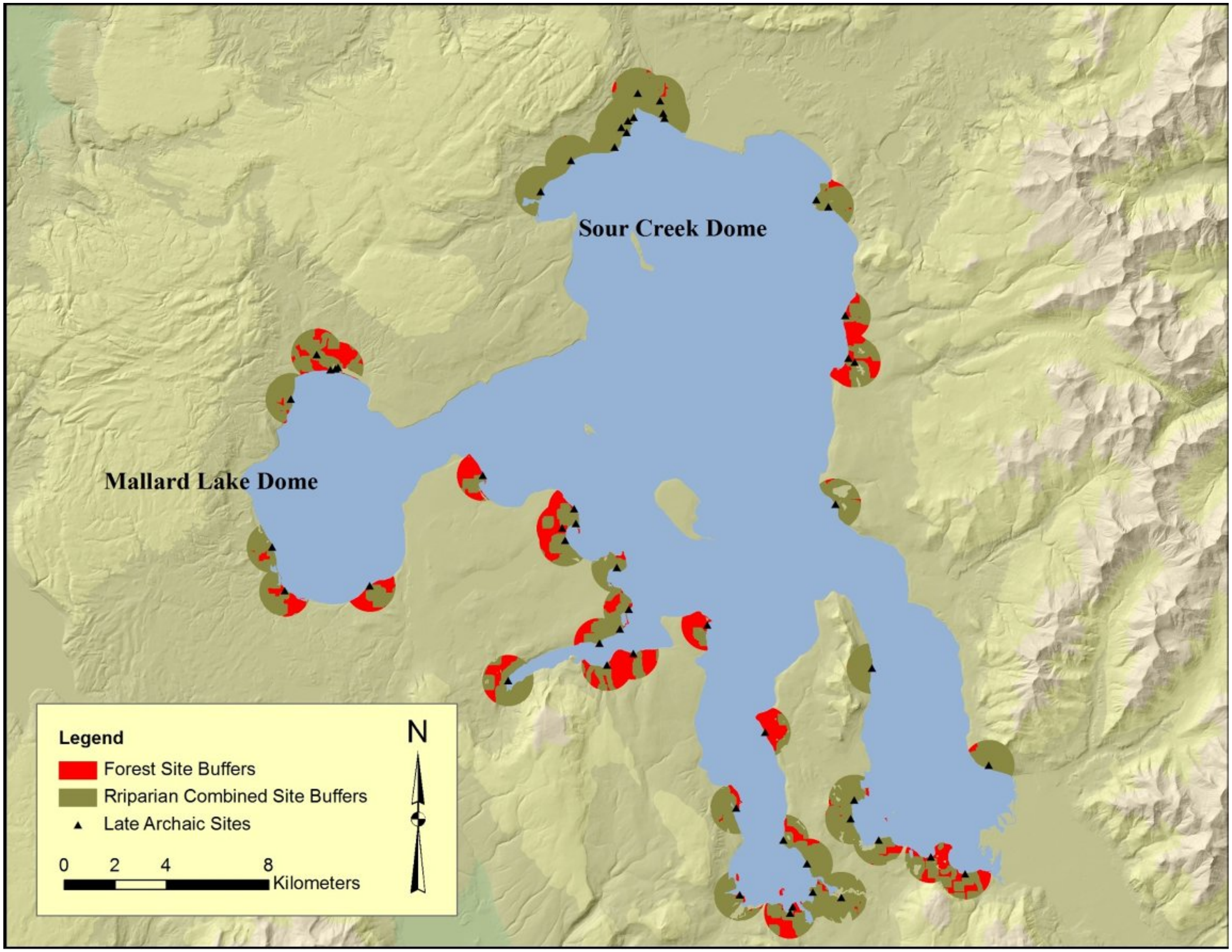


Figure 5.11 This an example of the 1km buffers around prehistoric site locations that contrast between forest and all riparian and grassland type patches.

grassland patch-types during the Paleondian period are 1.82 times higher than they occur in forested patches (see table 5.8 and figure 5.13). This rate continues to increase to 2.4 during the Early Archaic Period and continues to climb further to 3.03 in the Middle Archaic Period. Following this period the rate abruptly drops to 1.75 during the Late Archaic Period only to sharply increase again to its highest rate at 3.93 in the Late Prehistoric Period. This suggests that hunter-gatherers actively selected patch-types that are more productive in terms of subsistence resources. While the fluctuations in density rates are interesting to note, they will be considered in the next chapter's analysis concerning the effects of climate regimes.

When comparing the rates between just dated sites and the accumulative total of prehistoric sites the rates indicate that dated prehistoric sites have a higher rate of occurring in riparian and grassland type vegetation patches than the combination of both dated and unknown aged prehistoric sites (see table 5.8). Dated sites occur 2.31 times more in riparian and grassland patch-types than in forested patches compared with only 1.39 times observed when all sites are considered. This suggests that sites of unknown ages are slightly more dispersed between patch-types than dated sites. This result falls on the discussion earlier of differential site use, where upon sites that can be dated reflect longer occupations while the latter reflect short-term temporary occupations. It would make sense then to observe higher rates of longer term occupations occurring in the combined riparian and grassland patch-types and short term occupations occurring away from these areas.

Period	All Riparian-Type Patches Combined Density per 100 km²	Forest Patch Density per 100km²
Paleoindian	82	45
Early Archaic	85	38
Middle Archaic	97	32
Late Archaic	91	52
Late Prehistoric	110	28
Dated Prehistoric Sites	206	89
All Sites	263.0	189

Table 5.7 The table above illustrates the density of prehistoric sites falling within each patch-type. Note how the riparian/grassland patch-types have higher densities compared to forest patch-types.

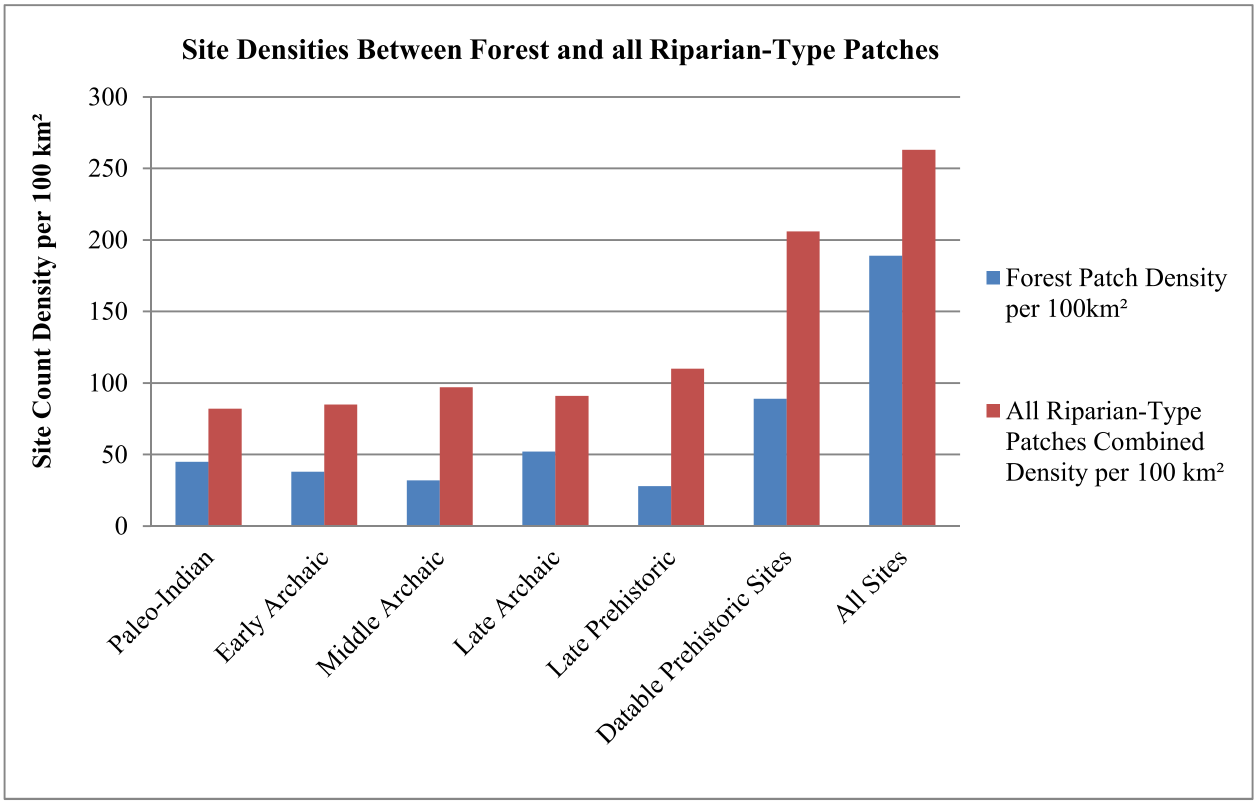


Figure 5.12 Graph illustrating the differences between patch-type densities.

Period	All Riparian-Type Patches Combined Density per 100 km²	Forest Patch Density per 100km²	Rates Between Non-Forested and Forest Patches
Paleoindian	82	45	1.82
Early Archaic	85	38	2.24
Middle Archaic	97	32	3.03
Late Archaic	91	52	1.75
Late Prehistoric	110	28	3.93
Dated Prehistoric Sites	206	89	2.31
All Sites	263.0	189	1.39

Table 5.8 The table above depicts the differences in densities between patch-types and the rates between non-forested and forested patches.

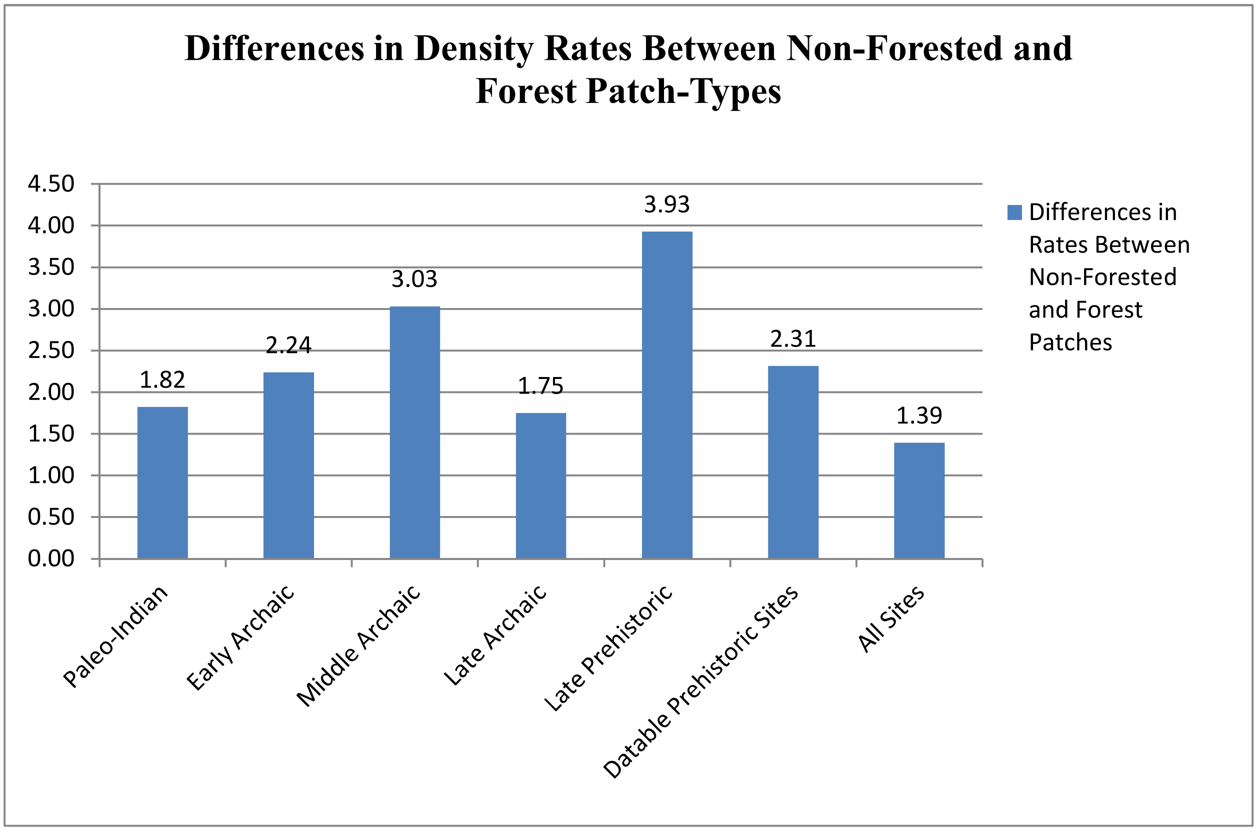


Figure 5.13 Graph illustrating the differences in rates between Riparian/Grassland and Forest patch-types.

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
All Riparian and Grassland Patch types - Forest Patches	65.857	28.440	10.749	39.555	92.159	6.127	6	.001

Table 5.9 Test results from a Students T-test to determine if the densities between all riparian and grassland patch-types were similar or dissimilar with forested patch-types. The results indicate that the distributions of densities were dissimilar to each other indicating a preferential selective behavior towards riparian/grassland patch types.

In a final test, a student T-test was performed to test the significance between the distribution of site densities associated with riparian and grassland patch-types and those of forested patch-types (see table 5.8). This was done to determine if the densities between all riparian and grassland patch-types were similar or dissimilar with forested patch-types. The null hypothesis was determined that if the distribution between riparian and grassland patch-types and those of forested patch-types were similar to each other, then hunter-gatherers had no preference in positioning their settlements in relation to patch-type. If the distributions were dissimilar to each other, then the null hypothesis would be rejected and indicate that hunter-gatherers were intently targeting non-forested patches.

The results indicate that the t-value to be 6.127 with six degrees of freedom and total significance value of .001 (see table 5.9). Therefore the null hypothesis is rejected since the probability of these distributions of being similar to each other is less than one tenth of one percent (0.1%). This suggests that the decisions to occupy a particular area were not arrived by random chance. Rather, there was a concerted effort amongst individuals to settle near geographic locations where subsistence resources were highly abundant and accessible. This will be explained in further detail in chapter eight in the conclusions section.

Chapter VI

The Implications of Climate Change on Hunter-Gatherer Subsistence and Settlement Strategies

Question 2

If hunter-gatherers were selected site placement based upon the availability and access to subsistence resources than how did fluctuations in climate affect these settlement patterns?

Hypothesis 2

If hunter-gatherers were selected riparian/grassland habitats I expect that the distribution and frequency at which sites occur over time to be dependent upon the conditions of the climate which influences the distribution and productivity of subsistence resources.

6.1 Introduction

Previously it has been demonstrated that hunter-gatherers selected the location of their settlements based on the access and availability to subsistence resources associated with riparian and grassland vegetative zones. The goal now is to assess the impact of climate change on site locations over time. This is to suggest that climate influences the makeup and diversity of all vegetative life, which in turn influences the biodiversity of animal life. Any alterations that may occur as a result of climate change, would have direct implications on the biodiversity of life at both localized and region wide scales. These disruptions would have profound impacts not only on the population sizes and geographic distribution of subsistence resources but also on human populations, since they are entirely dependent upon these resources.

This study examines over 11,000 years of paleo-climate history utilizing pollen data obtained from Cub Creek Pond (National Climatic Data Center, 2012) and Buckbean Fen (National Climatic Data Center, 2012) positioned at the northeastern and southern regions of Yellowstone Lake. These data are analyzed and compared with the prehistoric site data, leading from the Paleoindian Period up to the Late Prehistoric Period. The primary objective of this analysis is to determine if changes in vegetation compositions, associated with riparian and grassland vegetative communities correspond to changes in the frequency of site counts across time. Observed increases in riparian/grassland pollen counts should correspond with increased frequencies of site counts and vise versus. An increase in riparian/grassland pollen counts suggests increased availability of subsistence resources while low counts indicate a reduction in availability.

6.2 Procedures and Methods

The first procedure was to obtain pollen data that was within close proximity to the prehistoric sites in the Yellowstone Lake Basin. This was essential in the study so that any analyses carried out on the pollen data would reflect realistic climatic conditions of the basin region. Data was obtained from the National Climatic Data Center (http://www.ncdc.noaa.gov/paleo/paleo.html). Within the database of NOAA, seven pollen sets existed within the boundaries of Yellowstone National Park. Of these data sets only two were situated within the lake basin and were chosen for analyses in this study (see figure 6.1). The first pollen core was extracted by Herbert E. Wright (National Climatic Data Center, 2012) from Cub Creek Pond near the confluence of Cub Creek and Yellowstone Lake in the northeast region of the lake. The second pollen core was collected by Richard G. Baker (National Climatic Data

Center, 2012) from the southern end of Yellowstone Lake at Buckbean Fen. Together these pollen records reflect 12,000 years of climate history recording a detailed account of vegetation compositions.

To prepare the pollen sets for analysis, the pollen counts were classified between riparian/grassland and coniferous pollen types utilizing the software program C2 Data Analysis (see table 6.1). This was done to examine the increase and decrease in the expansion rates between forest and riparian/grassland vegetative zones. The classification of riparian/grassland pollen counts were also used to test the hypothesis, since it is believed that the settlement patterns were dependent upon the productiveness of these vegetative zones. The pollen types that were classified into the coniferous category included; *Abies* (White Fir), *Picea* (Spruce), *Pinus* (Pine Genus), *Pseudotsuga* (Douglas-fir), *Pinus albicaulis* (Whitebark Pine), *Pinus contorta* (Lodgepole Pine), and *Juniperus* (Juniper). Conversely, pollen types classified into the riparian/grassland category comprised of; *Acer negundo* (Box Elder), *Alnus incana* (Grey Alder), *Ambrosia* (Ragweed), *Artemisia* (Sagebrush), *Betula* (Birch), *Chenopodiaceae* (Goosefoot), *Cyperaceae* (Sedge Family), *Equisetum* (Horsetail), *Eriogonum* (Buckwheat), *Asteraceae* (Sunflower Family), *Nuphar* (Pond-lily), *Salix* (Willow), *Sarcobatus vermiculatus* (Greasewood), *Populus* (Cottonwood), *Poaceae* (grasses) and *Potamogeton* (Pondweed).

Coniferous (Forest)	**Riparian/Grasslands**		
Abies	*Acer negundo*	*Equisetum*	*Poaceae*
Picea	*Alnus incana*	*Eriogonum*	*Potamogeton*
Pinus	*Ambrosia*	*Asteraceae*	
Pseudotsuga	*Artemisia*	*Nuphar*	
Pinus albicaulis-type	*Betula*	*Salix*	
Pinus contorta-type	*Chenopodiaceae*	*Sarcobatus vermiculatus*	
Juniperus	*Cyperaceae*	*Populus*	

Table 6.1 Pollen family or species types categorized into two groups. Left column reflects Coniferous pollen varieties while the left column reflects pollen types associated with riparian or grassland vegetative types.

After these pollen counts were classified into two groups (riparian/grassland and forest) the data sets were subdivided into five age groups reflecting the time ranges of cultural periods leading from the Late Paleoindian period up to the Late Prehistoric Period. Within each of these age limits the pollen counts were calculated for their average count, since the majority of dated sites cannot be assigned to a specific point in time observed with pollen counts. This resulted in an average pollen count for each cultural period reflecting both riparian/grassland and forest types at Buckbean Fen and Cub Creek Pond core sites (see table 6.2 and figure 6.2).

With average pollen counts reflecting each cultural period, this data was ready to be utilized in several analyses to be compared against prehistoric site data ascertained from the previous chapter. This primarily comprised of datasets concerning the occurrences of sites associated with a specific cultural period. In addition, data pertaining to site densities were also compared against the pollen data. In the next section these analyses will be clearly introduced, giving more clarity to the reader about their primary intent and role in determining if climate played a factor in hunter-gatherer settlement strategies

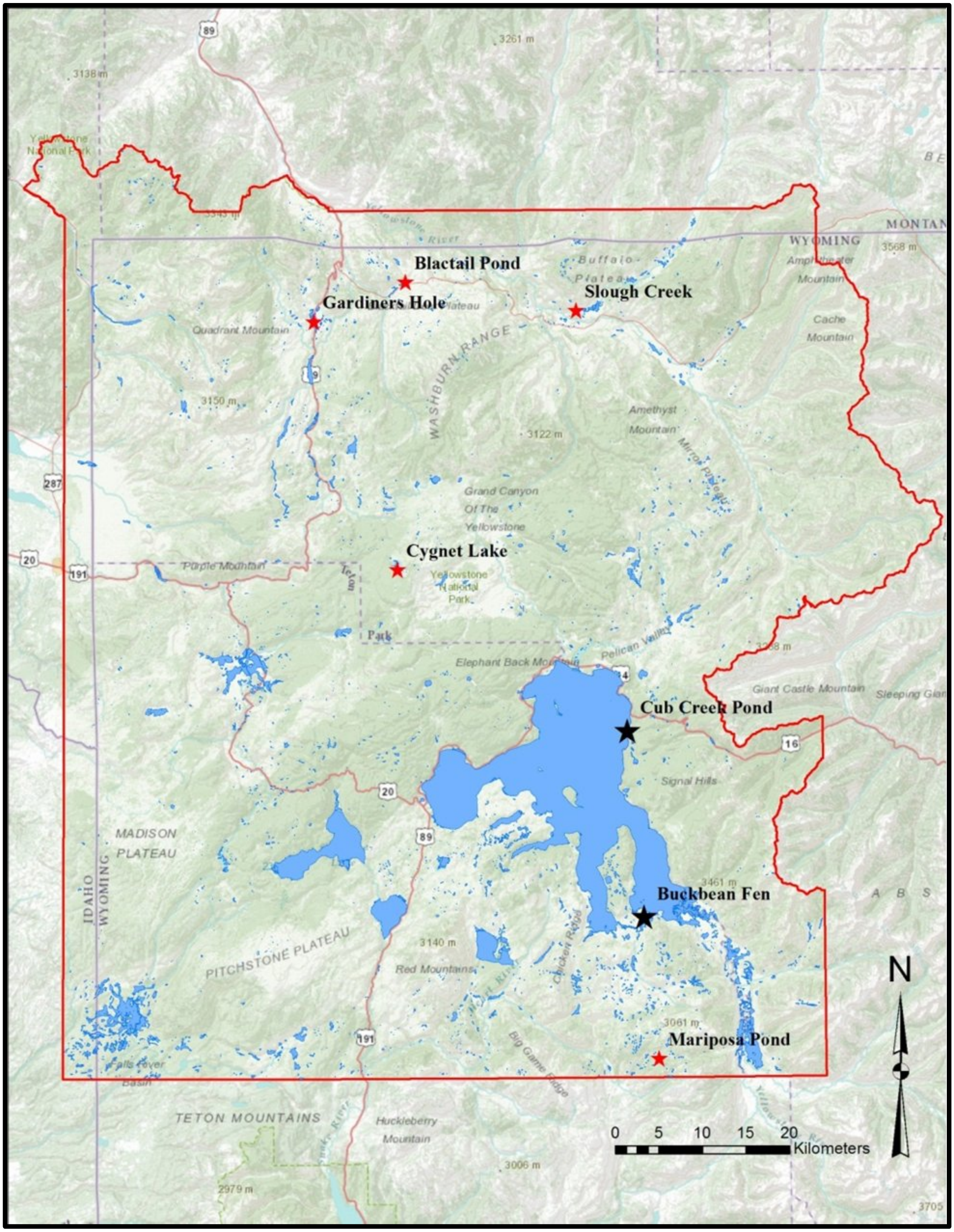


Figure 6.1 Spatial Distribution of pollen core sites. Black stars represent pollen data used in this study while red stars denote other core locations within the boundaries of Yellowstone National Park.

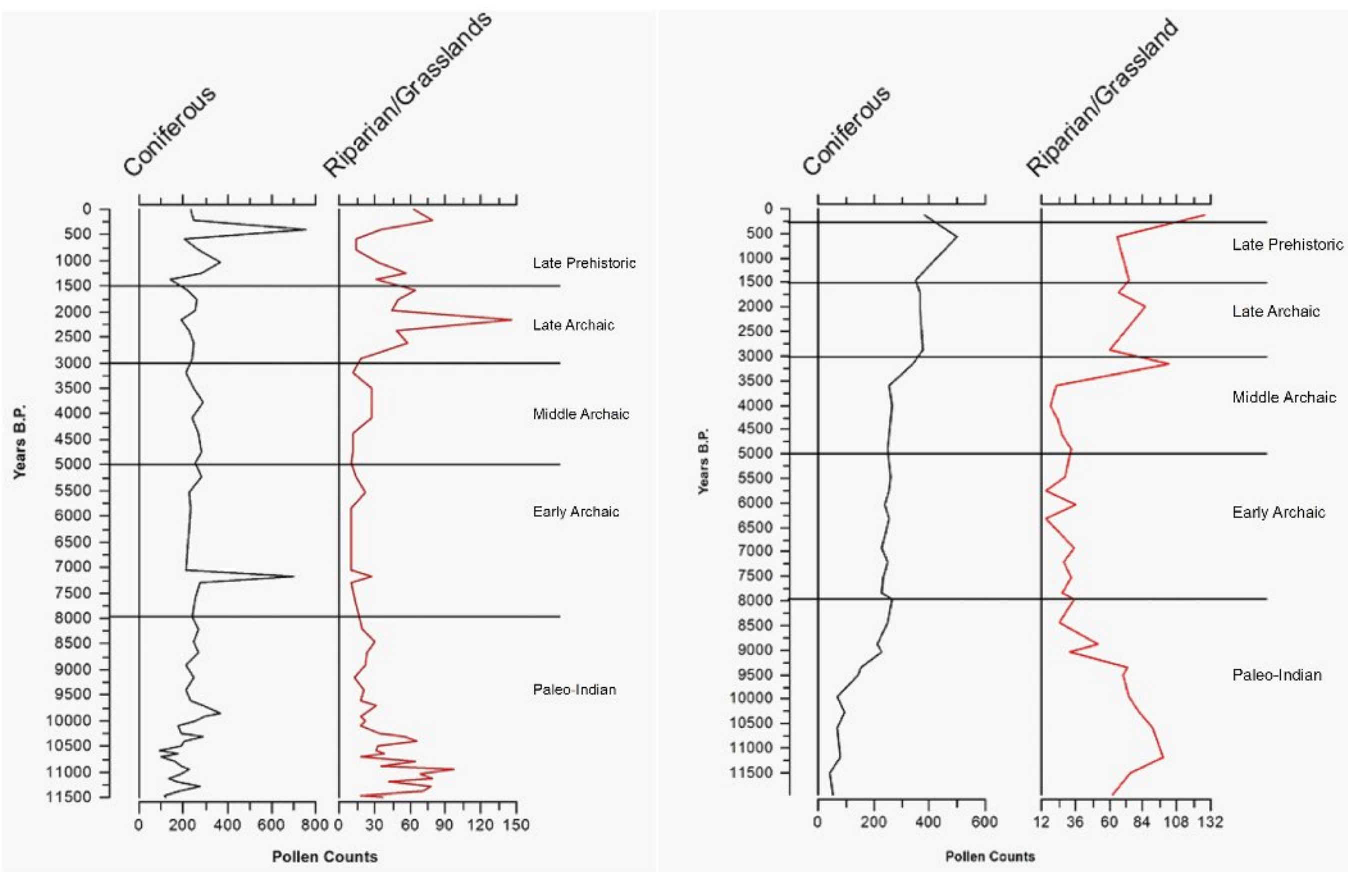
Buckbean Fen

Cultural Period	Time Range	Coniferous Average Pollen Counts	Riparian/Grassland Average Pollen Counts
Paleoindian	12,000- 8,000 B.P.	275.000	22.500
Early Archaic	8000 - 5,000 B.P.	238.000	14.500
Middle Archaic	5,000 - 3,000 B.P.	255.000	18.286
Late Archaic	3,000 - 1,500B.P.	234.000	61.571
Late Prehistoric	1,500 - 300 B.P.	337.333	30.800

Cub Creek Pond

Cultural Period	Time Range	Coniferous Average Pollen Counts	Riparian/Grassland Average Pollen Counts
Paleoindian	12,000- 8,000 B.P.	176.667	54.3
Early Archaic	8000 - 5,000 B.P.	246.111	28.1
Middle Archaic	5,000 - 3,000 B.P.	257.400	24.8
Late Archaic	3,000 - 1,500B.P.	362.250	79.0
Late Prehistoric	1,500 - 300 B.P.	425.500	70.0

Table 6.2 Average pollen counts between coniferous and riparian/grassland pollen types pertaining to each cultural period. The upper table pertains to Buckbean Fen pollen data while the lower table reflects Cub Creek Pond pollen data.



Buckbean Fen Cub Creek Pond

Figure 6.2 Pollen diagrams of Buckbean Fen and Cub Creek Pond reflecting the compositional changes between Coniferous and Riparian/Grassland pollen counts over time.

6.3 Analysis and Results

Several analyses were conducted to determine if climate patterns affected human settlement patterns in the Yellowstone Lake Basin. The first analysis set out to examine the significance of any compositional changes occurring over time between riparian/grassland and forest vegetative communities. The second analysis examined the significant differences occurring overtime between site densities associated with riparian/grassland and forest patch-types, and then compared those results with the first analysis. The third analysis examined how the frequency of pollen counts between Cub Creek Pond and Buckbean Fen corresponded with any changes occurring over time between the frequencies in site counts in the vicinity to the pollen cores. The final analysis replicated the above analysis but examined regional variations in site frequencies originating away from where the pollen cores were collected.

The intent of these analyses was based upon the premise that fluctuations in climate patterns impact the production levels of riparian/grassland vegetative communities. Disruptions in vegetative communities would have direct implications affecting the overall carrying capacities of prey species and production levels of edible plant resources. Consequently, these disruptions would ultimately influence where hunter-gatherers allocated their subsistence resources in addition to their overall group size. It is then expected that the aforementioned analyses will give clear indications of the circumstances just mentioned.

The purpose of the first analysis was to determine if there were any significant changes in vegetative communities across time that would suggest disruptions in the climate. If any disruptions are observed to be significant it could be suspected that hunter-gatherers were also affected (this will be examined in the second analysis). To determine if such significances existed, a chi-square was performed to test the significance between riparian/grassland and forest pollen counts as they transitioned between cultural periods. These tests were performed on both the Cub Creek Pond and Buckbean Fen pollen data (see tables 6.3-6.5).

The results from the Buckbean Fen pollen analysis suggest that there were no significant differences in vegetation compositions between the Paleoindian and Early Archaic periods. The value was .5 which reflects no substantial changes occurring between riparian/grassland and forest communities (see table 6.5). Both vegetative communities reflect a decrease in pollen counts with the transition into the Early Archaic Period, suggesting a decrease in biomass production (see table 6.6 and figure 6.5). This trend is also observed in figure 6.3 which depicts five vegetation types responsive to changes in moisture and temperature. The record indicates that this period was synonymous with the Hypsithermal Climatic Episode (i.e. Altithermal), which brought hotter and drier conditions to much of the Rocky Mountains and Great Plains and lasted from 8,000 B.P. to 5,000 B.P.

Proceeding this period, biomass production slightly increased with the transition from the Early Archaic Period into the Middle Archaic Period, suggesting cooler and moister conditions returning to the region. Milspaugh (1994) characterizes this shift in cooler and moister conditions as the Neo-Glacial Period lasting from 5,000 to 3,000 B.P. This is also reflected in the pollen record with the increased pollen counts of, *Picea* (Spruce) which are well adapted to colder temperatures (see figure 6.3). Although both riparian/grassland and forest communities began to rebound, the chi-square value of .858 highly suggest that there were no significant differences in vegetative compositions occurring between the Early Archaic and Middle Archaic periods (table 6.5).

Only during the transition between Middle Archaic and Late Archaic periods do significant changes begin to occur in the composition of pollen counts. This is indicated by the chi-square significance value of 0.00 (see table 6.5). The transition into the Late Archaic Period is marked with the expansion of riparian/grassland vegetative communities and the overall decline of forests (see table 6.6 and figure 6.5). The climate transitions from cool and moist conditions observed during the Middle Archaic period into moister and slightly warmer conditions. Warmer conditions are reflected by the increase pollen counts of *Pinus contorta*, (Lodge Pole pine) in spite of the overall decreases in coniferous pollen types (see figure 6.3). On the contrary, moister conditions are reflected by the sharp increase in pollen counts of *Cyperaceae* (Sedge family), which are akin to moist conditions. Another indicator that conditions were becoming wetter is observed with the decline of *Chenopodiaceae* (Goosefoot Family), which are well adapted to dry conditions. Any decline of pollen counts observed in this family is highly suggestive that conditions are becoming moister. Overall, the changes in vegetation observed between the Middle and Late Archaic periods are very significant and likely had profound positive impacts on the distribution of wild game and edible plant resources.

However, the warm and moist conditions of the Late Archaic Period would not last forever and neither would the abundance of riparian/grassland habitats conducive for a wide range of animal life. Riparian/grassland pollen counts drop by more than half while coniferous pollen climbs to its all-time high (see table 6.6 and figure 6.5) during the transition into the Late Prehistoric Period. The chi-square significance value is again 0.00, suggesting that the changes in vegetation

Buckbean Fen Chi-Square Tables				
Paleoindian to Early Archaic Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Early Archaic	238	15	253
	Paleoindian	275	23	298
Total		513	38	551
Early Archaic to Middle Archaic Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Early Archaic	238	15	253
	Middle Archaic	255	18	273
Total		493	33	526
Middle Archaic to Late Archaic Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Late Archaic	234	62	296
	Middle Archaic	255	18	273
Total		489	80	569
Late Archaic to Late Prehistoric Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Late Archaic	234	62	296
	Late Prehistoric	337	31	368
Total		571	93	664

Table 6.3 Chi-Square tables reflecting Buckbean Fen pollen data.

Cub Creek Pond Chi-Square Tables				
Paleoindian to Early Archaic Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Early Archaic	246	28	274
	Paleoindian	177	54	231
Total		423	82	505
Early Archaic to Middle Archaic Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Early Archaic	246	28	274
	Middle Archaic	257	25	282
Total		503	53	556
Late Archaic to Late Prehistoric Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Late Archaic	362	79	441
	Middle Archaic	257	25	282
Total		619	104	723
Late Archaic to Late Prehistoric Period		Pollen Type		Total
		Coniferous Pollen	Riparian/Grassland Pollen	
Cultural Period	Late Archaic	362	79	441
	Late Prehistoric	425	70	495
Total		787	149	936

Table 6.4 Chi-Square tables reflecting Cub Creek Pond pollen data.

Chi-Square Results		Buckbean Fen		Cub Creek	
Cultural Periods	**Durational Span**	**Significance Value**	**Significant**	**Significance Value**	**Significant**
Paleoindian to Early Archaic	12,000-5,000 B.P.	0.500	no	0	**yes**
Early Archaic to Middle Archaic	8,000 -3,000 B.P.	0.858	no	0.665	no
Middle Archaic to Late Archaic	5,000-1,500 B.P.	0.000	**yes**	0.001	**yes**
Late Archaic to Late Prehistoric	3,000-300 B.P.	0.000	**yes**	0.128	no

Table 6.5 Results of chi-square test that tested significance between riparian/grassland and forest pollen counts as they transitioned between cultural periods.

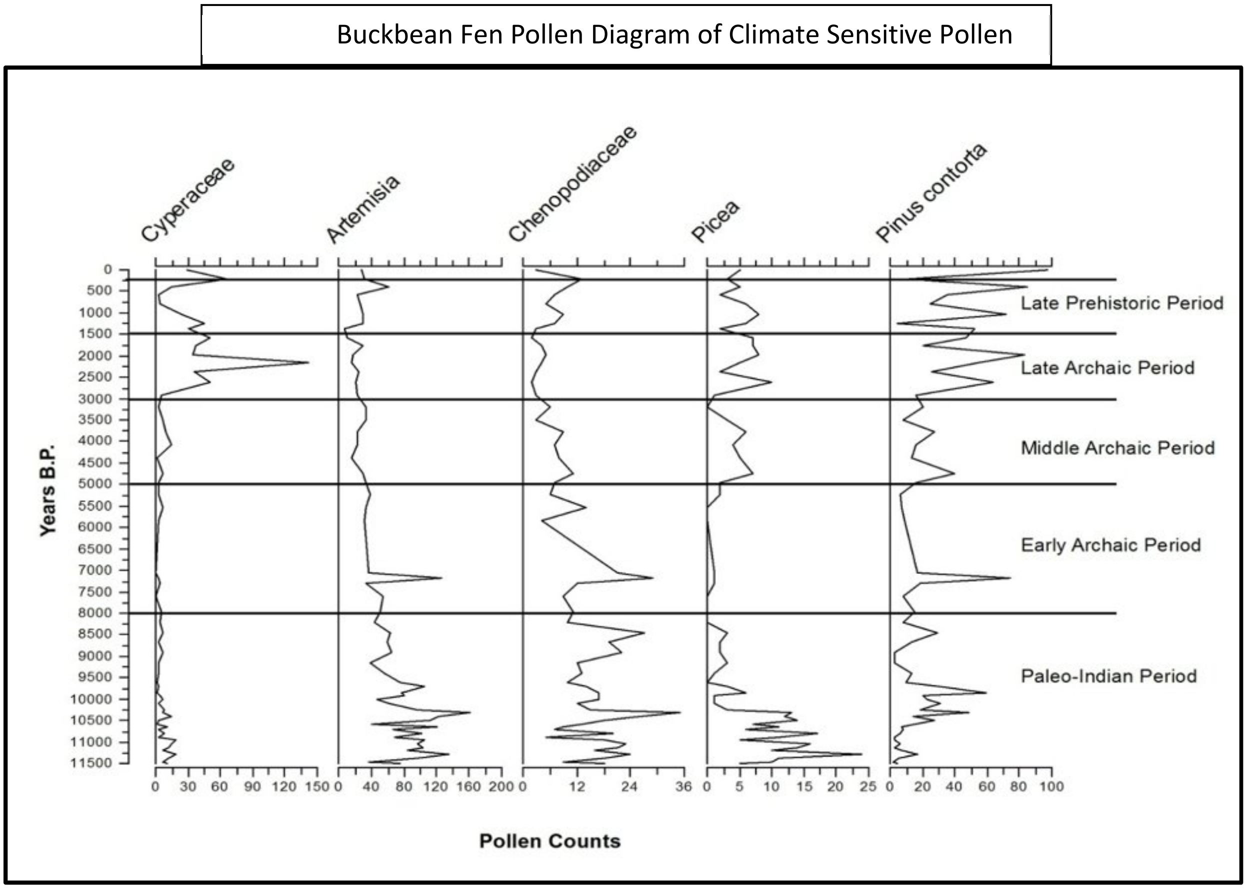


Figure 6.3 Pollen diagram of Buckbean Fen depicting pollen types sensitive to shifts in moisture and temperature.

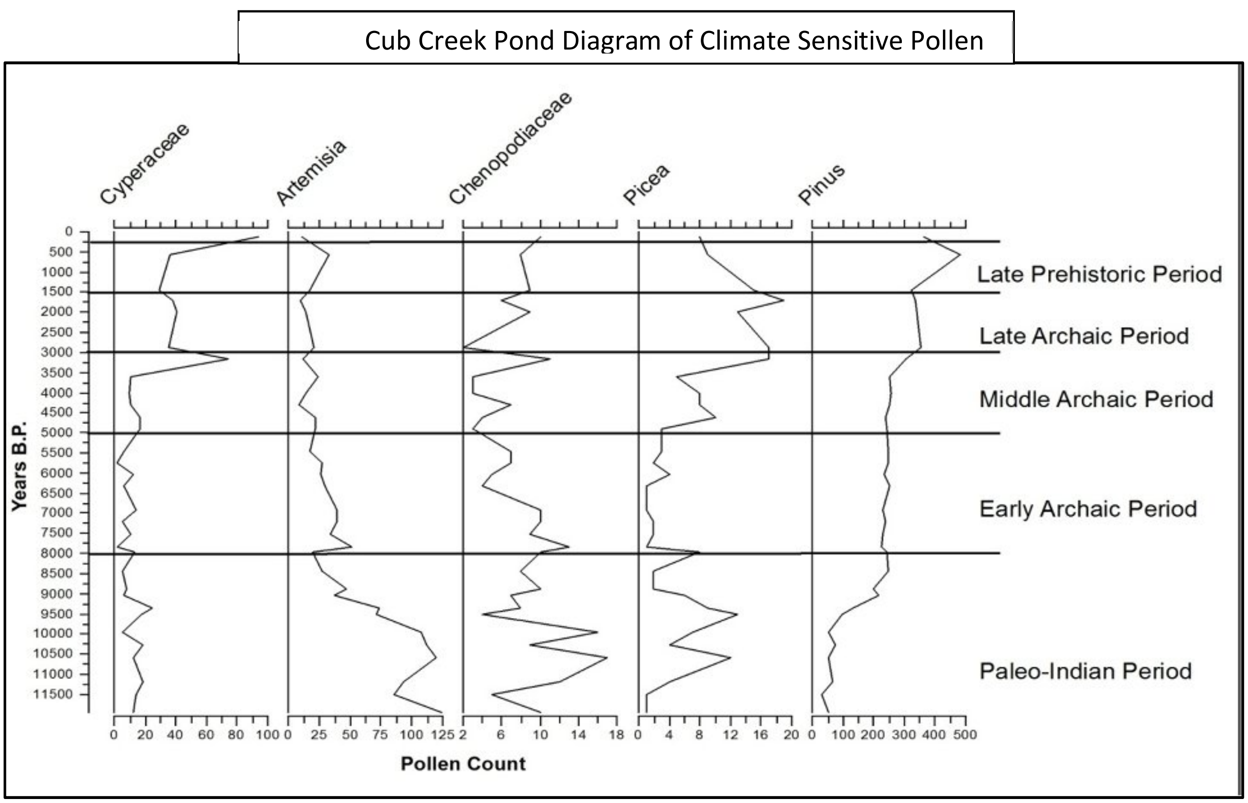


Figure 6.4 Pollen diagram of Cub Creek Pond depicting pollen types sensitive to shifts in moisture and temperature.

Buckbean Fen

Cultural Period	Time Range	Coniferous Average Pollen Counts	Riparian/Grassland Average Pollen Counts
Paleoindian	12,000- 8,000 B.P.	275.000	22.500
Early Archaic	8000 - 5,000 B.P.	238.000	14.500
Middle Archaic	5,000 - 3,000 B.P.	255.000	18.286
Late Archaic	3,000 - 1,500B.P.	234.000	61.571
Late Prehistoric	1,500 - 300 B.P.	337.333	30.800

Cub Creek Pond

Cultural Period	Time Range	Coniferous Average Pollen Counts	Riparian/Grassland Average Pollen Counts
Paleoindian	12,000- 8,000 B.P.	176.667	54.3
Early Archaic	8000 - 5,000 B.P.	246.111	28.1
Middle Archaic	5,000 - 3,000 B.P.	257.400	24.8
Late Archaic	3,000 - 1,500B.P.	362.250	79.0
Late Prehistoric	1,500 - 300 B.P.	425.500	70.0

Table 6.6 Average pollen counts of riparian/grassland and coniferous pollen varieties amongst each cultural period.

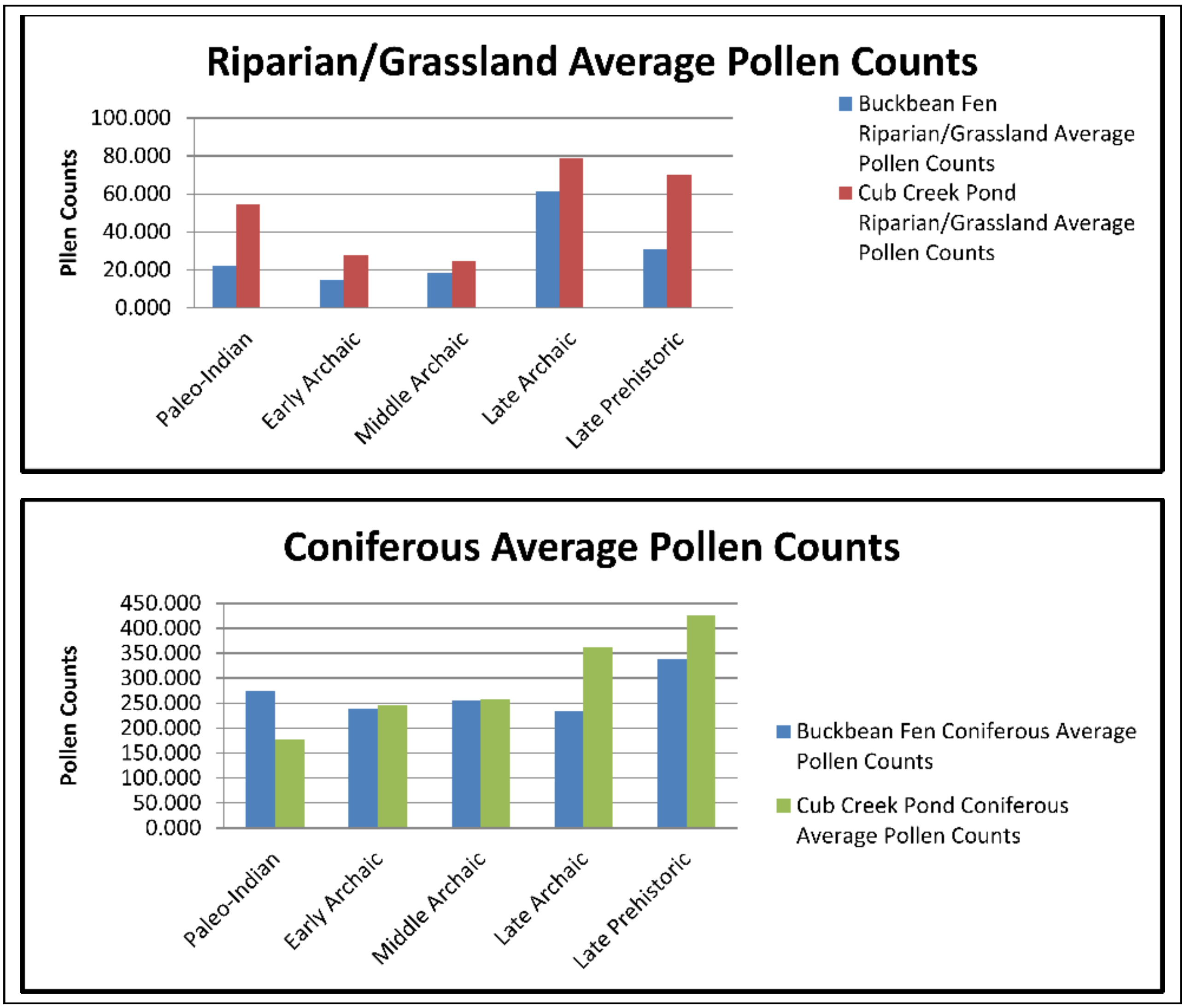


Figure 6.5 Average pollen counts of riparian/grassland and coniferous forest varieties. Top graph illustrates the comparison between riparian/grassland pollen counts of Buckbean Fen and Cub Creek Pond. The bottom illustrates this comparison between coniferous pollen types.

compositions are very significant (see table 6.5). The pollen record indicates a dramatic drop in *Cyperaceae,* and an increase in *Artemisia*, suggesting that conditions became drier (see figure 6.3). With the decrease in moisture to the region, forests soon overran riparian/grassland vegetative communities and ultimately destroyed habitats suitable for wild game and edible plant resources. The expansion of forests and the decline of riparian/grassland habitats would have caused an entire redistribution of subsistence resources across the Yellowstone Plateau and surrounding regions.

In comparison, the pollen analysis from Cub Creek Pond indicates that significant changes had occurred between riparian/grassland and forest communities during the transition between the Paleoindian and Early Archaic periods. This was indicated by the chi-square analysis that resulted in a significance value of 0.00 (see table 6.5). Between these two cultural periods, riparian/grassland pollen counts significantly dropped while coniferous pollen counts increased considerably (see table 6.6 and figure 6.5). This suggests that forests replaced much of what was primarily sage brush steppe during the Paleoindian Period.

The transition into the Early Archaic Period reflects a period becoming hotter and drier. This is indicated by the decrease in *Artemisia,* pollen counts and the fairly stabilized counts of *Cyperaceae* (see figure 6.4). Normally a reduction in *Artemisia* pollen would indicate an increase in moisture, but the pollen counts of *Cyperaceae* (i.e. sedges), remain fairly stable indicating no net gain of moisture throughout the period. Further supporting this is the proliferation of *Pinus*, which begins just prior to the Early Archaic Period. Lodgepole Pine forests, (adapted to warmer conditions), begin to expand and out-compete the cold adapted Picea (Spruce) conifers as climatic conditions climb to their maximum warmth. Together, the contraction of sage steppe and expansion of warm adapted temperate Lodgepole Pine forests indicates that conditions were becoming warmer and drier, and reflects a period where climatic conditions were indicative to the Hypsithermal climatic episode.

During the transition from the Early Archaic into the Middle Archaic Period, the pollen counts reflecting both vegetative communities do not show any apparent signs of significant changes. There is a continued decrease in riparian/grassland pollen counts while coniferous pollen types are only slightly increasing (see table 6.6 and figure 6.5). The chi-square significance value of .665 suggests that these changes are not significant (see table 6.5). However, after examining individual pollen types, it becomes apparent that conditions did become cooler as observed with the marked increase in *Picea* pollen counts (See figure 6.4). These increases in *Picea* pollen are very much similar to those observed in the Buckbean Fen pollen data set and suggest the effects of the Neo-Glacial Period were impacting the entire lake Basin. It's also interesting to note that the moist conditions as indicated by *Cyperaceae* pollen counts occur 500 to 700 years earlier in the Cub Creek pollen data set than in the Buckbean Fen dataset (See figures 6.3 and 6.4). It is unclear if these conditions are truly reflective of the period or perhaps discrepancies in the data.

Despite these conflicts, significant changes began to occur again during the transition from the Middle Archaic Period into Late Archaic Period. This was reflected in the chi-square significance value of 0.001 (see table 6.5). Both forest and riparian/grassland pollen counts dramatically increased and may suggest a continued period of wetter conditions first occurring at the tail end of the Middle Archaic Period. Pollen counts associated with *Picea* begin to decrease slightly, indicating warmer conditions. This warmth is also observed with the increase of *Pinus* pollen (See figure 6.4). Since coniferous forests were allowed to expand in this region it suggests that the amount of moisture was not intense enough to inhibit the growth of coniferous trees.

Finally, during the transition from the Late Archaic Period into the Late Prehistoric Period there were an increase in coniferous pollen counts and a slight decreasing in riparian/grassland pollen counts (see table 6.6 figure 6.5). The chi-square analysis resulted in a significance value of .128 and indicates that these changes in vegetative compositions are not considered significant (see table 6.5). During this period there is an increase and decrease of *Artemisia* and *Picea* pollen counts indicating that conditions were becoming drier and warmer (see figure 6.4). These conditions further fostered the expansion of forests as observed in the spike of *Pinus* pollen counts. Although the chi-square indicates that the composition between vegetative communities is not significant, it is still fairly low enough to indicate that the changes occurring in the vegetative compositions are fairly substantial.

The analysis between the two datasets has indicated that both have similarities and dissimilarities to each other. The Buckbean Fen dataset suggests that changes in vegetative compositions were most significant during the transitions between Middle and Late Archaic periods and the Late Archaic and Late Prehistoric periods. These periods saw a rise in riparian/grassland communities in the Late Archaic period followed by proliferating forests in the Late Prehistoric period. In contrast, the Cub Creek Pond dataset indicates that significant changes had occurred during the transition between the Paleoindian and Early Archaic periods and Middle Archaic and Late Archaic periods. The transition between the Paleoindian Period and Early Archaic Period saw an increase in coniferous forest pollen and a sharp decrease in riparian/grassland pollen. The next significant change had occurred between the Middle and Late Archaic periods with marked increases of both coniferous forest and riparian/grassland pollen types. Compared together, the significant changes in vegetative compositions between the two data sets are not fully in sync with each other.

It is unclear if the pollen data set of Cub Creek Pond truly reflects regional or localized conditions since there does exist dissimilarities when the data is compared against the Buckbean Fen dataset. Perhaps still, the data may reflect chronological errors concerning when changes in the frequency of pollen counts had actually occurred. This is noticeable with the pollen counts of *Cyperacea.,* In the Cub Creek Pond record pollen counts begin to increase 500 to 600 years prior to the increases observed in the Buckbean Fen record. The Cub Creek Pond dataset indicates that the rise of *Cyperaceae* began around 3,500 B.P. and peaking just prior to 3,000 B.P. In contrast, the Buckbean Fen record shows this pattern beginning around 3,000 B.P. and reaching its apex just prior to 2,000 B.P. Since the distance is less than 14 miles of where the core samples were collected, it would be more reasonable to believe that any shifts in vegetative compositions would occur correspondingly rather than centuries apart. Whatever the cause is for the dissimilarities between pollen sets, whether regional variations or chronological errors, the proceeding analyses will demonstrate that the pollen record of Buckbean Fen compliments the prehistoric record more so than the pollen record of Cub Creek Pond.

In the second analysis the site densities associated with riparian/grassland patch-types and forest patches (from the previous chapter), were tested for any significant changes in densities occurring overtime. These results were then compared against the results from the first analysis. The purpose of this was to determine if the significant changes observed in the pollen records corresponded to any significant changes occurring with site densities. If significant changes in densities corresponded to significant changes in pollen records, then an argument could be made that there is a clear indication that the climate influences the settlement strategies of hunter-gatherers. This is to suggest that any significant increases or decreases in either riparian/grassland or coniferous pollen counts effects the availability and abundance of subsistence resources and ultimately influences where people must position themselves to allocate those resources.

In this analysis Chi-square tests for independence were performed to determine the significance in site densities between riparian/grassland patch-types and forest patches as they transitioned between cultural periods, leading from the Paleoindian Period up to the Late Archaic Period. The table below reflects the densities of sites occurring within the two primary patch-types; riparian/grassland and forest patches (see table 6.7). These densities were ascertained from the analyses in the previous chapter and reflect the occurrences of sites within a 100 km area (see chapter V for methods). These results are reflected in the table below (see table 6.7).

Period	All Riparian/Grassland Patch-Types Density per 100 km²	Forest Patch Density per 100km²
Paleoindian	82	45
Early Archaic	85	38
Middle Archaic	97	32
Late Archaic	91	52
Late Prehistoric	110	28

Table 6.7 Densities of sites occurring between riparian/grassland and forest patch-types.

Results from this analysis reflect two transitional periods where the changes in site densities achieved significant values below the .05 confidence level (see table 6.8). These had occurred first during the transition between the Middle Archaic Period into the Late Archaic Period and the second occurring from the Late Archaic Period into the Late Prehistoric Period. The earlier transitional periods from the Paleoindian Period up to the Middle Archaic Period did not achieve significance values to be considered significant. The overall chi-square results are as follows; Paleoindian to Early Archaic, .502; Early Archaic to Middle Archaic, .325; Middle Archaic to Late Archaic, .049; Late Archaic to Late Prehistoric, .004.

During the transition between the Paleoindian and Middle Archaic Periods there are no significant changes in site densities between Riparian/grassland and forest patch-types. This suggests no apparent changes in settlement strategies between the two periods. This pattern is also reflected between the Early Archaic and Middle Archaic Periods. It is not until the transition from the Middle Archaic Period into the Late Archaic that a significant change in density occurs between the patch-types. This is observed with an increased density of sites occurring within forested patch types during the Late Archaic Period. This suggests an expansion of territory due to favorable climatic conditions coinciding during this period. Following Late Archaic Period, the transition into the Late Prehistoric incurs yet another significant change in patch-type site densities. This was reflected by a reversed trend, where sites became less apparent within forested patches and more concentrated within riparian/grassland patch-types. This indicates a contraction of territorial use compared to the expansion observed during the Late Archaic Period.

Comparing these results with the pollen records it becomes apparent they share more commonalities with the Buckbean Fen dataset rather than the Cub Creek Pond data. This is observed with the significant changes occurring between both the fluctuations in riparian/grassland pollen counts and patch-type densities (see table 6.9). The Buckbean Fen data suggests that there were no significant changes occurring in the vegetative compositions between the cultural periods beginning from the Paleoindian Period and leading up to the Late Archaic Period. Since there were no substantial changes occurring during this breadth of time, it would make sense for there to be little variation occurring in site densities among forest and riparian/grassland patch-types. In other words, there are no substantial disturbances in the environment that would deter hunter-gatherers away from their normal subsistence and settlement strategies.

In contrast, the periods leading after the Middle Archaic Periods had sustained substantial changes in both the densities of sites and the compositions between vegetative communities. The transition into the Late Archaic Period resulted in significantly increased productions of riparian/grassland communities and the contraction of forests. During this period the densities of sites within forested patches significantly increased, suggesting an expansion of territory. However, this expansion does not necessarily suggest direct intentions to exploit forest resources, but rather it reflects the margins of where riparian/grassland habitats existed before they dramatically contracted during the Late Prehistoric Period. Ultimately this period reflects a period of optimal conditions for hunter-gatherers since there was an explosion of riparian/grassland resources which would have sustained increased populations of prey species.

However, the transition into the Late Prehistoric Period resulted in a complete reversal in the compositions of vegetative communities. The biomass production of riparian/grassland habitats were dramatically reduced and forests completely encroached upon the shores of Yellowstone Lake. These environmental impacts would have posed significant problems for hunter-gatherers as their resource base was dramatically diminished and dispersed. As a result the densities of prehistoric sites became more concentrated within riparian/grassland patches (see table 6.7). This suggests that hunter-gatherers were concentrating their efforts on riparian/grassland patches that had not yet been overtaken by forests. It also indicates that hunter-gatherers became tethered to these remaining patches and had to travel further distances between patches to allocate subsistence resources. This increased mobility also meant that hunter-gatherers had to select resource patches that could sustain them long enough in order to make their increased travel costs worth the effort.

Paleoindian to Early Archaic Period		Patch-Type		
		Forest density/100km2	Riparian/grassland density/100km2	Total
Cultural-Period	Early Archaic	38	85	123
	Paleoindian	45	82	127
Total		83	167	250

Early Archaic to Middle Archaic Period		Patch-Type		
		Forest density/100km2	Riparian/grassland density/100km2	Total
Cultural-Period	Early Archaic	38	85	123
	Middle Archaic	32	97	129
Total		70	182	252

Middle Archaic to Late Archaic Period		Patch-Type		
		Forest density/100km2	Riparian/grassland density/100km2	Total
Cultural-Period	Late Archaic	52	91	143
	Middle Archaic	32	97	129
Total		84	188	272

Late Archaic to Late Prehistoric Period		Patch-Type		
		Forest density/100km2	Riparian/grassland density/100km2	Total
Cultural-Period	Late Archaic	52	91	143
	Late Prehistoric	28	110	138
Total		80	201	281

Cultural Periods	**Time Lapse**	**Significance Value**	**Significant**
Paleoindian to Early Archaic	12,000- 5,000 B.P.	0.502	no
Early Archaic to Middle Archaic	8,000 - 3,000 B.P.	0.325	no
Middle Archaic to Late Archaic	5,000 - 1,500 B.P.	0.049	**yes**
Late Archaic to Late Prehistoric	3,000 - 300 B.P.	0.004	**yes**

Table 6.8 Chi-square tables and results illustrating the significance in site densities between riparian/grassland patch-types and forest patches as they transitioned between cultural periods.

		Site Densities	**Buckbean Fen**	**Cub Creek**
Cultural Periods	Time Lapse	**Significant**	**Significant**	**Significant**
Paleoindian to Early archaic	12,000- 5,000 B.P.	no	no	**yes**
Early Archaic to Middle Archaic	8,000 - 3,000 B.P.	no	no	no
Middle Archaic to Late Archaic	5,000 - 1,500 B.P.	**yes**	**yes**	**yes**
Late Archaic to Late Prehistoric	3,000 - 300 B.P.	**yes**	**yes**	no

Table 6.9 Comparison of Chi-square test results of patch-type site densities with the Chi-square test results of vegetative pollen types.

Unfortunately, the Cub Creek Pond data does not compare well with the significant changes occurring with the site density data (see table 6.9). The pollen record indicates a significant change occurring in vegetation between the Paleoindian and Early Archaic periods, but there were no significant changes occurring in site densities during this period. Another discrepancy arises during the transition between the Late Archaic Period and the Late Prehistoric

Period. The pollen record has no indications of significant changes occurring, but during this transitional period there is a dramatic increase in site densities. The argument to be made here is that the Cub Creek Pond data fails to adequately explain the changes that are observed with the site density data. If the pollen record was truly reflective of environmental conditions encompassing the entire lake basin, then fluctuations in site densities should correspond to any environmental disturbances. In contrast the shifting patterns observed in the Buckbean Fen pollen data are synonymous with those observed in the site density data. In the following analyses, it will become clear that the pollen record of Buckbean Fen reflects environmental conditions of the Yellowstone Lake Basin rather than Cub Creek Pond.

In the third analysis, pollen records were compared with the spatial distribution of prehistoric sites radiating away from where the pollen cores were extracted (see figure 6.6). The intent of this comparative analysis was to examine how the frequencies at which sites occurred among each cultural period corresponded to changes in riparian/grassland communities, over fixed distances away from pollen extraction points. The primary objective of this was to determine if effects of climate shifts could be observed in the prehistoric site data. Secondly the objective was to determine how far reaching the climatic conditions observed on a localized scale (i.e. immediate vicinity of the pollen extraction point), could be on a broader regional scale.

This analysis will either support or reject the main hypothesis, which postulates that any disturbances affecting the productiveness of riparian/grassland vegetative communities (resulting from shifts in climate patterns), will have direct impacts on the subsistence and settlement strategies of hunter-gatherers. Any observed increases in riparian/grassland pollen counts should correspond with increased frequencies of site counts. Increased pollen counts of riparian/grassland vegetation would indicate an increased production of biomass that could sustain larger populations of prey species in addition to increased productions of edible plant resources. The increased production of these resources would have been a powerful attractor for hunter-gatherers to frequent these patches and exploit them of their resources. Conversely, any reduction in the riparian/grassland pollen counts should correspond with reduced frequencies of site counts. A reduction in riparian grassland pollen counts would indicate a reduction of biomass production and adversely affect the availability of subsistence.

To conduct this analysis, the linear regression analysis tool in IBM's SPSS statistics program was utilized to determine a goodness-of-fit between riparian/grassland pollen counts and the occurrences of site counts at two kilometer intervals leading away from the pollen extraction points. In figure 6.6 is a map depicting ringed buffers radiating away from the pollen extraction points (represented by stars) at two kilometer intervals with the last interval ending at10 kilometers. Within these buffered zones and elsewhere on the map are the locations of all dated prehistoric sites represented by triangles. Prehistoric sites that were spatially distributed within these ringed buffer zones were utilized to perform goodness-of-fit tests with the Buckbean Fen and Cub Creek Pond pollen data sets.

Results from these comparative analyses are shown in the tables 6.10-6.13. Tables 6.10 and 6.11 reflect the data inputs and results from the Buckbean Fen analysis while the proceeding tables reflect the Cub Creek Pond analysis (see tables 6.12 and 6.13). The organization of the table 6.10 is such that each interval distance is denoted by its own column with the frequency of sites within the interval's radial distance away from the pollen extraction points. Prehistoric sites that fall within these buffered zones are then classified into their respective cultural period. Columns on the far left denote the cultural period, time spans and the average riparian/grassland pollen counts reflective of those periods. Table 6.11 depicts the results from the linear regression analysis, with the far left column denoting the interval distances away from pollen extraction point and the rest denoting the correlation coefficient (R), coefficient of determination (R^2) and the analysis of variance (ANOVA).

The results from these analyses have demonstrated two different outcomes in the goodness-of-fit tests between the prehistoric site data and the two pollen datasets. The Buckbean Fen analysis indicated that the climatic conditions observed through the changes in riparian grassland pollen counts were characteristic across broader regions than Cub Creek Pond. The correlation coefficient became very strong as distances increased further away from the Buckbean Fen extraction point. Correlation coefficient values reached as high as .9 at the 6km to 8 km intervals before they dropped at 10 kilometers (see table 6.11). The ANOVA f-scores of.028 and .024 reached at the 6km and 8 km intervals indicate that that there was very little variance between the riparian/grassland pollen counts and the frequency of sites over time. These ANOVA f-scores demonstrate very good, goodness-of-fit test results.

Despite the diminished correlation coefficient values observed in distances closer than 4 km of the Buckbean Fen pollen extraction point, there is no reason to be alarmed by this. It's actually a good indication of the extent of environmental conditions in the region. The fact that a goodness-of-fit can only become significant at 6km away from the extraction point suggests that hunter-gatherers were not confined to a particular resource patch, but had more freedom in exploiting resources further away from Buckbean Fen. This indicates that the environmental conditions observed within the vicinity of Buckbean Fen were analogous across further distances away.

Buckbean Fen Cultural Period	Years B.P.	Riparian/Grassland Pollen Counts	Radial Distance 2 KM Site Counts	Radial Distance 4 KM Site Counts	Radial Distance 6 KM Site Counts	Radial Distance 8 KM Site Counts	Radial Distance 10 KM Site Counts
Paleoindian	12,000-8,000	22.5	1	2	2	3	3
Early Archaic	8,000-5,000	14.5	0	2	2	3	5
Middle Archaic	5,000-3,000	18.3	2	4	5	6	8
Late Archaic	3,000-1,500	61.6	2	8	12	16	16
Late Prehistoric	1,500-300	30.8	1	2	4	4	5

Table 6.10 This table depicts the average pollen counts of riparian/grassland pollen types observed in the Buckbean Fen pollen record amongst the cultural periods. It also depicts the frequencies of prehistoric sites occurring over time at incremental distances away from the pollen extraction point.

Radial Distance km	Pearson R	Pearson's R2	ANOVA	Significant
2	0.552	0.304704	0.335	no
4	0.862	0.743044	0.06	no
6	0.928	0.861184	0.028	yes
8	0.925	0.855625	0.024	yes
10	0.862	0.743044	0.06	no

Table 6.11 Results reflecting a linear regression analysis between the average pollen counts occurring over time against the frequencies of prehistoric sites at incremental distances away from the extraction point.

Cub Creek Pond Cultural Period	Years B.P.	Riparian/Grassland Pollen Counts	Radial Distance 2 KM Site Counts	Radial Distance 4 KM Site Counts	Radial Distance 6 KM Site Counts	Radial Distance 8 KM Site Counts	Radial Distance 10 KM Site Counts
Paleoindian	12,000-8,000	54.3	N/A	N/A	1	1	1
Early Archaic	8,000-5,000	28.1	1	1	2	2	2
Middle Archaic	5,000-3,000	24.8	1	1	2	3	3
Late Archaic	3,000-1,500	79.0	3	3	5	6	6
Late Prehistoric	1,500-300	70.0	2	3	6	7	7

Table6.12 This table depicts the average pollen counts of riparian/grassland pollen types observed in the Cub Creek Pond pollen record amongst the cultural periods. It also depicts the frequencies of prehistoric sites occurring over time at incremental distances away from the pollen extraction point.

Radial Distance km	Pearson R	Pearson's R2	ANOVA	Significant
2	0.952	0.906304	0.048	yes
4	0.99	0.9801	0.010	yes
6	0.736	0.541696	0.156	no
8	0.696	0.484416	0.192	no
10	0.696	0.484416	0.192	no

Table 6.13 Results reflecting a linear regression analysis between the average pollen counts occurring over time against the frequencies of prehistoric sites at incremental distances away from the extraction point.

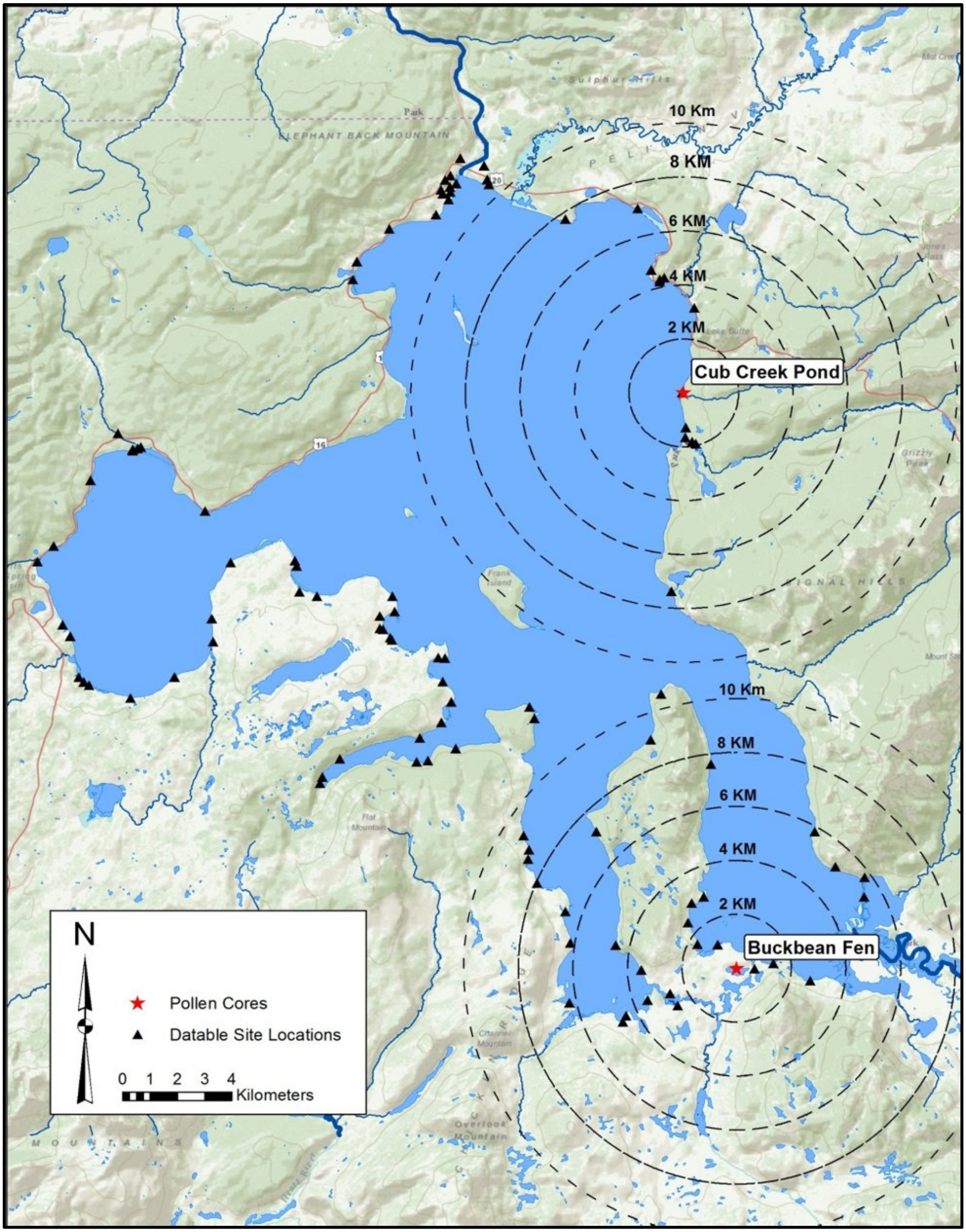


Figure 6.6 Map depicting the distribution of prehistoric sites. Red stars represent the location of pollen cores while dashed lines represent incremental distances of 2 km away from the pollen extraction points. The incremental buffers were utilized in the third analysis to compare the frequencies of site counts (marked by triangles) occurring away from the pollen extraction points with pollen count frequencies of riparian/grassland pollen varieties.

In contrast, the Cub Creek Pond analysis reflects very different results of those from Buckbean Fen. Within two kilometers of the pollen extraction point, the correlation coefficient between riparian/grassland pollen counts and prehistoric site frequency, obtains a value of .952 with an ANOVA f-score of .048, suggesting very significant results (see table 6.13). The goodness-of-fit value becomes more significant within the 4km interval distance with a correlation coefficient of .99 (a near perfect correlation), and an ANOVA f-score of .01 indicating very minute variances between the two variable sets. However, the goodness-of-fit scores diminish substantially beyond the 4 km interval distance, with correlation coefficients falling below .75 and reflecting values for correlation of determinations well below .60.

Since poor goodness-of-fitness levels dramatically decline beyond 4 km away from Cub Creek Pond, it may indicate that environmental conditions were only conducive to that region only. This would indicate that the availability of subsistence resources were limited to this particular region and were not characteristic across much broader areas as observed with the Buckbean Fen analysis. This would have confined groups of mobile foragers to exploit resources within a micro-ecological niche. Today, the vicinity of Cub Creek is enveloped by dense forests with few forest clearings characterized by mesic wetlands; most of which are positioned up to 4 km away near the vicinity of Clear Creek (see figure 6.7). It is suspected that the results from this analysis are analogous only to the conditions of these mesic wetlands rather than conditions covering much greater distances.

In light of the Cub Creek Pond analysis, the discrepancies in the pollen data discussed in the previous analysis may not after all reflect errors in the data but may instead reflect unique climatic conditions to this area alone. In contrast, the Buckbean Fen pollen record appears to compliment the prehistoric settlement patterns over broad regions of up to 8 kilometers. In either case, whether reflecting local or broader regional conditions the linear regression analyses have shown that there is a direct association between fluctuations in climate and the frequencies at which prehistoric sites occur. In the next analysis, a closer examination will be made on how the pollen records compare to regional variations in site frequencies at different regions around Yellowstone Lake.

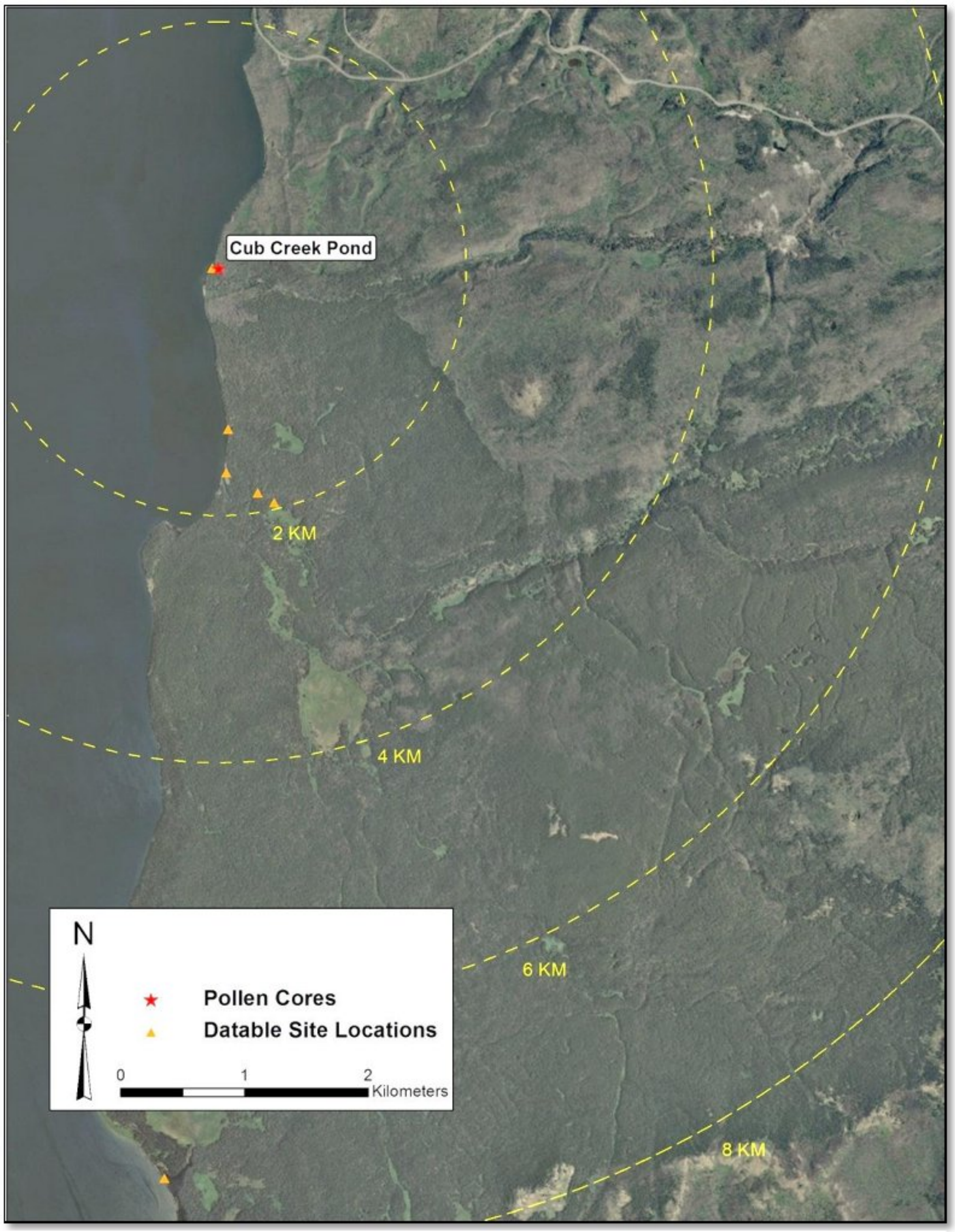


Figure 6.7 Aerial Image of the buffered ring zones leading away from Cub Creek Pond. Note the few forest clearings within the region which would have tethered subsistence resources within or in close proximity to these areas.

In the final analysis, a closer examination was made to determine if the pollen records of Buckbean Fen and Cub Creek Pond corresponded to variations in site frequencies occurring in different regions around Yellowstone Lake. The purpose of this analysis was to understand if the climate conditions observed through the Cub Creek Pond and Buckbean Fen pollen records had larger implications on settlement patterns occurring on a region wide scale of the lake basin. If this is the case, then an analysis could be made to determine which of the two could serve as a best-fit model reflecting climatic conditions during the past 12,000 years of the Yellowstone Lake Basin. Moreover, this analysis will further substantiate that climate not only influenced the production and distribution of subsistence resources but also influenced where hunter-gatherers had to position themselves to allocate such resources.

Five zones were selected around Yellowstone Lake to determine a goodness-of-fit between riparian/grassland between the frequencies of sites and riparian/grassland pollen counts assessed from Buckbean Fen and Cub Creek Pond pollen records (see figure 6.8). The first zone is situated in the northern end of the Yellowstone Lake in the vicinity of Fishing Bridge. The second zone comprises of the entire West Thumb of Yellowstone Lake and the third is situated adjacently to the east along the southwest shores of Yellowstone Lake. The fourth zone is located in the southern end of the lake near Buckbean Fen and the final zone is located on the east side of the lake at the confluence of Clear Creek and Yellowstone Lake. Lastly, an additional analysis was carried out on the cumulative total of all dated prehistoric sites within the lake basin.

Table 6.14 depicts the breakdown of data used to perform the regression analyses between pollen records and the site count frequencies of the five zones. Columns on the left half the table depict the, cultural period and their time spans and the average pollen counts per period of the Buckbean Fen and Cub Creek Pond pollen records. The remaining columns are a breakdown of the number of sites occurring within each regional zone and their respective cultural period. Results from these analyses are depicted in tables 6.15 and 6.16.

The results indicate that comparative analyses between the pollen records and site count frequencies of the five regional zones ends in mixed results. This is reflected in the ANOVA f-scores which indicate that confidence levels were not met in much of the comparative analyses between both pollen sets and regional site count frequencies (see tables (6.14 and 6.16). In the Buckbean Fen comparative analysis, only the South and Southwest Zones obtained significant f-scores, indicating very little variances in the relationship between pollen counts and site count frequencies. Unfortunately, the remaining zones (North Shore, West Thumb and Clear Creek Zone), fail to reach such levels, indicating that variances occur between the two data sets. In comparison, the regression analysis with Cub Creek Pond indicates that only the Clear Creek zone reached a significant ANOVA f-score of .01. This suggests there is very little variance between pollen data and prehistoric site data. In contrast, all other zones reflect insignificant ANOVA f-scores indicating that variances between the datasets are substantial enough to be considered not significant.

What is interesting is that between the Buckbean Fen and Cub Creek Pond comparative analyses, both obtain incredibly high ANOVA f-scores for the West Thumb region (see tables (6.14 and 6.16). This is particularly noticeable with the Cub Creek Pond analysis, where there is absolutely no relationship between pollen data and prehistoric site data. This is observed with an ANOVA f-score of .997. In contrast, the Buckbean Fen comparative analysis resulted in an ANOVA f-score of .656 which is only a slight improvement in the compatibility between datasets. It is unclear why this occurs in the data and there may be numerous possibilities why the West Thumb region reflects such poor ANOVA f-scores.

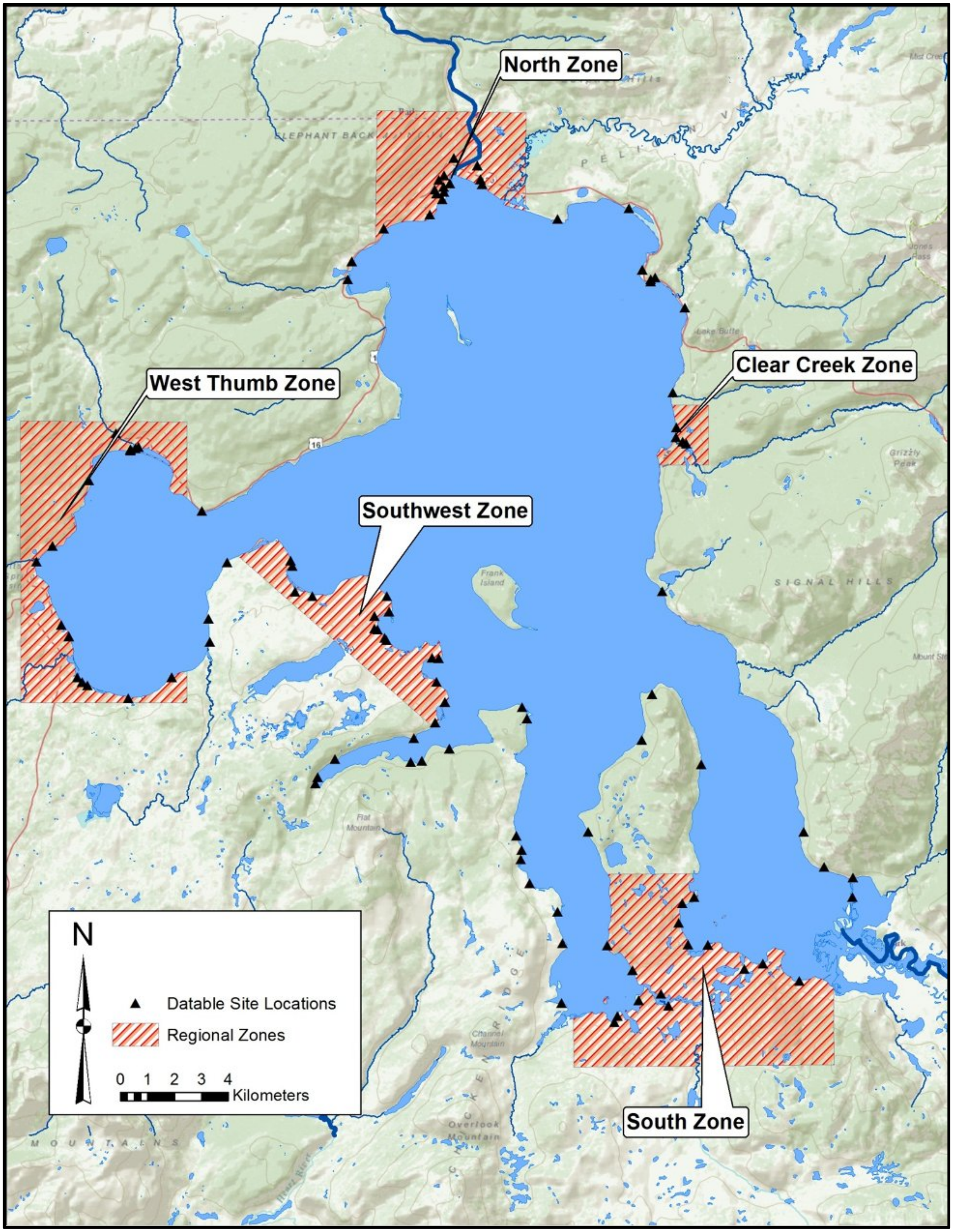


Figure 6.8 Map illustrating the regional zones from which the pollen records were compared against the prehistoric site count frequencies to conduct regression analyses.

Cultural Period	*Time Range in years B.P.*	*Buckbean Fen Riparian/Grassland Pollen Counts*	*Cub Creek Riparian/Grassland Pollen Counts*	*North Shore Zone Site Counts*	*West Thumb Zone Site Counts*	*Southwest Zone Site Counts*	*South Zone Site Counts*	*Clear Creek Zone Site Counts*
Paleoindian	*12,000-8,000*	*22.500*	*54.3*	*5*	*4*	*4*	*2*	*N/A*
Early Archaic	*8,000 5,000*	*14.500*	*28.1*	*4*	*5*	*3*	*2*	*1*
Middle Archaic	*5,000-3,000*	*18.286*	*24.8*	*7*	*10*	*4*	*4*	*1*
Late Archaic	*3,000 -1,500*	*61.571*	*79.0*	*10*	*8*	*8*	*11*	*2*
Late Prehistoric	*1,500-300*	*30.800*	*70.0*	*9*	*8*	*5*	*2*	*2*

Table 6.14 This table depicts the average pollen counts of riparian/grassland pollen types observed in the Buckbean Fen and Cub Creek Pond pollen records amongst the cultural periods. It also depicts the frequencies of prehistoric sites occurring over time within regional zones selected around Yellowstone Lake. These zones occur in the northern, eastern, southern, southwestern and western regions around the lake.

***Buckbean Fen* Regression Analysis on Regional Zones**

Regional Area	Pearson's R	Pearson's R^2	ANOVA	Significant
North Shore Zone	0.818	0.669	0.09	no
West Thumb Zone	0.274	0.075	0.656	no
Southwest Zone	0.993	0.986	0.001	yes
South Zone	0.902	0.814	0.036	yes
Clear Creek Zone	0.805	0.648	0.195	no

Table 6.15 Results reflecting the linear regression analysis between the riparian/grassland pollen record of Buckbean Fen with different regional zones around the lake.

Cub Creek Pond Regression Analysis on Regional Zones

Regional Area	Pearson's R	Pearson's R^2	ANOVA	Significant
North Shore Zone	0.742	0.551	0.151	no
West Thumb Zone	0.018	0.000	0.997	no
Southwest Zone	0.817	0.667	0.091	no
South Zone	0.519	0.269	0.37	no
Clear Creek Zone	0.990	0.980	0.01	yes

Table 6.16 Results reflecting the linear regression analysis between the riparian/grassland pollen record of Cub Creek Pond with different regional zones around the lake.

These may include climate patterns unique only to the region, or perhaps subsistence and settlement strategies unaffected by changes in climate. Perhaps still, the West Thumb region may indicate land use patterns unrelated to subsistence strategies. Whatever the case may be, it is unclear why the frequencies of site counts do not compliment either of the pollen records.

However, between the comparative analyses it becomes apparent that the pollen record of Buckbean Fen compliments the prehistoric site data more so than the Cub Creek Pond data. This is observed by considerably higher correlation of coefficient values and lower ANOVA f-scores than those observed with the Cub Creek Pond analysis. This is especially seen with the Southwest Zone, where the correlation coefficient was .993 and an ANOVA of .001, suggesting that there were only very minute variances between the datasets and that both had very high correlations to each other. Considering, that the area is characterized by mostly low lying relief, the region would have naturally been susceptible to water logged conditions all throughout the Holocene and thus supporting wetlands and other type of riparian habitats. Even today the region still supports wetlands, bogs and a shallow lake further inland (Delusion Lake). So it's no surprise that site frequencies correlate well with the data from Buckbean Fen, since both regions share similar characteristics in low lying relief that could foster conditions for riparian/grassland patch-types.

Since the Buckbean Fen pollen data indicate an increased association with prehistoric site data then Cub Creek Pond data, they may serve as a best-fit-model for the entire region. This is because the previous analysis only examines arbitrary selected boundaries and fails to consider prehistoric sites that fall outside these boundaries that may either improve or inhibit the results of the analysis. It is believed that if all dated prehistoric sites were considered in a regression analysis (i.e. SPSS linear regression tool) to ascertain a goodness of fit, ANOVA f-score and correlation values, then a more accurate assessment could be made about the effects of climate on a much larger regional scale of the lake basin. Therefore, additional regression analyses were carried out between both pollen datasets and all dated prehistoric sites, in efforts to obtain a best-fit model that could adequately explain the variations in site count frequencies through the ages (see table 6.17).

The results from these analyses are depicted in the tables below (see table 6.18). With a correlation coefficient of .88 and an ANOVA f-score of .049, the regression analysis indicates that the Buckbean Fen pollen data is attributable to 77% of the variation observed in the frequencies of prehistoric sites. In contrast, the regression analysis with the Cub Creek Pond Data indicates that with a correlation coefficient of less than .6, it only accounts for 36% of the variation observed in the frequencies of prehistoric sites. This clearly indicates that the Buckbean Fen serves as the best-fit-model that best reflects the variation in prehistoric site data over the past 12,000 years. This is also substantiated with the ANOVA f-score of .049 indicating its significance. It also indicates that in fact, climate did influence the distribution and production of subsistence resources that in turn influenced the subsistence and settlement strategies of hunter-gathers.

What is more interesting to note, is that if the Buckbean Fen regression analysis did not consider any of the sites from the West Thumb region of the lake, the correlation coefficient would be .953 with an ANOVA f-score of .012. This would suggest that the Buckbean Fen pollen data could be attributed to approximately 90% of the variation observed in the frequencies of prehistoric sites. It is unclear why the frequencies of site counts in the West Thumb do not correspond with changes in climate conditions. This may reflect differences in land use patterns compared to other regions around the lake basin or perhaps substantial differences in climate history that result in poor correlations. In any case the results from this final analysis indicate that the climatic conditions observed through the Buckbean Fen pollen data serve as a best-fit model to explain the variation observed in the frequencies of prehistoric sites.

		Buckbean Fen	Cub Creek Pond	
Cultural Period	**Time Range in years B.P.**	**Riparian/Grassland Pollen Counts**	**Riparian/Grassland Pollen Counts**	Yellowstone Lake Basin Site Counts
Paleoindian	12,000-8,000	22.500	54.3	25
Early Archaic	8,000 -5,000	14.500	28.1	22
Middle Archaic	5,000-3,000	18.286	24.8	38
Late Archaic	3,000-1,500	61.571	79.0	54
Late Prehistoric	1,500-300	30.800	70.0	36

Table 6.17 Results reflecting the linear regression analysis between the riparian/grassland pollen record of Buckbean Fen with the cumulative total of all prehistoric site count frequencies within the Yellowstone Lake Basin.

Regression Analysis of the Yellowstone Lake Basin		
Statistical Value Type	**Buckbean Fen Regression Analysis**	**Cub Creek Pond Regression Analysis**
Pearson R	0.880	0.599
Pearson's R^2	0.7744	0.359
ANOVA	0.049	0.286
Significant	Yes	no

Table 6.18 Results reflecting the linear regression analysis between the riparian/grassland pollen record of Cub Creek Pond with the cumulative total of all prehistoric site count frequencies within the Yellowstone Lake Basin.

In summary, the results from the analyses in this chapter are very encouraging and indicate that climate impacted settlement and subsistence strategies. In chapter eight, I will use the results of these analyses to support the premise that climate conditions influenced the productivity of subsistence resources that in turn influenced where hunter-gatherers positioned themselves to intercept and allocate such resources.

Chapter VII

Spatial Relationships Between Lakeshore Deformations and the Archaeological Record

Question 3

Do the spatial locations of sites along the z-axis (elevation) reflect the fluctuations of lake levels over time caused by the inflation and deflation cycles of the Sour Creek and Mallard Lake resurgent domes?

Hypothesis 3

Prehistoric sites will be spatially distributed among shoreline terraces that were exposed only during the time of occupancy. This is to argue that archaeological materials that were deposited during a specific lake level in Yellowstone Lake's history should not be found on terraces that reflect younger lake stands.

7.1 Introduction

The objective of the final question is to determine if relationships exists between dated archaeological material and paleo-shorelines that encompass Yellowstone Lake. These paleo-shorelines reflect the elevations of past lake levels spanning as far back in time to the Late Pleistocene when glaciers finally retreated, allowing the Yellowstone Lake Basin to fill with water. It is expected that archaeological material pertaining to any one particular cultural period should not be associated with paleo-shorelines that reflect younger lake stand heights. Archaeological material that has been transported and deposited through natural erosional processes or through human intervention (i.e. recycling or reuse of a tool or other artifacts) are considered secondary deposits and are the exception to this rule.

The primary cause of fluctuating lake stands over the course of 12 to 14 thousand years is primarily the result of oscillating elevations in the outlet of Yellowstone Lake (Pierce, 2002). This phenomenon exists because the outlet traverses over the primary axis between the Mallard Lake and Sour Creek Domes (Locke and Meyer, 1994; Pierce et al. 2002, 2007) (see figure 7.1) The domes reflect the primary centers of the ring fracture zone that characterize the ongoing unrest of the Yellowstone Volcanic Field (Christiansen, 2000). Below the Earth's surface, magma is pooled underneath these structures causing the crust above to swell and bulge from the confidence of immense pressure that has built up. The volume of magma within these chambers is also in constant flux with one another, causing either of the two dome structures and the surfaces around them to increase or decrease in elevation (Christiansen, 2000; Pierce and Morgan, 1992; Smith and Siegel, 2000). Since the axis between the two resurgent domes runs perpendicular to the outlet of Yellowstone Lake at Le Hardys Rapids and because the Sour Creek Dome lies juxtaposed, any increase or decrease in elevation associated with changes in underlying pressures will directly affect lake level elevations (Locke and Meyer, 1994; Pierce et al. 2007). For a thorough review on lake shore deformations please refer to Chapter II on the geology of Yellowstone National Park.

To determine if archaeological sites pertaining to a particular cultural period could be associated to a specific paleo-shoreline, two major analyses were conducted. First the elevations of prehistoric sites were compared against models presented by Locke and Meyer, (1994), Pierce et al. (2007) and field work analyses carried out by Dr. Mark Hendrix and Dr. Michael Hoffman (Hoffman and Hendrix 2012) from the University of Montana. The second analysis only compared the spatial distributions between prehistoric sites and paleo-shorelines observed in northern region of the lake utilizing georeferenced data from Pierce et al. (2007). The necessity for the second analysis arose from the inadequacies related to poor and inaccurate data utilized in the first analysis. The second analysis served to come to more definite terms concerning the relationship between the ages of paleo-shorelines and their association to prehistoric sites. The inadequacies related to the first analysis will be explained in more thorough detail in the paragraphs to come.

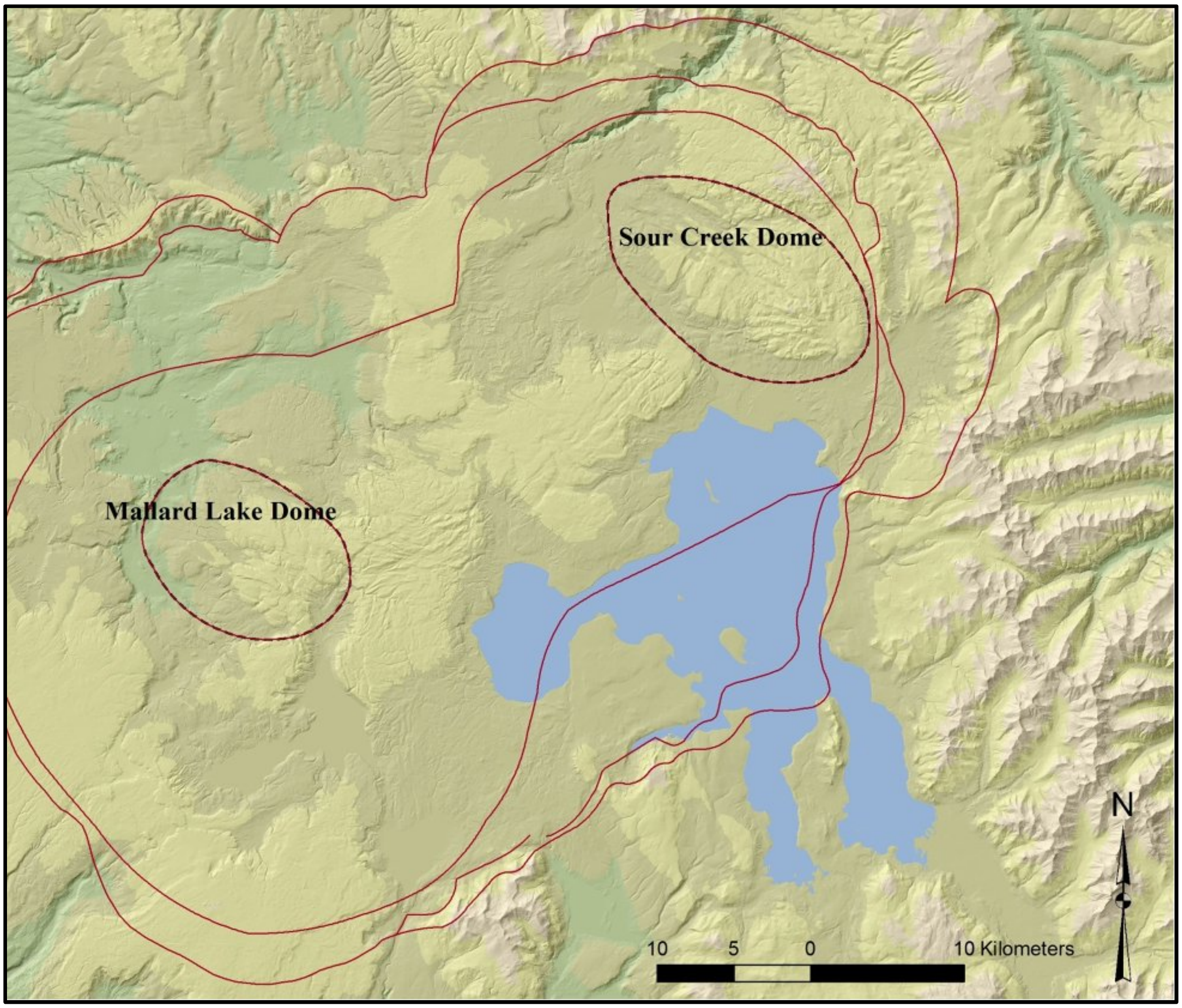


Figure 7.1 Map depicting the locations of the Mallard Lake and Sour Creek Domes.

7.2 Procedures and Methods

To begin, prehistoric site data were compiled into a geodatabase using ArcGIS software, where prehistoric sites were classified into their respective cultural periods. These classifications comprised of the following periods; Paleoindian (12,000 to 8,000 B.P.); Early Archaic, (8,000 to 5,000); Middle Archaic (5,000 to 3,000); Late Archaic (3,000 to 1,500 B.P.) and Late Prehistoric, (1,500 to 300 B.P.). Prehistoric sites that could not be associated to a cultural period were excluded from the database since there is no definitive means in associating their unknown ages to past lake levels of Yellowstone Lake. Essentially, the prehistoric site data was the same data used in both the prior research studies, with each site record obtaining not only its associated time period but also its easting and northing coordinates in NAD1983 Universal Transverse Mercator UTM projections.

Next a digital elevation model (DEM) of Yellowstone National Park was retrieved from the Geosciences Department from the University of Montana. The DEM had a cell resolution of 10 x 10 m where by each pixel reflects an area of $100m^2$. In terms of accuracy, this is one of the most accurate digital representations one may obtain of the park. However, the most precise and sought after digital elevation models are those obtaining 1m x1m cell resolutions which are acquired through Light Detection and Ranging (LIDAR) technology. These are the most expensive applications in mapping techniques and data are hard to come by. Yet still, the 10m x 10 m DEM used for this study still presented the best available data to conduct this analysis.

After the DEM and prehistoric data was secured, the next step was to select prehistoric sites from the geodatabase to test against the lake shore models developed by Lock and Meyer, (1994), Pierce et al. (2007) and field work analyses carried out by Dr. Mark Hendrix and Dr. Michael Hoffman from the University of Montana. Since the models only characterize the northern, eastern and southeastern paleo-shorelines, only the prehistoric sites found within these regions were selected for this initial analysis. These regions were classified into three regions; the Northern, Central and Southern zones (see figure 7.2). The reason for these zones is to account for regional variations in shoreline heights that result from geological processes related to regional uplift and drop from caldera breathing, and also regional stretching from extensional faults.

Paleo-shorelines in the northern region of the lake tend to be higher in elevation and more exaggerated than shorelines observed in the southern reaches. This occurs because changes in regional elevation are far greater in this region due its close proximity to the Sour Creek Dome (Locke and Meyer 1994; Pierce et al. 2007). Moving further south towards the central regions of the east shore, the shorelines slump inward toward the caldera rim before rising up again in elevation in the southern most reaches of the lake. Locke and Meyer (1994) attribute this slumping to regional extensional fault systems, similar to Great Basin extensional fault systems. Accounting for theses geological processes by comparing shoreline data to separate regions of the lake will ensure the most accurate analysis later to come.

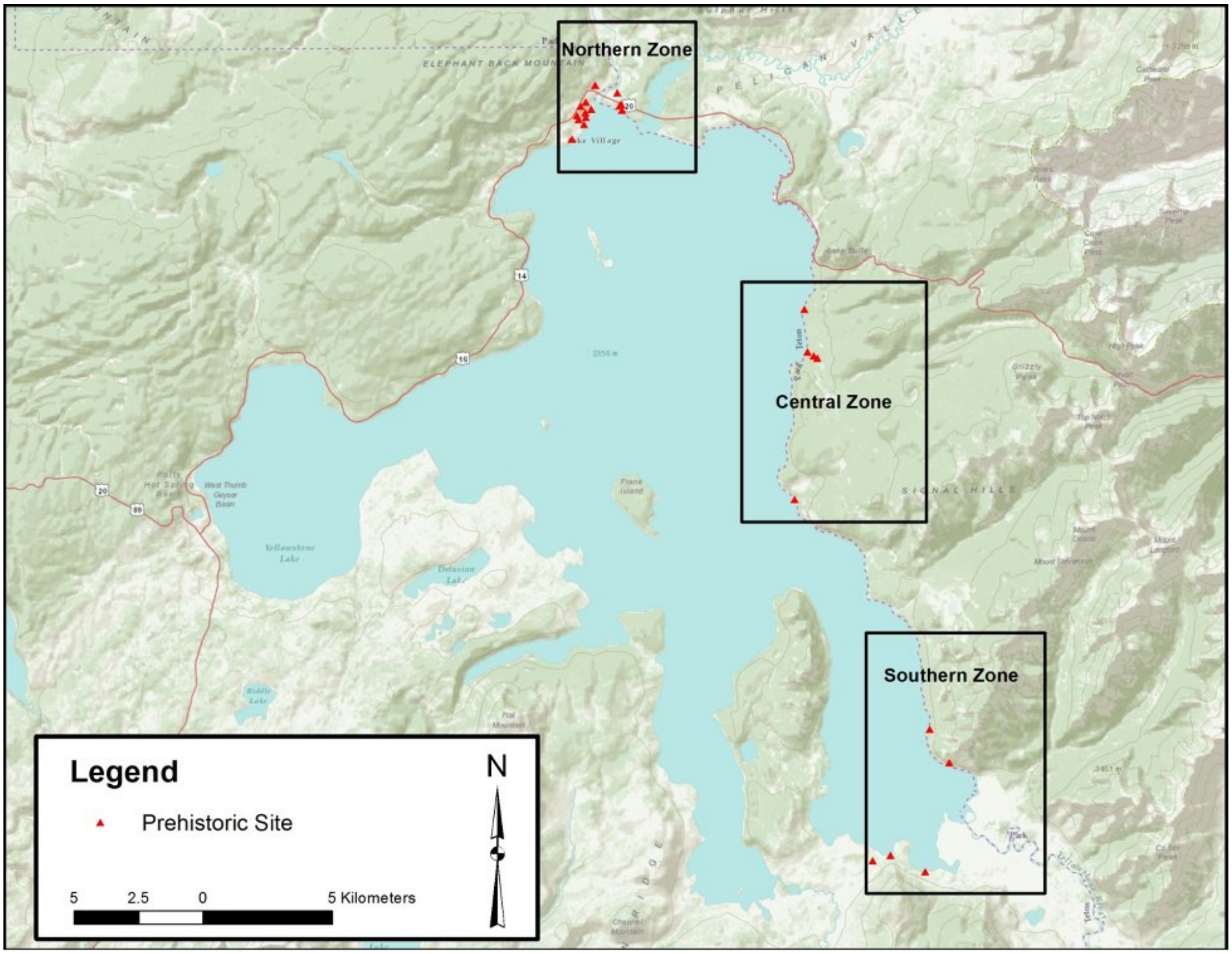


Figure 7. 2 Map depicting the the three regional zones used in this study. Red triangles reflect the positions of prehistoric sites used to test against models proposed by Pierce et al. (2007), Locke and Meyer (1994) and Hoffman and Hendrix, (2012).

The selection of sites was determined by first organizing a smaller pool of prehistoric sites that exhibited intact archaeological contexts. Archaeological sites that had obtained dated features such as hearths or roasting pits were among the first to be included into the selection pool. If sites did not obtain any dated features, then prehistoric sites were selected based on their stratigraphic integrity. In other words prehistoric assemblages found scattered along beach ridges or near the confluences of stream mouths were excluded from the selection pool, since these have a higher potential to reflect secondary deposits. After prehistoric sites were carefully chosen they were then recorded into a new geodatabase for use in the initial analysis.

Next the prehistoric site data from the new database were overlaid in the digital elevation model using ArcGIS software. Using the tool 'Extract by Attributes', information relating to elevation from the DEM that lie directly underneath each prehistoric site location was extracted and recorded into a new table column in the prehistoric site's geodatabase. The modified database now obtained information relating to a site's relative or absolute age, which study region they fell within (i.e. Northern, Central, or Southern Zones) and their elevation with respect to the digital elevation model. Lastly, this information was organized into table depicted below (see table 7.1).

The procedures necessary for the second analysis only required the comparison between the spatial distributions of prehistoric site data with georeferenced data from Pierce et al. (2007). Prehistoric sites from the northern end of the lake were compared against georeferenced LIDAR data taken from Pierce et al.'s (2007) report, 'Postglacial Inflation-Deflation Cycles, Tilting and Faulting in the Yellowstone Caldera Based on Yellowstone Lake Shorelines'. The report depicted a high resolution map with a cell resolution of 2x2 meter. The figure also illustrated the various paleo-shorelines that follow along with Pierce's shoreline model. This figure was extracted from the report and georeferenced to the exact position overlying the digital elevation model (see figure 7.4). In the next section the analyses will be further explained in detail along with results.

Northern Zone

Paleoindian		Early Archaic		Middle Archaic		Late Archaic		Late Prehistoric	
Site Number	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**
48YE304	2381.1	48YE381	2360.4	48YE419	2360.7	48YE1556	2371.3	48YE2109	2388.1
48YE1558	2363.7	48YE1	2361.9	48YE1	2361.9	48YE380	2359.1	48YE2102	2383.2
48YE1553	2384.5	48YE1558	2363.7	48YE1558	2363.7	48YE1785	2366.5	48YE2111	2361.3
48YE1	2361.9	48YE549	2360.1	48YE304	2381.1	48YE1	2361.9	48YE1	2361.9
				48YE381	2360.4	48YE1558	2363.7	48YE1553	2384.5
				48YE549	2360.1	48YE304	2381.1	48YE1558	2363.7
						48YE381	2360.4	48YE304	2381.1
						48YE419	2360.7	48YE381	2360.4
						48YE549	2360.1	48YE549	2360.1

Central Zone

Paleoindian		Early Archaic		Middle Archaic		Late Archaic		Late Prehistoric	
Site Number	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**
No Sites Available		No Sites Available		No Sites Available		48YE2080	2371.3	48YE2082	2364.6
						48YE678	2358.0	48YE2080	2371.3
						48YE2075	2360.7	48YE678	2358.0
						48YE2092	2358.0		

Southern Zone

Paleoindian		Early Archaic		Middle Archaic		Late Archaic		Late Prehistoric	
Site Number	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**	**Site Number**	**Elevation**
No Sites Available		No Sites Available		48YE249	2378.0	48YE1497	2361.0	48YE707	2359.8
						48YE2103	2380.5		
						48YE248	2357.9		

Table 7.1 Depicts the names of prehistoric sites and their DEM elevations that fall within in the northern, central and southern zones of study.

7.3 Analyses and Results

The objective of the first analysis was to compare the elevations of prehistoric sites with the shoreline models presented by Locke and Meyer, (1994), Pierce et al. (2002, 2007) and Hoffman and Hendrix (2012). The hypothesis is that prehistoric sites should be spatially distributed among shoreline terraces that were exposed only during the time of occupancy. In other words, archaeological materials that were deposited during a specific lake level in Yellowstone Lake's history should not be found on terraces that reflect younger lake stands. The data used to compare with the models were ascertained by acquiring the elevations of prehistoric sites by extracting the values from a DEM and recording them to each site record, as outlined in the previous section.

These records were then categorized into three regional groups; Northern, Central and Southern zones (see figure 7.2 and table 7.1). From these data, prehistoric sites that exhibited the lowest elevation within each regional zone and cultural period were selected to test against the models. These sites should reflect the lowest occupational point on an exposed landform at the time they were deposited (see table 7.2 and figure 7.3).

However, the models presented by the researchers present differences in chronology of when paleo-shorelines and terraces were formed, suggesting that geologic processes are more complex than previously thought. Part of the challenge of this analysis was to determine which of the models is the most accurate in terms of shoreline age limits while at the same time determining if expectations about the hypothesis could be achieved. For example, Pierce et al. (2007) noted that the paleo-shoreline ages that Locke and Meyer (1994) dated were actually much older by thousands of years. In contrast Hoffman and Hendrix (2012) found sufficient evidence in the central and southern portions of the lake to support the original findings of Locke and Meyer. With this in mind it is uncertain which models reflect the correct chronologic sequences in relation to the archaeological record or if they are mutually exclusive to one another.

In Locke and Meyer's shoreline model they identified 11 paleo-shorelines but five of these were distinct and ran continuously around Yellowstone Lake. These were identified as the S3, S4, S5, S7, and S9 shorelines (see table 7.3). In the northern region of the lake the elevations of these paleo-shore lines above the modern lake datum elevation of 2,356.74 m were as follows; S3, 5.7m; S4, 8.7m; S5, 12.2m; S7, 17m and S9 at 23.7m above datum. In the central portions along the east shore near Clear Creek and Columbine Meadows the paleo-shorelines above datum were; S3, 1.2 m; S4, 3.7m; S5, 5.7m; S7, 13.7m and S9 at 20.7m above the modern lake elevation. In the southern region near Beaver Dam Creek paleo-shoreline elevations were recorded at; S3, 2.2 m; S4, 3.7m; S5, 8.7m; S7, 15.7m and S9 at 23.7m above the modern lake elevation. The ages of these shorelines are interpreted by Locke and Meyer as; S3, 2ka; S4, 3ka; S5, 4.5 ka; S7, 9 ka and S9 at 11.5 ka.

Locke and Meyer (1994) interpret that the rates of declining lake levels are marked by two periods of rapidly decreasing levels and a shorter period of gradual decline in lake levels. The rate of decline between the S11 and S7 (14 ka to 9 ka) was estimated to be about 3m/kyr. The time span between S7 and S6 (9ka to 5.5 ka) noticed a declining rate of only .5m/kyr while the rate picked back up again to 3m/kyr from S6 to S1 (5.5 ka to modern time of current shoreline). These rates are very similar to those achieved from field analyses conducted by Hoffman and Hendrix (2012).

Cultural Period	Northern Zone Site Number	Northern Zone Minimum Elev.	Northern Zone M Above Lake Elev. 2356.74	Central Zone Site Number	Central Zone Minimum Elev.	Central Zone M Above Lake Elev. 2356.74	Southern Zone Site Number	Southern Zone Minimum Elev.	Southern Zone M Above Lake Elev. 2356.74
Paleoindian	48YE1558	2363.7	7.0	N/A	N/A	N/A	N/A	N/A	N/A
Early Archaic	48YE549	2360.1	3.3	N/A	N/A	N/A	N/A	N/A	N/A
Middle Archaic	48YE549	2360.1	3.3	N/A	N/A	N/A	48YE249	2378.0	21.3
Late Archaic	48YE380	2359.1	2.4	48YE678	2358.0	1.3	48YE248	2357.9	1.2
Late Prehistoric	48YE549	2360.1	3.3	48YE678	2358.0	1.3	48YE707	2359.8	3.0

Table 7.2 reflects the elevations of prehistoric sites within each regional zone and cultural period that obtain the lowest elevated positions extracted from the digital elevation model.

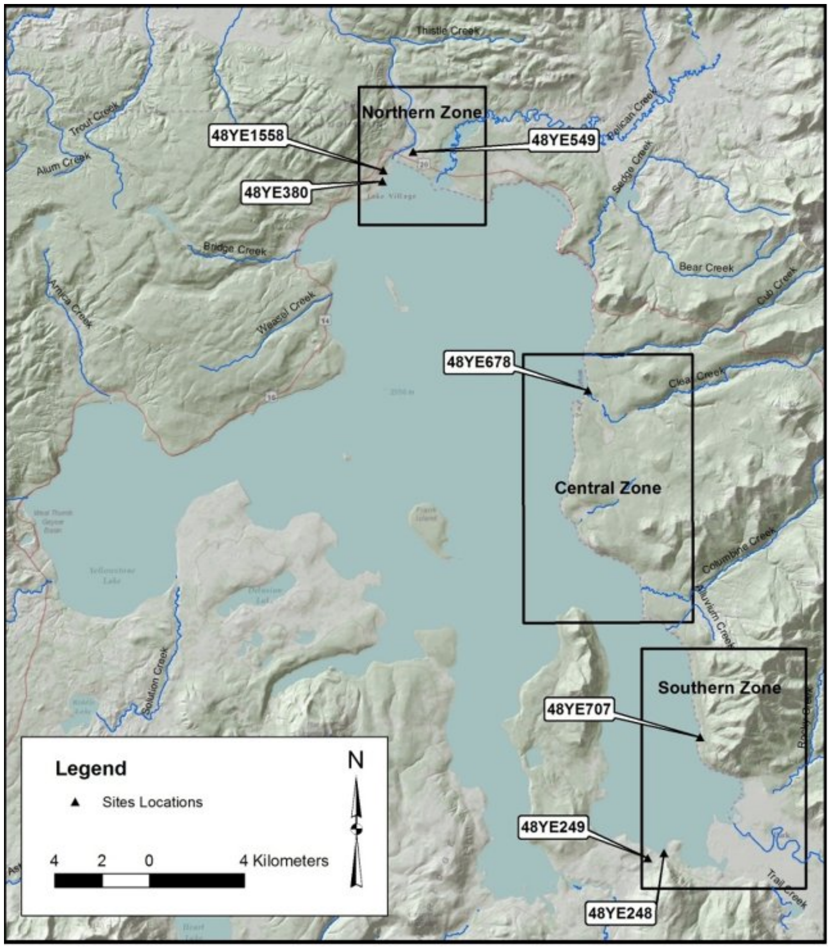


Figure 7.3 Distribution of Prehistoric site locations exhibiting the lowest elevation as noted from table 7.2 above.

Locke and Meyer (1994) Shoreline Model				Northern Zone		Central Zone		Southern Zone	
Cultural Period	**Years B.P.**	**Paleo-Shoreline**	**Shr. Line Ages in Years B.P.**	**Minimum Elevation**	**M Above Lake Elev. 2356.74**	**Minimum Elevation**	**M Above Lake Elev. 2356.74**	**Minimum Elevation**	**M Above Lake Elev. 2356.74**
Late Archaic	3,000-1,500	S3	2000	2362.2	5.7	2357.7	1.2	2358.7	2.2
Late Archaic	3,000-1,500	S4	3000	2365.2	8.7	2360.2	3.7	2360.2	3.7
Middle Archaic	5,000-3,000	S5	4500	2368.7	12.2	2362.2	5.7	2365.2	8.7
Late Paleoindian	10,000-8,000	S7	9000	2373.2	16.7	2370.2	13.7	2372.2	15.7
Early Paleoindian	12,000-10,000	S8	11500	2380.2	23.7	2377.2	20.7	2380.2	23.7

Table7.3 Table reflects the elevations and ages of paleo-shorelines from Locke and Meyer's shoreline model (1994) that stretches from the north shores at Fishing Bridge down along the east shore and ending at the delta of Yellowstone Lake. These heights have been calibrated to reflect Locke and Meyer's (1994) lake datum elevation of, 2,356.48 m above sea level. The approximate elevation today is 2,356.74 m above sea level. A quarter of a meter was subtracted from Locke and Meyer's shoreline heights to account for elevation displacement since their field studies in the 1980s'.

Hoffman and Hendrix (2012) Shoreline Model		Central Zone			
Cultural Period	**Years B.P.**	**Shoreline Ages Calibrated C13 years B.P.**	**Minimum Elevation**	**M Above Lake Elev. 2356.74**	**Specific location**
Early Paleoindian	12,000-10,000	10390 +/-150	2377.74	21	Alluvium Creek
Middle Archaic	8,000-5,000	4,150 +/-80	2363.74	7	Clear Creek
Late Archaic	3,000-1,500	2,795 +/-55	2359.74	3	Columbine Creek

Table 7.4 Radiometric analysis from Hoffman and Hendrix, (2012) of carbon samples extracted from stream cuts, and abandoned channels situated ate in the areas of Alluvium Creek, Clear Creek and Columbine Creek.

Pierce et al. (2007) Shore line Model			Northern Zone		
Cultural Period	**Years B.P.**	**Paleo-Shoreline**	**Shr. Line Ages in Years B.P.**	**Minimum Elevation**	**M Above Lake Elev. 2356.74**
Late Prehistoric	1,500-300	S1	2000	2357.74	1.0
Late Paleoindian	10,000-8,000	S2	8,000	2361.74	5.0
	10,000-8,000	S3	8,600	2362.74	6.0
Early Paleoindian	12,000-10,000	S4	10,700	2364.74	8.0
	12,000-10,000	S5	12,600	2370.74	14.0
	12,000-10,000	S5.5	13,600	2373.74	17.0
	12,000-10,000	S6	14,200	2376.74	20.0

Table 7.5 Paleo-shoreline model proposed by Pierce et al. (2002, 2007) in the northern region of Yellowstone Lake. The model reflects the northern outlet area and spans eastward to the eastern edge of Mary Bay.

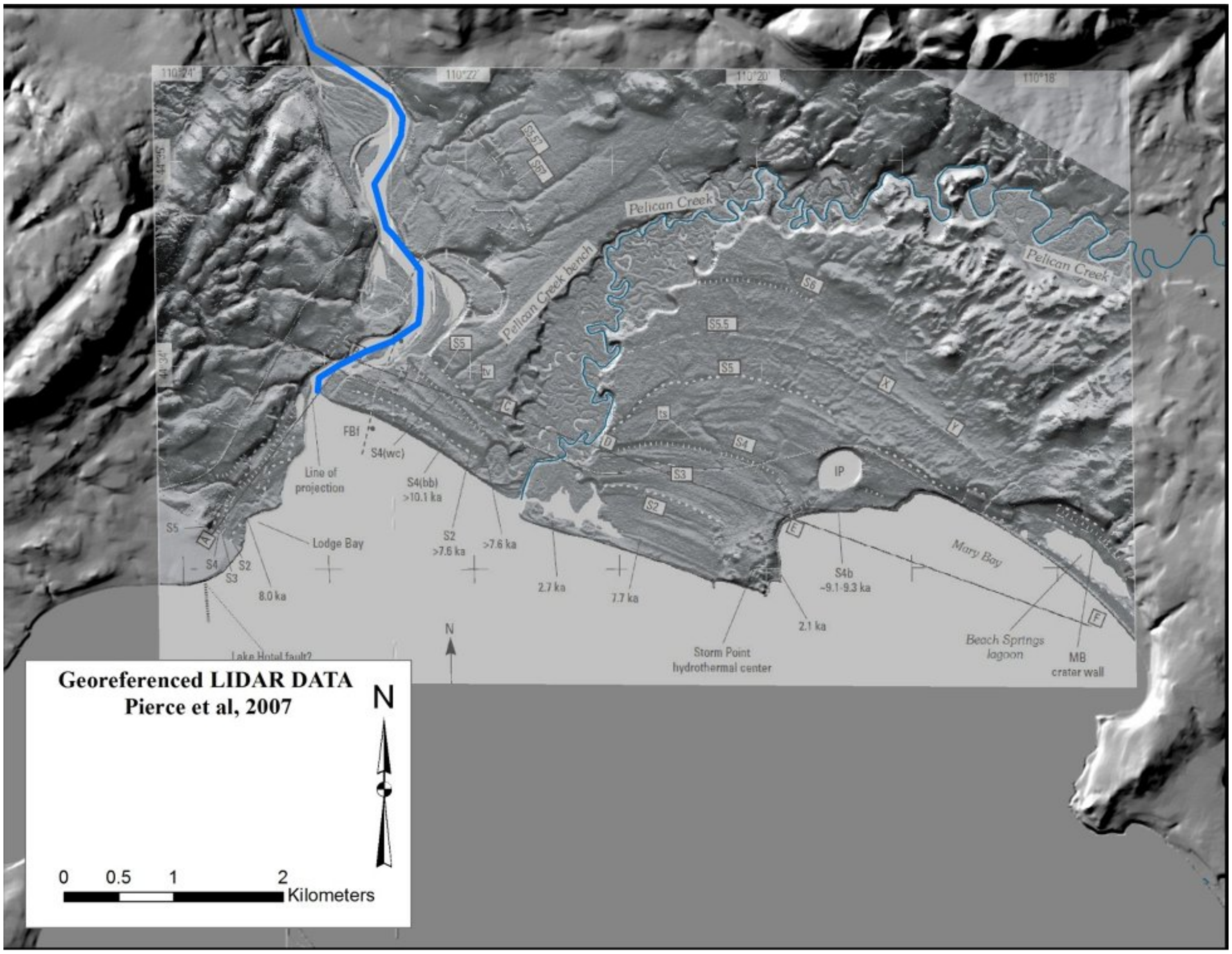


Figure 7.4 Georefernced LIDAR data taken from Pierce et al. (2007); 'Postglacial Inflation-Deflation Cycles, Tilting and Faulting in the Yellowstone Caldera Based on Yellowstone Lake Shorelines'.

During their field season surveys between 2010 and 2011, Drs Hoffman and Hendrix conducted geomorphological field studies on several formational terraces along the eastern and southeastern shores of Yellowstone Lake. They recovered a carbon sample from coarse gravels (23m above datum), that form the proximal part of the Alluvium Creek Gilbert-style delta, that dates to 10390 +/- 150 B.P. (Hoffman and Hendrix, 2012). Another sample was recovered nearby in an abandoned stream channel of Columbine Creek. The sample was recovered somewhere between 3 and 4 meters above datum with an age of 2,795 +/- 55 cal. B.P. A final carbon sample was recovered 2m above the Clear Creek streambed and positioned approximately 7 m above datum. This sample obtained an age of 4,150 +/- 80 cal. B.P (see table 7.4).

Hoffman and Hendrix (2012) infer that there were two distinct periods of differing rates of declining lake levels. The first period indicates a rate of decline between 2.5m/kyr and 3m/kyr during the time span between 10,390 +/- 150 cal. B.P. and 2,795 +/- 55 cal. B.P. The last period which spans from 2,795 +/- 55 cal. B.P. to modern times indicates a substantial decrease in rate to only .5m/kyr. While carbon samples were limited in their analysis to achieve more accurate interpretations, they do bare some semblances to Locke and Meyer's model. Hoffman and Hendrix also note that a Gilbert-style delta near Trail Creek in the Southeast Arm of Yellowstone Lake share very similar morphologies to Alluvium Creek Gilbert-style delta further to the north (see figure 7.5). They infer that these similarities indicate that the lake level histories between the two formations were the same.

In contrast to the findings of Meyer and Locke (1994), and Hoffman and Hendrix (2012), Pierce et al. (2007) has found that the paleo-shorelines in the northern region of the lake to be much older (see table 7.5). Pierce et al. (2007) identified seven prominent shorelines in the northern regions of Yellowstone Lake in the vicinity of Fishing Bridge and Mary Bay. Using both archaeological evidence and the recovery of carbon samples, he dated the ages of shorelines to the following; S2, 7.8 to 8 ka; S3, 8.5 to 8.6 ka; S4, 10.7 ka; S5, 12.6 ka; S5.5 13.6 and S6 14 to 14.4 ka. In the northern outlet area, Pierce recorded the heights of S2, S3, S4 and S6 to be 5m, 6m, 8m, and 20 m above lake datum at Fishing Bridge. In the Mary Bay area he recorded the heights of S5 and S5.5 to be 14 to 17 meters above lake datum.

The findings from Pierce et al. (2007) clearly indicate discrepancies between the other two lake studies and pose very interesting questions concerning the geomorphological history of the paleo-shorelines. Despite this the models can be tested by comparing the elevations of prehistoric sites that were deposited just prior to any observed drops in lake levels.

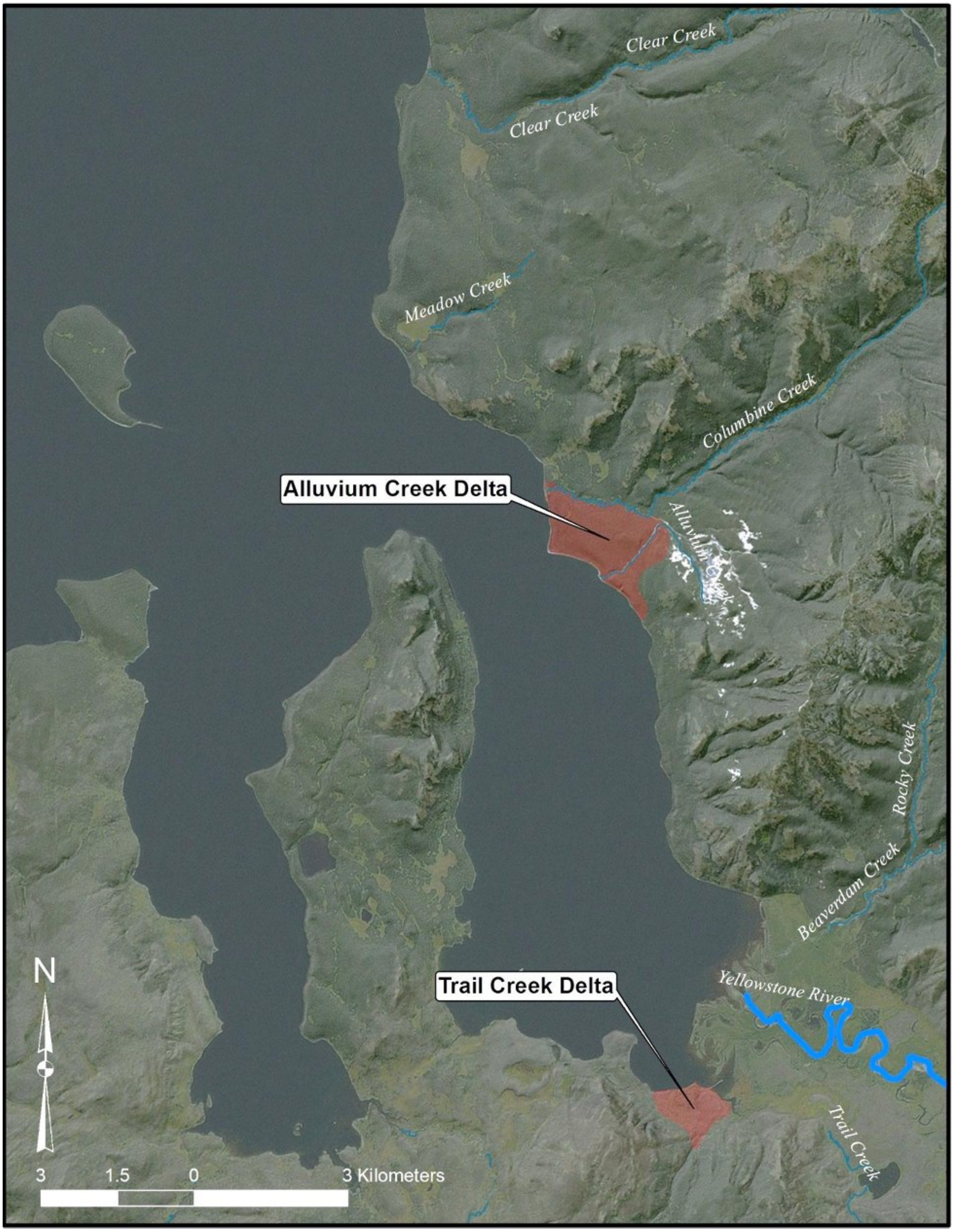


Figure 7.5 Satellite Imagery depicting Alluvium and Trail Creek Deltas.

This relies back on the premise that prehistoric sites from a specific time period should not be associated with younger lake stands. Therefore the prehistoric site data obtained from the North, Central and Southern Zones, should reflect the lowest occupational point on an exposed landform (see table 7.2) and will be used to test against the models presented by Meyer and Locke (1994), Hoffman and Hendrix (2012), and Pierce et al. (2007).

In the northern region of Yellowstone Lake, prehistoric hunter-gatherers have been occupying this area since the Paleoindian Period beginning about 10,000 years ago. In reference to table 7.2, site 48YE1558 reflects the lowest elevated site during this period at an elevation of 2,363 meters above sea level. In fact this site is characteristic of the Cody Complex dating back to the Late Paleoindian Period (10,000 to 8,000 B.P.). In the Early Archaic Period the lowest lying site is 48YE549 with an elevation of 2,360.1 m and continues to be the lowest lying site in the area until after the Middle Archaic Period. It is not until the Late Archaic Period that there is a drop in the elevation of prehistoric sites with 48YE380 that rests at an elevation of 2,359.1 meters. 48YE380 reflects the lowest lying site in the northern study region. The lowest lying site in the Late Prehistoric Period was again 48YE549 at an elevation of 2,360.1 meters.

In the central region, 48YE678 reflects the lowest lying site obtaining good integrity and reflects occupations dating to the Late Archaic and Late Prehistoric periods. In the southern most region of study, 48YE249 reflects the lowest lying Middle Archaic site at an elevation of 2,378 meters above sea level. Prehistoric site 48YE248 reflects the lowest lying site for the Late Archaic Period with an elevation of 2,357.9 meters. Finally, the lowest lying site that is reflective of the Late Prehistoric Period is 48YE707 at an elevation of 2,359.8 meters above sea level. Unfortunately there are an insufficient number of prehistoric sites that obtain ages old enough to test against the models of Locke and Meyer (1994), and Hoffman and Hendrix (2012).

Therefore, comparing archaeological data with the models within these regions is restricted to the last 5,000 years since the beginning of the Middle Archaic Period.

When the elevations of prehistoric sites from the northern, central and eastern zones were compared against the lake-shore models, the preliminary analysis indicated that there were no relationships between prehistoric site data and the shoreline models. In most cases the observed elevations of prehistoric sites fell well below the expected elevations posed by Meyer and Locke (1994), Hoffman and Hendrix (2012), and Pierce et al. (2007). The differences were so great that there was no need to even perform any statistical analyses. It became immediately clear that the discrepancies observed derived from the inaccuracy of the digital elevation model (DEM) used to obtain the elevations of prehistoric sites. Even though the DEM reflected a cell resolution of 10m x10m, the resolution was neither high enough nor accurate enough to portray true elevations of the area. To illustrate this, in figure 7.6 is a georeferenced LIDAR image taken from the report of Pierce et al. (2007) and overlaid the DEM in the exact coordinate positions. The red contour lines reflect the modeled shoreline elevations of Pierce et al. (2007), through the digital elevation model. In contrast, the yellow dashed contours reflect the true positions of Pierce's shorelines based on his georeferenced LIDAR data. The differences between the two are unmistakable and indicate that the DEM serves as a poor medium to test the elevations of prehistoric sites against any of the models.

Since the DEM proved to be an insufficient medium to test if prehistoric sites reflected the ages and elevations of paleo-shorelines modeled after Meyer and Locke (1994), Hoffman and Hendrix (2012), and Pierce et al. (2007), the only course of action available was to compare prehistoric site data with Pierce's LIDAR data. This was carried out because Pierce's LIDAR data obtains such a high resolution that sub-aerial shorelines and terrace features are clearly distinct and visible. In addition the paleo-shorelines are clearly marked in Pierce's data, thus preventing any confusion about the ages concerning the geomorphologic features. Thus it can only be studied in the North where LIDAR data are available.

Comparing the spatial location of prehistoric sites and their associated ages with Pierce's data will determine if the prehistoric record supports Pierce's model. Pierce's model will be validated if prehistoric sites dating to the Paleoindian Period are above the demarcation of his S2 or S3 paleo-shorelines, since lake levels would have prevented settlements beyond this point. Locke and Meyer's model can be tested as well because their S3 shoreline dates to 2 ka and runs along between the outlet of the Yellowstone Lake and Pelican Creek and is very similar to the elevations of Pierce's S2 and S3 shoreline which date to 8 to 8.6 ka. This would indicate that Pierce's S3 is the upper bounds for Locke and Meyer's S2 shoreline. If prehistoric sites are positioned below the S3 and are older than 3 ka it would nullify Locke and Meyer's model in the northern region of lake and further lend support to Pierce's model. This is based on the premise that if Locke and Meyer's S2 is the same as Pierce's S3 and reflects an age of 2 ka, then it would be impossible for occupations dating prior to this period to be positioned below this threshold.

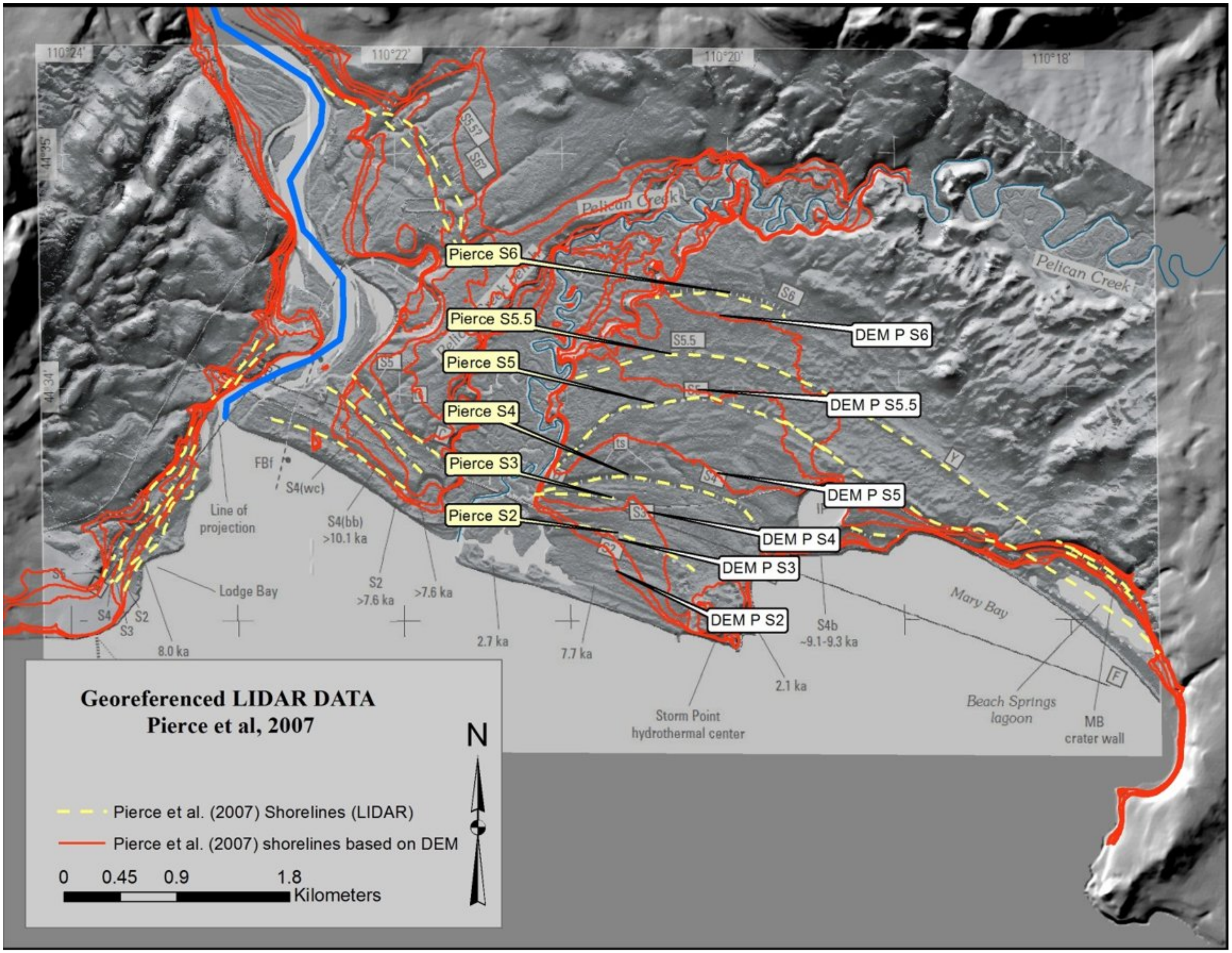


Figure 7.6 This is an image depicting LIDAR imagery from Pierce et al. (2007) superimposed (i.e. georeferenced) over the digital elevation model. Red contour lines reflect the modeled shoreline elevations of Pierce et al. (2007), through the digital elevation model, while yellow dashed contours reflects the true position of Pierce's shorelines.

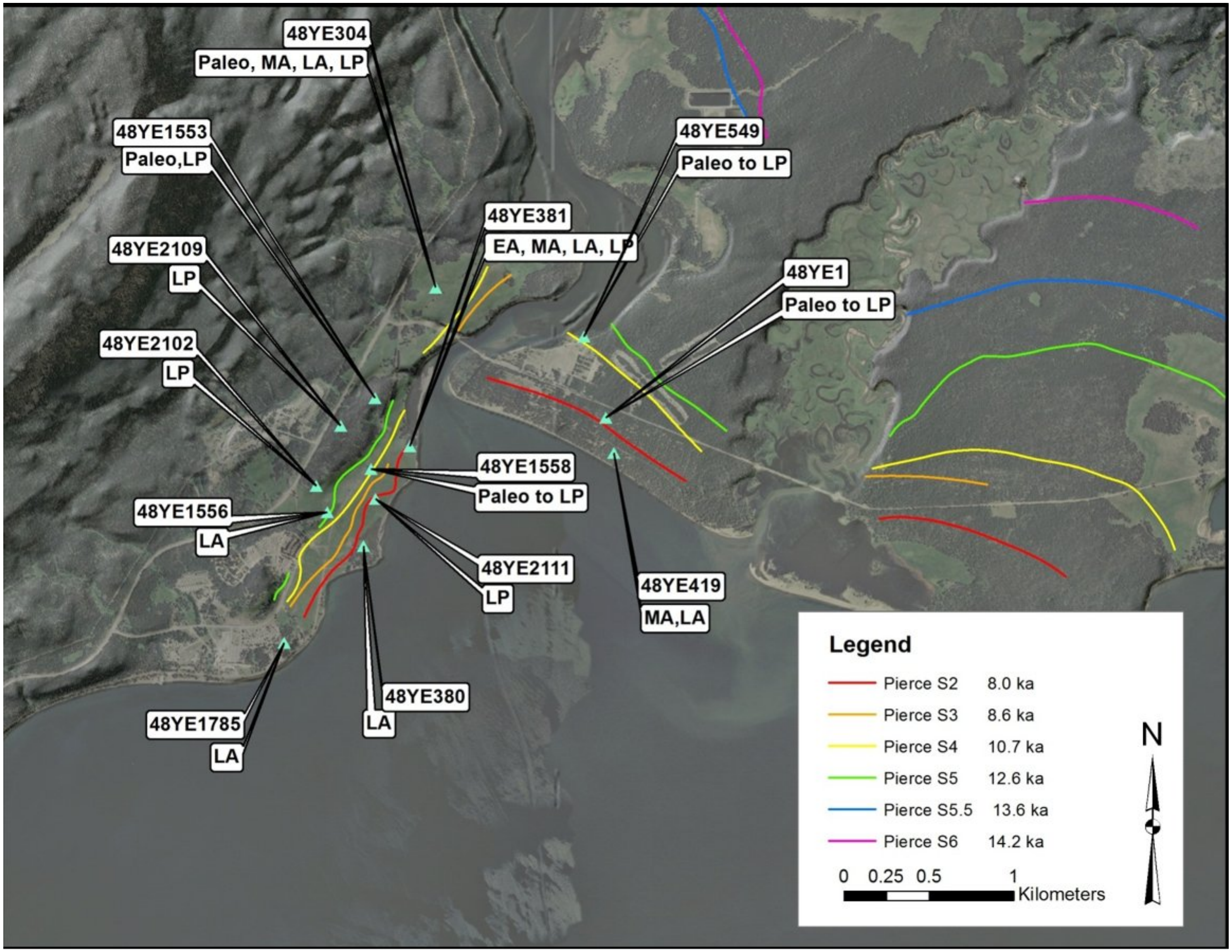


Figure 7.7 Map depicting the shorelines modeled by Pierce et al. (2007) along with the distribution of prehistoric sites.

Results from this analysis have determined that the model proposed by Pierce et al. (2007) is in agreement with the prehistoric site data in the northern region. This was determined by comparing the spatial locations of Paleoindian era settlements (48YE1, 48YE1553, 48YE1558 and 48YE304) with Pierce's S2 shoreline which is dated to be older than 8 ka. All the Paleoindian era sites in this area are associated with the Late Paleoindian Period lasting from 10,000 B.P. to 8,000 B.P. Most of the diagnostic artifacts associated with this period have been diagnostically typed to the Cody Complex which was the predominate culture occupying the outskirts of Yellowstone Lake during this time frame. Not one of these settlements fell below Pierce's S2 shoreline, indicating that lake levels restricted settlements to the water's edge.

In contrast, Locke and Meyer's model was rejected (at least in the northern region). This was observed by the presence of prehistoric sites that dated beyond the bounds of their S2 age (2,000 B.P.), that were spatially distributed below the subaerial shoreline. Since Locke and Meyer's S2 shoreline reflects the upper bounds of Pierce's S3 shoreline, any prehistoric site older than 2 ka should be restricted above this threshold point. It was observed that prehistoric sites dating as far back as the Early Archaic Period (8,000 to 5,000 B.P.) were present below this threshold. In fact 48YE419 a prehistoric site dating to the Middle Archaic Period (5,000 to 3,000) was spatially position well below Locke and Meyer's S2 shoreline (see figure 7.7). This clearly indicates that paleo-shorelines in this region do in fact reflect older ages as Pierce et al. (2007) suggests. It's also interesting to note that 48YE381 is positioned right on the transition of Pierce et al's S2 and S1 terrace. The site obtains a hearth feature dating it to the Early Archaic Period with a calibrated age of 6,860 to 6,640 B.P. and is the first ever site of its period to be dated within the park boundaries (MacDonald and Livers 2011; MacDonald et al. 2012). This site is significant because it indicates that hunter-gatherers were still utilizing this terrace at the time of its abandonment while the newly exposed land surfaces positioned below were much too rocky or unstable to place an encampment.

In summary, it has been observed that utilizing a DEM serves as a poor medium to test whether or not the elevations of prehistoric sites coincide with proposed lake shore models of Locke and Meyer (1994) Pierce et al. (2007) and Hoffman and Hendrix (2012). However, it has been observed that by comparing the spatial distribution of prehistoric sites with georeferenced LIDAR data (Pierce et al. 2007) the prehistoric site data concurs with Pierce's paleo-shoreline model. While the second analysis was restricted to the north region of Yellowstone Lake, the findings do support the hypothesis that prehistoric sites will be spatially distributed among shoreline terraces that were exposed only during the time of occupancy. Without more accurate data reflecting the same level of precision and accuracy as Pierce's LIDAR data, there can be no definitive conclusions drawn concerning the varying elevations of subaerial shorelines and their ages on a lake wide scale. However, since it was observed and demonstrated that the deposition of archaeological sites still follow the law of superposition, it is expected that sites found elsewhere and in good context will be restricted only to terraces that were exposed during the time of deposition.

Final conclusions and interpretations concerning the results from theses analyses will be presented in chapter eight. The conclusions will also offer an interpretive analysis of paleo-shorelines on the central and southern zones of Yellowstone Lake. Due to the lack of older aged archaeological sites along the east shore and the inaccurate digital elevation model, precise results could not be achieved during the analyses conducted on the central and southern shores. Therefore only an interpretive analysis is offered concerning the central and southern regions of Yellowstone Lake. Inferences gained from this interpretation should not be considered as resolute fact but rather as circumstantial evidence that lends support to the main hypothesis. Without an accurate means to achieve accurate results this interpretive analysis is only offered in the summary section to lend support of the hypothesis.

Chapter VIII,

Conclusions to Research Questions

Question 1

Were hunter-gatherers actively selecting settlement positions based upon the availability and access to subsistence resources?

8.1 Conclusion to Research Question One

In Chapter five the primary objective of the research question was to examine if hunter-gatherers selected their settlement positions based upon the availability and access to subsistence resources. It was expected that prehistoric settlements would be positioned within patch types that reflected riparian and grassland vegetative communities. The analyses that were performed indicated that the results were in strong agreement of the hypothesis which postulated that a greater density of sites would occur within in or near proximity to riparian and or grassland patch-types. This is based on the fact that riparian and grassland patches offer an abundance and well diverse suite of subsistence resources compared to forest patches which incur a deficiency in the availability and abundance of subsistence resources. Settling near or within these patches would have greatly increased the rates of encountering both fauna and plant resources , whereby the time and energy spent foraging is dramatically reduced compared to foraging in forest patches.

Results from the vegetative model indicated that 86% of all sites that could be relatively dated fell within patch-types comprised of riparian and grassland patch-types. A Cohen's-Kappa test was performed to test the accuracy of the model to determine the significance of these results. The test received a kappa score of .831, which is considered outstanding and suggests the kappa value is in very strong agreement with the model's outcome. However, the accuracy of the model diminished slightly when site data relating to unknown aged prehistoric sites was incorporated. The Kappa value decreased to.714 but still indicated that the score was considered good and in substantial agreement with the model's outcome.

The discrepancy with these values can only be attributed to differential site use as noted by Binford (1978, 1980). Binford argues that hunter-gatherers that are constantly mobile, (moving from patch to patch exploiting the resources within them and will generally establish residential base camps that act as the main nuclei for activities (Andrefsky, 2005; Binford, 1978, 1980; Bettinger, 1991). From these residential bases, parties will depart to collect resources and then return back to the residential base camp. In the event these parties encounter a resource and begin to extract it, the immediate location becomes classified as a site specific task site. These types of sites are occupied over very short periods of time and do not allow for substantial amounts of discarded artifacts to accumulate (Binford, 1978, 1980; Andrefsky, 2005; Chatters 1987; Surovell, 2009).

This suggests that the high tendency for dated prehistoric sites to occur within riparian grassland patch-types indicates they functioned as residential base camps while sites of unknown ages reflect site specific tasks. This is substantiated in the archaeological record because sites that can be assigned to a specific cultural period are identified only through absolute and relative dating of features and diagnostic artifacts. Typically, for these types of characteristics to manifest, a site must either be frequented more often or occupied over longer durations of time. Prehistoric occupations that comprise multiple hearth features or large accumulations of discarded artifacts are characteristic of residential base camps. Conversely, many of the unknown prehistoric sites encompassing Yellowstone Lake are comprised of light lithic scatters suggesting very short-term occupations and are indicative of task specific sites.

Results concerning the analysis of site densities have also shown that hunter-gatherers were targeted riparian and grassland patch-types over forest patches. The density rates between riparian and grassland patch-types and forest patches indicate that dated prehistoric sites were 2.31 times more frequent within riparian and grassland patches than forest patches. However, this rate decreases to 1.39 when unknown aged sites were incorporated into the analysis. This suggests that unknown sites are more dispersed compared to dated sites and thus affecting the overall density. It also supports that differential site use is occurring as previously mentioned.

Additionally, a two sample students T-test was conducted on the densities and revealed that there was a less than one percent chance that site settlement patterns were randomly selected. Based upon the results from the analyses, the hypothesis should be accepted. It is clear that riparian and grassland habitats were favored more amongst hunter-gatherers than forest patches. This is also supported by the results reflecting the accuracy and significance of the vegetative model. Establishing settlements within or near proximity to riparian and grassland vegetative zones would have allowed hunter-gatherers to have access to patches that were abundant in both fauna and edible plant resources. Bison would have been available within grassland vegetative zones while deer and elk would have been encountered either along the peripheral edges of grassland patches or within riparian type vegetative communities. Edible plants would have been encountered in grassland and riparian vegetative communities but more so in riparian zones where the soils are more moist and well drained.

Conversely, forest communities are very poor in subsistence resources. This is due to the lack of biomass production which is required to support more diverse ecosystems. Without adequate biomass production to support life of more organisms, humans would have found it equally difficult to survive in such disparate conditions. While small forest clearings were likely to have occurred, they may have been passed up in favor of more productive patches. In any case, forests entirely comprised of coniferous evergreens are essentially inhospitable to humans due to their lack of biodiversity and inadequate resource base.

Overall, the added benefits of positioning settlements near riparian and grassland vegetative zones are beneficial for four reasons. First, the search costs (i.e. energy expenditure) needed to search for subsistence resources are reduced. Secondly, the search time to find resources is also reduced since high encounter rates are more likely to occur in riparian and grassland patches than forests. Lastly, individuals have more time to engage in social activities as well have increased opportunities to enhance their reproductive fitness.

In summary, the benefits of positioning settlements within or near proximity to riparian grassland patches are highly rewarding for mobile foragers. These areas were apparently a strong motivating selective factor in influencing the decisions of hunter-gatherers of where to settle in efforts to obtain subsistence resources. The prehistoric site data has clearly shown this to be the case and supports the main hypothesis. Forested regions were largely avoided due to the lack of subsistence resources and high energy costs in acquiring them. Therefore forests communities had very little selective factor in influencing the decisions of hunter-gatherers in their subsistence and settlement strategies. In closing, it is recommended that the hypothesis be fully accepted.

Question 2

If hunter-gatherers were selected site placement based upon the availability and access to subsistence resources than how did fluctuations in climate regimes affect these settlement patterns?

8.2 Conclusion to Research Question Two

In Chapter six the primary objective of the research question was to examine if changes in climate affected subsistence and settlement strategies. The results from the many analyses performed throughout this study have clearly demonstrated that climate does play a role in the settlement strategies of hunter-gatherers. This is based on the premise that climate conditions affect the distribution and productivity of riparian/grassland vegetative communities that support a myriad of prey species and edible plant resources used for subsistence needs. Any significant disruptions to the distribution or productivity to these communities ultimately affect the decisions of where hunter-gatherers must position themselves to intercept these resources. Increases in riparian/grassland production to any particular patch would present highly favorable conditions for hunter-gatherers to exploit its resources. In contrast, patches exhibiting decreases in biomass productions would present unfavorable foraging conditions for hunter-gatherers and the patch would simply be passed up for a more productive one.

Evidence for these types of behaviors have been observed at the southern and eastern regions of the Yellowstone Lake as prehistoric site data were compared against the pollen records of Buckbean Fen and Cub Creek Pond. Here analyses were performed (utilizing IBM's SPSS linear regression tool function) to determine if changes observed in the riparian/grassland pollen counts corresponded to changes in the number of prehistoric sites over time. Both analyses indicated that there existed a positive relationship between the abundances observed in riparian/grassland pollen counts relative to the frequency of prehistoric sites occurring over time. As riparian/grassland vegetative communities expanded so did the number of prehistoric settlements and vise versus.

However, the Buckbean Fen analysis demonstrated that this relationship occurred across broad regions of up to 8 km from where the core was extracted from in the southern end of the lake. This suggests that climate conditions were not restricted to a confined region but were more macro-scale in size. This would suggest the existence of a large homogenous patch that was controlled by the same environmental inputs observed in the vicinity of Buckbean Fen. Furthermore it would have enabled hunter-gatherers more flexibility in positioning their settlements near these resources without having to cluster into tight groupings.

In contrast, the Cub Creek Pond analysis demonstrated the opposite effect and indicated that climate conditions were more localized. This was observed by substantial increases in ANOVA f-scores, as sites further than 4 km from the extraction point were applied to the regression analysis. Upon further inspection of satellite imagery it became apparent the area encompassing Cub Creek Pond is predominately forested with few clearings comprised of mesic-wetlands. Since the pollen record indicates that the region became fully forested shortly after the beginning of the Holocene, these wetlands indelibly became the only riparian/grassland patches available in the area. These isolated patches would have restricted the mobility of hunter-gathers and increased their dependency on the production and availability of subsistence resources therein. Understanding this, it makes sense for prehistoric sites in the immediate region to reflect the conditions of the isolated patches.

The outcomes of these analyses are highly significant because they both clearly support the hypothesis that climate affects the productivity and distribution of subsistence resources which in turn affect the subsistence and settlement strategies of hunter-gatherers. However, these results are reflective of localized conditions and do not account for the entire Yellowstone Lake Basin. Therefore, further analyses were performed to understand what effects climate may have had on subsistence and settlement strategies on a lake wide scale. This was accomplished by performing regression analyses between both pollen records and incorporating all prehistoric site data encompassing Yellowstone Lake.

The results from the analyses indicated that the Buckbean Fen pollen record demonstrated the strongest relationship between the fluctuations occurring in pollen counts and the frequency of site counts over time. The results reflected a correlation coefficient of .88 and an ANOVA f-score of .049 indicating its significance. In contrast, the Cub Creek Pond received a much lower correlation of coefficient at .599 and an ANOVA f-score of .286. These results indicated that there was a poor relationship between the fluctuations occurring in Cub Creek Pond's pollen counts and the frequency of site counts over time. However, this supports the notion that the Cub Creek Pond pollen record only reflects localized climate conditions.

Between the two comparative analyses the Buckbean Fen pollen record clearly suggests that it serves as a best-fit model for climatic conditions spanning the last 12,000 years. This was validated by the ANOVA f-score of .049 and its correlation of determination of .774. However, it is interesting to note is that if the Buckbean Fen regression analysis did not consider any of the sites from the West Thumb region of the lake, the correlation coefficient would be as high as .953 with an ANOVA f-score of .012. It was determined in previous analyses in chapter VI that when regression analyses were conducted on separate regional zones around the lake, the entire West Thumb was incomparable to either of the pollen datasets. It is unclear why this occurs but it is suspected that this may reflect differences in land use patterns or perhaps substantial differences in climate existed in this region. Another suspicion is that this area could reflect intensive fishing practices, but this is highly speculative and there is yet any substantial data to support this. Whatever the case may be, the Buckbean Fen pollen record compliments the prehistoric record quite well and perhaps more so if the West Thumb of Yellowstone Lake was taken out of the equation.

While the Buckbean Fen analysis served to promote the contention that it served as a best-fit model of the entire lake region, two other analyses were performed to help validate this claim. This comprised of the first and second major analyses in Chapter VI. The first analysis set out to test the significance in climate changes between cultural periods by conducting Chi-square tests between riparian/grassland and forest pollen counts and their transition into the succeeding cultural period. The second analysis then tested the significance of site densities between cultural periods by conducting Chi-square tests between the site densities that either fell within riparian/grassland or forest patches and there transition into the next period. The results from both analyses were then compared against each other to determine if the significant changes observed in pollen counts corresponded to the significant changes observed in site densities.

The comparative analysis indicated that the significant changes occurring overtime between riparian/grassland pollen types of the Cub Creek Pond pollen record did not correspond with the significant changes occurring between site densities. The disagreement between these analytical results further suggests that Cub Creek Pond reflected localized climatic conditions as opposed to broader regional scales. However, the Buckbean Fen comparative analysis was a complete match. It indicated that in periods of no significant changes in vegetation, there were also no significant changes observed in site densities. Likewise, periods experiencing significant changes in climate were also met with significant changes in site densities.

This clearly indicates that the analyses do support the hypothesis. First, the regression analyses used to determine the ANOVA f-score and correlative values, suggests that climate was a major contributing factor in the distribution and productivity of subsistence resources, which then affected the settlement patterns of hunter-gatherers. The Chi-square test substantiates this by indicating that significant changes in the distributions of site densities also coincided with significant changes observed in vegetation types (i.e. riparian/grassland and forest pollen types). In other words, major changes in the distribution (i.e. densities) of prehistoric sites only occurred during major shifts in the climate.

In conclusion it has been proposed that climate did in fact influence the distribution and production of subsistence resources that in turn played a major contributing role in the subsistence and settlement strategies of hunter-gatherers. The hypothesis clearly states that, 'The distribution and frequency at which sites occur over time will be dependent upon the conditions of the climate which influences the distribution and productivity of subsistence resources.' It was demonstrated that significant changes in climate had occurred, as it was demonstrated through the significant shifts in vegetation types between riparian/grassland and coniferous pollen types. These significant changes in vegetative communities then had substantial implications on settlement patterns. This was observed through significant changes occurring in prehistoric site densities, which indicates that the distributions of prehistoric sites were either expanding or contracting in size (i.e. territorial range) depending upon the availability and production levels of subsistence resources. Finally, it was demonstrated through regression analyses, that fluctuations in climate were directly associated to the varying changes in site count frequencies over time. In closing, these assessments clearly support the main hypothesis and it is therefore accepted.

Question 3

Do the spatial locations of sites along the z-axis (elevation) reflect the fluctuations of lake levels over time caused by the inflation and deflation cycles of the Sour Creek and Mallard Lake resurgent domes?

8.3 Conclusion to Research Question Three

In Chapter 7 the primary objective of the research question was to determine if prehistoric sites corresponded to fluctuating lake levels driven by inflation/deflation cycles of caldera breathing. It was postulated that prehistoric sites should be spatially distributed among shoreline terraces that were exposed above lake levels during the time of occupancy. This would suggest that archaeological material that was deposited during a period in time when lake levels were high should not be found among shoreline features that reflect younger lake stands. The exception to this rule would be archaeological deposits that were removed from their original stratigraphic contexts either through erosional or anthropogenic processes. To test the hypothesis, prehistoric site data was tested against three models proposed by Locke and Meyer, (1994), Pierce et al. (2007) and Hoffman and Hendrix (2012).

In the northern region of the Yellowstone Lake it has been demonstrated that Pierce's model compliments the prehistoric site record. This was observed with prehistoric occupations dating to the Late Paleoindian Period being restricted only to Pierce's S2 shoreline which reflects lake levels approximately 8,000 years ago. The significance of this suggests that the general hypothesis is true since prehistoric sites obtaining ages older than 8 ka and exhibit intact contexts do not fall below the S2 shoreline. When the prehistoric data was compared against Locke and Meyer's model in the northern region, prehistoric sites were found to be positioned out of bounds of the ages ascribed to subaerial shorelines. This discrepancy was observed with the presence of prehistoric occupations dating as far back to the Early Archaic Period (8,000 B.P.-5,000 B.P.) positioned below Locke and Meyer's S2 shoreline which reflects the approximate height of Pierce's S3 but with an assigned age of 2 ka.

However, if we were to compare the models of Locke and Meyer (1994) and Hoffman and Hendrix (2012) against the limited archaeological data in the central and southeastern portions of lake, it can be inferred that the models are in partial agreement with the archaeological record and cannot be rejected. This inference is primarily supported by archaeological evidence in the vicinity of Clear Creek. Prehistoric site, 48YE678 is positioned on a low-lying terrace about 2 -2.5 m above datum and is actively being cut by high lake levels. Carbon samples collected from hearth features at this site obtained dates just near 1,500 B.P.; right at the transition between the Late Archaic Period and Late Prehistoric Period. Comparing the elevation and age of this site with the age and elevation of the Columbine Creek carbon sample, 10-CO-100 (2, 797 +/- 55 cal. B.P./// 3m above datum) (Hoffman and Hendrix 2012), the rate of declining lake levels is very similar to the rate of change posed in the last three thousand years of Hoffman and Hendrix's model. In Hoffman and Hendrix's model the rate of decline is .35kyr relative to 2011 field season lake levels (2m above datum), while the rate of lake level decline at 48Y678 is .33m/kyr relative 2011 field season lake levels. This suggests that the elevation of 48YE678 is in congruence with their model and supports their findings.

Additionally, prehistoric sites distributed further up the Clear Creek stream valley atop a high terrace bench may indicate the presence of Middle Archaic occupations (pending MYAP 2011 field analyses). This may indicate that lake levels were much higher prior to 3,000 B.P. This is supported from radio-isotopic analysis of carbon extracted (carbon sample 10-CC-10) from a test pit just 2 m above the modern level of the Clear Creek streambed (7m above lake datum), dated to 4,150 +/- 80 cal. B.P. (Hoffman and Hendrix, 2012). Interestingly, Locke and Meyer have identified terraces in this region to be of the same approximate age and elevation (see Locke and Meyer, 1994, Figure 4) indicating that lake levels were high during this period over 4,000 years ago. The relationships between Locke and Meyer's findings and those of Hoffman and Hendrix (2012) would indicate that the carbon collected from these deposits was likely deposited in a lacustrine environment. Therefore, it would indicate that lake levels were high enough to restrict occupational settlements on the higher elevated terrace benches situated upstream from the confluence of Clear Creek and Yellowstone Lake.

While there are no occupational settlements that reflect older time periods, there is no way to test both models against archaeological data beyond 4,000 years ago. However, Hoffman and Hendrix (2012) noted that between the Alluvium Creek delta and the Trail Creek delta, both are very similar to each other in their morphologies. Both indicate the same elevations in slope break and the transition from delta top to the delta front (Hoffman and Hendrix, 2012). Hoffman and Hendrix (2012) interpret that these similar morphologies suggest that both areas experienced very similar lake histories. It also suggests that paleo-shorelines become more stabilized between Clear Creek and Trail Creek compared to the substantial deformations observed in the northern regions at Fishing Bridge or Mary Bay. Understanding that northern shores are influenced more by caldera breathing and experience more deformation processes than anywhere else around the lake, it would be acceptable for Locke and Meyer's and Hoffman and Hendrix's models to be more applicable where deformation processes are not so strenuous on land surfaces.

The formational processes of Yellowstone Lake's subaerial shorelines are highly complex with lots of questions yet to be answered. With inflation and deflation cycles affecting the northern regions or elsewhere where hydrothermal or volcanic activity is prominent, the deformation of shorelines is highly variable. As a result, models must be developed for specific areas to account for these processes. However, the archaeological record is in support of the hypothesis that prehistoric sites will be spatially distributed among shoreline terraces that were exposed prior and during the time of occupancy. In the northern portion of Yellowstone Lake near the outlet, paleo-shorelines reflect older ages than previously thought. In contrast, as shorelines progress further away from areas immediately impacted by caldera breathing, the shorelines reflect ages similar to Locke and Meyer (1994) and Hoffman and Hendrix, (2012).

In future archaeological investigations it should be considered that intact archaeological sites older than 8 ka will only be found above Pierce's S2 in the northern region of the lake. Younger occupations may be found below or above the S2 but generally most are positioned above the S2. It's unclear why the majority of these younger occupations occur above the S2 but the terrace may reflect more stabilized living surfaces in comparison to the much younger terraces. Erosion may be another major cause why so few sites are identified below the S2. This results from increased wave activity during storm surges where waves actively cut away at the soft sediments of terraces causing prehistoric sites to erode into the lake.

Archaeological investigations conducted in the southern portions of the lake should consider the models of Locke and Meyer (1994) and Hoffman and Hendrix (2012). Despite the limited archaeological evidence to lend stronger support for the models, the data available does support them. However, without the presence of older archaeological sites dating beyond the Late Archaic Period (3,000-1,500 B.P.), testing these models on the basis of archaeological data alone will be difficult. Despite this, the geomorphological analyses conducted by Hoffman and Hendrix (2012) do support similar interpretations made by Locke and Meyer (1994) in the eastern central and southeastern portions of Yellowstone Lake. These similarities are significant and suggest that both could serve as useful models in these areas.

It is unknown how the models presented in this study will compare against other regions of the lake. Without the use of a precise and accurate digital elevation model, the exact elevations of prehistoric sites (relative to the lake datum at Fishing Bridge) cannot be ascertained. Precision is an absolute must, especially when dealing with one meter differences in elevations amongst paleo-shorelines. These differences in height can be very significant and may reflect differences in age that may vary from just a few centuries to a thousand years or more. In future studies concerning the genesis of paleo-shorelines it is recommended that either LIDAR or high precision GPS units be used in mapping both the elevation of prehistoric sites and the profiles of sub-aerial shorelines in addition to traditional geomorphologic analyses. In closing, the models thus far are considered applicable to the northern, eastern and southeastern portions of Yellowstone Lake and give us new insight on the complexities of the geological processes that are still undergoing today.

8.4 Final Summary

Since the close of the Late Pleistocene, the Yellowstone Lake Basin has been an important region for hunter-gatherers that has provided abundance and diverse subsistence resources. Bison, the largest land mammals in North America forage freely for the alpine grasses in the Hayden Valley just north of Yellowstone Lake. Deer, elk and waterfowl are abundant in the Pelican Creek Valley, juxtaposed to the northeast shores of the lake while they are also found in riparian and mesic-meadows found elsewhere around the lake boundaries. In large meadow clearings, vast fields of flowering plants important for their carbohydrates grow in vast droves. Together, the diversity of plant and animal life found throughout the lake basin would have been a primary selective factor in influencing the decisions of mobile foragers to occupy and exploit the subsistence resources in this region.

It has been demonstrated in this thesis that the subsistence and settlement strategies of hunter-gatherers were based on the abundance and availability of subsistence resources. These strategies comprised of positioning settlements either within or at least very close proximity to riparian and grassland patches. These patches offer key advantages over forested patches. First, increased encounter rates of subsistence resources would have reduced the search times in acquiring resources. Secondly, increased encounter rates would also require less energy expenditures in obtaining resources. Lastly, the saved time and energy allowed individuals to participate in group activities or perhaps devote more time towards enhancing their own reproductive fitness.

On a macro-evolutionary scale it was demonstrated that climate change played a major role on the subsistence and settlement strategies of hunter-gatherers. Disturbances in the climate were observed by the increasing or decreasing rates of pollen counts between riparian/grassland and forest pollen types. Fluctuations observed with riparian and grassland pollen counts had a direct relationship with the frequencies observed in prehistoric site counts. This demonstrates that disturbances in biomass production affected the availability and abundance of subsistence resources that in turn affected the subsistence and settlement strategies of hunter-gatherers. When subsistence resources declined due to diminishing biomass productions, hunter-gatherers responded by seeking more productive patches. In contrast, when subsistence resources became more productive, hunter-gatherers intensified their efforts in exploiting these resources by either frequenting the area more often or occupying sites over longer durations of time.

This thesis also suggests associations between archaeological deposits and paleo-shorelines of Yellowstone Lake. In the northern portion of Yellowstone Lake the spatial distribution of archaeological sites correlated with the shoreline model proposed by Pierce et al. (2007). Pierce's model was based on high precision mapping using LIDAR and dating shoreline features from collected carbon samples. It was observed in this thesis that archaeological site data did in fact concur with the findings of Pierce et al.'s (2007) LIDAR study and supports his model for shoreline deformation in the northern region of Yellowstone Lake. Unfortunately, with no available data to accurately ascertain the precise elevations of prehistoric sites, further analyses could not be conducted to accurately determine the elevations of past lake levels. This discrepancy resides in the digital elevation model which does not achieve the accuracy needed to obtain precise elevation data for the prehistoric site data or for the elevations of paleo-shorelines.

However, in a stratigraphic context, prehistoric sites in the central and southern shores along the east flank of Yellowstone Lake do concur with the shoreline models presented by Locke and Meyer (1994) and Hoffman and Hendrix (2012). This was observed in the Clear Creek region, where potentially older Middle Archaic sites are positioned atop higher terraces which Hoffman and Hendrix (2012) interpret from carbon dating were the only exposed landforms prior to 4,000 years ago. In addition, prehistoric sites obtaining intact stratigraphic contexts and dating to or beyond the Middle Archaic Period have yet to be identified in the lower terraces closer to the lake's edge.

It was also determined that hearth features identified from 48YE678 situated on lower terraces near the confluence of Clear Creek and Yellowstone Lake reflected the estimated lake levels presented in Hoffman and Hendrix's model. At Columbine Creek they had dated a low-lying terrace to be approximately 2.8 ka and 3 m above datum and estimated a declining lake level rate of .35m/kyr which corresponded with the rates observed from 48YE678 at .33m/kyr. This indicates that lake levels were at the approximate predicted height according to Hoffman and Hendrix's model. It also indicates that lake levels were only slightly higher than today's modern lake levels which can fluctuate up to a meter or more due to seasonal variations in lake levels.

The evidence observed from the Clear Creek Valley demonstrates that in a stratigraphic context the supposition of archaeological sites coincides with the dated shoreline models of Hoffman and Hendrix (2012). Furthermore, since the findings of Locke and Meyer (1994) are very similar to Hoffman and Hendrix's investigations in the central and southern regions of Yellowstone Lake, it would be safe to argue that Locke and Meyer's shoreline model also validates the stratigraphic contexts of archaeological sites in the central and southern regions.

Despite the deformational in-congruencies between paleo-shorelines in the northern and central/southern regions of Yellowstone Lake, the superposition of archaeological sites do indicate that they are only associated with surface features that were exposed above lake levels during the time of occupancy.

However, these outcomes indicate that Pierce et al.'s (2007) model of the northern shorelines is mutually exclusive to those of Locke and Meyer (1994) and Hoffman and Hendrix's (2011) shorelines positioned in the eastern and south eastern regions of the lake.

This indicates that major tilting of shorelines is occurring in the northern region where deformational processes are more pronounced due to the effects associated with Caldera breathing. In contrast shorelines that are further away from the Sour Creek resurgent dome are hardly affected if at all by caldera breathing and appear more uniform across broader regions.

In conclusion, the results from all the analyses presented throughout this thesis are in agreement with the hypotheses proposed. It was determined that hunter-gatherers were positioning their settlements within riparian/grassland patches that offered greater abundances of subsistence resources than forest patches. It was then determined that shifts in climate affected the productions of resource patches which in turn influenced the decisions of hunter-gatherers to either reoccupy or proceed to a more productive patch. Lastly, it was determined that the superposition of archaeological sites exhibiting intact contexts can be used as indicators of past lake level heights despite the availability of more precise data.

In closing, it will be very interesting in future research to apply similar behavioral ecological models elsewhere in Yellowstone National Park to understand where hunter-gatherers were positioning their settlements in relation to subsistence resources and how these practices changed over time. Finally, future geomorpholocal studies are needed to understand the full scope of the deformational processes occurring with paleo-shorelines around Yellowstone Lake. However, due to the large extent of area the lake covers, the research needed will be expensive. It is recommended that in future studies precision GPS and mapping techniques be utilized to achieve greater accuracies in determining the elevations of archaeological sites and paleo-shoreline features. With this data, inference could then be made to associate the ages of archaeological sites in relation their superposition of paleo-shorelines.

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