Assessing the Ability of the LAMAP Predictive Model to Locate Hunter-Gatherer Sites: An Alaskan Case Study

by

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Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Arts

in the
Department of Archaeology
Faculty of Environment

SIMON FRASER UNIVERSITY
Spring 2021

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Abstract

Evidence from archaeological sites and ancient and modern DNA suggests that people first entered northern North America via Beringia no later than 15,000 years ago, and potentially as early as 24,000 years ago. When people moved south to colonize the rest of the American continents is still debated. The presence of ice sheets means that two routes were the most likely: down the unglaciated coast of the Pacific Northwest, and/or via an interior route characterized as the ice-free corridor. Large areas of Late Pleistocene land on the coast were submerged when sea levels rose at the beginning of the Holocene, around 10,000 years ago, making it difficult to locate potentially early sites. There is now a need to develop and test methods that identify high potential locations for finding sites on those now-submerged landscapes.

The LAMAP method (Carleton et al. 2012) has been successful in predicting areas of high archaeological potential associated with permanently occupied settlements of agrarian societies. This study is the first application of LAMAP to mobile hunter-gatherer sites. A study area was defined in the Tanana Valley, Alaska, and the location and age of known archaeological sites was sourced from files in the Alaska Heritage Resources Survey database. The location of each site was plotted on a raster map produced in QGIS using six Digital Elevation Models accessed from the USGS's National Elevation Dataset. This provided information relating to six physical variables for each site: Elevation, Slope, Aspect, Distance to Drainage, Viewshed and Convexity. The study area was divided into more than 700 million cells. LAMAP calculates the similarity of each cell to the cells found in a 1-km sample area around each known site. Mapping the distribution of similarity indices created a map of archaeological potential. We ran LAMAP on 91 randomly selected site locations to create a map of archaeological potential, and tested it by examining the location of the second set of 91 sites from the study area. Areas of high archaeological potential contained more of the second set of sites, confirming LAMAP's ability to predict high potential areas for mobile hunter-gatherer sites. A second analysis, using pre and post 10,000 cal BP sites, showed the same results, demonstrating that long-standing physical features of the landscape are robust predictors of high potential areas, regardless of the time period.

LAMAP is one of a number of methods for modelling high potential areas, each of which has advantages and disadvantages, for the preliminary exploration of now-submerged terrestrial landscapes.

Keywords: Predictive Modelling, Remote Sensing, Paleoenvironmental Reconstruction, Beringia, Peopling of the Americas, Marine Archaeology

“If you want to go quickly go alone but if you want to go far go together”!

African Proverb

Acknowledgements

I would like to thank the members of my supervising committee, Dr. Jon Driver, Dr. Mark Collard and Dr. Chris Carleton. I would also like to thank former committee member Dr. George Nicholas for his input on earlier versions of this thesis. Special thanks goes to Dr. Carleton for all his help, input and guidance. He has developed a new predictive model unlike any other, which I feel, shows great promise. This is a major accomplishment in its own right and I am grateful for the opportunity to use LAMAP, for the first time, in a hunter-gatherer context.

I would also like to thank Dr. Francesco Berna for being my External Examiner, Dr. Rolf Mathewes for being my Second External Examiner, Dr. Dana Lepofsky for being the Chair of my defence, the Department of Archaeology, Simon Fraser University (SFU) and the Social Sciences and Humanities Research Council (SSHRC). When I started graduate school in 2017, I was awarded the Graduate Entrance Scholarship from SFU. Subsequently, I was awarded a SSHRC Masters Scholarship (2018), and now, a SSHRC PhD Scholarship (2021). In 2019, I also received the Michael Smith Foreign Study Supplement through SSHRC, which allowed me to travel to Alaska to do my research. These scholarships have allowed me to pursue my research, and, for this I am extremely grateful.

In Alaska, I was graciously helped by Dr. Dianne Hanson, Dr. Charles Holmes and, recent PhD graduate from the University of Alaska (Fairbanks), Dr. Gerad Smith. I am so grateful for all of your support and ongoing friendship. Thank you.

I am fortunate to have a great group of colleagues and friends. My thanks goes to Laura Termes, Earl Stefanyshen, Goran Sanev, Galan Akin, Tom Beasley, Jost Schokkenbroek, Jurian ter Horst, Jackie Fekete-La Mouri, Sarah Maya Vercruysse and others. Special thanks goes to Laura Krutz, who both inspired and supported me along the way. I couldn’t have done this without you!

I would also like to thank Merrill Farmer, Archaeology Department Manager, for believing in me and helping organize a new 200-level class about Underwater Archaeology, that I hope to teach in 2021. And, I would like to thank Kristina Pohl, Graduate Program Assistant, for helping with the paperwork. You are a lifesaver!

I’d also like to thank Catherine Louie from SFU’s WAC Bennet Library. Librarians are the unsung heroes of the university. Thank you so much for all your help in preparing this thesis for publication.

Most importantly, I would like to thank my mentor, Dr. Barbara Winter. You welcomed me into the Museum, literally, making a space for me. But more than that, you have talked me through some difficult times, and, you continually reminded me, “you can do this”! Thank you Barb. I am so, so grateful for both your mentorship and friendship.

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Chapter 1.

Introduction

When and how people first arrived in the Americas remains one of archaeology's greatest unsolved mysteries. Currently, the majority of archaeologists agree that people first made their way into modern-day Alaska from Siberia sometime before 15,000 years ago (Hoffecker et al. 1993, 2016). Central Alaska is "the longest continually inhabited area in the Western Hemisphere" (Potter 2008:1). People have lived there longer than anywhere else in both North and South America, even though some archaeological sites elsewhere have been dated to be even older. The oldest archaeological site, Swan Point dates to 14,450 cal BP and is located in Central Alaska's Tanana River Valley, in what would have been eastern Beringia at that time.[1]

In this thesis I have chosen to use the term "population expansion" instead of "colonization" (see Chapter 2). The expansion of peoples from Siberia to North America was most likely not a deliberate migration or colonization effort (in the Colonial sense of the word). Rather, "First Peoples" were likely following the big game that they depended upon. As herds of mammoth, bison, horse and other Late Pleistocene mega-fauna moved eastward across Beringia so too did First Peoples. The word "colonization" is also a loaded term that carries many negative connotations, especially for today's First Nations people, who are the descendants of the original First Peoples who arrived in North America before 15,000 cal BP.

While there is consensus amongst most archaeologists that First Peoples arrived in North America from Siberia, they do not agree on the route First Peoples used to expand into what are now the lower 48 states of the USA (Potter, Baichtal, et al. 2018). The 'Ice-Free Corridor Hypothesis' is a long-standing view of how people entered and dispersed across North America (Potter et al. 2017). According to this hypothesis, the primary entry route into the continent was through the interior of Alaska and then through an unglaciated corridor on the eastern side of the Rocky Mountains, between the

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[1] All dates in this thesis have been expressed as calendar years before present (1950), as reported in the relevant literature.

Cordilleran and Laurentide Ice Sheets (Pedersen et al. 2016; Potter et al. 2017). However, in the last four decades a growing body of research has supported an alternative expansion route—down the western coast of North America. Dubbed the ‘Coastal Migration Hypothesis’, its supporters argue that people travelled, first, down the coast of the Pacific Northwest and then further south along the coast of California and beyond either on foot or by boat (Davis and Madsen 2020).

When Knut Fladmark (Fladmark 1979) first proposed the existence of a coastal route most scholars rejected the idea because ice sheets were assumed to have covered the now submerged North Pacific Continental Shelf. But since the 1970s an expanded body of research has demonstrated that parts of the Pacific Northwest Coast (PNWC), including portions now inundated by post-glacial rising sea levels, had likely been ice-free refugia and were ice free much earlier than previously thought (Hoffecker et al. 2016; Lesnek et al. 2018; Waters 2019). Specific parts of the PNWC could have supported First Peoples as early as 17,000 years ago on land surfaces that are now underwater (McLaren et al. 2020).

Since Fladmark’s work in the 1970s, there has been a significant increase in knowledge about the peopling of the Americas (Potter et al. 2017; Waters 2019). Archaeological data from northeast Asia are providing a clearer picture of the technology and adaptation of Late Pleistocene populations from which the first Americans are most probably descended, and research in interior Alaska has demonstrated similarities between artifacts in that region and western Siberia (Buvit et al. 2015, 2016; Graf 2014; Graf and Buvit 2017; Terry et al. 2016). Advances in Quaternary geomorphology and radiometric dating have also provided a better understanding of the timing and environmental conditions of potential routes into the Americas (Froese et al. 2019). In addition, the ability to analyze ancient human genomes has added information about when and how populations expanded out of Siberia and into the Americas (Raff 2019; Raff and Bolnick 2014). Figure 1.1 provides the geographic setting for these debates, as well as locations of some key sites and landscape features.

The long term goal of my research is to look for underwater archaeological evidence of the first expansion of people into the Americas. Given the possibility that First Peoples utilized now-submerged terrestrial landscapes off the coast of the PNWC, we need tools to help locate their archaeological sites, including predictive models that identify areas where sites are most likely to be found. In particular, we need models that have been effective in identifying high probability locations for hunter-gatherer sites. My MA thesis will test the Locally Adaptive Model of Archaeological Potential, known as LAMAP (Carleton et al. 2012), as a tool for modelling mobile hunter-gatherer sites on a terrestrial landscape. LAMAP is a predictive computer model that uses known-site locations to estimate the archaeological potential of a study area. Known-site locations provide us with information about the geographic and ecological characteristics of a landscape used by people in the past. The goal of my research is to see if LAMAP can estimate the archaeological potential of a region occupied by hunter-gatherers.

In the first two applications LAMAP was used in studies of sedentary societies. To train and test the model on mobile hunter-gatherers I will use archaeological sites from the Tanana River Valley of Central Alaska. In addition to being the longest inhabited region of North America, it is possible that these sites are also analogous for potential human settlement on the PNWC in late glacial times.

LAMAP uses distributions of landscape variables, such as elevation and slope, to make predictions about past human land-use decisions. Most predictive models attempt to locate areas where unknown sites are likely to be. LAMAP, on the other hand, takes the data from known site locations in a region and then looks for similar areas. The question then is not “where are there sites”, but rather, is “where are there (new) areas that are most similar to known site locations”. The predictive model then rates these in terms of continuous probability values, ranging from 0-1. LAMAP looks at the data surrounding a site instead of simply looking at the coordinates of a known site’s location. For example, instead of using the elevation value at a known site’s recorded location, in this study LAMAP uses all elevation values in a 1 km radius around the site. This provides a more comprehensive picture of the site’s setting, which LAMAP then uses to search for similar areas in the larger target region.

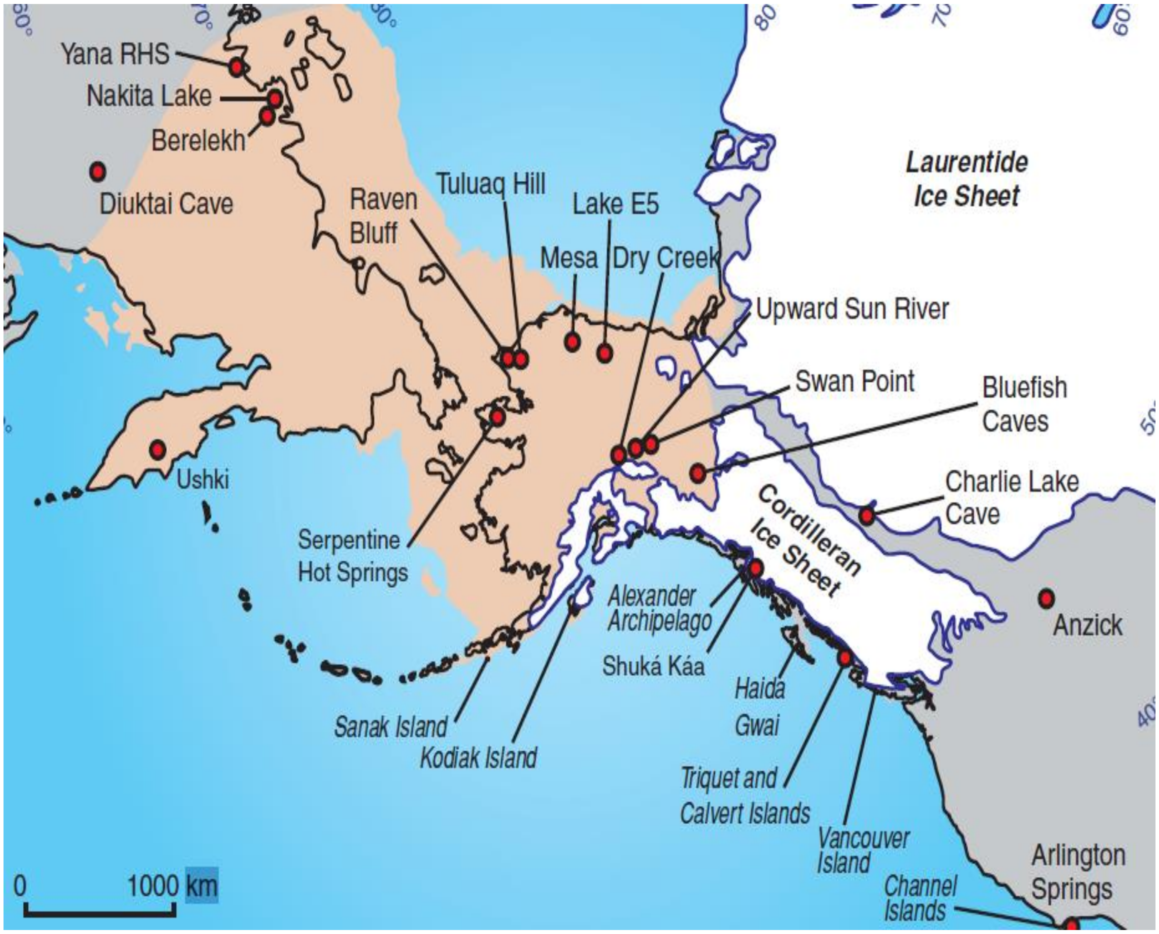

Figure 1.1. Map of Beringia and adjacent regions . Used with permission. Showing Beringia (brown), Laurentide and Cordilleran ice sheets (white), the ice-free corridor between the ice sheets, the Pacific coastal route and the location of key archaeological and geological sites. The Tanana Valley study area includes Swan Point and Upward Sun River sites. (Figure from Waters 2019).

While this thesis is intended primarily to lay the necessary groundwork for developing a method for locating sites off the PNWC, it has broader implications. First, some of the conclusions may be applicable more generally to attempts to find once-terrestrial sites that are now submerged in places such as the English Channel, the North Sea and off the coasts of Australia (Astrup et al. 2019; Bailey et al. 2017; Benjamin et al. 2020; Bicket A. R. et al. 2016). Second, the thesis is the first trial of LAMAP on the sites of mobile hunter-gatherers, and this will be of broader relevance to the study of hunter-gatherer archaeology worldwide.

I apply the LAMAP model to archaeological sites in the Tanana River Valley in Alaska. This region was in the eastern part of unglaciated Beringia during the Late Pleistocene, and includes one of the oldest widely accepted sites in North America, Swan Point, as well as a number of other sites that pre-date 10,000 cal BP. The region, the oldest continuously occupied area in North America (Potter et al. 2017), was also inhabited by mobile hunter-gatherers throughout the Holocene and has been the subject of numerous archaeological projects. As a result, the Tanana River Valley is a good area to test a model that predicts hunter-gatherer site locations.

In this thesis I examine two questions. First, can LAMAP be used to identify regions within the Tanana Valley that have a high potential for finding hunter-gatherer sites? Second, does a model built on the location of known Late Pleistocene sites also predict the location of Holocene hunter-gatherer sites?

Before using LAMAP to estimate potential underwater locations, I first need to test it on land using known archaeological sites that can reasonably serve as analogues for the now-submerged archaeological record. This is the focus of this thesis. It is structured as follows: In Chapter 2, I summarize the current state of knowledge of the early peopling of the Americas. Chapter 3 explains how LAMAP works, and then tests its ability to predict areas of high archaeological potential, using the data from hunter-gatherer sites in Alaska. Chapter 3 is presented as a multi-authored article that is currently being prepared for submission to an academic journal. The co-authors include the members of my supervisory committee, notably Chris Carleton, who developed LAMAP (Carleton et al. 2012). Dr. Carleton was responsible for running the LAMAP computer program and analyzing the modelling results statistically, while I was responsible for preparing the data from the 182 known-sites in Alaska used in the study and gathering the geographic and environmental data necessary for the LAMAP model. Chapter 4 discusses the results of using LAMAP in Alaska. I also examine its potential for locating archaeological sites on the now-submerged, formerly terrestrial, landscapes off the coasts of Alaska and British Columbia, and, I discuss the advantages and disadvantages of using LAMAP for exploration underwater offshore.

Chapter 2.

Review of the Current State of Knowledge Regarding the Peopling of the Americas

In this chapter I provide an overview of the present-day understanding of how and when people first entered North America. First, I focus on what archaeological research tells us about the movement of peoples from Asia to America, from west to east across Beringia; when this occurred and where it occurred. Second, I look at how the use of DNA adds to our understanding of the "peopling process", and third, I review what the published research on paleo-environmental reconstructions tells us about the possible routes First Peoples used to enter the North American continent. Although it is common to refer to the peopling of the Americas as one or more "migrations" or "colonizations", I have used the term "population expansion" because it seems more likely that the peopling of the North American continent occurred as populations expanded, rather than people deliberately migrating.

There are many hypotheses as to how and when people first arrived in the Americas. Some are more widely accepted than others, some are supported with a larger degree of physical evidence and some are not. In this thesis I use the term "reliably dated". I have three criteria in defining the reliability of a date assigned to an archaeological site. 1.) A site needs to have good stratigraphic context (Harris 1989). 2.) A site needs to contain artifacts, found in association with the site's stratigraphy. 3.) A site needs to be dated using one or more well-tested methods, one of which should be radiocarbon dating, and, the dates should be consistent with the stratigraphy.

Radiocarbon dating is the most widely used method for assigning ages to paleo-ecological and archaeological phenomena during late Pleistocene and Holocene times. Radiocarbon (^{14}C) is a naturally occurring isotope found in the earth's atmosphere (Canadian Archaeology 2020; Jull and Burr 2013; Ramsey et al. 2012; Taylor 2014). Plants take up ^{14}C as CO_2 during photosynthesis and animals acquire ^{14}C by eating plants and/or other animals. When an organism dies, radioactive decay results in the loss of ^{14}C atoms, such that the ratio of ^{14}C to ^{12}C and ^{13}C (stable isotopes of carbon) declines. Because the half-life of ^{14}C is known, this ratio can be converted into an estimate of time. In conventional radiocarbon dating, estimates of ^{14}C concentration were made by counting radioactive decay events, when a beta-particle is released. These methods were superseded by the development of accelerator mass spectroscopy (AMS) that allows researchers to count ^{14}C and ^{12}C atoms using an accelerated ion beam. This technique requires a much smaller sample size of organic material than conventional radiocarbon dating (Canadian Archaeology 2020; Harris 1987; Kutschera 2016). For example, a radiocarbon date can now be derived from a single plant seed using AMS dating. Most dates that form the basis for chronologies discussed in this thesis are AMS dates.

Radiocarbon dates require calibration because the amount of ^{14}C produced in the atmosphere has varied over time. As a result, different calibration curves have been developed to reconcile this. These curves compare radiocarbon dates against the known age of a variety of naturally occurring materials, such as the tree rings of very old trees, fossilized ocean corals, mineral deposits found in deep caves, lake bottom sediments or ice cores from glaciers in Greenland and Antarctica (Hajdas 2014; Reimer, Reimer, et al. 2013; Reimer 2012; Reimer, Bard, et al. 2013). In this thesis I have used calibrated dates as reported in the relevant literature.

A critical question for the interpretation of any radiocarbon date is its association with the event that one wishes to date. A radiocarbon date measures the time since the death of a plant or animal. For a date to be used most effectively in archaeology one needs to demonstrate that the organism was alive (or very recently deceased) at the same time as the event one wishes to date. For example, a piece of driftwood used for a campfire on a beach may date much older than the people who made the fire, because the tree from which the wood came died hundreds of years before. The date accurately provides a time for the death of the tree, but that date is not associated with the event of interest – the time when people built a fire. Bone collagen is second only to charcoal as the preferred radiocarbon dating material (Canadian Archaeology 2020). It is also often easier to associate bone with human activity at a site than it is with charcoal.

Other dating methods are also being used to determine the age of some archaeological sites. These include, but are not limited to, luminescence dating (Munyikwa et al. 2017), cosmogenic radionuclide dating (Menounos et al. 2017) and optically stimulated luminescence dating (OSL) (Bluszcz 2005). Again, to reliably date an archaeological site these dating techniques should be used in conjunction with one of the two forms of radiocarbon dating.

For a long time, archaeologists considered the oldest artifacts in North America to belong to the Clovis Complex, which is known for its large fluted bifaces (Haynes 1964). First found in the 1930s near Clovis, New Mexico, stone tools from this Cultural Complex date between 13,200 and 12,800 cal BP (Goebel and Buvit 2011; Graf and Goebel 2009; Holmes 2011; Potter et al. 2014). Numerous Clovis sites have been found throughout the Americas indicating that by this time people had rapidly expanded into both North and South America (Madsen 2015; Potter et al. 2017).

Other archaeological sites have subsequently been found that pre-date the time of Clovis, and are defined as being “pre-Clovis” sites. Reliably dated pre-Clovis sites include Swan Point (14,450 cal BP) and others in Alaska (Potter, Baichtal, et al. 2018) , Monte Verde (14,600 cal BP) in Chile (Dillehay et al. 2008), the Page-Ladson site in Florida (14,550 cal BP) (Waters 2019) and others on both continents. It is important to remember that such early sites denote the *terminus ante quem* for the arrival of First Peoples in the Americas and are not the actual date of their arrival. New archaeological sites continue to be found, some of which will be discussed in this thesis. These recently excavated sites both deepen our understanding of the peopling process of the Americas and pushes back the arrival time of people in the Americas. There is now general consensus within the archaeological community that people first arrived in North America before 16,000 cal BP (Braje et al. 2017; Potter, Beaudoin, et al. 2018; Waters 2019).

2.1. No Longer Valid

In recent years, several peopling hypotheses of the Americas have fallen out of favour largely because of the preponderance of new evidence. The first is the Solutrean Migration Hypothesis (SMH). This theory purported that Solutrean peoples migrated from Europe to North America either by boat or on foot along the frozen edge of the North Atlantic ocean before 17,000 years ago (Bradley and Stanford 2004; Stanford and Bradley 2012). Centered in France and Spain, the Solutrean Cultural Complex is defined as existing between 21,000 and 17,000 BP (Straus 1986).

While popular with the media and the public, archaeologists had problems with the SMH right from when it was first advanced in the late 1970s. The SMH was based primarily on the similarities of lithic artifacts found at Solutrean sites in Europe (which date between 21,000 and 18,000 cal BP) with stone tools found at sites in North America (which date after 13,000 cal BP) (O'Brien et al. 2014). For example, the "Cinmar stone knife" was recovered underwater in the 1970s more than 100 kms offshore in Chesapeake Bay by the commercial fishing vessel "Cinmar" while it was dredging for scallops (Stanford and Bradley 2012). This large laurel leaf biface, that Stanford and Bradley believed to be pre-Clovis in origin, was recovered from a depth of approximately 75 meters beneath the sea along with the partial skeletal remains of a mastodon, most of which was distributed amongst the ship's crew as souvenirs. Eventually, a third upper molar, a partial tusk and the stone biface made their way to the Gywnn's Island Museum in Mathews County, Virginia. The tusk was later dated to 23,000 cal BP by the Smithsonian Institute using conventional radiocarbon dating.

Just because archaeological artifacts, such as stone tools, or features from different parts of the world and different time periods look similar doesn't mean that they were produced by the same peoples. Archaeologists refer to this phenomenon as "convergence" or "parallelism" (Straus et al. 2005). No alleged Solutrean site or artifact, such as the Cinmar stone knife, has ever been found in North America that can be reliably dated (in a stratigraphic context). The problem with the mastodon tusk found in (loose) association with the Cinmar knife is that it, likely, dates to a much older time period (similar to the example of older driftwood being used in a more recent campfire). This has been a problem with many other alleged pre-Clovis sites found in the Americas, some of which I will discuss later in this chapter.

Several archaeologists have argued that there are more differences than similarities between Solutrean-produced lithics and much more recent Clovis-period stone tools found on the opposite side of the Atlantic ocean (O'Brien et al. 2014; Straus et al. 2005). Likewise, other scientists argue that it is unlikely that Solutrean people could have survived the 5,000 km plus journey across the North Atlantic either by boat or on foot over the ice. The marine environment along the ice's edge was not likely capable of supporting them, if a continuous ice shelf even existed at all (Westley and Dix 2008). There is no palaeoceanographic or paleo-environmental evidence to support the SMH, and, there is no evidence in the European archaeological record of Solutrean peoples ever hunting sea mammals, such as seals, producing or using watercraft or foraging for marine resources (O’Brien et al. 2014).

Also, there is no genetic evidence that Solutrean peoples made their way to North America and, if they did, passed on their genetics through their descendants. Genetics research in the last 20 years demonstrates unequivocally that indigenous peoples in both North and South America descended from a common ancestral source population in either northeastern Asia or Beringia more than 20,000 years ago (see later in this chapter).

Another migration hypothesis that is no longer considered viable is the possibility that ancient Polynesians travelled across the Pacific, either by canoe or sailing vessel, arriving on the shores of South America sometime before 15,000 cal BP (Matisoo-Smith and Ramirez 2010). The oldest known site on the southern continent is Monte Verde, which dates to 14,600 cal BP (Dillehay et al. 2008, 2012). Most recently, several stone artifacts there have been recovered that exhibit the remains of seaweed on the tools’ working edges. This suggests that people there were reliant on marine resources as part of their diet. Beach pebbles from the nearby ancient shoreline were used to make stone tools, but there is no archaeological evidence of watercraft being produced or used at the site.

In fact, the earliest evidence anywhere in the Pacific of people having the technology and ability to travel vast distances across open ocean doesn’t appear in the archaeological record until approximately 3,000 years ago, with Lapita peoples intentionally colonizing islands in eastern Polynesia and across Oceania (Irwin 2008). The results of genetics research also demonstrates that any admixture of genes between Asian and Pacific peoples happened much later than first thought, and, most likely resulted from a subsequent migration and not from the original peopling of the Americas event (see later in this chapter).

In addition to theories of migration falling out of favour, many pre-Clovis archaeological sites are now viewed as being problematic, although for different reasons. One such example is the Cerutti Mastodon site in California. It was originally excavated in the early 1990s as part of a highway expansion project near San Diego (Holen et al. 2017). The remains of a juvenile male mastodon were uncovered along with the fossilized skeletal remains of several other Late Pleistocene fauna, including mammoth, horse, camel and ground sloth. Given that no organic material was found at the site, Uranium-thorium dating (Dutton 2015) was used by the team of paleontologists, who determined that the site dated to around 130,000 years ago. Also found at the site were rocks that the researchers described as being “cobble tools”, early stone tools, that were used by humans to break apart the mastodon’s bones. These claims attracted a great deal of media attention, but most archaeologists were quick to disagree with such an early date for people being in North America because the majority of the earliest reliably-dated sites do not date before 15,000 years ago. Subsequent research determined that the marks found on the mastodon bones were the result of earth moving equipment at the site (as part of the freeway construction) and were not evidence of early human tool use (Ferrell 2019).

Similarly, in the 1990s several researchers in Alberta identified what they believed to be cobble tools at two alleged archaeological sites; one near Calgary and the other near Grimshaw, that they claimed dated to 21,000 years ago (Chlachula 1994a, 1994b, 1996; Chlachula and LeBlanc 1996; Chlachula and Leslie 1998). However, their critics pointed out that various natural processes can produce attributes on rocks that mimic human modification (Driver 2001a, 2001b). And, just because the described cobbles resembled those from a known later site (that were modified by humans) doesn’t mean that they were produced in the same manner. As one of their critics noted, better evidence is needed (than what was presented) to support the argument for humans being in western Canada before Clovis (Driver 2001b). The oldest known site in Alberta is the Wally’s Beach site (Kooyman et al. 2006), which was found on the banks of the St. Mary’s river in the southwestern part of the province. It dates to 13,300 cal BP and contains the skeletal remains of seven horses and one camel that were butchered there using stone tools (Waters et al. 2015).

In British Columbia, the oldest known inland site is Tse’K’wa (formerly known as Charlie Lake Cave). This site dates to 12,500 cal BP (Driver et al. 1996) and is found in the Peace River region near the town of Fort St. John. Several lithic artifacts were found at the site, including a partial fluted point (Driver et al. 1996). The skeletal remains of two ravens were also found at the site and are considered to be the oldest evidence of (spiritual) ritual in Canada (Driver 1999).

Another site with a dating problem is Bluefish Caves in the Yukon. The site, two small caves and several small rock-shelters, was first discovered in 1978 (Cinq-Mars 1979). Several lithic artifacts and debitage were found in association with the faunal remains of several Late Pleistocene animals, including horse and mammoth. Using two conventional radiocarbon dates, the site was originally dated as being between 10,000 and 14,000 years old. In 2017, new research was conducted on an bone artifact found at the site in the late 1970s (Bourgeon et al. 2017). It was part of a horse mandible with what appeared to be cutmarks on it, described as evidence of human modification. Samples of the mandible were taken and radiocarbon dated to 24,000 cal BP. Researchers contended that this is evidence of the site being much older than originally described.

However, like the example of the driftwood, the mandible could be much older than the Bluefish Caves site itself. In fact, this scenario has also been observed at other early archaeological sites, including some of the oldest reliably dated sites in Alaska. At several of the earliest sites there, including Swan Point, examples of “fossil ivory” used as tools have been found (Holmes 2001). These date between 20,000 cal BP to 18,000 cal BP and are significantly older than the sites where they were found. The samples from each site were reliably dated using radiocarbon dates obtained from samples of bone collagen and hearth charcoal, in conjunction with lithic artifacts found in contextual stratigraphy at each site.

The Debra L. Friedkin site, located north of Austin, Texas, is another site that some allege is older than it likely is (Waters, Forman, et al. 2011). A number of stemmed projectile points have been found at the site, which is situated on an alluvial floodplain. No organic material was found at the site, negating the use of radiocarbon dating. Instead, OSL was used on river sediments in which the artifacts were found, and, the site was dated to 15,500 cal BP. This is not to say the dates assigned, using the OSL method, are inaccurate. Rather, as previously noted, using only one form of dating technique is less reliable than using radiocarbon dating in conjunction with another dating method. It should also be noted that similar “stemmed” fluted points are not found in Alaska before 12,400 cal BP (Goebel et al. 2013). Given that the later sites are found closer to the initial point of entry into the North American continent suggests one of two things: the Friedkin site dates to a more recent time or it changes our understanding of the timing of the arrival of peoples in the Americas.

Another alleged pre-Clovis site is Meadowcroft Rockshelter in Pennsylvania (Adovasio et al. 1990). Situated on the banks of a small stream seven miles upstream from the Ohio River and 27 miles west of Pittsburgh, the site was originally dated to be 16,000 years old (Associated Press 2013). Critics of such an early date raised concern about the potential for contamination of the site by ancient carbon from coal-bearing strata in the watershed (Tankersley and Munson 1992). They suggested that the site is, in fact, much younger and likely dates, instead, to the beginning of the Holocene, around 10,000 cal BP.

Paisley Caves on Oregon's west coast is often held up as another example of a pre-Clovis site in North America (Gilbert et al. 2008). There, fossilized feces (coprolites) have been dated to 14,000 cal BP but there is debate about whether these are in fact human coprolites and whether the dates are accurate (Poinar et al. 2009). The presence of rodent middens indicates that burrowing rodents may have disturbed the integrity of the deposits (Jenkins et al. 2012). Another possibility is that between the intervening years, liquid water or animal urine may have moved DNA molecules between strata (Poinar et al. 2009).

One recent archaeological site that may, in fact, be a bona-fid pre-Clovis site is the "Cooper's Ferry" site in Idaho (Davis et al. 2019). It reliably dates to 16,000 cal BP, using radiocarbon, and is located beside a creek that flows, first, into the Salmon River, and then, into the Columbia River. It is possible that the Columbia River could have been a possible entry route for First Peoples coming into the interior of North America south of the Cordilleran Ice Sheet. While being more than 500 kms from the Pacific, the Cooper's Ferry site may, in fact, be evidence of the first expansion of peoples into the continent from the coast.

Another possible entry point into the North American continent south of the ice sheets is the Chehalis River in Washington State. Dubbed the "Chehalis River Hypothesis" (CRH), its proponents suggest that the Chehalis River Drainage and southern Puget Sound, which are both located on the PNWC north of the Columbia River, may have been inhabited by First Peoples before 15,000 cal BP (Croes and Kucera 2017). The closest early site is the Manis mastodon site at Sequim, Washington, which is located 120 kms to the north of the Chehalis River. It dates to 13,800 cal BP (Waters, Stafford, et al. 2011). Proponents of the CRH cite the Manis site to support their hypothesis, but, no other (earlier) archaeological sites have yet been found in the Chehalis River and Puget Sound areas. In addition, to support their hypothesis, they also cite other early Clovis-period sites in the region, such as Ayer Pond (Kenady et al. 2011) on Orcas Island (Wilson et al. 2009), which dates to 12,000 cal BP. Orcas Island, which is the largest of the San Juan Islands in northern Washington State, is located 190 kms northwest of the Chehalis River. Croes and Kucera (2017) also suggest that the region was ice free by 16,000 cal BP and would have been capable of supporting First Peoples.

2.2. Across Beringia

By approximately 34,000 cal BP people were moving eastward across the vast Mammoth Steppe region of Beringia (Hoffecker et al. 2014) This region, the Bering Land Bridge, encompassed modern-day western Siberia, the now flooded Bering Sea and much of present-day Alaska and existed as early as 28,000 cal BP and lasted in some areas until as late as 10,000 cal BP (Buvit et al. 2016; Graf and Buvit 2017; Hoffecker et al. 2014) (Figure 1.1). The Yana RHS site in modern-day northern Siberia is the oldest, dating between 33,000 and 31,000 cal BP (Graf and Buvit 2017; Pitulko et al. 2016). Other sites in northwestern Beringia (present-day eastern Siberia) date between 30,000 to 23,500 cal BP (Buvit et al. 2015; Graf and Buvit 2017).

At the height of the LGM (26,500 to 19,000 cal BP) it was too cold and harsh for people to live in northern Beringia. They were forced out, first, south into central Beringia, and then, even farther south into what is today Russia’s Far East and Japan’s northernmost islands, which were then connected to the mainland by another land bridge (Buvit et al. 2015; Graf and Buvit 2017). But, by 16,000 cal BP, when environmental conditions had improved, people returned to western Beringia as evidenced by finds at Diuktai Cave , considered the “gateway to Beringia” (Graf 2014:72).

Microlithics, or microblades, first appear in the archaeological record in the Transbaikal region of central Siberia (western Beringia) around 22,000 cal BP (Terry et al. 2016). This technology likely developed either in place there during the LGM or further to the south, in modern-day Mongolia or Japan, when people were forced out of Beringia because of the cold at the height of the LGM, and was introduced on their return when environmental conditions improved. Small thin uniform blades only a few millimeters thick are struck from a lithic wedge or conical shaped core using pressure flaking or indirect percussion. Each microblade has parallel sides 4 to 8 mm apart and are 15 – 50 mm long. The width of a microblade is its key attribute. It is generally accepted that microblades were used as insets for composite tools, such as projectile points made of bone and antler. The wider the microblade the easier it would have been to haft and secure in place.

The oldest site exhibiting the large-scale production of microblades in western Beringia is Urez-22, which is today situated in northern Siberia in the Maksunuokha River Valley near the shore of the East Siberian Sea (Pitulko et al. 2016). It is considered the northernmost paleolithic site in the world and dates to 14,900 cal BP. A large collection of stone tools, including microblades, was found there along with 200 complete bones from at least 11 individual mammoths. Based on the large quantity of ivory chips found at the site, most of the animals were small to medium-sized female mammoths with straight tusks. Fragments indicate that the microblades used there were very short in length (-30 mm), thin (1 mm), and narrow in width (around 2 mm) and were not made of locally-sourced lithic materials. Much of the debitage at the site is made up of lithic flakes and chips, many of which are broken, indicating that microblade cores were repeatedly modified and that most tools had their working edges re-sharpened several times before being broken and subsequently discarded.

Forty kilometers to the east lies the Lake Nikita site. It dates to 13,800 cal BP (Pitulko et al. 2016). The remains of 20 mammoths or more, as well as bison and horse, have been excavated there. Again, based on the large number of straight-tusk mammoth ivory chips found at the site, researchers concluded that hunters there in the Late Pleistocene preferred medium-sized, most likely female, mammoths. Butcher marks were found on a number of rib bones and one contained the partial remains of a lithic projectile point. Unlike the Urez-22 site though, no microblades were found at the Lake Nikita site. In fact, no evidence was found of people making or modifying tools there. But, a half dozen complete biface points were found along with a modified section of ivory tusk – referred to as an ivory rod blank or preform. The tear-drop shaped points, referred to as “Chindadn points”, were made and retouched from large flakes of fine-grained yellow-gray quartzite. They are important because they have been described as some of the best evidence for a cultural connection between peoples on both sides of Beringia (Easton et al. 2011; Pitulko et al. 2016).

When it comes to the process of making microblades there are two basic methods, the Yubetsu method and the Campus method (Hirasawa and Holmes 2017). Evidence of the Yubetsu method, considered an Old World technology, is found at sites mostly in western Beringia. The Swan Point site in Alaska is the only site in eastern Beringia where evidence has been found of microblades being produced with the Yubetsu method (Holmes 2011). This makes the Swan Point site important because it is the earliest site that demonstrates “cultural continuity” between northern Eurasia and North America and the only one with the relevant microblade technology.

Microblades produced in the Yubetsu method are struck from a microcore that is bifacially prepared. Microblades produced in the Campus method are struck from a core that is unifacially prepared. Campus microcores and blades are associated with the (younger) Denali Complex sites (Hirasawa and Holmes 2017). The name “Campus” is derived from the Campus site in Fairbanks, Alaska, which was first excavated in the early 1930s.

However, some researchers do not accept that Chindadn and Nenana, another early pre-microblade complex named after sites found in Alaska’s Nenana Valley (Goebel and Potter 2016; Holmes 2001), are unique technological complexes and lump them together under the heading, the “East Beringian Tradition” (Hirasawa and Holmes 2017; Holmes 2001). These include the earliest Alaskan assemblages that are most similar to the Dyuktai culture in Western Beringia. The variability in artifact assemblages may be explained by several factors other than that different “culturally distinct” groups made different tool types. Other factors may include the availability of raw materials, the maker’s understanding of the environment, and the environment itself, including the climate and the changing of the seasons. Different lithic tools were likely made for different activities at different sites at different times of the year.

It has been suggested that in a cold environment, like Beringia in the Late Pleistocene, osseous points (made of bone, antler or ivory) with inserted (inset) microblades were more durable than points made with lithic bifaces (Hirasawa and Holmes 2017). As a result, researchers have used the characteristics of different artifact assemblages from different sites across Beringia to group and categorize them. Chindadn points and microblades were first found together in Alaska in the late 1960s in the Tanana River Valley at the Healy Lake Village site, which dates to 11,000 cal BP, and were defined as the Chindadn Complex. Chindadn points have been found as far east as the Little John site in the Yukon, which is situated at the eastern end of the Tanana River Valley. This site dates to 14,000 cal BP (Easton et al. 2011, 2007; Easton and MacKay 2008).

In the 1970s and 1980s, sites in Alaska's Nenana River Valley were found to contain Chindadn artifacts in the oldest (lowest) stratum. Lower strata contained only points and uniface scrapers, with the younger strata above containing microcores and microblades. Despite this, all artifacts were re-classified as the "Nenana Complex" (Hirasawa and Holmes 2017). Assemblages of artifacts assigned to the Nenana Complex date between 13,400 – 11,500 cal BP. All are from sites in central Alaska at relatively low elevations (none are above 520 m asl). Given the dates of these sites and the fact that the earliest contain bifaces and no microblades, some researchers equate the Nenana Complex to that of the Clovis Complex.

Chronologically speaking, the next artifact complex found in central Alaska is the Denali Complex, which dates after 12,500 cal BP (Holmes 2011). Assemblages at sites are most often found in strata above those containing Nenana Complex artifacts. But, unlike the former, sites with Denali Complex artifacts are found throughout Alaska and at higher altitudes. Some early Holocene (post 12,000 cal BP) sites are found as far away as the Alaskan Peninsula. Denali Complex artifacts include microblades but also include large lithic blades, lanceolate bifacial projectile points and knives.

Swan Point is important for understanding this chronology. Its oldest component (CZ4b) dates to 14,450 cal BP. Charles Holmes, the site's principal investigator, interprets the oldest assemblage of artifacts as evidence of a "specialized workshop" - where a small group of knappers worked for several days making projectile points from bone and antler with inset microblades sourced from grayish green igneous rock, chalcedony and rhyolite, found onsite (Hirasawa and Holmes 2017).

He believes that the people who first used the site must have been well acquainted with the surrounding area and chose the site because it afforded them a suitable place to procure the lithic and faunal materials they needed to replenish their tool kit. The faunal evidence at the site from this time period indicates that people hunted megafauna, such as mammoth, horse, bison and caribou, as well as smaller game, including hare and birds. The faunal remains also indicate that only select parts of animal carcasses were brought to the site, suggesting that they were hunted or scavenged elsewhere. This, combined with the physical evidence of using the Yubetsu method for producing microblades, may also indicate a common Mammoth Steppe environment that existed across all of Beringia at this time and that the people who occupied the Swan Point site, most likely seasonally, had either come from western Beringia or were the direct descendants of those who did (Hirasawa and Holmes 2017; Holmes 2001, 2011; Lanoë and Holmes 2016). Holmes considers Swan Point CZ4b to be the most eastern branch of western Beringia’s Dyuktai Culture.

Swan Point is also important for another reason. Holmes considers it ancestral to the Denali Complex. Microcores made with the Campus-method were found in more recent layers (CZ1b and 2) which date after 8,300 cal BP. The analysis of the different artifact assemblages over time shows that, despite changing the way they were produced, from the Yubetsu-method to the Campus-method, microblades remained consistent in their width and thickness (Coutouly and Holmes 2018; Hirasawa and Holmes 2017).

A possible explanation for this is because microblades were part of a very specialized hunting tool. Composite osseous points using microblades are well documented in the archaeological record of Siberia (Goebel and Potter 2016; Hirasawa and Holmes 2017). While the design and the method in which microblades were produced changed over time, they remained morphologically the same. Another reason may be related to the environment in which osseous points were used. Studies show that organic points are more flexible and durable than lithic points in a cold environment. This means that using points made of bone or antler, instead of stone, with small inset microblades would have been much more advantageous than using large single component tools, like spears, that are prone to break in a cold environment.

The frozen, tree-less Mammoth Steppe was replaced by the more temperate, boreal forest of the Taiga period, beginning around 7,500 cal BP. Larger mega-fauna, such as the woolly mammoth and the horse became extinct around 12,500 cal BP but other species, such as the steppe bison and Dall sheep survived (Lanoë and Holmes 2016). Studies show that microblade components at different archaeological sites are most commonly associated with the remains of steppe bison, moose and elk (Hirasawa and Holmes 2017). This suggests that microblades, as part of osseous points, were used primarily to hunt large mammals in the Late Pleistocene and Early Holocene in central Alaska. As the environment changed over time so too did the technology used by people there, as demonstrated by the archaeological record at sites like Swan Point and others in central Alaska (Lanoë et al. 2017, 2018).

2.3. The Main Event

There are two main hypotheses about how people first expanded into North America. The first hypothesis is that peoples travelled eastward across the Beringian land mass (Figure 1.1) from Siberia to Alaska, and then down an ice-free corridor of open land between the Cordilleran and Laurentide ice sheets as big game hunters (Potter et al. 2017). The other hypothesis focuses on the coastal Pacific route. According to this hypothesis, as ice receded at the end of the Last Glacial Maximum (LGM) people moved down the Pacific Northwest coast either on foot or by boat (Erlandson and Braje 2011).

However, the routes are not mutually exclusive (Potter, Baichtal, et al. 2018; Potter, Beaudoin, et al. 2018; Waters 2019). Assuming that the initial entry point into the Americas was through Siberia, it is quite possible that some First Peoples travelled down the coast of modern day Alaska, British Columbia and Washington State, while others expanded inland, entering the interior of the North American continent by moving down the east side of the Rocky Mountains (Froese et al. 2019; Lesnek et al. 2018; Misarti et al. 2012).

Our understanding of how and when people first arrived in the Americas is changing rapidly with the announcement of new finds. It turns out that the Interior Corridor route may have been open by 15,000 cal BP (Dawe and Kornfeld 2017). A coastal route may also have been viable by this time. In recent years, a handful of early sites have been found on both the PNWC and further south in California and Mexico (McLaren et al. 2020). These include sites in BC’s Hakai Passage on the Central Coast.

e.g. Calvert and Triquet Islands. At Calvert Island, researchers claim to have found close to 30 human footprints in a paleosol dating to 13,000 cal BP (McLaren et al. 2020).

But, given that the footprints were found in the intertidal zone and that they are extremely hard to date reliably, some archaeologists have questioned their age. At nearby Triquet Island, which is to the immediate northwest of Calvert Island, charcoal from a hearth feature has been dated to 14,000 cal BP. At Quadra Island, located in the Inside Passage between Vancouver Island and the mainland, artifacts have been dated to 12,900 cal BP (McLaren et al. 2020). Quadra Island is known to have been ice-free by 14,000 cal BP (Fedje et al. 2011). Several sites in southwestern BC, near Stave Lake, have dated as early as 12,460 cal BP. The area is thought to have been ice-free by 14,500 cal BP (McLaren et al. 2020). Two recent sites on the southern Oregon coast, “Indian Sands” and “Devil’s Kitchen” date to 12,000 cal BP and 13,400 cal BP respectively (McLaren et al. 2020). All of these sites exhibit evidence of a terrestrially-adapted subsistence strategy. It seems likely that the earliest peoples in the Americas were hunters who travelled on foot.

As will be discussed later, there is also compelling evidence from the world of DNA analysis that supports the idea that people in Alaska separated from their Siberian ancestors genetically sometime between 25,000 and 18,000 cal BP. This genetic “stand still” most likely occurred in central Beringia (much of which is now submerged), after which a small group expanded into eastern Beringia (Alaska) around 16,000 cal BP (Hoffecker et al. 2014).

The coastal landscape may also have been accessible much earlier than once thought. Deglaciation began by 19,000 cal BP, with some areas open to animals and people by 18,000 cal BP, and, by 15,000 cal BP an unimpeded land route south along the PNWC may have existed (Graf and Buvit 2017; Potter et al. 2017). At the height of the LGM, what is now the seafloor of the Chukchi and Bering Seas was exposed, forming the Bering Land Bridge (central Beringia) which effectively blocked moisture from entering eastern Beringia (Elias and Crocker 2008). As a result, the former sea bottom of central Beringia, as well as exposed parts of the Continental Shelf to the south (along the coasts of Alaska, BC and further south), were “steppe like”. In Haida Gwaii (formerly known as the Queen Charlotte Islands), a “treeless and tundra-like environment” existed by at least 13,700 cal BP (Hetherington et al. 2003:1758). The term “steppe like” refers to the “Mammoth Steppe” which was a vast grassland – the ideal habitat for grazing animals such as mammoth, bison and horse (Schwartz-Narbonne et al. 2019; Zimov, Zimov, Tikhonov, et al. 2012; Zimov, Zimov, and Chapin 2012).

Paleoenvironmental reconstructions from fossil pollen, macroplant fossils and insect fossils in Beringia shows that at the end of the LGM the environment was similar to tundra regions found today in the high Arctic - except that it was much colder and dryer. This evidence was derived from sediment cores taken either offshore in the Bering Sea, such as at St. Lawrence Island and St. Paul’s Island, or at modern coastal locations, such as the Seward Peninsula. Prior to 14,000 cal BP, the landscape of central Beringia was covered in grasses and sedges with few trees and shrubs (Elias and Crocker 2008).

There are also some finds of megafauna from coastal Washington State and British Columbia. As already noted, the remains of a mastodon, with an osseous projectile point in it, was found at the Manis site in northern Washington State and dates to 13,000 cal BP (Waters, Stafford, et al. 2011). The butchered remains of a male *Bison antiquus* from Ayer Pond on Orcas Island, in northwestern Washington’s San Juan Islands, dates to 11,700 cal BP (Kenady et al. 2011). Previously, the area had been steppe-like but by this time it was more of a pine parkland. The remains of other *Bison antiquus* have also been found on nearby Vancouver Island – suggesting a land bridge between it and the nearby mainland at that time (Kenady et al. 2011; Wilson et al. 2009). The remains of mammoth and other Late Pleistocene animals, such as mastodon, muskox, horse and bison, have also been found on Vancouver Island – most notably in the “Saanichton Gravels” at the southern end of the island. A mammoth’s humerus found there dated to 17,000 cal BP (Keddie 1979). Faunal evidence from the Port Eliza cave on the northwestern coast of Vancouver Island included the remains of small mammals such as marmot, vole and marten as well as other animals and indicates that, between 18,000 cal BP to 16,000 cal BP, the area was open parkland with a cool climate. And while no evidence of human occupation was detected at the site, the evidence found does suggest that the environment there at that time may have been able to support humans (Ward et al. 2003).

As the world warmed at the end of the LGM and beginning of the Holocene, approximately 10,000 cal BP, sea levels worldwide rose (Dobson et al. 2020). Most of the coastline and exposed continental shelf on the PNWC, as much as 40 to 50 kilometers distant from modern shorelines, disappeared beneath the advancing waves (Carrara et al. 2007). In some parts of the PNWC, sea level rose as much as 150 meters (Mackie et al. 2018; Shugar et al. 2014).

2.4. Genetics

The results from the research on human ancient DNA supports the expansion of peoples from west to east across Beringia before 15,000 cal BP. Researchers determined that people on the eastern side of Beringia "diverged" from those on the western side sometime between 25,000 cal BP and 18,000 cal BP (Faught 2017; Graf and Buvit 2017; Hoffecker et al. 2014; Llamas et al. 2017; Mulligan and Szathmáry 2017). This split in populations, referred to mostly commonly as the "Beringia Standstill Model" (Tamm et al. 2007), is believed to have occurred somewhere in Beringia when people were confined to a specific region, likely because of "ecological barriers" (Tamm et al. 2007:1). Essentially, people were likely pushed out of more northern latitudes because of the harsh environmental conditions, e.g. the extreme cold, that existed there prior to 15,000 cal BP. Where the genetic "standstill" occurred is still not clear. It could have happened anywhere in Beringia, which was more than 4,000-km-wide at the height of the LGM. According to recent genetics research, a small group, less than 2,000 persons, moved out of central Beringia and into eastern Beringia sometime between 20,000 cal BP and 15,000 cal BP, likely coinciding with improved environmental conditions (Llamas et al. 2016; Schurr and Sherry 2004).

The results of this study are consistent with another larger one that suggests Native Americans diverged from their East Asian ancestors no earlier than 23,000 cal BP, and that the "standstill period" (when they were geographically isolated) lasted no more than 8,000 years, after which they were able to expand eastward into present-day Alaska (Raghavan et al. 2015). Several studies looking at DNA from both archaeological remains and living Native Americans shows that Native Americans inherited their mitochondrial DNA (mtDNA) from a founding source population in Beringia. This ancestral population remained there long enough for genetic variation to occur – separating them from their Asian sister-clades (Tamm et al. 2007). After 15,000 cal BP peoples in eastern Beringia continued to diversify genetically and expand outward, first into North America and then into South America until ultimately there were the two genetically distinct branches of Native Americans.(Llamas et al. 2016, 2017; Rothhammer and Dillehay 2009; Skoglund et al. 2015).

Research also shows that, after 13,000 cal BP, the founding haplotypes are evenly distributed across both North and South America and are not “nested” from north to south (Llamas et al. 2017; Poznik et al. 2016; Rothhammer and Dillehay 2009). A haplotype is a set of DNA variations that are inherited together – such as a set of alleles found on the same chromosome (Bailey-Wilson 2020). This indicates that the peopling of the Americas was a rapid progression and not a gradual dispersal. The pattern of genetic variation on both continents, as observed in the human remains found in the archaeological record, also shows that after the initial expansion event there followed the development of regional haplotypes and further genetic variation in Native American populations (Llamas et al. 2016; Scheib et al. 2018).

This means that the rate of expansion was not the same in all parts and that peoples settled in some areas while others expanded into new ones. Different groups also came into contact with others so that over time genetic differences developed (Perego et al. 2009). More recently, increased study has led to a better understanding of Native American-specific haplotypes as well as the worldwide mtDNA phylogeny. Today, for example, the overall number of recognized founding Native American maternal lineages has gone from five to a current count of 15. Of these, seven are found distributed across both North and South America, and, of the five haplogroups found in Native American populations today on both continents, four are estimated to have entered North America from Asia between 18,000 cal BP to 15,000 cal BP (de Saint Pierre 2017). The origin of the fifth has yet to be determined conclusively but is likely the result of genetic admixture from a later time and most likely also originates from (coastal) Beringia. Research relating to the nuclear genome has also found an allele unique to the Native Americans populations studied, along with two populations in Northeast-Asia (Hoffecker et al. 2016). The allele is absent in the rest of the world. This adds credibility to the idea that the Native American and northeastern Asian populations derive from a common ancestor. Other studies looking at the expansion of people into South America describes the process there as a series of population splits, with decreasing genetic variation from west to east (Borrero 2015; Rothhammer and Dillehay 2009).

It is important to note that while the study of “paleo-genomics” has provided compelling evidence relevant to the expansion of peoples on both continents, it hasn’t answered, definitively, some of the biggest question relating to the peopling of the Americas, such as what route(s) people took, when they travelled them and how long it took for people to get from one part of the Americas to another. One thing is for sure though, reliably dated pre-Clovis sites in Alaska, as well as those south of the ice sheets, such as Cooper’s Ferry (Davis et al. 2019), are compatible with the genetic data.

What is clear is that the results of recent genetics research does not rule out the possibility that First Peoples expanded into North America before 15,000 cal BP. Exactly where the “Beringia Standstill” occurred is still not known, but the research indicates that people could have moved into eastern Beringia (Alaska) as early as 20,000 cal BP. Sites like Swan Point, Broken Mammoth, Mead and others, all of which are in the interior of Alaska, lend credibility to the idea that even older sites are likely to exist in Alaska, closer to the initial point of entry for peoples expanding into eastern Beringia. In addition to new sites being found closer to the coasts of Alaska, other sites are likely to be found offshore in the neighboring Bering Sea, in what would have been central Beringia prior to the beginning of the Holocene, approximately 10,000 cal BP, when sea levels rose to their current levels.

2.5. Possible Routes

Both archaeological and genetic evidence now supports the idea that people first arrived in eastern Beringia sometime before 15,000 cal BP and from there expanded into the rest of the Americas (Braje et al. 2020; Froese et al. 2019; Potter, Baichtal, et al. 2018; Waters 2019). Debate continues regarding which of the two predominant routes, the Ice-Free Corridor (IFC) or the Pacific Coastal Route (PCR) were environmentally viable and whether one was preferred over the other. In fact, both may have been followed, but possibly at different times. The possibility of either route having been used first is largely dependent on the state of glaciation at various times (Lesnek et al. 2018; Misarti et al. 2012). At some point, when either or both the Cordilleran and western Laurentide ice sheets started to recede, pathways would have opened up (Dawe and Kornfeld 2017; Heintzman et al. 2016). A central question is how long did it take between when the ice receded and environmental conditions improved to the point where a local environment could have supported both plants and animals, and in turn, humans. In the case of the IFC, proponents contend that people moved out of Alaska via the lowlands of the Tanana and Yukon rivers, into the Mackenzie River Valley then down along the eastern side of the Rocky Mountains and into the rest of North America (Potter et al. 2017). Those arguing for the PCR suggest that, after the Cordilleran Ice Sheet receded, people were able to travel down the length of the Pacific coast by boat, entering the continent from its western shores (Dixon 2013; Erlandson et al. 2008; Erlandson and Braje 2011; Madsen 2015).

2.5.1. Interior Route

There are more than 100 archaeological sites in eastern Beringia that predate 10,000 cal BP (Potter et al. 2014, 2017). Of these, more than 70 are located in Alaska and the Yukon. There are only two sites that predate 14,000 cal BP – Swan Point in the Tanana River Valley and Little John in the Yukon River Valley. Supporters of the IFC route contend that these two sites, and other later ones, are the best evidence for the initial expansion of people out of Beringia via the IFC route (Jackson et al. 2020; McLaren et al. 2020; Potter et al. 2017). Some researchers have suggested that the IFC was not an actual corridor between the two ice sheets, but rather, was a series of different pathways through the Laurentide ice sheet (Dawe and Kornfeld 2017). These pathways would have allowed First Americans to travel south alongside the Rocky Mountains and then onto the unglaciated Plains to the east and to the south.

As to when the IFC was passable, supporters of the IFC route suggest that there is no consensus on the exact timing of deglaciation, despite critics arguing that the IFC was not open until after 13,000 cal BP – too late for it to be the initial entry point into North America (Pedersen et al. 2016). But, new dating techniques, such as luminescence and cosmogenic dating, have recently produced dates for the ice sheets separating around 15,000 cal BP (Dawe and Kornfeld 2017; Ives et al. 2013). Glacial valleys along the way would have become ice-free refugia and could have supported plant and animal life as well as humans. They point to several radiocarbon dates from the remains of several small mammals found in northeastern British Columbia (BC), which date to 15,000 cal BP, as supporting evidence for this (Hebda et al. 2008).

2.5.2. Coastal Route

Only a couple of dozen sites predating 10,000 cal BP have been found on the Pacific Coast (McLaren et al. 2020; Potter et al. 2013, 2017). Of these, only six reliably predate 13,000 cal BP (McLaren et al. 2020) and only one, the Cooper's Ferry site in western Idaho, predates 14,000 cal BP (Davis et al. 2019). Technically not a coastal site, being more than 500 kms from the ocean, this recently-found site is situated on the banks of a creek that flows into the Snake River, which in turn, flows into the Columbia River. The Columbia River does flow to the Pacific and it is the largest river in the Pacific Northwest. It is also the fourth largest river, by volume, in the United States (Kammerer 1990). The Columbia River Valley could have been a possible entry point into the interior of the continent for people migrating down the coast. Further south, several sites in California's Channel Islands and Mexico's Baja Peninsula have dated as early as 13,500 cal BP (Des Lauriers 2005; Des Lauriers et al. 2017; Erlandson and Braje 2011; Wade 2017).

There is no evidence in the archaeological record of Siberia (western Beringia) in the Late Pleistocene of people being marine-adapted (Davis et al. 2016; Potter et al. 2017). In eastern Beringia (Alaska) the earliest archaeological evidence of people fishing, for salmon, dates to 11,500 cal BP and comes from the Upward Sun River site in the Tanana River Valley (Halfman et al. 2015). It is not on the coast and it is the oldest evidence of people fishing for salmon anywhere in North America. Direct evidence of people using marine-adapted technologies, such as fish hooks and harpoons, doesn't appear anywhere on the Pacific coast of the Americas until 12,500 cal BP from several small islands off the coast of Baja, Mexico (Fujita 2014). There, small fish hooks made of polished marine shell have been found in the oldest components (Des Lauriers et al. 2017). On the coast of Alaska the earliest evidence of a marine adaptation doesn't occur until 9,000 cal BP in the Aleutian Islands (Davis et al. 2016).

Just like the IFC, the ability of people to move down the length of the Pacific coast was most likely dictated by two factors; the state of deglaciation at the time and the state of the environment being able to support an expanding population (Amick 2017; Froese et al. 2019; Lesnek et al. 2018; Misarti et al. 2012). Dubbed the "Kelp Highway Hypothesis", some researchers have suggested that First Peoples could have survived on a diet based on marine resources (Erlandson et al. 2008), But, there is no archaeological evidence to support this. In fact, the evidence from the oldest archaeological sites on the Pacific coast strongly suggests that people lived on a diet of mostly big game. For example, a projectile-point embedded in the rib of a mastodon at the Manis site in northern Washington State dates to 13,800 cal BP (Waters, Stafford, et al. 2011). Lithic artifacts from the more recently discovered Cooper's Ferry site include non-fluted projectile points, used for hunting game, and date between 16,000 cal BP and 13,000 cal BP (Davis et al. 2019).

So far, all of the sites found on the PNWC demonstrate that their earliest occupants were terrestrially-adapted big game hunters. They were not marine-adapted. The earliest archaeological evidence in BC comes from K1 Cave in west-central Haida Gwaii where stone points and flaked tools associated with bear hunting have been found, dating between 12,800 – 12,500 cal BP (Fedje et al. 2011).

Along the southern coast of Alaska deglaciation began to occur by 19,000 cal BP (Misarti et al. 2012). The Alexander Archipelago, which borders BC, may have been free of ice as early as 15,000 cal BP (Kiefer and Kienast 2005; Taylor et al. 2014; Wilson and Ward 2006). The faunal remains of Late Pleistocene animals have been found on Prince of Wales Island in southern Alaska, dating to 15,000 cal BP, as well as on the Haida Gwaii Islands, dating to 17,000 cal BP (Darvill et al. 2018). Pollen and faunal data recovered from the Port Eliza Cave on the north-west coast of Vancouver Island indicates an environment capable of supporting people existed there as early as 18,000 cal BP (Al-Suwaidi et al. 2006; Ward et al. 2003). Prior to sea levels rising, starting around 12,000 cal BP, a 30-kilometer distance (now the Hecate Strait) separated the islands of Haida Gwaii from the mainland (Fedje et al. 2011). Pollen samples extracted from a pond at Kilgii Gwaay (Ellen Island) at the south end of Haida Gwaii indicates that by 14,500 cal BP a shrub-tundra environment existed there (Mathewes et al. 2019). Charcoal also found in core samples recovered from Kilgii pond demonstrates the presence of campfires, indicating people were on the landscape there as early as 13,000 cal BP. But, archaeological evidence of a maritime adaptation at Kilgii Pond does not appear until 10,800 cal BP – as demonstrated by the remains of a (largely mussel) shell midden – after sea levels rose, inundating most of the formerly terrestrial Hecate Strait.

The steppe-like environment of the then exposed Hecate Strait and continental shelf to the west would have been familiar to its first inhabitants, who would have experienced the same further to the north in central and eastern Beringia. Other studies suggest that the PCR would have been free of ice and environmentally viable for first peoples by 16,000 cal BP (Dixon 2013; Erlandson and Braje 2011; Mackie et al. 2011; Madsen 2015; Shugar et al. 2014). Regardless, the overwhelming majority of archaeological evidence to date supports the idea that the earliest migrants on the PNWC were big-game hunters (before 13,000 cal BP) and that they were not marine adapted until much more recently (after 13,000 cal BP).

2.5.3. Both Routes Viable

A growing body of evidence from the disciplines of genetics and archaeology supports the idea that people entered North America before 15,000 cal BP. In addition to understanding when people first arrived, new research is providing evidence as to where people first moved into the continent.

For a long time, the IFC was viewed by the majority of researchers as being the preferred route for the initial expansion of people into the Americas. More recently, researchers began to favor the PCR as the preferred route. But, neither route is exclusive. Even more recent research demonstrates that both routes could have been viable, likely much earlier than previously thought. The IFC could have been viable as early as 15,000 cal BP (Potter, Baichtal, et al. 2018) and the PCR could have been viable by 17,000 cal BP (McLaren et al. 2020).

Archaeological evidence from sites such as Kilgii Pond and others along the PNWC may speak to First Peoples adapting *In situ*, moving from a terrestrially-adapted big game subsistence to a marine-adapted one, as environmental conditions changed at the beginning of the Holocene. The first expansion of peoples out of eastern Beringia, present-day Alaska, and into the rest of North America may have been down the coast of the Pacific Northwest via the PCR, or, it may have been through the interior of the North American continent via the IFC. Likewise, both routes are in line with the genetic data that shows people entered the continent before 16,000 cal BP.

So far, only the Cooper’s Ferry site in Idaho (Davis et al. 2019), which reliably dates to 16,000 cal BP, favors the PCR over the IFC. Time will tell though, with the addition of more sites to the archaeological record.

Chapter 3.

Assessing the Ability of the LAMAP Predictive Model to Locate Hunter-Gatherer Sites: An Alaskan Case Study

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Publication: to be submitted

Statement of Contributions of Joint Authors

Rondeau, Rob (Candidate): Primary data collection and input, interpretation, wrote and compiled manuscript, prepared figures and table

Carleton, Chris (Committee Member): Designed and established research method (LAMAP), data analysis and interpretation, prepared figures, edited and co-authored manuscript

Collard, Mark (Committee Member): Assisted with research design, edited and co-authored manuscript

Driver, Jon (Senior Supervisor): Assisted with research design, edited and co-authored manuscript

3.1. Introduction

Archaeologists have long sought ways of assessing whether an unsurveyed area contains archaeological sites (Mehrer et al. 2005; Wheatley and Gillings 2002). Recently, Carleton et al. (2012) have proposed a new approach, called the Locally-Adaptive Model of Archaeological Potential, or LAMAP. It differs from existing techniques in that it does not treat archaeological sites like points on a map and it does not depend on having “non-site locations” to make its “potential” predictions. LAMAP does not try to predict the probability, or odds, of finding sites given a set of landscape variables. Instead, LAMAP considers the distribution of values for landscape variables around known sites and then uses these data to classify and map the archaeological potential of the unsurveyed parts of the study area. In effect, LAMAP is estimating the similarity of known site locations to the unsurveyed parts of the study area.

So far, only two tests of LAMAP have been published. Carleton et al. (2017) initially tested LAMAP with data from an area around the large Classic Maya centre of Minanha, in west-central Belize. They used the locations of 69 known Classic Maya civic-ceremonial centres to produce a high-resolution predictive model for a 280 km^2 study area around Minanha. The LAMAP predictions were then tested with a combination of ground-truthing survey and LiDAR data. The evaluation revealed a strong correlation between the LAMAP predictions and the number of previously unrecorded sites. There were in excess of 300% more sites in areas that were deemed high potential by the LAMAP model, as compared to areas that the model predicted as having low potential.

The second test of LAMAP was reported by Wilett et al. (2019). These authors used LAMAP to identify high and low potential areas in the Sagalassos region of southwestern Turkey. The model was then tested using a pedestrian survey. In total, 15 previously unknown sites were discovered, many represented by multi-period artifact concentrations. Like Carleton et al.(2017), Wilett et al. (2019) found markedly more sites in areas that LAMAP predicted to have high archaeological potential than in areas that LAMAP predicted to have low archaeological potential.

While LAMAP has shown promise, its use has so far been limited to largely sedentary agricultural societies from more recent time periods. Each of the two case studies are different in their own right and the results need to be assessed individually. In the case of the Belize case study, the survey area consisted of several Classic Mayan regions that were surveyed over several years. The first pedestrian field survey covered about 50 km^2. The next survey was remote, covering 400 km^2, and was conducted using recently produced high-resolution LiDAR data. “Sites” were defined as architectural features and included domestic structures as well as large ceremonial centres. Following the development of a map of archaeological potential, a random sample of one hundred 500 m X 500 m survey blocks were investigated using a pedestrian survey in combination with a LiDAR (desktop) survey to test the LAMAP predictions (Carleton et al. 2017). In the Turkey case study, seven LAMAP surface maps were produced - one for each time period the researchers were interested in studying -with data acquired from satellite imagery for the 1,200 km^2 study area. (Wilett et al. 2019). The study area was divided into 50 m X 50 m cells. The LAMAP model was tested by ground truthing 101 randomly selected cells. “Sites” ranged in nature from rock shelters to stone-built structures and water wells.

LAMAP has not yet been applied to the problem of assessing archaeological potential in relation to hunter-gatherer sites and we cannot simply assume that LAMAP will work as well for hunter-gatherer sites as it seems to do for sedentary agricultural sites. Hunter-gatherer sites were often used only briefly and, hunter-gatherers were often highly mobile. Decisions about where to locate may have depended more on immediate circumstances and context, and less on long-term considerations. Given these considerations, it is important to formally evaluate LAMAP’s ability to estimate archaeological potential in relation to hunter-gatherer sites. Here, we report such an assessment.

In this study, we used part of the Tanana River Valley in central Alaska as a test case (Figure 3.1). The valley was part of unglaciated Beringia during the Late Pleistocene and includes Swan Point (14,450 cal BP), which is the oldest continually-occupied archaeological site in North America. Archaeological evidence, from the Late Pleistocene to the Historic period, demonstrates that people have lived there, and at other sites in the Tanana River Valley, longer than anywhere else in the Americas. Swan Point is equally important for being the only site in North America to exhibit cultural continuity between western and eastern Beringia. Microblades, produced using the Yubetsu method, evidence of Dyuktai Culture, have only been found there. Many other documented sites that pre-date 10,000 cal Before Present (BP)[2] are also found in the study area. As such, the study area is an excellent location to evaluate LAMAP’s ability to estimate archaeological potential in relation to hunter-gatherer sites. A further benefit of using the Tanana River Valley as a test case is that it may also provide researchers with tools for locating other early sites in North America. This is particularly important for finding new sites in Beringia, which at the end of the Pleistocene was a vast “mammoth steppe” covering 2.5 million square kilometers (Schwartz-Narbonne et al. 2019).

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[2] All dates presented in this article are calibrated and “Present” refers to 1950.

We addressed two questions in the study. The first was, can LAMAP be used to identify areas within the Tanana Valley that have a high potential of containing hunter-gatherer sites? To answer this question we carried out an analysis using random cross-validation. Half of the currently known sites were randomly selected to use as a training dataset and the remaining sites were used to test the model. We reasoned that if the LAMAP method is suitable for identifying high potential areas for hunter-gatherer sites, there should be a strong positive correlation between LAMAP predictive classes and the number of cross-validation sites associated with those predictions. The second research question we addressed was, does a model built on the location of sites occupied during one period predict areas of high potential for sites from a different time period? We first divided the sample into pre-10,000 cal BP sites and post-10,000 cal BP sites. We then used the pre-10,000 cal BP sites to train the model and the post-10,000 cal BP to test it. This analysis also allowed us to investigate whether site location preferences shifted over time. We reasoned that if the LAMAP method was suitable for hunter-gatherer sites despite the significant passage of time, there should be a strong correlation between LAMAP predictive values and the numbers of cross-validation sites—i.e., places with higher LAMAP values should contain more sites.

3.2. Background

3.2.1. LAMAP

LAMAP uses known-site locations to estimate archaeological potential (Carleton et al. 2012). The model's key assumption is that known-site locations provide us with insight into the geographic and ecological characteristics of places used by people in the past. If people spent time at a location, as evidenced by material culture remains, this implies that the landscape around the site was suitable for whatever activity was taking place there. For instance, if a known site appears to have been a base camp it is reasonable to assume that the location was suitable for base camp activities. This implies that other areas possessing the same geographical and ecological characteristics were probably also suitable for a base camp. In other words, target areas that resemble known sites were probably selected on other occasions. Thus, without knowing exactly why humans made certain land-use decisions in the past or even what precisely people were doing in a given place, we can estimate the suitability of any target location given known-site locations as a basis for comparison. This *'known site suitability assumption* is the foundation of LAMAP (Carleton et al. 2012).

LAMAP assesses archaeological potential by comparing unsurveyed areas in a target region to areas around known-sites. Specifically, it uses empirical data to estimate the probability of finding areas in the target region that are similar to areas around known-sites with respect to a set of landscape variables. Ideally, the landscape variables represent persistent landscape characteristics that change relatively slowly so that measurements at different locations would have remained relatively constant with respect to each other through time. It is also preferable to use variables for which data are readily available, such as derivatives of physiography (e.g. elevation and slope), ecological and environmental observations (e.g. vegetation or soil type), or the product of computation (e.g. distances to water or intervisibility estimates).

LAMAP employs a raster image (i.e. a grid of cells) representing the study area. Each cell/pixel in the raster image corresponds to a spot on the Earth's surface for which we want to estimate archaeological potential (Ebert 2004). The study area was chosen because it represents a "swath" of the Tanana Valley that includes all of the oldest sites in Alaska. All of the site data within the study area was first compiled in a QGIS database. QGIS a free and open source Geographic Information System (GIS) (QGIS Group 2020).

LAMAP employs a simple algorithm to estimate the archaeological potential of unsurveyed areas. The algorithm scans the raster image for the study area and assigns a probability value to every cell. The probabilities are derived from the distributions of landscape variables around a set of known site locations. These distributions are based on the cells in the raster image located around the known-sites. Each cell contains a value for a given landscape variable - say, the elevation value of the terrain in meters above sea level at the corresponding location on the ground. Together, the cells then represent the distribution of values for the relevant landscape variable around the known-site locations - e.g., the distribution of elevation values. With these distributions, the algorithm can then estimate the probability of finding a target cell with a given value for a given landscape variable that is similar to the sample area around any and all known-sites. The estimate is effectively the empirical likelihood of finding a spot in a target location that is similar to the sample area around known archaeological sites.

As noted, LAMAP's estimates of archaeological potential are probabilities. They are calculated on a cell-by-cell basis to produce a LAMAP raster surface. A LAMAP estimate for the target cell is like a response to the question, "what is the probability of finding a cell similar to the target one within the area around a known-site"? With a set of landscape variables in mind, the question then is, "what is the probability of finding a spot within a known-site area that has X elevation multiplied by Y slope, multiplied by Z aspect, and so on"? The LAMAP algorithm uses empirical frequency distributions of measurements for the relevant variables around a given known-site location to estimate the probability. So, for six landscape variables, there would be six probabilities for a single comparison between one target cell and one known-site location. These probabilities are then multiplied to give the probability of finding a spot like the target cell in the area around the known-site. The same calculation is performed for every known-site, producing a list of probabilities for a given target cell. Each element of the list is the LAMAP estimate comparing the target cell and one known-site location. Every cell in the study area is compared to each known-site sample area. Then, the probabilities in the list are weighted according to the distance between the target cell and the relevant known-site. Lastly, the weighted probabilities are combined using the "Law of Total Probability", a formula for determining the overall probability of an outcome (find similar spots in all known-sites) that can be realized by multiple distinct events (find a similar spot at one site). The calculation results in a value ranging from 0 to 1 for every cell in the study area. The higher the value for a given cell, the higher its archaeological potential. The estimates can then be binned into categories (e.g., quantiles) and re-classified into an ordinal variable ranging from 1 to 5 (to facilitate evaluating the model's utility). These ordinal values indicate relative potential, with higher values indicating higher archaeological potential. Areas with the highest LAMAP values should contain more sites than areas with lower LAMAP values.

Prior to computing the LAMAP values, the landscape variables are typically transformed with Principal Component Analysis to facilitate faster computation and improve the contrast between locations. PCA is a dimension reduction technique usually used to emphasize variation and reduce redundancy among variables in an analysis (Jolliffe 2002). It takes a set of potentially correlated variables (in this case, elevation, slope, distance to drainages, and so on) and reduces them to a new set of uncorrelated ones. Fewer variables, means faster calculations. The PCA also helped to avoid rounding or floating-point computational limits. Computers have a limited number of decimal places to work with, so multiplying small probabilities by other small probabilities can lead to false zeros. Perhaps most importantly, though, the use of PCA improved the LAMAP algorithm's ability to discern potential differences between locations in the study area, which would make discerning high- and low- potential areas easier.

3.2.2. Study Area

The study area comprises 7,000 km^2 of the valley of the Tanana River (Figure 3.1). It was chosen because it includes all of the oldest sites in Alaska as well as many later archaeological sites. The Tanana River is a tributary of the Yukon River and lies between the Alaska Range of mountains to the south and the Yukon River to the north. It is fed by meltwater from glaciers in the Alaska Range and flows northward to the Tanana Lowlands. The Tanana River Valley bottom ranges in width from less than a kilometer-wide to 6.4 kms (Reger et al. 2008). The study area is made up of rounded ridges and bedrock hills, with a maximum elevation of 681 meters (Reger et al. 2011). Large free-standing craggy rock outcrops, known as tors, are found on summits or ridge crests.

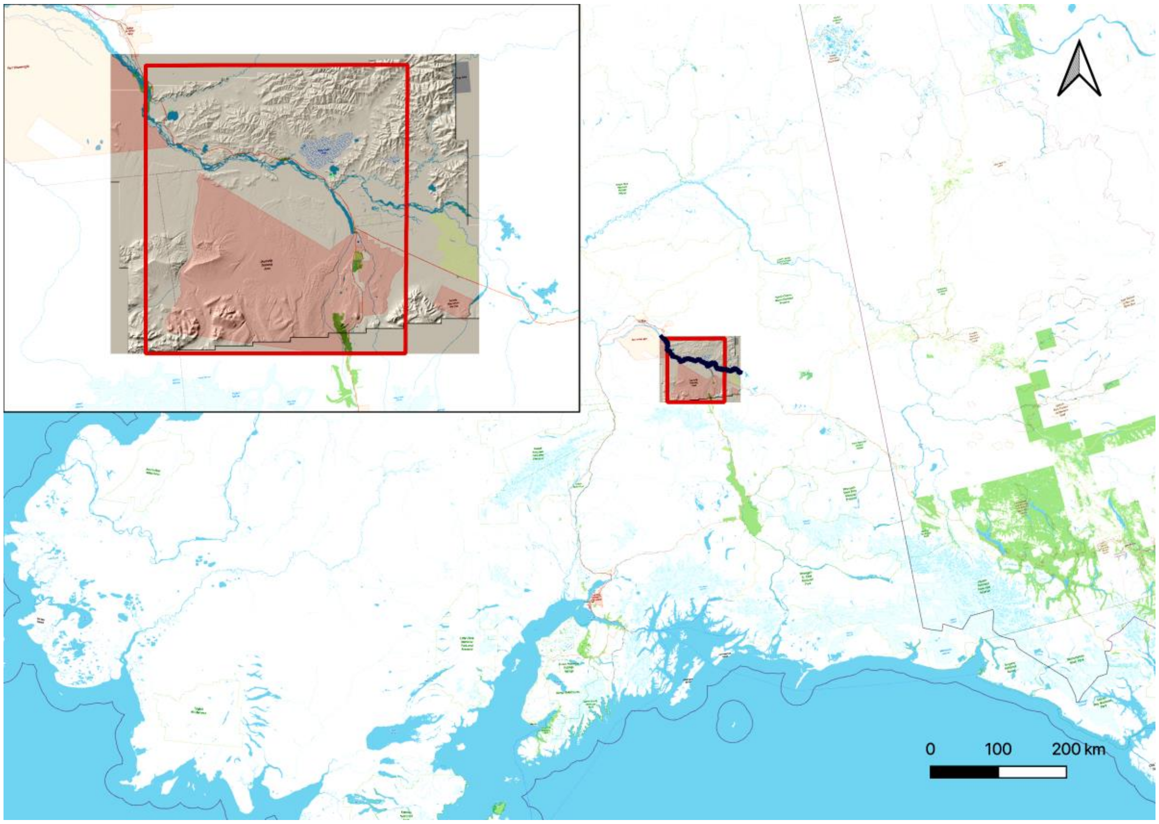

Figure 3.1. Map of study area within the Tanana River Valley of Central Alaska.

The valley floor is covered in thick layers of river silt and lowland loess (Reger et al. 2008). Strong katabatic winds, high-density dry air coming off the Alaska Range of mountains, have been active in the area for millennia, especially during the Late Pleistocene. Such winds are found today in Antarctica. They sweep down off glaciers and contribute to reducing snowfall there (Grazioli et al. 2017). In the Tanana River Valley, katabatic winds strip sand and silt from unvegetated stream bars and exposed slopes. The thickest concentration of loess soils, made up of minerals from igneous and metamorphic rock, are found on lower north-facing slopes. See Figure 3.2.

Figure 3.2. A photo of typical north-facing slopes in the Tanana River Valley.

The average summer temperature in the valley is 17 degrees Celsius and the average winter temperature is -23 degrees Celsius. The typical annual precipitation in the valley is 27 centimeters (Pattison et al. 2018). The area is considered a “Dfc climate type”, which is a subarctic climate (Alaska Department of Fish and Game 2020; Kottek et al. 2006)

The valley is covered by subarctic boreal forest of the Nearctic Ecozone (Pattison et al. 2018). Black spruce forest makes up 68% of all tree species, followed by birch, balsam poplar, white spruce, tamarack, and aspen. Common shrub species include lingonberry, black spruce, birch, alder, Labrador tea, prickly rose, and blueberry (Schulz 2015). Recent studies show that the vegetation in both the Tanana Valley and across Alaska is changing as a result of climate change. In some areas, shrubs are replacing tundra, and hardwoods, like aspen, are replacing softwoods, such as black and white spruce. An infestation of pests is also on the rise and this will, undoubtedly, have an effect in the future on the composition of vegetation both within the valley and across the rest of the state (Schulz 2015). Today, wetlands provide habitat for a variety of wildlife, including many game animals and migratory birds.

3.2.3. Human history in the Tanana River Valley

The name ‘Tanana'' comes from the Denaakke term ‘tene no, tenene’, which means ‘trail river’ (Bright 2004). Denaakke (also known as Koyukon) is part of the Dene-Athabaskan language family (Holton 2020). The Goodpaster River, a tributary of the Tanana River, is the demarcation line in the Tanana Athabaskan language area, separating upriver speakers of the Upper Tanana languages from the Lower and Middle Tanana speakers downriver. Descendants whose traditional territories include the study area are the Salcha(ket) and the Delta-Goodpaster (Smith 2020).

Tanana Athabaskans have always relied on a hunter-gatherer subsistence. Prior to Contact, they were semi-nomadic and lived in semi-permanent settlements in the lowlands of the Tanana River Valley (Haynes and Simeone 2007). Traditionally, they relied on hunting big game in the fall, including moose, caribou, and Dall sheep. Throughout the rest of the year, they trapped beavers, wolverines, and other fur-bearing animals, and hunted bears, wolves, and other fauna. They also fished for salmon and trout in the rivers and streams, foraged for berries, and harvested other plants and natural resources. The economy of Tanana Athabaskans today is a mixed cash-subsistence one, like many other Indigenous communities in Alaska, and still includes the hunting and gathering of wild resources (Haynes and Simeone 2007; Shinkwin and Case 1984).

Figure 3.3. **Dr. Charles Holmes stands over part of Cultural Zone 4b at the Swan Point site, one of the oldest archaeological sites in the Americas (dating to 14,450 cal BP). Photo taken in June, 2019.**

Early archaeological sites found in the Tanana River Valley are conventionally divided into two time periods—14,000 cal BP to 13,000 cal BP and 13,000 cal BP to 9,500 cal BP (Holmes 2001). Lithic assemblages from the earliest time period include microblades and burins that are similar in design and production to those found in the area that was once western Beringia and are assigned to the Dyuktai Culture. This time period includes sites such as Swan Point (East Beringian Tradition, 13,000 cal BP) (Holmes 2001). The earliest layers at Swan Point show evidence of 'steppe grazers' including horse, bison, and mammoth (Potter et al. 2014). After 12,000 cal BP, people subsisted on mostly bison and wapiti, with the addition of small game, birds and fish (Holmes 2001; Lanoë and Holmes 2016; Potter et al. 2014). Sites from the more recent period include Broken Mammoth, Healy Lake, Gerstle River, and others. This period is referred to as the 'Transitional Period' (13,000 cal BP to 9,500 cal BP) (Holmes 2001). Some sites from this period do not include microblades, favouring smaller bi-faces instead. This indicates a possible shift in subsistence strategy, with hunters moving away from hunting bigger game, such as mammoth, to smaller animals, such as caribou and bison. The term 'transitional' reflects the environmental and technological changes that started to occur at the beginning of the Holocene, around 10,000 cal BP.

The climate became warmer and wetter, some animals such as the mammoth, became extinct, and the 'steppe-like' environment was replaced by boreal forest. The results of pollen studies at Broken Mammoth demonstrate that from 13,800 cal BP to 12,000 cal BP the environment there was a birch-shrub tundra. After 11,000 cal BP, this changed to a woodland, or parkland, environment that included both hardwood trees and shrubs, such as Alder, and softwood trees and shrubs, such as Spruce. The faunal remains of Red squirrel and porcupine from Broken Mammoth, dating to 9,100 cal BP, support the idea that by the early Holocene the area became more forested (Holmes 2001).

Archaeological evidence also suggests that early hunter/gatherers in the Tanana River Valley lived in small groups, were highly mobile, hunting migratory animals, and situated their seasonal base camps, as well as their temporary hunting and kill processing campsites, usually on bluffs or rises. Some sites within the Tanana River Valley have been described as "overlook" or look-out places (Holmes 2004). For example, Swan Point (Figures 3.3, 3.4) is located on the top of a ridge (at 322 meters above sea level) and strategically overlooks up to 86% of the surrounding area (Lanoë and Holmes 2016).

Figure 3.4. **The Swan Point site is referred to as an "overlook site" because of its commanding view over the surrounding landscape, including nearby creeks and streams, which can be seen through the trees. Photo taken in June, 2019.**

3.3. Materials and Methods

The dataset included information about 182 archaeological sites in the middle Tanana River Valley. Twelve of the sites predate 10,000 cal BP; 17 date between 10,000 cal BP and 5,000 cal BP; 23 sites post-date 5,000 cal BP; and 130 are undated at the moment. Site data were compiled from the Alaska Heritage Resources Survey, with permission from the State of Alaska's Office of History and Archaeology. Details of the individual sites are provided in Supplementary Materials.

We used six variables in LAMAP to predict the location of previously unknown sites: elevation, slope, aspect, distance to drainages, cumulative viewshed, and convexity. The variables were selected for several reasons. They represent landscape features that have likely changed little over time and are readily available from satellite imaging data. We did not use vegetative cover as a variable, for example, because there are no palaeoecological records available for the area that could be used to infer vegetation change over time or with a level of detail that would reflect variation between known sites. We chose the variables that we did because they would have been important to hunter-gatherers, and, because the six variables do have a relationship with other environmental variables such as vegetation, temperature and soil.

The variable “elevation” was determined from the satellite data used. The variable “slope” was also derived from the elevation data. “Distance to drainage” values were, likewise, extracted from the elevation data using GRASS, a GIS used for geospatial modelling (OSGEO Foundation Project 2019). After extracting the drainages, “R” was used to create the raster map containing the distance from every cell in the study area to the nearest drainage cell from the extracted drainages map (The R Foundation 2020). The variable “aspect” was derived from the slope data. The variable “convexity” describes the degree to which a focal-cell represents a convex/concave location on the landscape, i.e. the degree to which the cell is on a hill-like surface or a depression-like surface. It was derived from the elevation data and was processed using the GIS spatial algorithm “Terrain Surface Convexity” provided through SAGA (System for Automated Geoscientific Analyses) (The SAGA Group 2020). The variable “cumulative viewshed” describes the visibility of a given cell in the study area from a large grid of points that was overlaid on the area using QGIS’s “Viewshed Analysis” algorithm. The grid contained thousands of points spaced 1,000 meters apart covering the entire study region. It was also derived from the elevation data and assumes a tress-less, obstruction-free view of the land surface from a height of 1.6 meters.

A total of six Digital Elevation Models (DEMS) for the study area were obtained from the United States Geological Survey’s publicly-accessible National Elevation Dataset (USGS 2020). These DEMs were imported and merged into a single geo-referenced raster (surface) map. The DEMs acquired were very high resolution, with each cell measuring 5 X 5 m. This is an unusually high resolution for publicly-accessible satellite data. Typically, the average resolution for such data has been 30 X 30 m. The higher 5 X 5 m resolution had the potential to produce very high-precision estimates, but it had implications for processing the data. In their raw form, the six DEMS included 1.6 billion 5 X 5 m cells, which would have meant unreasonably long processing times, even with a high-performance computing cluster. To reduce the amount of processing time, the six DEMS were resampled at 15 m x 15 m resolution by using a moving-average window after they were stitched together. The lower-resolution raster map was then cropped to fit the study area, focusing specifically on the region where sites were located. Lastly, the map was re-projected from a geographic to Universal Transverse Mercator (UTM) projection (Natural Resources Canada 2008), with the longitude and latitude coordinates converted into meters.

Every cell in the study area was compared to those in a 1-km diameter circular sample area around each known site. There were roughly 3,500 15 m X 15 m cells in each 1-km diameter sample area, depending on where precisely the circle overlapped the cells. The simplest way to quantify the character of the landscape around a known-site was to sample places in the vicinity of that site, measure a given landscape variable, and estimate the corresponding frequency distribution of measurements. From this distribution it was possible to estimate the empirical probability of finding a spot within the site's vicinity that is similar to a location of interest. Each target location was then assigned a probability value that reflects its similarity to the landscape around known sites. The procedure was repeated for each of the six landscape variables used to derive the LAMAP estimate for each target cell compared to each known-site. Once these calculations had been completed, all target locations were divided into five classes (quintiles) of equal size based on their probability values, and ranked from 1 (lowest potential) to 5 (highest potential). The distribution of target locations in each class was then mapped.

In the first LAMAP analysis, half of the known-sites (n=91) were randomly selected to use as the training dataset and the remaining 91 sites were used to validate the model. In the second analysis we divided the dataset into pre- and post-10,000 cal BP sites. We then used the 12 pre-10,000 cal BP sites to train the model and the 60 post-10,000 cal BP known-sites to test it. The validation sample was small because the post-10,000 cal BP set of sites did not include any pre-10,000 cal BP sites with a post-10,000 cal BP component, such as Swan Point. A site was never used to both train and test the model. And, for obvious reasons, no sites of unknown age were used in the second analysis. To prevent data loss due to potential interruptions (like network and/or power outages) each tile was processed separately and then all of the tiles were stitched together.

We used a simple regression analysis to determine whether LAMAP was performing adequately in each analysis. As mentioned, the LAMAP estimates were reclassified into ordinal classes with higher classes representing higher archaeological potential. Thus, if the method was producing useful estimates, there should be more validation sites located on raster cells assigned higher potential classes. Following the validation approach taken in the earlier Belize case study (Carleton et al. 2017), we counted the number of validation sites located in cells of each predictive class and then compared the number of sites to the corresponding predictive class value. The comparison was done with a simple Poisson regression model, chosen because the data are comprised of counts of sites per predictive class. In each model, we used LAMAP class as the “predictor/independent” variable and validation site count as the “response/dependent” variable. We then examined the estimated regression coefficients. Assuming the LAMAP approach was useful, we expected to find evidence for a statistically significant, positive relationship between site counts and LAMAP classes, which would be indicated by positive regression coefficients associated with the LAMAP class variable. In both analyses, the slope of the regression was demonstrably positive. All analyses were conducted in R (see https://github.com/wccarleton/lamap for relevant scripts) and computed on the WestGrid high performance computing cluster that is managed by Canada’s national computing science partnership, Compute Canada (https://www.computecanada.ca/home/).

3.4. Results

In Figure 3.5, the randomly selected training set of sites are represented by white circles while the sites used to test the model’s predictions are represented by blue circles. Areas of high archaeological potential contained most of the second set of validation sites. There is a trend (as demonstrated by the regression results), with more sites being located in higher than lower LAMAP classes. This confirms LAMAP’s ability to predict high potential areas.

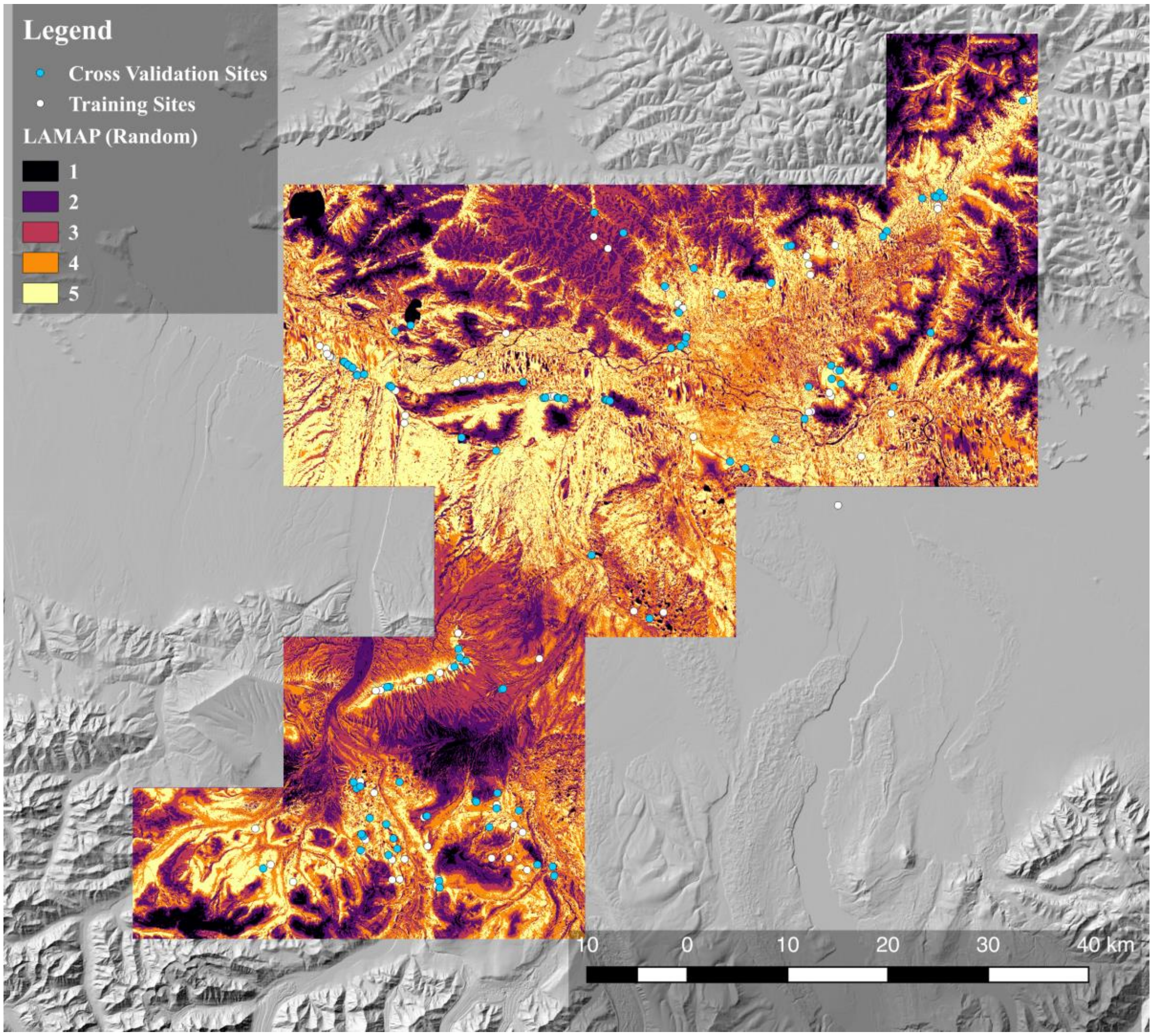

Figure 3.5. **Map of Archaeological Potential based on 91 randomly selected sites (white) and tested with 91 other sites (blue. The five classes of archaeological potential are coded from 1 (lowest potential) to 5 (highest potential).**

As Figure 3.5 shows, more of the sites used to test the LAMAP model (blue circles) are located in areas that LAMAP classifies as Class 3 or higher, with most in Class 4 or 5 locations. There were 19 sites in Class 2 and 21 sites in Class 5 (Table 3.1). While these numbers appear close in magnitude, it is only in the absolute sense. The closeness actually reflects the positive slope of the model's regression results. The differences between potential estimates across classes is not huge unless one goes from a lower class, e.g. Class 1, to a higher one, e.g. Class 5. The model's regression results indicate that the higher classes yield more sites on average. By inference, then, one is better to look in a Class 5 area than a Class 2 area if the goal is to maximize the number of sites found. But, the regression results are not saying that Class 5 is the best area – only that it is likely to be the best area on average.

Certain features of the landscape stand out as having a particularly high potential according to the model, in LAMAP Classes 4 and 5. Some of these features include prominent landscape features, like river valley corridors and the plains between ridges. According to the Poisson regression model results, increasing the LAMAP class by one level corresponds to a 12% increase in the number of sites identified, on average. Despite this, the number of potential sites did not go up, when going from Class 4 to Class 5. This is most likely due to random sampling. The only way to known if the projected average increase is consistent is to rerun the analysis many times and ground truth the model's results. Running the model over and over again does not get away from the problem that LAMAP, like any other predictive model, is biased by the (known sites) data it used to train itself. In practice though, one could expect to find 12% more sites in regions estimated to have a Class of 2 than those estimated to have a Class of 1. Going from a Class 1 region to a Class 5 region, one could expect to find nearly 88% more sites in the latter region compared to the former.

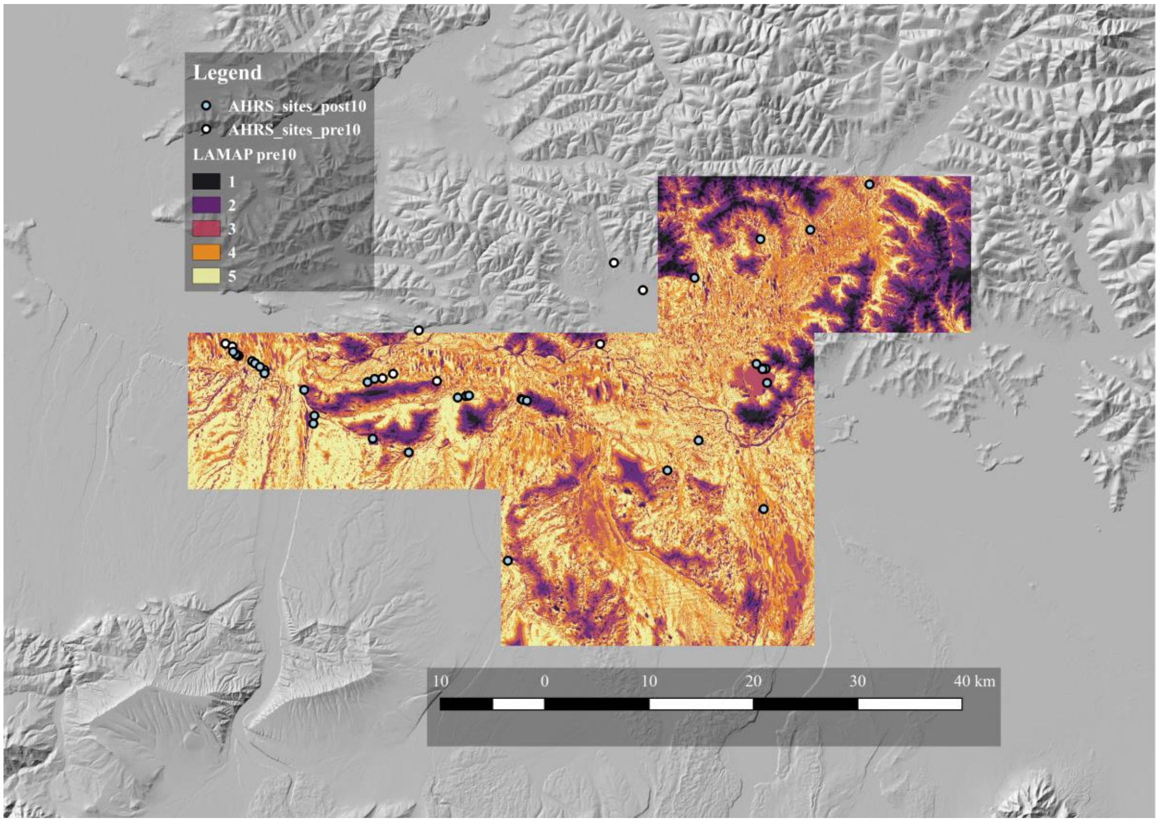

Figure 3.6. **Map of Archaeological Potential based on the location of pre-10,000 cal BP sites (white and tested with post-10,000 calBP dated sites. Sites are dated by radiocarbon and/or artifact typology. Undated sites excluded from analysis. The five classes of archaeological potential are coded from 1 (lowest potential) to 5 (highest potential).**

In Figure 3.6 the pre-10,000 cal BP training set are represented by white circles while the post 10,000 cal BP sites are represented by green circles. As the figure shows, the vast majority of the post-10,000 cal BP sites are located in areas with LAMAP Classes of 3 or higher, with most in Class 4 or 5 locations. The same features highlighted by the first analysis were also highlighted in this second map. These include the same river valleys and plains. The results from the second analysis also demonstrated areas of high archaeological potential and contained more of the later (Holocene) sites. In this analysis, a one class level increase corresponded to a 50% increase in the number of identified sites on average, according to the relevant Poisson regression model. Going from a Class 1 to a Class 5 region would, therefore, be expected to yield nearly 657% more sites on average.

This is an average estimate given the data, results and model used. The estimate is simply that, an estimate, and does not speak to the real underlying distribution of sites in the study area. The results from both analyses suggest that the model is 1) “working” in the sense that there is a relationship between site density and potential as estimated by the model and 2) LAMAP is useful for planning future surveying in the study area.

Table 3.1. Number of sites per LAMAP Class of Archaeological Potential in Both studies.

Class	Random	Pre/Post
1	6	0
2	19	4
3	21	8
4	25	13
5	21	8

Table 3.1 shows the results of both analyses numerically, with the number of sites listed for each LAMAP class. In both analyses, Class 4 had the largest number of sites within it. In the first analysis, 25 sites were found to be located in it. In the second analysis, 13 sites were found in the Class 4 region.

The regression models, one for the first random cross-validation analysis and the other for the second post 10,000 cal BP analysis, were based on the “Poisson Distribution” because the data (number of sites found in each LAMAP Class) are count data. A Bayesian approach to estimate the regression parameters was also used. This involved using a Markov Chain Monte-Carlo (MCMC) simulation for sampling the distribution of the relevant parameters. The MCMC simulations were run for a minimum of 20,000 iterations to ensure convergence. The priors used for the model parameters had a wide variance.

Both sets of regression results support the visual impression that more validation sites are found in areas deemed higher potential by the model. The MCMC chains for both model parameters (Figures 3.7 and 3.8) indicate convergence, which means that the simulation found stable estimates for the posterior distributions of the model parameters.

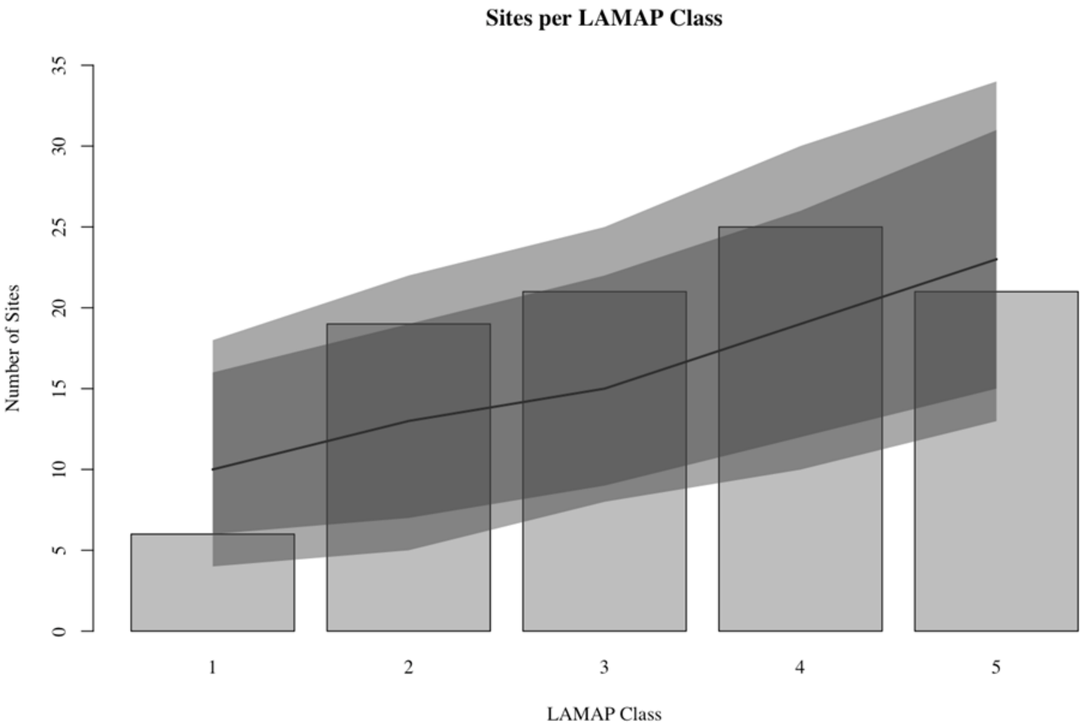

Figure 3.7. LAMAP Counts – Random.
Results of a Poisson regression for each prediction. The grey vertical bars indicate the number of sites located in a region with the given potential estimate.

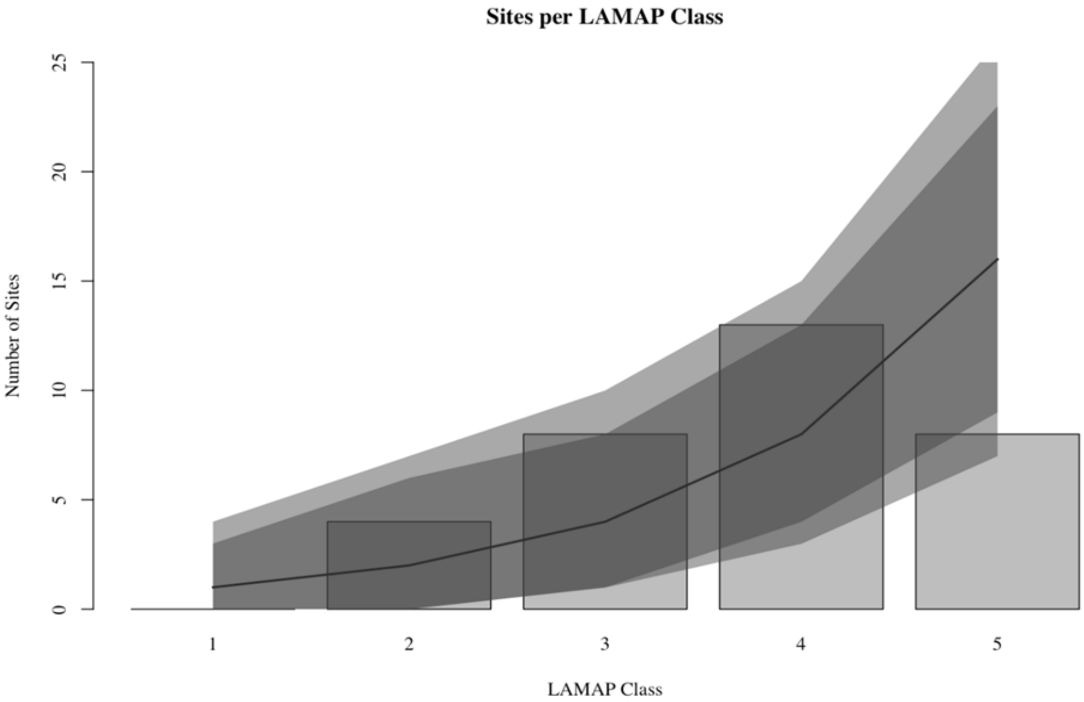

Figure 3.8. LAMAP Counts – Pre-10,000 cal BP.
Results of a Poisson regression for each prediction. The grey vertical bars indicate the number of sites located in a region with the given potential estimate.

Figures 3.7 and 3.8 show the results of a Poisson regression for each prediction. The grey vertical bars indicate the number of sites located in a region with the given potential estimate. Both plots show that more sites were found in areas the LAMAP model predicts to have higher potential. There were more randomly chosen cross-validation sites located in high potential areas than in low potential areas. Similarly, there were more post-10k sites located in high potential areas than in low potential ones.

The regression models confirm this impression. The solid black trend-lines in both plots indicate the expected number of sites for a given LAMAP class according to the Poisson regression model. This line trends upwards for both predictive surfaces. The 95% and 99% posterior predictive intervals (indicated by the darker and lighter grey transparent ribbons in Figures 3.7 and 3.8) also include the observed data and indicate an upward trend.

The regression models also provide estimates of the effect of increasing LAMAP class on the number of sites identified in each analysis. This estimate is given by the posterior distribution of the regression coefficient (Figures 3.9 and 3.10).

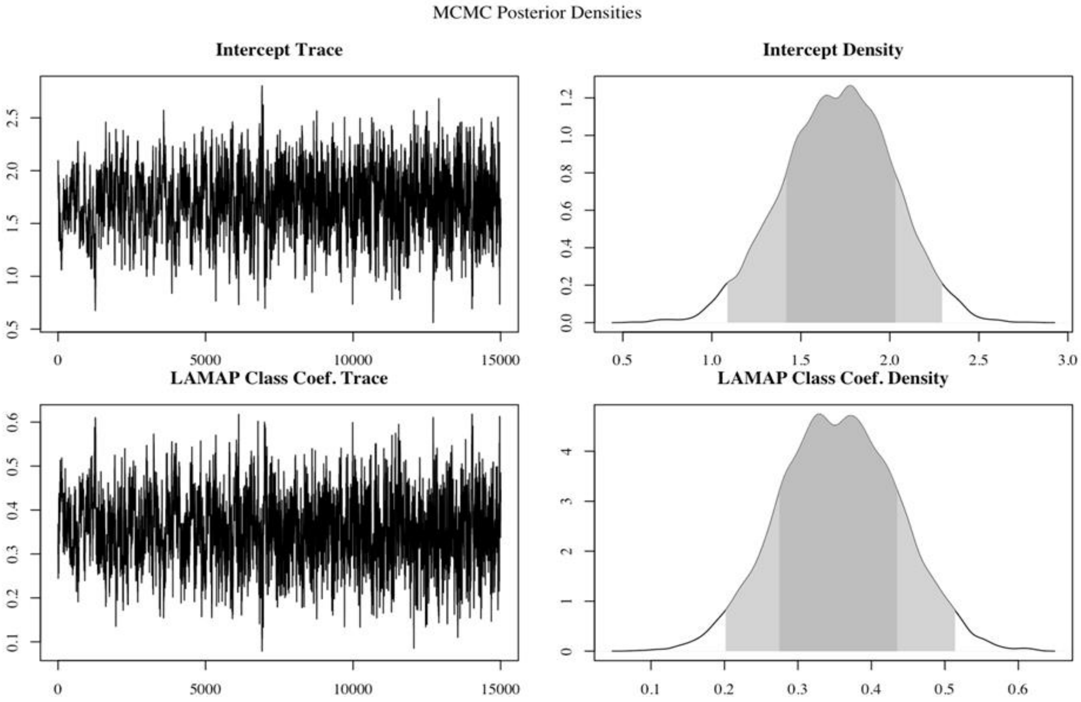

Figure 3.9. Plot showing the regression results for the random model.
On the left, the diagnostic of Class levels & number of sites. On the right, the distribution of the regression coefficient & the intercept.

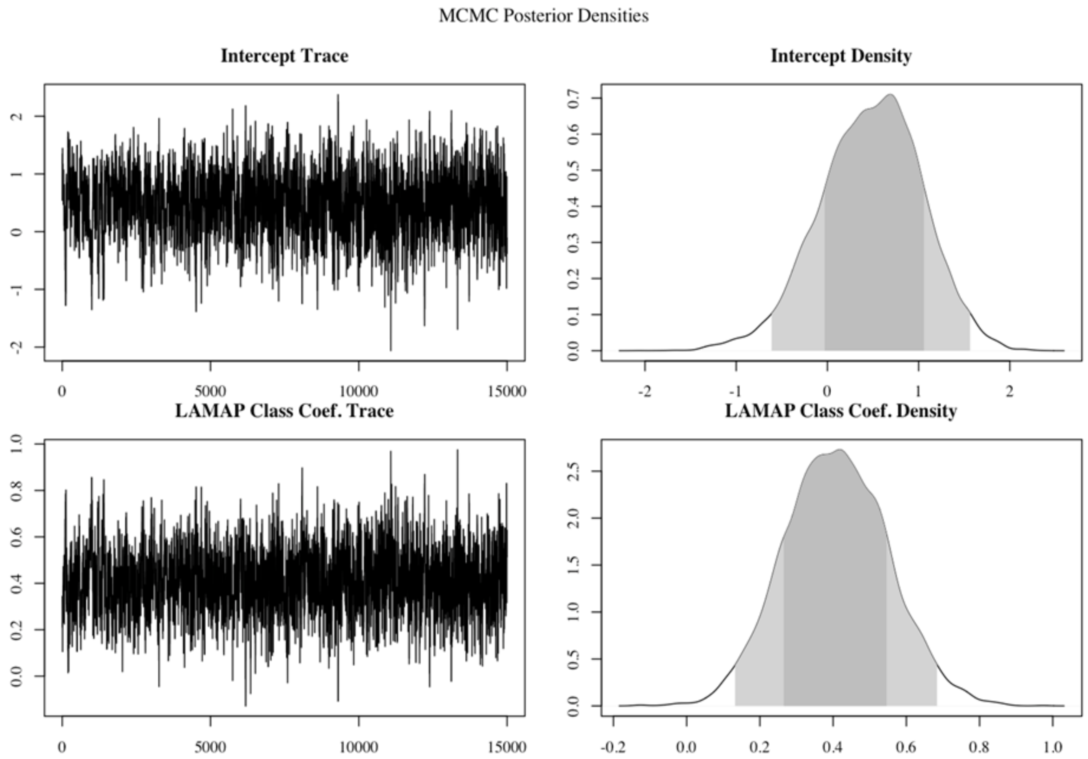

Figure 3.10. Plot showing the regression results for the Pre-10K.
On the left, the diagnostic of Class levels & number of sites. On the right, the distribution of the regression coefficient & the intercept.

The model's regression results demonstrate that the higher classes have the best chance of containing sites within them, even if there are small differences between potential estimates, the number of sites per class. The results of the second analysis may appear to be better, but it is important to consider that it is a very limited subsample of the original data. As a result, the small sample size is more susceptible to sampling effects, which could give a false impression about the relationship between LAMAP class and the number of sites in the test sample. Since the sampling effects may give rise to a false impression, archaeological potential may be over estimated.

3.5. Discussion

This is the first application of LAMAP to a region occupied by mobile hunter-gatherers. The first part of the study used the location of a random selection of known sites from all time periods to model the archaeological potential of the study area within the Tanana River Valley of Central Alaska. The data that were considered related to the underlying structure of the landscape (variables such as elevation and slope), rather than the resources that might potentially be exploited by hunter-gatherers (such as stone tool sources or concentrations of game). The model was tested by analyzing the location of a second set of randomly selected known sites. Areas of high archaeological potential defined by the first set of sites contained higher frequencies of sites from the second set, and thus validated the model's ability to predict areas of higher archaeological potential.

The second part of the study built a model based only on data from 12 pre-10,000 cal BP sites. The model was then tested with sites from later time periods (post-10,000 cal BP). The areas of high potential based on the earlier (Late Pleistocene) sites were validated by the higher frequencies of later (Holocene) sites. These results suggest that relatively stable landscape variables (such as aspect or distance to drainages) structure hunter-gatherer site locations, even though biotic variables may have changed through time.

Six variables were used in this study; elevation, slope, aspect, distance to drainages, cumulative viewshed and convexity. Much of the highest potential region (Class 5) includes prominent features overlooking a river valley. The PCA indicated that the landscape variables aspect, convexity and distance to drainages account for 70% of all variation. But, the variables distance to drainages, elevation and slope correlate the most with each other. The PCA showed that all the variables load on the top three principal components to some extent but that the top three, aspect, convexity and distance to drainages, together dominate the variability in the landscape, and as such, have the greatest potential for distinguishing between locations. The variables contributing most to variation in the landscape allow us to discriminate between high and low potential areas. While LAMAP looks at the correlation of all six variables as a whole, we can gain insight by reviewing the data associated with each variable. In this regard, distance to drainages is an important variable to consider. It factors into both the overall variation and in the first PCA.

Given that distance to drainage features so prominently in this study's results suggests that the variable was important to early hunter-gatherers in the Tanana River Valley. Accessing a reliable water source would have been important to First Peoples for a variety of reasons, such as sourcing water for drinking, washing, bathing and other activities. Waterways such as rivers, streams and creeks would also have attracted animals that were an important food source for First Peoples. Waterways were also important travel routes, especially in mountainous terrain. When travelling on foot, the easiest way for people to move from higher elevations to lower ones would have been for them to follow a gently sloping, incised drainage, such as on the shore beside a river or stream. Larger drainages, such as a river valley, would also have acted like highways for both people and animals, especially in winter.

These reasons, as well as others, would be good material for a deeper discussion about the LAMAP predictive model and may have implications for future research. One future research question could be, why does the variable distance to drainage correlate so strongly with the first PCA? Clearly, there is something about this study area that causes distance to drainage (that's distance to relatively major drainages, not just any potential drainage) to be so highly variable.

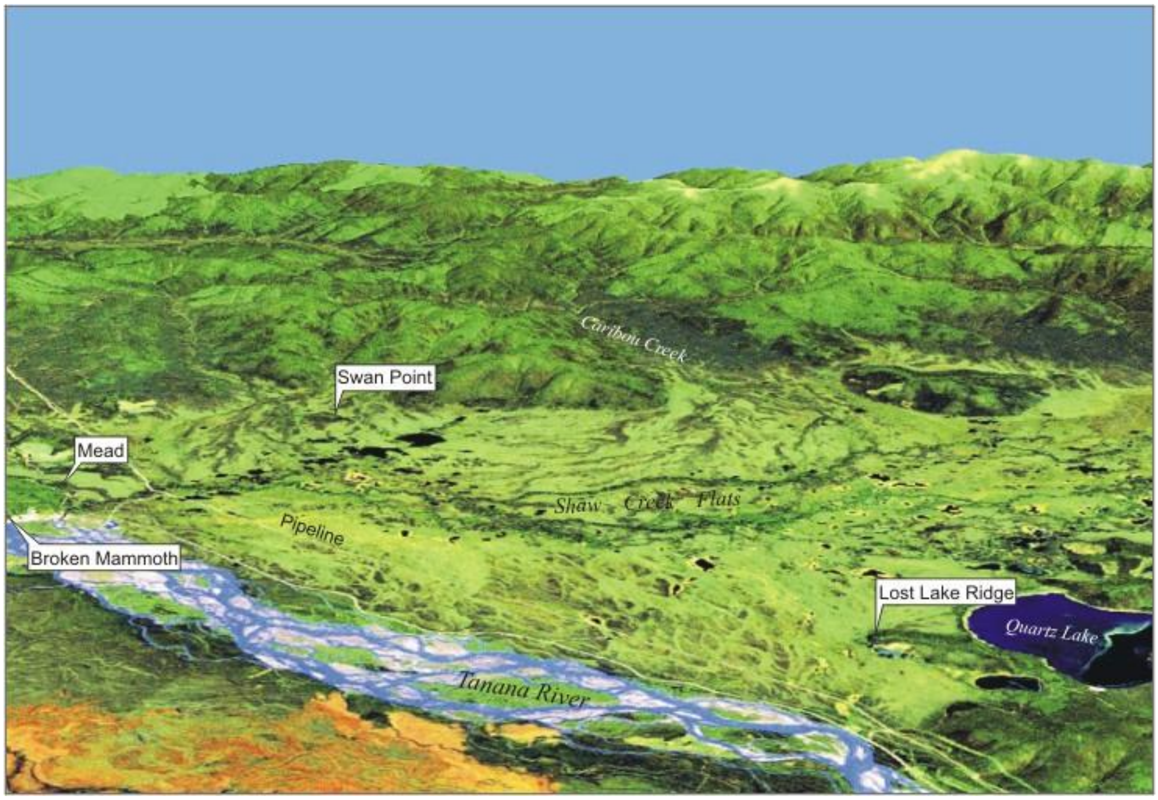

Figure 3.11. A DEM of relevant archaeological sites in the Lower Shaw Creek Valley. Used with permission. Retrieved from: http://www.alaska.net/~taiga2/Swan_Point.html.

Swan Point is located on top of a ridge at 322 meters above sea level and strategically overlooks up to 86% of the surrounding Shaw Creek and Tanana and Yukon Rivers Uplands (Lanoë and Holmes 2016). The site's location is striking because it lies at the boundary of uplands and lowlands and has a high vantage point over the surrounding landscape (Figure 3.11). Clearly, the LAMAP variables of distance to drainage, elevation and slope are factors in this area. However, Swan Point is not located in the highest potential area (Figure 3.12).

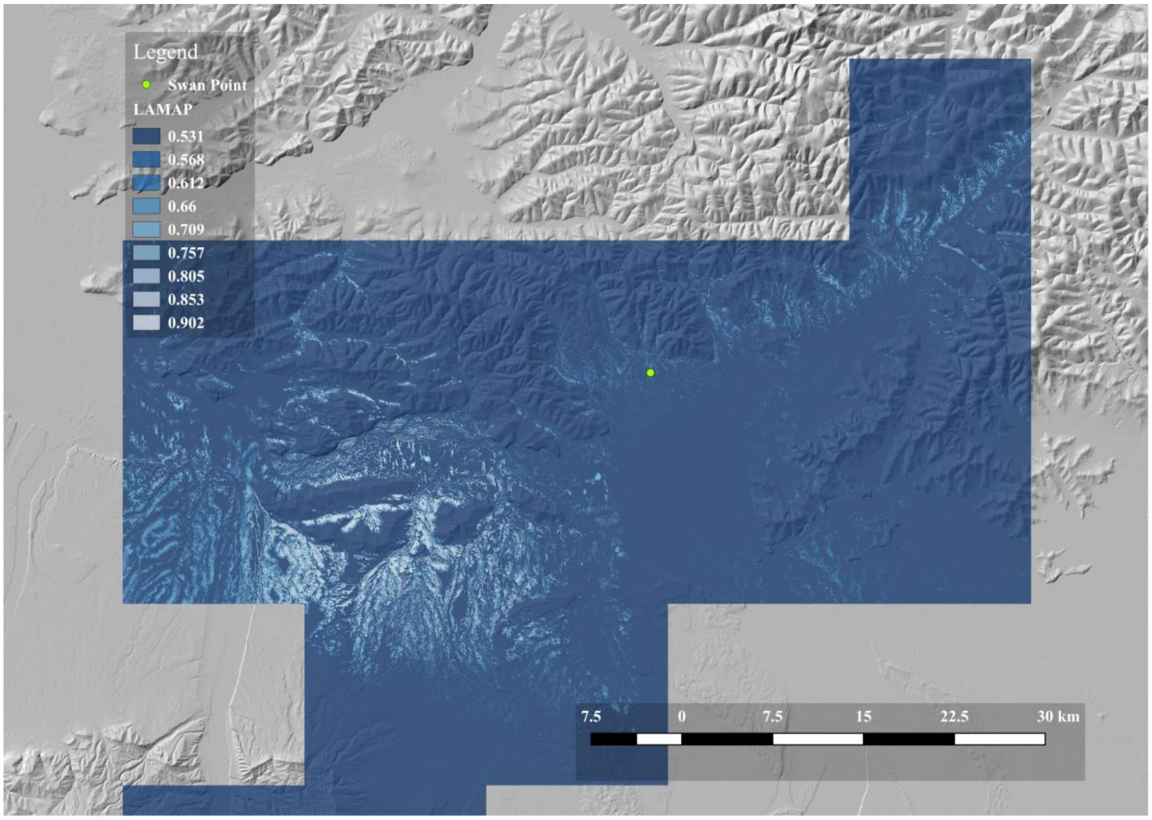

Figure 3.12. Swan Point in relation to the Top 10 Percent of the LAMAP Class 5 predictive area.

LAMAP, like any other predictive model, cannot differentiate between earlier and later sites in terms of landscape use – site age is not being predicted. If there is no difference between older and younger sites in terms of locational preference, there is no way to specifically target older sites with LAMAP. But, the model did predict more sites, both older and younger, in higher potential areas, such as Classes 4 and 5. Therefore, older sites, such as Swan Point, are just as likely to be found in higher potential areas.

In June of 2019, Rob Rondeau visited central Alaska and saw first-hand several pre-10,000 cal BP sites in the Tanana River Valley including the oldest, Swan Point (Figures 3.3 & 3.4). Most of these sites were located within the Shaw Creek basin, a major tributary of the Tanana River. In fact, all of the sites in the study area dating before

10,000 cal BP are found overlooking tributaries or tributary confluences with the Tanana River, Canyon Creek, and the Big and Little Delta Rivers.

3.5.1. Limitations

As with any other predictive model, LAMAP is biased towards the training dataset which is made up of the known archaeological sites in the study area. The LAMAP model, or any other model for that matter, can only make predictions based on the training data used. The data sample used in this study is the only information we have about the location of prehistoric sites in the Tanana River Valley. Therefore, it is the best source of data for us to use in predicting the location of additional sites there. Because the site database is the result of numerous archaeological projects with different objectives, we clearly do not have a representative sample of the universe of archaeological sites preserved in the study region. But, given that the sites in the training data set were used by First Peoples, we can say that the LAMAP model is indicative of landscape behaviour (people's preference for certain locations) for at least some sub-set of the site types. The model is indeed telling us about past site location preferences even if it is biased by the sampling preferences of the archaeologists.

The LAMAP model was successful in identifying areas in the Tanana River Valley that have high potential for containing archaeological sites, demonstrating that the model is useful in making predictions about archaeological potential in a hunter-gatherer context. In addition to finding sites, understanding the landscape preferences of hunter-gatherers in the past is equally important. This research improves our understanding of how people in the distant past situated themselves on the landscape, opening the door to further archaeological investigation.

3.5.2. Future Directions

This study indicates that LAMAP can successfully predict the location of areas that have a high potential to contain hunter-gatherer sites in Central Alaska, just as previous studies have shown that LAMAP can predict the location of areas that have a high potential to contain Mayan sites in Belize or Imperial Roman sites in Turkey (as well as other sites there from different time periods). In this case study, LAMAP identified areas of high predictive value that warrant further investigation. The only real way to know if the LAMAP model works in Alaska though is to field test (ground truth) the results. Just like in the other two previous case studies, it will be a matter of surveying all areas of potential, not just the high potential ones, and comparing the results.

3.6. Conclusions

The results may reflect the biases of the archaeologists who excavated the known sites. For example, most known sites within the Tanana River Valley are found near major highways or the Trans- Alaska Pipeline (Pipeline 2011). But, LAMAP identified “high potential” areas in the study area that have never been investigated by archaeologists. As a result, these key areas warrant further archaeological investigation. Key landscape features include ridges, hills and knolls overlooking rivers. There is a high probability that as yet undiscovered sites, which pre-date 15,000 cal. BP, exist within the Tanana River Valley.

Using LAMAP allowed us to see how people in the Tanana River Valley may have used the landscape there in the distant past. This is in line with what archaeologist Charles Holmes believes. He suggests that Swan Point and other nearby early sites, such as Broken Mammoth or Mead, represent “overlook sites” from which game could be spotted and a variety of microenvironments exploited (Holmes 2004). Both LAMAP predictive maps suggest possible “corridors of use” – the areas that are brightest in colour – which may reflect resource pathways or how people moved on the landscape.

3.7. Supplementary Materials

AHRS Sites Database

Data from the Alaska Heritage Resources Survey, the State of Alaska's Office of History and Archaeology.

Site	Components	Stratified	Pre-10K BP	10–5K BP	5K BP - Present	Date Unknown
HEA_00102	Single	No				X
HEA_00103	Single	No				X
HEA_00104	Single	No				X
HEA_00685	Single	No				X
XBD_00010	Single	No				X
XBD_00011	Single	No				X
XBD_00012	Single	No				X
XBD_00013	Single	No				X
XBD_00014	Single	No				X
XBD_00015	Single	No				X
XBD_00017	Single	No				X
XBD_00018	Single	No				X
XBD_00019	Single	No				X
XBD_00028	Multi	Yes	X			
XBD_00031	Single	No				X
XBD_00042	Single	No				X
XBD_00071	Multi	No				X
XBD_00072	Single	No				X
XBD_00073	Single	No				X
XBD_00089	Single	No				X
XBD_00106	Multi	No			X	
XBD_00107	Single	No				X
XBD_00108	Single	No				X
XBD_00109	Single	No				X
XBD_00110	Single	No			X	
XBD_00131	Multi	Yes	X	X	X	
XBD_00155	Multi	Yes	X	X		
XBD_00156	Multi	Yes	X	X	X	
XBD_00157	Single	No				X
XBD_00158	Single	No				X
XBD_00159	Single	Yes			X	
XBD_00160	Single	No				X
XBD_00161	Single	No				X
XBD_00165	Single	No				X

Site	**Components**	**Stratified**	**Pre-10K BP**	**10–5K BP**	**5K BP - Present**	**Date Unknown**
XBD_00166	Single	No				X
XBD_00167	Single	No				X
XBD_00171	Multi	Yes				X
XBD_00183	Multi	Yes			X	
XBD_00235	Single	No			X	
XBD_00247	Single	No				X
XBD_00265	Single	No				X
XBD_00283	Single	No			X	
XBD_00286	Single	No			X	
XBD_00287	Single	No			X	
XBD_00288	Single	No		X		
XBD_00289	Single	No	X			
XBD_00290	Single	No	X			
XBD_00291	Multi	No	X			
XBD_00297	Single	No	X			
XBD_00298	Multi	Yes	X			
XBD_00299	Single	No				X
XBD_00300	Single	No				X
XBD_00301	Single	No			X	
XBD_00302	Single	No				X
XBD_00303	Single	No		X		
XBD_00304	Single	No				X
XBD_00305	Single	No				X
XBD_00306	Single	No				X
XBD_00307	Single	No		X		
XBD_00308	Single	No	X			
XBD_309	Single	No				X
XBD_00311	Single	No		X		
XBD_00312	Single	No		X		
XBD_00313	Single	No		X		
XBD_00314	Single	No				X
XBD_00315	Single	No				X
XBD_00316	Single	No			X	
XBD_00317	Single	No		X		
XBD_00318	Single	No				X
XBD_00319	Single	No				X
XBD_00320	Single	No				X
XBD_00321	Single	No				X
XBD_00322	Single	Yes				X
XBD_00323	Single	Yes				X
XBD_00324	Single	No			X	
XBD_00325	Single	No		X		

Site	Components	Stratified	Pre-10K BP	10–5K BP	5K BP - Present	Date Unknown
XBD_00326	Single	No		X		
XBD_00327	Single	No				X
XBD_00328	Single	No			X	
XBD_00335	Multi	Yes			X	
XBD_00338	Multi	Yes	X			
XBD_00339	Multi	Yes		X	X	
XBD_00340	Single	No		X		
XBD_00341	Single	No		X		
XBD_00342	Single	No			X	
XBD_00343	Single	No				X
XBD_00344	Single	Yes			X	
XBD_00345	Single	No				X
XBD_00361	Single	No			X	
XBD_00362	Single	No			X	
XBD_00363	Single	No	X			
XBD_00371	Single	No				X
XBD_00374	Single	No				X
XBD_00377	Single	No				X
XBD_00378	Single	No				X
XBD_00383	Single	No				X
XBD_00389	Single	No				X
XBD_00390	Single	No				X
XBD_00391	Single	No				X
XBD_00392	Single	No				X
XBD_00393	Single	No				X
XBD_00407	Single	No				X
XBD_00410	Single	No				X
XBD_00411	Single	No		X		
XBD_00412	Single	No			X	
XBD_00413	Single	No				X
XBD_00415	Single	No				X
XBD_00416	Single	No				X
XBD_00417	Single	No				X
XBD_00418	Single	No				X
XBD_00419	Single	No				X
XBD_00421	Single	No				X
XBD_00422	Multi	Yes				X
XBD_00425	Single	No				X
XBD_00426	Single	No				X
XBD_00427	Single	No				X
XBD_00428	Single	No				X
XBD_00429	Single	No				X

Site	Components	Stratified	Pre-10K BP	10–5K BP	5K BP - Present	Date Unknown
XBD_00430	Single	No				X
XBD_00431	Single	No				X
XBD_00444	Multi	Yes		X	X	
XBD_00445	Single	No				X
XBD_00448	Single	No			X	
XMH_00232	Single	No				X
XMH_00233	Single	No				X
XMH_00234	Single	No				X
XMH_00235	Single	No				X
XMH_00236	Single	No				X
XMH_00237	Single	No				X
XMH_00299	Single	No				X
XMH_00300	Single	No				X
XMH_00301	Single	No				X
XMH_00302	Single	No				X
XMH_00303	Single	No				X
XMH_00304	Single	No				X
XMH_00305	Single	No				X
XMH_00306	Single	No				X
XMH_00307	Single	No				X
XMH_00310	Single	No				X
XMH_00313	Single	No				X
XMH_00829	Single	No				X
XMH_00830	Single	No				X
XMH_00831	Single	No				X
XMH_00832	Single	No				X
XMH_00833	Single	No				X
XMH_00834	Single	No				X
XMH_00835	Single	No				X
XMH_00836	Single	No				X
XMH_00837	Single	No				X
XMH_00839	Single	No				X
XMH_00840	Single	No				X
XMH_00841	Single	No				X
XHM_01414	Single	No				X
XHM_01415	Single	No				X
XMH_01434	Single	No				X
XHM_01435	Single	No				X
XMH_01436	Single	No				X
XMH_01437	Single	No				X
XMH_01438	Single	No				X
XMH_01439	Single	No				X

Site	Components	Stratified	Pre-10K BP	10–5K BP	5K BP - Present	Date Unknown
XMH_01440	Single	No				X
XMH_01441	Single	No				X
XMH_01442	Single	No				X
XMH_01443	Single	No				X
XMH_01444	Single	No				X
XMH_01445	Single	No				X
XMH_01446	Single	No				X
XMH_01447	Single	No				X
XMH_01448	Single	No				X
XMH_01449	Single	No				X
XMH_01450	Single	No				X
XMH_01451	Single	No				X
XMH_01452	Single	No				X
XMH_01453	Single	No				X
XMH_01454	Single	No				X
XMH_01491	Single	No				X
XMH_01492	Single	No				X
XHM_01544	Single	No				X
XHM_01545	Single	No				X
XHM_01549	Single	No				X
XHM_01550	Single	No				X
XHM_01551	Single	No				X

Note: GPS Co-ordinates for each site have been redacted to protect site locations.

Chapter 4.

Discussion

The results for LAMAP in Alaska demonstrate that the model was successful in predicting archaeological potential in the Tanana River Valley of Central Alaska. Two analyses were run. In the first, half of the sites in the dataset were randomly selected to train the model. The other half were used to test LAMAP. The areas deemed to have the highest potential for containing sites (LAMAP Classes 3, 4 and 5) contained most of the second half of the validation sites, thereby confirming LAMAP's ability to predict high potential areas. In the first analysis, increasing the LAMAP class by one level corresponded to a 12% increase (on average) in the number of sites identified. This would mean that one could expect to find 12% more sites in areas estimated to be Class 2 compared to those areas estimated to be Class 1. This is expressed visually in the (surface) map (Figure 3.5), with the highest class, Class 5, being the brightest in colour (yellow), and, the subsequent classes, 4,3,2 and 1, being darker in colour, with Class 1 being black. Going from a Class 1 region to a Class 5, one could expect to find nearly 88% more sites (in Class 5 compared to Class 1). In the second analysis, the pre-10,000 cal BP sites were used to train LAMAP and the post-10,000 cal BP sites were used to test the model. However, this time one could expect to see a 50% increase in sites when moving from one class to another, i.e. going from Class 1 to Class 2 and so on. When going from Class 1 to Class 5 though one could expect nearly 657% more sites on average. Again, the model's results are visually displayed in the map (Figure 3.6) with Class 5 being bright yellow and Class 1 being black in colour.

The first random analysis was run only once. In a sense, we were looking at a sample of a sample. If we re-ran the analysis many times, we don't know what the results would be. They may be better, but they may be worse. So, the patterns we see in the results shouldn't be seen as being “stable”. Likewise, we shouldn't focus on the specific number of sites that fall into a given LAMAP class in either analysis. Rather, we should focus on the average trend (slope) of each model's results. The second analysis involved a small number of sites. Its results are even more susceptible to sampling fluctuations. It could appear to be performing very well when, in fact, the model is actually not. As a result, we need to be very careful in interpreting its results.

When interpreting all of the findings of this study we also need to consider how landscape use and landscape variability factors into the model's utility. For example, as more and more people occupied the study area, doing different activities at different sites at different times, we would expect LAMAP to have trouble distinguishing between areas of high and low archaeological potential. This is because there would be little difference in the underlying probabilities of land use for different locations, except at the extremes, i.e. there would be no sites on mountain peaks or at the bottom of a river. This would be even more true in a highly variable landscape.

But, by finding more sites, especially early ones, we can do a better analysis of the archaeological landscape of the Tanana River Valley. Theoretically speaking, finding more sites is not at odds with trying to understand the distribution of sites on a landscape. It is more a meta-analytical difference, with the one being sequential to the other. With more sites, you can do more detailed analysis.

The results from both analyses suggest that some landscape variables such as aspect and distance to drainages structure hunter-gatherer site locations. Given the model's results, there is no evidence of a change in First Peoples' landscape preferences over time. These two variables were clearly important to the earliest inhabitants of the Tanana River Valley, as evidenced by the earliest known site, Swan Point at 14,450 cal BP, to more recent sites dating from the Holocene. The archaeological evidence for all time periods confirms that First Peoples preferred sites situated on a hillside or hilltop that were also close to a major water source, such as a river or stream. It is quite possible that the rationale for these site preferences had to do with the hunting and processing of the game that they relied upon, such as mammoth, bison and caribou. Both of the variables, aspect and distance to drainage are key indicators that researchers should consider when focusing their efforts in the future to find undiscovered sites.

Just like in the two previous applications of LAMAP, in Belize (Carleton et al. 2017) and Turkey (Wilett et al. 2019), in Alaska the model gave us the ability to study a remote area that would otherwise be difficult to access. Modelling the archaeological potential of the study area also provided us with valuable insight into how people in the past occupied the landscape of the Tanana River Valley. In all three applications, the location of all known sites was entered along with the natural landscape variables that influenced the land-use choices made by people in the past. In the Turkey case study, cultural variables such as the proximity to urban centers and ancient roadways were also used. The results from all three applications of LAMAP showed that the model produced potential estimates that strongly correlated with the archaeological resources found within the study area – although the results from Alaska have yet to be field-tested. This means that the variables used were important to past human-landscape interaction.

The Alaska application of LAMAP also demonstrates the model's usefulness for identifying areas on a terrestrial landscape that have high potential for containing hunter-gatherer sites. As such, it would be a useful technique for heritage management in other regions where mobile hunter-gatherers dominate the archaeological record, such as in Canada's boreal forest. Given that large datasets of site information now exist in many regions, the result of decades of archaeological surveys mandated by local and national legislation, researchers could develop similar LAMAP models for other regions – just as we did in Central Alaska.

4.1. Looking for Sites Underwater

The idea now is to take LAMAP and apply it to parts of the PNWC in an attempt to find new archaeological sites underwater. Some formerly terrestrial sites now underwater have been found accidentally, such as the discovery of the "Cinmar stone knife" (see Chapter 2). This large laurel-leaf biface was found on the bottom of the sea by the commercial scallop dredging vessel Cinmar in Chesapeake Bay, off the coast of Virginia in the 1970s (Stanford and Bradley 2012).

On the PNWC, to date no pre-10,000 cal BP archaeological sites have been found underwater either accidentally or by archaeologists intentionally looking for sites. In the mid-1970s, fragments of mammoth and mastodon tusks were recovered at a depth of approximately 40 meters by a NOAA research expedition taking sediment samples from the bottom of the Bering and Chukchi Seas. There was no evidence of human involvement though (Dixon 1983). Archaeological sites have been found in the inter-tidal zone on the PNWC by archaeologists who have extended their surveys on the shore into shallow water. A large-scale wooden stake fish trap was investigated at Comox Harbour on Vancouver Island (Greene et al. 2015). It dates to 1,400 cal BP and was used by Indigenous peoples to catch salmon. Evidence of ancient shellfish mariculture has also been found on the PNWC (Lepofsky et al. 2015). The process involves building “clam gardens”, intertidal terraces, which increase the productivity of bivalve habitat. Indigenous communities on the PNWC have a long history of using clam gardens to feed themselves. Some clam gardens on Quadra Island, for example, have been dated to 3,700 cal BP. Older, now submerged, clam gardens may yet be found at other locations, such as in the Gulf Islands or San Juan Islands, where sea levels have rose substantially since the beginning of the Holocene (Lepofsky et al. 2015).

In more recent years, archaeologists have also used underwater remote sensing technologies in an attempt to find sites in deeper water. In 2010, several Alaskan surveys were undertaken to identify archaeological potential in areas of the seafloor in Bristol Bay, Shaken Bay and the Gulf of Esquibel (Dixon and Monteleone 2014). Sediment samples were recovered using a Remotely Operated Vehicle (ROV) but no evidence of cultural occupation was recovered.

The only underwater archaeological survey project on the PNWV to produce archaeological evidence was conducted between 1997 and 1999 in western Hecate Strait near Haida Gwaii (Fedje and Josenhans 2000). A total of 10 km^2 of the sea floor was mapped using multibeam sonar. Using a clamshell grab bucket, researchers recovered and screened sediment from several sites. They recovered buried wood and other evidence of the ancient terrestrial environment. The only evidence of human occupation was a single basalt blade-like flake recovered from sediments at a depth of 53 meters at a site in Werner Bay, one kilometer offshore of Moresby Island. Based on the sea-level history for the area, researchers suggested 10,000 cal BP as the age of this site, but this was not confirmed by radiocarbon dating of barnacles adhering to the artifact.

In addition to archaeological sites being found using methods such as accidental finds, excavations in inter-tidal areas and through the use of underwater remote sensing technologies, some researchers are now using predictive modelling in an attempt to find new sites underwater.

4.2. Predictive Modelling For Surveying Underwater

There is little doubt that it will be extremely difficult to find former terrestrial sites on the PNWC that are now on the ocean floor. Not only are there huge technical and logistical challenges, but the potential survey area is vast. Using a predictive model like LAMAP, which can identify areas with high archaeological potential, could improve the chances of finding as yet undiscovered sites underwater.

In recent years, several different types of predictive modelling approaches have been used in an underwater or coastal archaeology context in other parts of the world. Some have been very successful in locating sites, such as the use of agent based modelling in Lake Huron, while others have been less so, i.e. the application of an ideal free distribution model at Santa Rosa Island, and some hold promise for the future, i.e. using agent based modelling in conjunction with other remote sensing technologies to study Doggerland.

4.2.1. Lake Huron Case Study

An agent based model (ABM) typically simulates the actions of “agents”, autonomous decision-making entities, to assess their effect on a system as a whole (Bonabeau 2002). The goal of an ABM is usually to see what happens when the various agents interact with each other. ABMs are often complex computer simulations not statistical models like LAMAP. It is easy for the programmer to make an agent(s) do what you want them to, such as in a video game. For example, if the programmer tells the agents to “do X”, they do it - which means that if your validation of the model involves seeing whether the agents “do X” it is guaranteed by the model’s design that they will. The more complex an ABM is the more likely it is to produce unintended behaviours that makes them hard to evaluate. Instead of calculating similarity, like LAMAP does, the goal of many agent-based models is to create a sense of realism, giving the viewer an idea of what a particular landscape looked like in the past. This isn’t to say that ABMs do not work. In a sense, all predictive models have some assumptions built into them and most “work” to some extent. They are all better than randomly picking places on the landscape to look for sites.

Researchers in Lake Huron were able to create an agent-based simulation of ancient caribou herd movements across the now submerged Alpena-Amberley Ridge, dating to approximately 9,500 cal BP locating archaeological sites there (Reynolds et al. 2014). Using present-day herd movement data and ethnographic information, they were able to predict the location of ancient hunting sites that are now submerged in over 40 meters of water. First, they detected “hot spots” on the submerged landscape, which represented areas likely to contain hunting structures (O’Shea et al. 2014). Then, by combining information about caribou migratory behaviour and ethnographic and archaeological data, researchers simulated how caribou and hunters might have interacted on the landscape.

An important result of the simulation was the prediction that there should be distinct seasonal routes, one in the spring and one in the fall. The simulation also highlighted two critical “choke points” within the study area - where all preferred migration routes for both seasons converged. Using the model’s results, the team identified underwater more than 60 drive lanes and hunting blinds, as well as possible caribou meat caches and associated artifacts (O’Shea et al. 2014; O’Shea and Meadows 2009). This modelling approach worked very well in this instance because caribou are well documented in the archaeological record for the area surrounding Lake Huron. It was an accurate assumption, on the researchers part, to assume that caribou behaved in the past the same way that they do in the present. A problem in using this approach on the PNWC is that we know very little about what game First Peoples hunted and how and where these animals moved on the landscape.

4.2.2. Doggerland Case Study

The University of Bradford’s (U of B) ongoing “Europe’s Lost Frontiers” project (Gaffney et al. 2017) aims to study past environments, ecological change, and the transition between hunter-gathering societies and farming in north western Europe during the Mesolithic. The project’s research team is using agent-based modelling in conjunction with relative sea level models and other data relating to climate and landform change to map and model ecological processes and simulate the interaction between animals, plants and the environment of “Doggerland” (Coles 2000). Until sea levels rose at the end of the LGM, approximately 10,000 cal BP, Doggerland, the area now under the North Sea, connected Britain to Scandinavia and the European continent.

The aim of the research is to recreate what the landscape looked like in the past. Researchers suggest that agent-based modelling allows for different hypotheses and "what if" scenarios, and ultimately, will allow them to better understand how people adapted to a changing landscape over time (University of Bradford 2020). The geophysical data being used by the U of B researchers to map the topography of the ancient drowned and buried landscapes of Doggerland comes from several sources, most notably from offshore petroleum exploration (Cohen and Peeters 2019; Gaffney et al. 2007). The database of donated 3D seismic data represents approximately 45,000 km^2 of inundated prehistoric landscape in the North Sea.

Researchers are attempting to reconstruct the palaeogeography of Doggerland prior to inundation (Bicket A. R. et al. 2016) using the donated underwater survey data. Using the data in conjunction with the archaeological data from known coastal sites, they are focusing on how relative sea level has changed over time For example, the radio-carbon date from hazelnut shells at one site confirmed that at 9,600 cal BP the shoreline was 1.3 kms farther out than it is presently. Researchers have been able to infer that, in this particular part of the English coastline at that time, people chose to establish their settlement at a site that was set back from the ocean shore, close to a small stream estuary. The researchers also speculated that larger known sites in the neighbouring area were likely associated with smaller processing ones that would have been closer to the shore, but are now underwater.

More recently, the U of B research team used the survey data to recover two pieces of flint from a depth of 32 m near Cromer (BBC 2019) . The smaller piece was possibly the waste product (debitage) of stone tool making, but the second larger piece appears to be part of a hammerstone. Researchers concluded that, before inundation, the area was once woodland. Previous offshore surveys in the areas identified geophysical features, such as the location of ancient river valleys, marshlands, hills and even cliffs, but never evidence of human activity.

While the use of an agent based modelling approach has not directly resulted in finding any sites in Doggerland, its use has contributed to a better understanding of what the now submerged paleo-landscape looked like in the past. This combined approach of using the results from several sources, e.g. predictive modelling, seismic and 3D survey data and others, is useful and is worth consideration in my future research.

4.2.3. Channel Islands Case Study

Researchers have used an Ideal Free Distribution (IFD) model to study the arrival of people on Santa Rosa Island, one of the Channel Islands off the coast of California (Jazwa et al. 2015). The IFD model is based on behavioral ecology and, basically, states that animals will distribute themselves amongst resource patches so as to maximize resource acquisition and minimize competition (Kennedy and Gray 1993). In this case study, habitat suitability was used to make predictions about how people situated themselves on Santa Rosa Island (Tregenza 1995). While not underwater, the survey area is situated in a coastal context and would have been used by prehistoric peoples who were marine-adapted. The goal of the IFD model was to calculate the relative suitability of different habitats on the island based on the spatial distribution of available environmental resources. The model predicted that people should first settle the habitat with the highest overall suitability. As population density increased on the island, resource exploitation and competition should have caused a decrease in the effective suitability of that habitat. As a result, people would have expanded into and settled in lower-ranked habitat. According to the IFD model, the earliest settlements there should occur at the highest-ranked locales.

Four locations on Santa Rosa Island were studied, with habitat value ranked from lowest to highest. The IFD model predicted that higher ranked areas should show evidence of resource depression before lower ranked ones. But, the archaeological evidence for the earliest sites on the island was distributed in both the high and middle-ranked areas. Researchers suggested that any of the better locations on Santa Rosa Island would have provided adequate resources for the first people who settled there. They noted that factors, such as the weather, could also have drawn smaller populations to the south coast of the island, which is sunnier and more protected from the wind. They noted that rising sea level may also have obscured evidence of the earliest occupations in the highest ranking areas. The IFD Model described involved a simple assumption that people move into more desirable places first.

However, on the PNWC I have no way of knowing where resources were distributed in the past. The examples presented here focused on environmental variables, e.g., the movement of herd animals, plant ecology or environmental factors such as weather and exposure to the sun. These models were more interested in reconstructing how resources were distributed on the landscape and identifying places that had the highest efficiency for people exploiting those resources.

LAMAP, on the other hand, focuses on measuring the similarity of sites (weighed by distance). Generally speaking, LAMAP is based on a much simpler assumption, that sites that are closest together should be the most similar. In theory, the LAMAP model will work on any landscape, providing there are quantifiable variables for it to use in making its comparisons. A big question now is can LAMAP work underwater?

4.3. Potential of LAMAP In Underwater Landscapes

LAMAP, like any other computer predictive model, is limited by the assumptions, rules and information built into it. In the Alaska case study this included the dataset of 182 known sites as well as the datasets for the six variables used. These were derived from high-resolution satellite imagery in the form of DEMs. The marine equivalent to this is multibeam sonar, which produces high-resolution bathymetry. Hundreds of narrow sonar beams, arranged parallel to each other in a fanlike swath, provides high angular resolution and digital accuracy of the seafloor (Theberge and Cherkis 2013).

High-resolution bathymetry is not nearly as available as satellite data though. Oceans cover two-thirds of the earth’s surface, approximately 140 million square miles, of which less than 10 percent has been surveyed (Mayer et al. 2018). Bathymetric data is available for some areas of the world, such as the territorial waters of the United States (USGS 2020), but is limited in other parts, such as off both coasts of Canada. Large-scale surveying efforts are now underway worldwide though to increase the amount of high-resolution bathymetry available. One project, Seabed 2030, which is a joint project of two non-governmental agencies, the Nippon Foundation and the General Bathymetric Chart of the Oceans, aims to map the entire ocean floor by 2030 (Mayer et al. 2018). The project’s goal is to provide the most authoritative, publicly available bathymetry datasets for the world’s oceans. Government agencies, such as the International Hydrographic Organization and, here in Canada, Natural Resources Canada, are also making efforts to increase their number of bathymetric surveys. Having more detailed bathymetric data will allow LAMAP to better model the archaeological potential of submerged landscapes.

4.4. Suitability of LAMAP Variables When Surveying Underwater

Another future research question involves the potential variables used by the LAMAP model and its settings. In the Alaska case study LAMAP used the six variables; elevation, slope, aspect, distance to drainages, cumulative viewshed and convexity. These variables were selected because of their physiographic nature, i.e. their physical form has changed very little over time unlike other possible variable choices that are more likely to vary through time, such as the presence and distribution of flora or fauna.

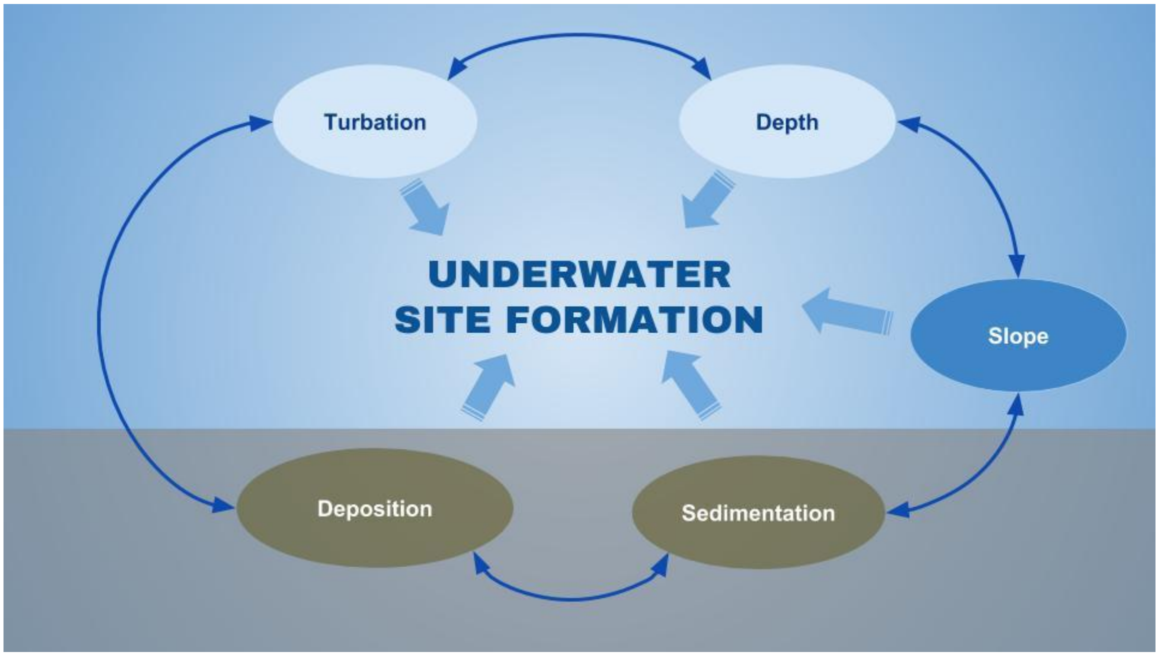

Figure 4.1. Some Underwater Site Formation Processes.

In determining where is the best spot to find formerly terrestrial sites now underwater, consideration will need to be given not only to the location of a site at the time of inundation but also to how sea levels rose, where it did and when. One strategy to deal with this, when using LAMAP, will be to exclude areas of the modern seafloor that have (a) been subject to significant sedimentation, or (b) subject to significant erosion.

The taphonomic processes that impact terrestrial sites are different than those site formation processes that affect sites underwater. Such processes include, but are not limited to, how sites were inundated, i.e. sites that are currently closest to shore have been impacted by wave action while sites farther offshore, that are in deeper water, have been impacted less. In addition to the processes shown in Figure 4.1, erosion is another process that will need to be considered when looking for sites underwater. The amount of erosion that took place as sea levels rose will depend on; (a) the rate at which sea levels rose, with more rapid rates causing less erosion (Zhang et al. 2004), (b) the resistance of the surface deposits to erosion (Carter and E. Guy 1988) and (c) the slope of the surface of the land that is being inundated (Passeri et al. 2015).

In terms of sedimentation, prior to 10,000 cal BP on the PNWC, "outwash plains" (Salamon 2009) would have been created by rivers carrying easily-eroded unconsolidated sediments downriver and spilling them out onto the sea floor where a river met the ocean (Stanley 2005). Likewise, "alluvial fans" (Blair and McPherson 2009) would also have developed at the mouth of rivers and streams. At the time of inundation, both coarse and fine sediments from up-river would have piled up at the discharge point of rivers and streams, in these semi-circular, fan-shaped bodies, potentially burying evidence of archaeological sites, in some cases under several meters of sediment.

Over time, sediments also extended seaward to form a delta (Hoy and Ridgway 2003; Seybold et al. 2007) similar to an alluvial fan (Stanley 2005). Long shore currents would have deposited sediments up and down the coast of the PNWC and wave energy would also have moved sediments around (Haghani and Leroy 2016). Wave action decreases with depth, i.e. waves are strongest at the surface (Khattak 2020). As a result, only coarse sediments are deposited in shallower water. As the water depth increases there is less wave action, resulting in finer sediments falling to the bottom. The sediments deposited range from sands near the shore to silts and clays farther offshore.

Sedimentation may seriously impede LAMAP's ability to predict the location of archaeological sites on formerly terrestrial, now submerged, landscapes. The answer may be a matter of resolution though. When looking at the bathymetry, at a larger scale, it is easier to determine the topography of the seafloor, i.e. when you pull back the bathymetry's depth of field you can see canyons, river valleys and the remnants of river estuaries. You can identify features such as down-cut paleo-river channels, paleo-river mouths, drowned delta floodplains and paleo-deltas. Then, by zooming in, increasing the digital terrain image's depth of field, you can better identify areas that may have experienced a high degree of sedimentation. Basically, you can zoom in to better examine what the sedimentation on the seafloor looks like.

In my PhD research, using the results from bathymetry, I will need to, first, determine if the LAMAP's results for Alaska are applicable to the PNWC. Then, I will need to identify the best areas off the PNWC that have, according to LAMAP, the highest archaeological potential. For example, a particular area of the coast may have a LAMAP Class 5 predictive value, but it may be an area that has experienced a high degree of sedimentation, such as an area in the estuary of a river. As a result, potential archaeological sites there may be buried under meters of sediment. The same is true when it comes to areas of the coastline that have experienced a great deal of erosion. LAMAP might identify such an area near a shoreline, for example, that has high archaeological potential. But, again, I might have to rate this area has having less excavation potential, should it be inaccessible due to wave action or other factors.

In my future research, I will also need to consider how to investigate a potential archaeological site underwater. The only previous attempt to do so on the PNWC (Fedje and Josenhans 2000) used a clam shell drop bucket to extract sediment from the sea floor (in which they found a single flaked tool). The problem with this method is that it does not capture the stratigraphy of a site. Instead, I plan to take core samples of the sea floor. This will protect the stratigraphic context of any potential archaeological site(s). I plan to use a system of coring technology referred to as "vibro-coring". The type of vibro-coring I am interested in using is similar to that used recently off the coast of Northwestern Scotland and the Shetland Islands by environmental scientists to collect sediment cores to help them better understand what happened to Scotland's ice sheets at the end of the last Ice Age (McDaid 2017).

4.5. Limitations

Another question that I will need to answer going forward, in attempting to use LAMAP offshore on the PNWC, is whether it can model archaeological potential for an area where there are few known archaeological sites or none at all. Presently, LAMAP uses the data from known sites to predict the location of other, as yet undiscovered, sites in a defined survey area. It is important to differentiate the "archaeological potential" of a survey area versus "the probability of finding a site" within it. While the distinction may seem subtle it is important.

The odds of finding a site at random, especially underwater, are totally unknown. This is why I need to consider using a predictive model, such as LAMAP, to narrow down the survey area. Beringia underwater is 2.5 million-square kilometers in size. The model's results, as in the Alaskan LAMAP class study, may tell one thing (about an area's potential) leading me to make interpretations about where to look (assertions of probability) that may or may not lead me to actually find sites. As so far demonstrated in Alaska, the model may be computationally accurate, but the oldest site(s), or any sites at all for that matter, may not be found in the highest LAMAP classes. Put more simply, the probability of finding a site underwater off the coast of the PNWC may be much less than the area's potential, as identified by LAMAP. While I am encouraged by the modelling results in Alaska, I need to make sure that I don't have unrealistic expectations as to whether or not a site, regardless of its age, will be found in an area designated by LAMAP to be of high-potential.

There are several possible ways to address the problem of where to look for sites. The first is to use the data that was used successfully in Alaska and look for areas off the PNWC that have similar landscape characteristics underwater. Essentially, we would use the six variables from the Alaska case study, along with the resulting data, as a proxy for known sites off the PNWC. Instead of using DEMs, like we did in Alaska, on the PNWC we would use the results of bathymetric surveys. Another alternative would be to create a new LAMAP model for an area where there are known Late Pleistocene sites underwater; such as off the coast of California, i.e. the Channel Islands (Laws et al. 2020), or Florida, i.e. Apalachee Bay (Hale et al. 2019; Halligan et al. 2016), in the Gulf of Mexico (Evans et al. 2013), in Lake Huron (O'Shea and Meadows 2009; Reynolds et al. 2014) or in the English Channel, i.e. Doggerland (Bicket A. R. et al. 2016; Tizzard L. et al. 2014). Then, we would apply the results from this new LAMAP case study to a study area off the shores of the PNWC. A third method would be to use LAMAP to create a generalized model of hunter-gatherer site location preferences that could be applied to the PNWC as well as other coastal areas worldwide.

4.6. Conclusion

The Alaska case study of LAMAP was the first application of LAMAP to a region in a hunter-gather context. Most other predictive models that have attempted to model archaeological site potential (especially underwater) have focused on the availability of resources in the past, such as the movement of big game on the landscape or where stone tool material could be found. LAMAP, on the other hand, focuses on the decisions made by people in the past, as evidenced by the archaeological record, as to where to situate themselves on the landscape.

The first part of the study used the random selection of known sites from all time periods to model archaeological potential for the study area within the Tanana River Valley of Central Alaska. The LAMAP model was tested, and validated, by analyzing the location of a second set of sites containing higher frequencies of sites than from the first set. For the second part of the Alaska case study, the LAMAP model was based only on data from the oldest, pre -10,000 cal BP, sites. It was then tested, and validated, with data from the more recent, post -10,000 cal BP, sites. The variables aspect and distance to drainages were found by LAMAP to be the most reliable in identifying areas with the highest potential of containing archaeological deposits.

Just like the two previous case studies before it, the application of LAMAP in Alaska was successful in predicting the location of archaeological sites that had not been used to build the model. LAMAP has demonstrated that it can predict the potential location of sites using quantifiable variables, such as landscape characteristics. In the Alaskan case study, these were physiographic variables. In the other two case studies, Belize and Turkey, LAMAP again was successful using both landscape and cultural variables. In the Turkey case study, the LAMAP predictive classes were also defined by time period.

The landscape characteristics of archaeological sites found in the Tanana River Valley are important because they are from some of the oldest sites in the Americas. As such, they are an important reference for developing the LAMAP predictive model in the future, whether it is looking for archaeological sites underwater off the PNWC or hunter-gatherer sites on land in other parts of the world.

The six variables used in the Alaska case study; elevation, slope, aspect, distance to drainages, cumulative viewshed, and convexity may be used, or modified, or replaced with other variables to work most effectively with a bathymetry model. For example, it may be harder to determine data from bathymetry (than DEMs) for the variable cumulative viewshed. And, as already noted, to use the LAMAP model for the

PNWC underwater site formation processes, including sedimentation, erosion and others will need to be factored in. But, even if the use of LAMAP does not lead to finding a single site underwater, this research is valuable because it will improve our ability to find undiscovered archaeological sites both on land and underwater.

Clearly, good chronological control of natural and human events and processes is vital to locating the earliest Paleoamerican sites. There are so few pre-Clovis sites in the Americas that it is now difficult to say with certainty which route, whether it was through the interior of the North American continent or down the coast of the Pacific, First Peoples used to expand into both continents. Finding even one site underwater that predates the Holocene on the PNWC would be significant (Tremayne and Winterhalder 2017). So far, the earliest archaeological evidence of marine adaptation on the West coast reliably dates to only 12,500 cal BP. This consists of a single shell fish hook found at a site on an island off the southern coast of California (Des Lauriers et al. 2017).

Evidence of marine-adapted technologies for either Siberia or Alaska are not found in the archaeological record before 13,000 cal BP (Davis et al. 2016; Halfman et al. 2015; Potter et al. 2014). This implies that earlier people were terrestrially-adapted and not marine-adapted. In British Columbia, the earliest sites show evidence of a terrestrially-adapted subsistence (Fedje et al. 2011; Mackie et al. 2011). Sites on Haida Gwaii demonstrate that people there were hunting bears at 12,600 cal BP (Fedje et al. 2011), and, at the Manis site in northern Washington State the remains of a projectile point found in one of the animal’s ribs shows that people were hunting mastodon there at 13,800 cal BP (Waters, Stafford, et al. 2011).

The archaeological evidence to date supports the idea that First Peoples travelled down the PNWC on foot, hunting mega fauna such as mammoth, bison and horse. The, then, exposed North Pacific Continental Shelf extended in some areas more than 40 km west of the present-day shoreline. Mammoth and other mega fauna in large numbers grazed on the area’s rich grasses and sedges. This is evidenced from the data acquired from numerous paleo-environmental reconstruction studies of the last forty years (Elias and Crocker 2008; Hetherington et al. 2003). Large grazing animals were an attractive food source for the First Peoples who occupied this landscape. As the world warmed at the beginning of the Holocene, around 10,000 cal BP, this area disappeared beneath the advancing waves.

As the coastal landscape changed, people adapted. Over time, they changed from being mobile (big-game) hunter-gatherers to become mostly marine-adapted fishers, marine mammal hunters and seafood foragers. It is important to remember that the (earliest) known sites found on the PNWC today were not directly “coastal” at the time of their deposition. They were, in fact, inland of the prehistoric coastline prior to inundation. It follows, then, that even older sites are expected to be found further to the west of today’s shores on the former Mammoth Steppe that extended down the coast of the Pacific Northwest. Using LAMAP, an example of the latest advancement in computer predictive modelling, and other underwater remote sensing technologies, such as the latest in sonar and underwater vehicles, we now have the potential to look for and investigate underwater the archaeological evidence left behind by First Peoples.

This research will help archaeologists and environmental scientists better understand site formation processes, both on land and below the ocean’s surface, and it will help archaeologists make better inferences about how people on the PNWC lived in the distant past. It will also allow them to better appreciate the deep time connections descendant First Nations communities have with the land of their ancestors.

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