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ASSESSING THE RELATIONSHIP BETWEEN GEOPHYTES AND THE ARCHAEOLOGICAL PRESENCE OF MAIZE IN NORTH AMERICA

by

Paige Dorsey

A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF SCIENCE
in
Anthropology

Approved:

Jacob Freeman, Ph.D. Major Professor	Molly Cannon, Ph.D. Committee Member
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UTAH STATE UNIVERSITY
Logan, Utah

2021

ABSTRACT

Assessing the Relationship Between Geophytes and the Archaeological Presence of Maize in North America

By

Paige Dorsey, Master of Science

Utah State University, 2021

Major Professor: Dr. Jacob Freeman
Department: Anthropology

This thesis attempts to understand the biogeography of maize cultivation in prehistoric North America. I ask: do regions of N. America where wild geophytes are more diverse, and (in theory) abundant, display less evidence of prehistoric agriculture than places where these potential resources were less abundant. To answer this question, first I create a stylized model of the effect of geophyte and maize production on the optimal allocation of labor to intensify the production of resources in various environments. The results from this allowed me to predict under which environmental conditions an intensification on maize would or would not occur. Following this, I collected data on geophytes as well as temperature and rainfall (variables that should affect the productivity of maize). Next, I used the data to statistically test the effects of geophyte species richness, temperature, and rainfall on the number of observed sites with evidence of maize. Results are as follows: the presence of archaeological evidence of maize is potentially impacted by the productivity of geophytes in the area. The concentration of rainfall during the growing season has a consistent effect on the number of archaeological sites with maize, and an unaccounted for spatial process accounts for much variability in the number of archaeological sites with maize across the continent of N. America. These results help us better understand under which biogeographical conditions people may invest in the cultivation of maize.

(113 pages)

PUBLIC ABSTRACT

Assessing the Relationship Between Geophytes and the Archaeological Presence of Maize in North America

Paige Dorsey

This thesis investigates the possible relationship between the archaeological presence of maize, in the United States, and historical environmental variables, rainfall and temperature, in addition to the number of underground plants that store energy and nutrients, in a given area. The thought behind this is that where the abundance of these underground plant species is highest, the lower the number of archaeological sites containing maize because such resources were a more attractive alternative food than maize. Conversely, where geophytes are less abundant, archaeological instances of maize should be more abundant because maize is a better option in such environments for individuals who need to produce more food. My results indicate that the presence of archaeological maize is potentially impacted by the productivity of geophytes in the area along with climate variables that impact the productivity of maize. The concentration of precipitation during the growing season, in particular, has a consistently significant effect on the number of archaeological sites with maize. By better understanding the environmental conditions that make maize productivity more favorable, we can better understand the transition to agriculture.

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I would like to thank my parents for everything they did to get me here; my gratitude for both of you can never be fully expressed. Next, I would like to thank my husband, Josh, for all his love and support throughout this process. Furthermore, I would like to thank those who took this journey with me: Cayla Kennedy, Kelly Jimenez, Gideon Maughan, and Alix Piven. A special thank you to Jennifer Pennell for her continued presence and friendship.

This manuscript is dedicated to the memory of my grandfathers, Leonard Jessen and William Ainsworth, both of whom continue to inspire and encourage me.

Paige Dorsey

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Chapter 1: Introduction

The goal of this chapter is to introduce the basic concepts upon which my thesis is built. In this chapter, I will discuss concepts and literature that provide the foundation of my thesis. Following this, I will pose the question that guided my research. Finally, I discuss the importance of my research.

A large body of literature in Archaeology and Anthropology illustrates that geophytes played an important role in prehistoric people's subsistence practices (Freeman 2007, Herzog and colleagues 2018, Louderback and Pavlik 2017, McGuire and Stevens 2016, Thoms 2009). Importantly, many authors propose that wild geophytes--species of tubers, bulbs, and corms with below ground, sugar rich storage organs (Brecht 2003)--may have served as an important alternative to the cultivation of maize in North America (Black and colleagues 1997, Freeman 2007, Herzog and colleagues 2017, Thoms 2009). Yet, a formal statistical analysis of the biogeographic relationship between the abundance of geophytes and the presence of maize cultivation in North America has not been conducted to test this hypothesis. In this thesis, I model and statistically analyze the relationships between geophyte species richness, biophysical constraints on the cultivation of maize, and the presence of maize cultivation in prehistoric N. America. I ask: Do regions of N. America where wild geophytes are more diverse, and (in theory) abundant, display less evidence of prehistoric agriculture than places where such resources were less abundant? This is an important question to answer because understanding when people will adopt or reject maize agriculture contributes understanding the transition to agriculture.

Chapter 2: Background and Hypotheses

This chapter's goal is to better understand the energetic gains of geophytes and maize in terms of energy gain per unit labor invested in production in various environments and use this knowledge to develop hypotheses for the biogeographic distribution of maize cultivation. First, I explore literature that informs my analysis by examining the importance of geophytes in ethnographically documented cultures. Subsequently, I model a comparison of production functions of the cultivation of maize and the harvest of geophytes. Following this, I discuss the possible importance of growing season rainfall and geophyte abundance and model their effects on the decision to adopt the cultivation of maize. Lastly, I state my expectations resulting from the model.

The idea that wild geophytes served as an important alternative resource to maize agriculture in North America has been proposed by many authors (Bettinger 2015, Black and colleagues 1997, Dickau and colleagues 2007, Freeman 2007, Johnson and Hard 2008, Madsen and Simms 1998, Simms 1999, Yu 2006). The basic idea is that when populations face a pressure to intensify their extraction of resources--whatever the complex set of causes--they will intensify on a resource set that optimizes an individual's fitness in a given environment. In environments where geophytes are abundant, these resources may serve as an alternative to maize agriculture to intensify production. These resources may provide an attractive alternative because the rate of energy gain from many geophyte species is often quite high compared with maize among ethnographically documented societies (Couture and colleagues 1986, Kelly 2013, Rhode 2016, Simms 1984).

For example, Couture and colleagues (1986), Kelly (2013), and Simms (1984) all found that bitterroot could produce upwards of 1,374 kcals per hour when gathered at the right time. Importantly, return rates vary with the density of targeted species; more dense patches have much lower collection times, and, thus, much higher return rates (Couture and colleagues 1986). Rates for gathering biscuit root species vary between 134 kcals per hour (Kelly 2013) and 3,831 kcals per hour (Kelly 2013). Sego lilies have a return rate of about 207 kcals per hour (Kelly 2013, Rhode 2016, Smith and Martin 2001). Unlike sego lilies, camas bulbs can provide 5,479 kcals per hour before collection, processing, transport, and storage and 2,042 kcals after all steps have been taken (Rhode 2016). Cattails can provide between 128 kcals and 9,360 kcals depending on the season within which it is gathered as well as the portion of the plant is gathered (Kelly 2013). Bulrush roots can provide between 160 and 257 kcals per hour (Kelly 2013). Further, geophytes are often roasted in large earth ovens (Black and Thoms 2014, Gill 2016, Morgan 2015, Smith 2003, Thoms and colleagues 2018, Yu 2006); and group processing decreases the handling costs for multiple individuals, increasing the net return from such resources via the process of increasing returns to scale (Yu 2006).

The return rates of geophytes, thus, compare favorably, *where they are highly productive*, with those of maize agriculture. For instance, Barlow (2002:72-73), concludes that "In Latin America, maize agriculture using only simple hand tools produces a gross energetic gain of approximately 300-1,800 kcal/hr with average maize harvests of approximately 3-50 bushels per acre." The return rates of maize may be higher using less labor-intensive strategies, such as planting and leaving maize (Barlow 2006). However, planting and leaving maize trades off a higher return rate for a much great risk of crop loss and a loss of seed corn (Freeman 2012, Huckell and colleagues 2002). It is only practiced ethnographically where foragers and farmers have sustained interactions, with the strategy highly unstable from year-to-year for any given household (Freeman 2012).

Table 1 compares types of geophytes and maize by examining processing methods, maximum return rate, minimum return rate, mean return rate, and sources from which the information was collected.

Species	Processing Strategy	Return rate max Kcal/hr	Return rate min Kcal/hr	Mean return rate	Reference
Maize	“Typical” Agriculture in Colorado	1,800	700	1,250	Barlow 2002
Balsamroot	Fresh, Peeled	369	120.2	244.6	Mullin and colleagues 1998
Bitter Root	Peeled and boiled	~2,300	~1,250	~1,775	McGuire and Stevens 2017
Bulrush	Peeled, eaten raw, boiled, or roasted	257	160	208.05	Kelly 2013 Rhode 2016
Camas	Cooked then eaten or dried then stored	5,479 kcals	2,042 kcals	3,760.5	Rhode 2016
Canby’s Biscuit Root	Peeled then prepared various ways	1,219	143	681	Rhode 2016
Cattails	Peeled and eaten raw, boiled, roasted, or dried and ground into flour	9,360	128	4,744	Kelly 2013 Rhode 2016
Epos/Yampah	Raw or roasted	2,600	172	1,386	Rhode 2016
Sego Lily	Eaten fresh or pit roasted	207	143	175	Rhode 2016 Smith and Martin 2001

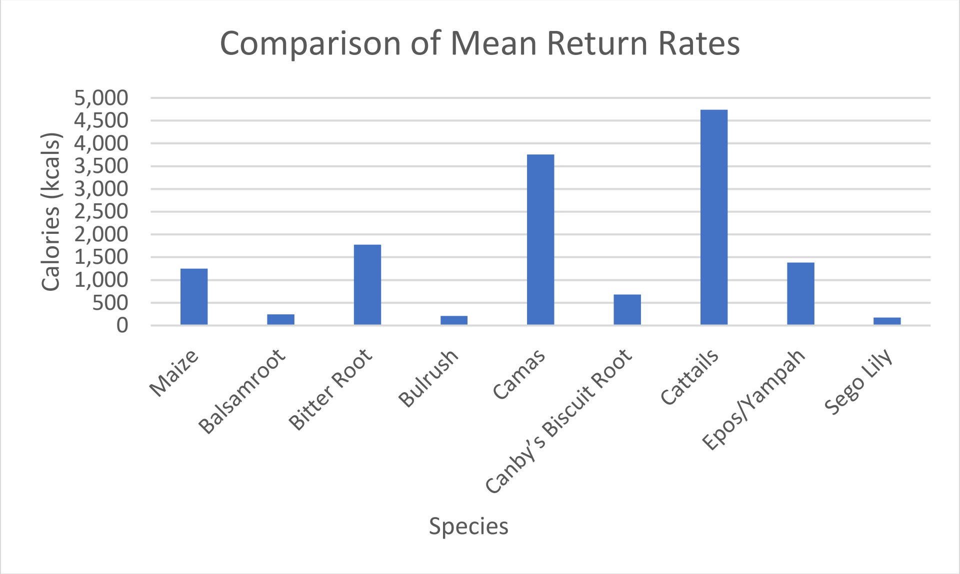


Figure 1 visually compares kilocalorie mean return rates of the geophytes, listed above, in addition to maize.

Though the return rates above indicate that geophytes can provide equivalent or better return rates than maize for individuals, if a geophyte resource and maize are available at the same time, this does not give us the full picture. The return rate of a resource changes as a function of the amount of labor invested in that resource. Thus, to compare the net benefits of intensifying on maize vs. geophytes, we need to understand the net benefits of allocating time (labor) to these different carbohydrate sources in various environments. The intensification of production is a time allocation process that substitutes one set of activities for another. For example, a shift in time spent hunting toward time spent gathering and processing plants is a process of substitution, shifting time from hunting to more plant gathering activities to increase productivity per unit area. The question can be simplified to: When does an average individual choose to invest time (labor) in geophyte production under different return rate functions for these resources? I use a microeconomic model that shares some similarities with a technological investment model (e.g., Bettinger et al 2006) to help answer this question and guide my analysis.

First, I assume that the technologies used to cultivate maize and harvest and process geophytes are very similar (e.g., digging sticks, stone metates, and monos), though the production ceiling (gross production) for maize may be higher than for geophytes. Second, I assume that individuals attempt to meet a required level of food production in as little time as possible (i.e., minimized time spent in food production activities). Third, I assume that maize cultivation requires more initial investment in labor before the resource can provide a return. This means that, at minimum, gardens must be cleared, sown, and, potentially, weeded. The upfront costs of producing maize, the cultivation premium, of course will vary from environment to environment. I assume here that the farther a biophysical environment is, on average, from the optimal niche for conducting rainfed maize agriculture, the higher the cultivation premium. Fourth, geophytes require a negligible initial labor investment in order for them to grow (i.e., little to no field preparation, irrigation construction and so on), though while gathering individuals may engage in tending behaviors and low-cost burring activities that promote the growth of geophyte species (Anderson 2005).

Given these assumptions, we can compare production functions of the cultivation of maize and the harvest of geophytes. Figure 2 graphically illustrates the interaction between a resource target and the gains from harvesting each respective resource type. In Figure 2, the resource target *(m)* simulates a pressure to intensify the production of resources for an average individual foraging in a fixed territory. In Figure 2A and 2B, at low resource targets, geophyte production is optimal in both low and high productivity

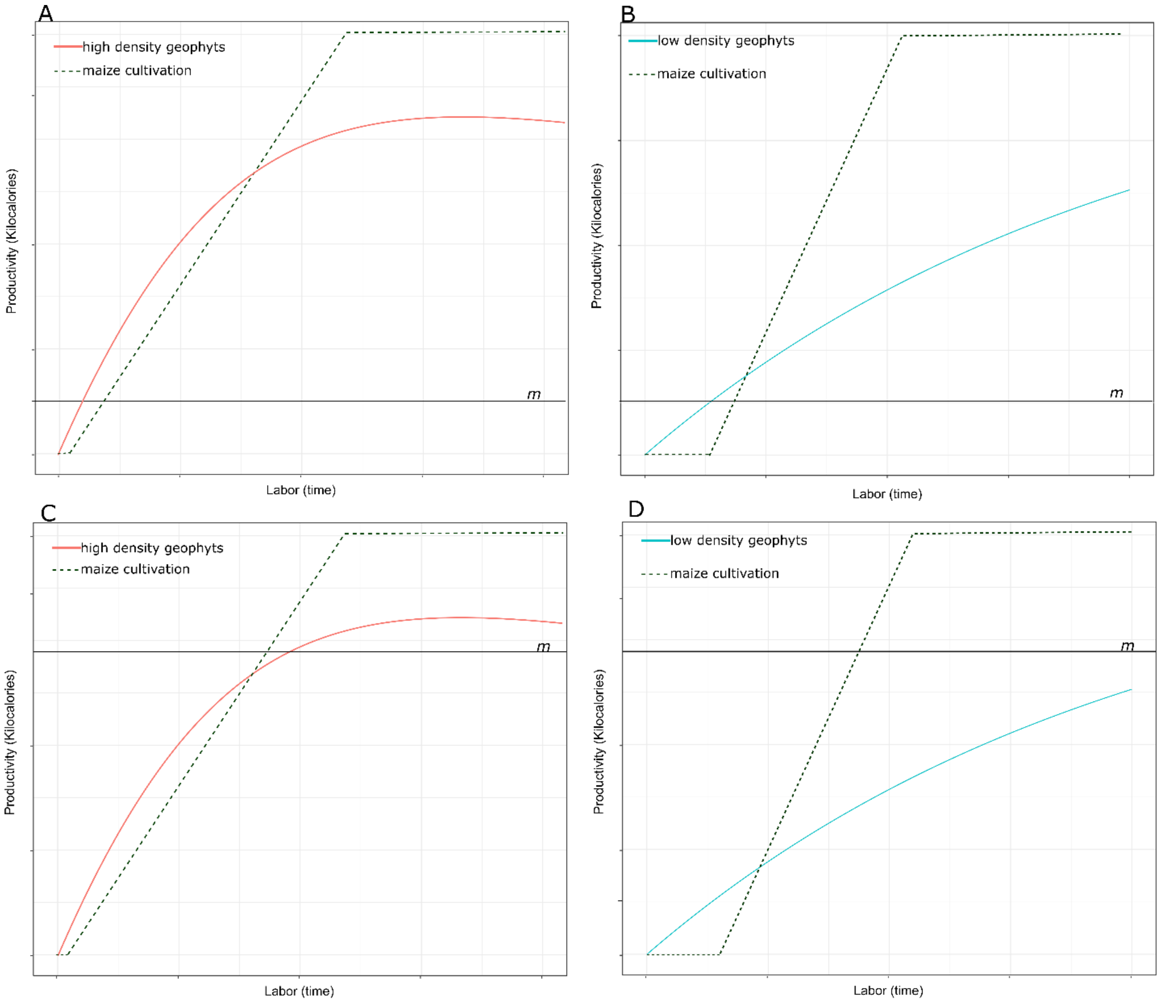


Figure 2: Comparison of productivity functions for maize and geophytes in high and low abundance geophyte environments. The parameter *m* defines the minimum level of production necessary to meet biological and cultural requirements. The function that reaches *m* first in each graph minimizes the time spent participating in subsistence activities. A-low population density, high geophyte density environment. B-low population density, low geophyte density environment. C-High population density, high geophyte density environment. D-High population density, low geophyte density environment.

geophyte environments. This strategy would allow an average individual to achieve their resource target in the least amount of time, even though maize production has a much higher ceiling than geophyte production. In Figure 2C and 2D the resource target is high. In this case, geophyte production is still optimal in high geophyte productivity environments (2C), but maize cultivation is optimal where geophyte productivity is lower (2D), even if maize cultivation has a high upfront premium to transform a landscape prior to viable cultivation.

Holding the productivity of maize constant, the above model leads me to predict that the productivity of geophyte species will directly influence the likelihood that prehistoric populations adopted maize cultivation and, thus, the biogeography of maize production. In each area of North America, I would expect a higher geophyte productivity to correlate with a lower abundance of archaeological maize agriculture. Conversely, I expect a lower geophyte productivity to correlate with a higher abundance of evidence for maize agriculture, prehistorically.

Similarly, if we hold m and geophyte productivity equal, then the steepness of the maize productivity curve should affect which option is optimal in any given environment. Two climate requirements may affect the optimal environment for growing maize at a biogeographic scale. The first factor that should be accounted for is the length of the growing season (temp). Bocinsky and Kohler (2014) estimated that the growing season should amount to 1800 F growing degree days from the month of May to September. The second requirement is “30 cm of precipitation for the previous October through the current September (the “water year” in most of the Southwest)” (Bocinsky and Kohler 2014). This affects the amount of moisture available during the growing season that may be available for rainfed farming. However, the absolute amount of moisture may not be as relevant as the concentration of moisture during the growing season for the adoption of maize cultivation. If water pulses through an environment during the growing season, it is much more accessible for plants and for humans to modify landscape features to capture such pulses of water and cultivate maize.

Figure 3 illustrates, conceptually, the effect of growing season rainfall on the maize production function. R_1 rainfall is concentrated during the growing season and this leads to a steeper increase in productivity per unit labor than R_2 and R_3 where rainfall is less concentrated during the growing season. In Figure 3A, we observe that maize is the better intensification strategy for an average individual to reach *m* than geophytes in an R_1 and R_2 environment. However, in an R_3 environment, geophytes provide the better intensification strategy. In Figure 3B, maize always provides the best intensification strategy. The insights from this set of relationships leads to the following predictions:

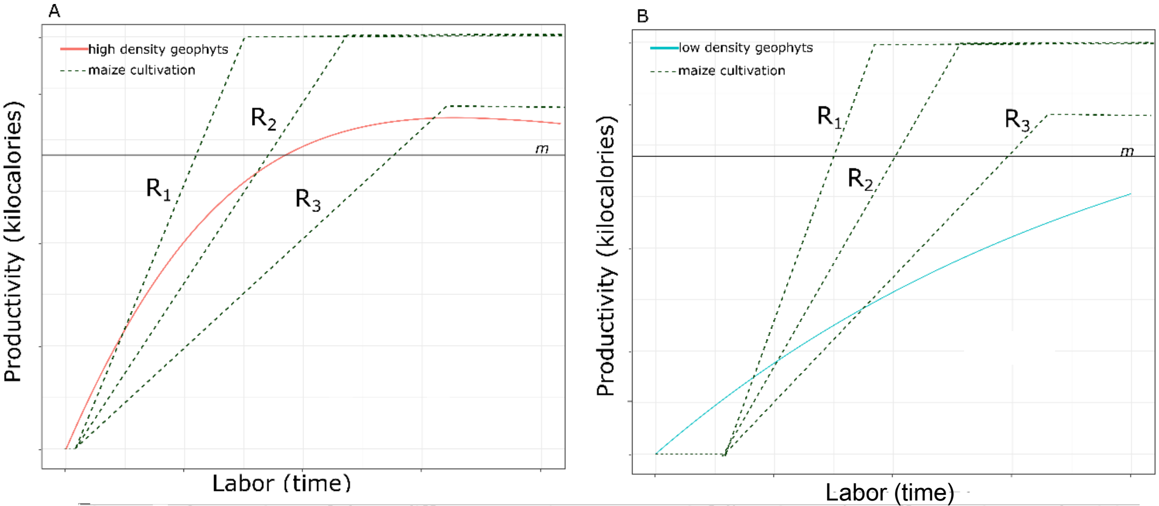


Figure 3: Comparison of three different growing season rainfall regimes that affect maize productivity in high (A) and low (B) geophyte productivity environments. The parameter m defines the minimum level of production necessary to meet biological and cultural requirements. R_1=high growing season rainfall; R_2=moderate growing season rainfall; R_3=low growing season rainfall.

Holding *m* equal, the interaction between the productivity of maize and the productivity of geophytes should determine the decision to intensify on maize cultivation. I predict that in high maize and high geophyte productivity environments, people will intensify on maize. In low maize productivity (lower concentration of growing season moisture) and high geophyte productivity environments, people will intensify on geophytes. Finally, in both low maize and geophyte productivity environments, people will intensify on maize.

Chapter 3: Data and Methods

In this chapter I will describe the data and variables used to the predictions outlined in Chapter 2. This is accomplished by dividing this chapter into 6 sections. The first section focuses on the analysis in R and the variables utilized. The second section pertains to how maize data, the dependent variable, was collected. The third section depicts maps of the maize data and discusses the methods utilized in making them. In section 4, I discuss how lists of geophytes were created and gathered. Furthermore, I introduce the independent variables (geophyte richness, growing season precipitation, annual precipitation, and temperature) and how their data were collected. In the next section, section 5, I present the maps created from the data from section 4 in ArcGIS and how they were created. Finally, section 6 describes the final data set used for analysis.

R Variables and Analysis Overview

To test my predictions, I needed to develop a dependent variable that tracks maize cultivation across the lower 48 US states and independent variables that estimate temperature, growing season precipitation (or the pulse of water through an environment during higher temperatures) and geophyte abundance. With these variables estimated (discussed below), I can test my predictions with the following general linear model

$$z_i=a+b1*temp+b2*rain+b3*geophyte+b4*(rain*geophyte)+\varepsilon \qquad (1)$$

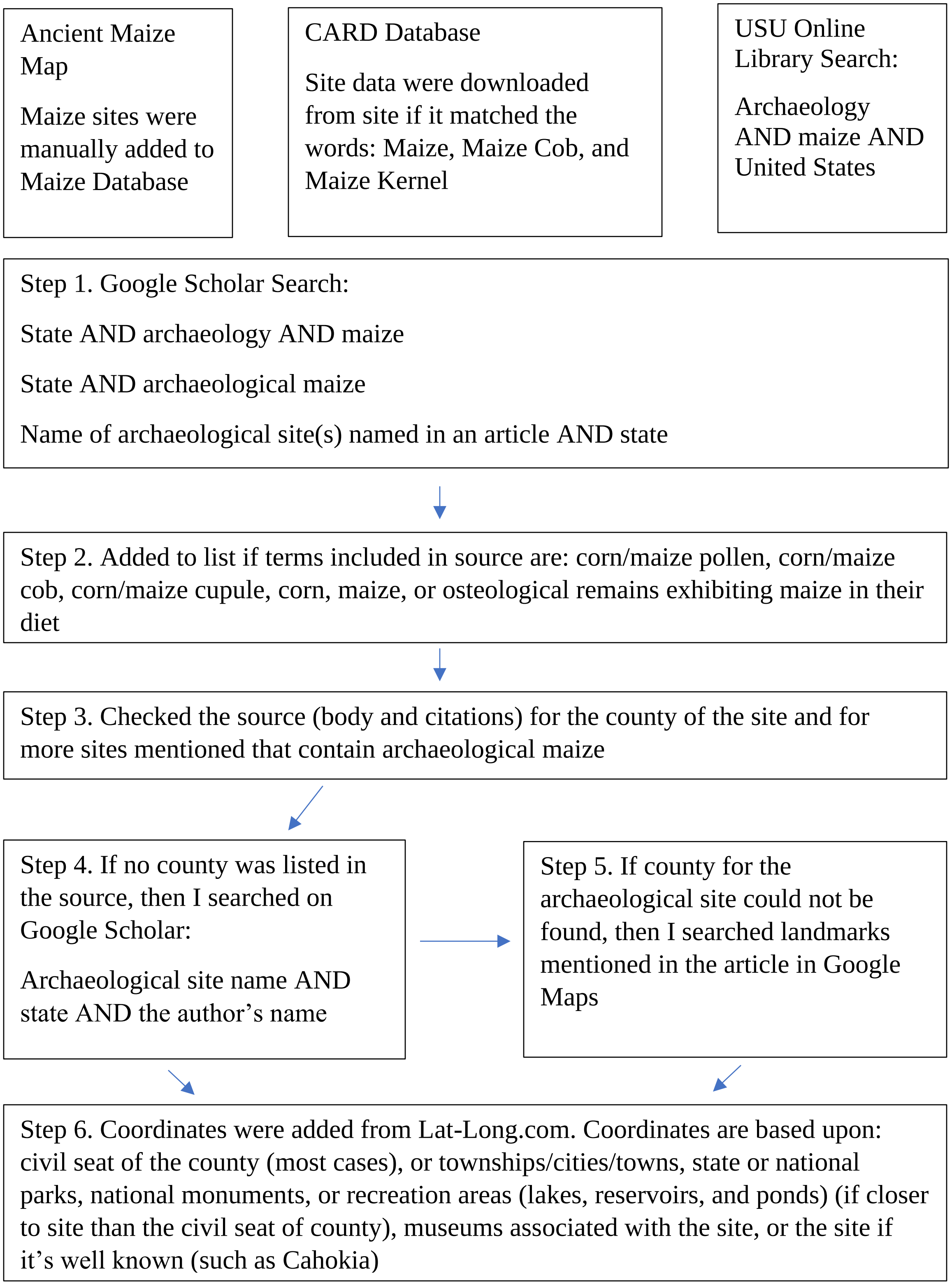
where z_i is a count of sites containing evidence of maize in the prehistoric record of a given geographic area *i*. *Temp* is mean annual temperature, rain is either the concentration of precipitation during the growing season or total growing season precipitation, and geophyte is either geophyte species richness or consumable geophyte species richness in a geographic area *i*. As discussed below, I assume that geophyte richness correlates positively with geophyte abundance. Finally, ε is the error or deviance in the count of maize sites not explained by the independent variables. Here, I use a poisson link function (see Appendix A) as I use count data to estimate the presence of maize cultivation (count of sites). Note the interaction between geophytes and rain. This interaction effect tests that maize cultivation is more frequent in high geophyte abundance and low growing season rainfall environments, but, as growing season precipitation increases, maize cultivation becomes less frequent, even in high geophyte abundance environments.

The above equation assumes that ε is independent of spatial area. This is not always or is even rarely the case. Thus, we use a Moran's I test of spatial autocorrelation in the ape package in R to test for spatial autocorrelation of residuals. Where we find significant spatial autocorrelation at $p<0.05$, we use the spam package in R to run a spatial regression, simply by adding latitude and longitude vectors for each spatial unit using a mixed effects model. Note, in all regression models I mean centered precipitation and geophyte variables using z-scores to avoid multicollinearity problems associated with variable interaction models.

Dependent Variable

I collected archaeological maize present in sites nationwide (based upon the terms pollen, cob, cupule, corn, maize, or osteological remains that show maize was part of the diet). These sites were collected from the Ancient Maize Map database, the CARD Database (Martindale and colleagues 2016), Utah State University's online database, of academic articles, as well as from sources available for free (which may bias the availability of information) from Google Scholar (searching state AND archaeology AND maize then searching archaeological sites that were named in those entries AND state). In total, 463 archaeological sites containing maize were gathered. Following this, I collected the civil coordinates of the county, found on Lat-Long.com, that the archaeological site is in (unless it has a designated museum or is located within a state or national forest or recreation area) so as to protect the site's location. The methods utilized are presented in a workflow table below, Figure 4.

Figure 4



Ancient Maize Map

Maize sites were manually added to Maize Database

CARD Database

Site data were downloaded from site if it matched the words: Maize, Maize Cob, and Maize Kernel

USU Online Library Search:

Archaeology AND maize AND United States

Step 1. Google Scholar Search:

State AND archaeology AND maize

State AND archaeological maize

Name of archaeological site(s) named in an article AND state

Step 2. Added to list if terms included in source are: corn/maize pollen, corn/maize cob, corn/maize cupule, corn, maize, or osteological remains exhibiting maize in their diet

Step 3. Checked the source (body and citations) for the county of the site and for more sites mentioned that contain archaeological maize

Step 4. If no county was listed in the source, then I searched on Google Scholar:

Archaeological site name AND state AND the author's name

Step 5. If county for the archaeological site could not be found, then I searched landmarks mentioned in the article in Google Maps

Step 6. Coordinates were added from Lat-Long.com. Coordinates are based upon: civil seat of the county (most cases), or townships/cities/towns, state or national parks, national monuments, or recreation areas (lakes, reservoirs, and ponds) (if closer to site than the civil seat of county), museums associated with the site, or the site if it's well known (such as Cahokia)

Figure 4 illustrates the steps taken to create the maize database utilized in my analysis.

Then, all of these data were recorded in an Excel sheet. Next, I imported the Excel sheet that contains the archaeological sites in the United States into ArcGIS along with the geophyte richness data and historic environmental variables. With these points projected (WGS_1984) together, I created maps to analyze possible relationships between the two. This allowed me to compare the presence of agriculture to geophyte species with the purpose of teasing out a possible correlation between the two.

Mapping the Dependent Variable

Figure 5 depicts the locations of archaeological sites with maize throughout the United States. The methods utilized in creating this map consists of importing the Maize Database excel sheet and downloading the continental U.S. state map from ArcGIS Online.

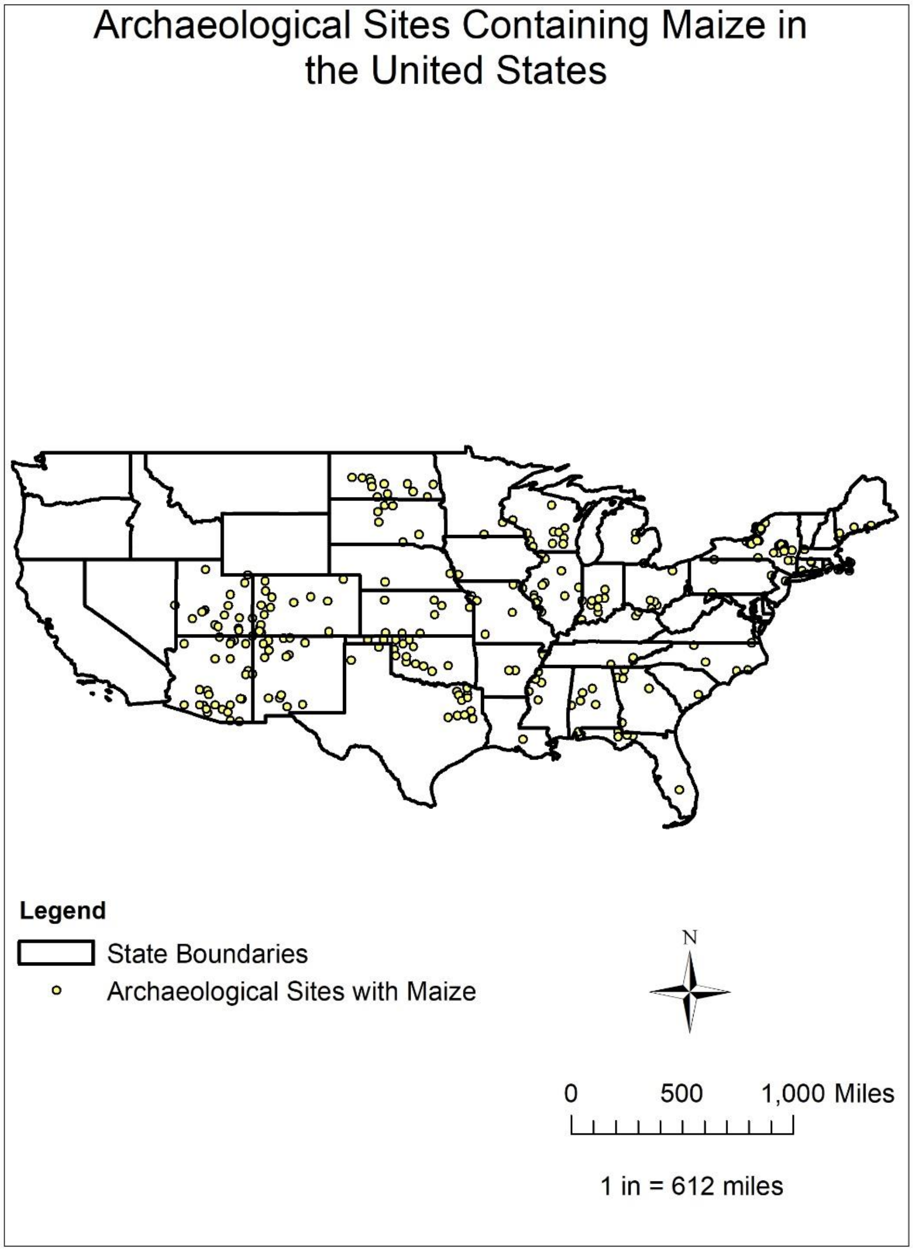


Figure 5 displays archaeological sites that contain instances of maize in the United States.

Figure 6 depicts the same data seen in the map of archaeological sites in the United States that contained maize. This map was created using the maps and ggplot package in R. This map better allows us to view clusters of archaeological maize within 2.5 by 2.5 grid cells, which form the spatial units of my analysis.

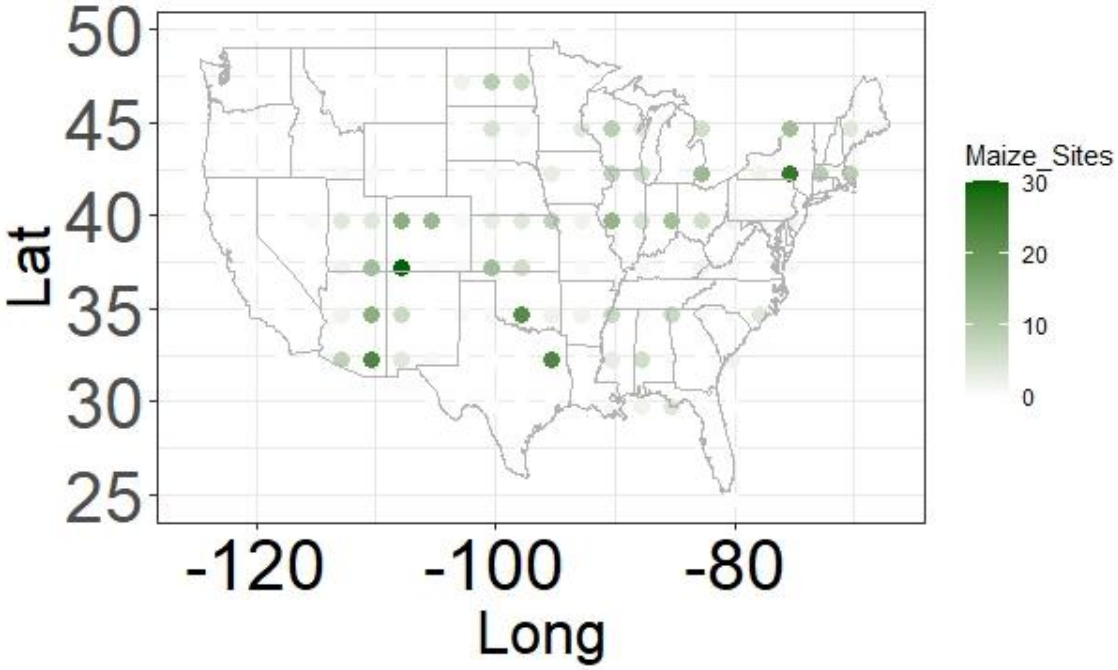


Figure 6 shows the clustering of archaeological maize sites in the United States among 2.5 x 2.5 grid cells.

Independent Variables

My model assumes that geophyte abundance matters, therefore, to operationalize my model, I use geophyte richness as a proxy for abundance. An ecological study determining the relationship between geophyte species richness and abundance, or productivity, when exposed to chronic nitrogen enrichment (Isbell and colleagues 2013), has revealed a link. To estimate geophyte abundance using species richness, I compiled two lists of geophyte occurrences in the United States. The lists of geophytes consist of entries found in the online Native American Ethnology Database (Moerman 2003), the USDA's manual for bulb identification (2011), and from *Native American Food Plants: An Ethnobotanical Dictionary* (Moerman 2010). The first list consists of geophyte genus' (named general geophyte list). A genus was added to the list if it matches key words (i.e., bulb, geophyte, corm, rhizome (rootstocks), root, taproot, or tuber) and if it was listed as a certain type of food (i.e., dried food, food, staple, starvation, unspecified, vegetable, or winter use food) in Moerman (2010). The second list is the consumable geophyte list, which consists of species, subspecies, and varieties, found in Moerman's book (2010) and was searched in the Native American Ethnology Database (Moerman 2003), that match the key words listed above (i.e., bulb, geophyte, corm, etc.) and is listed as a certain type of food that is listed above as well (i.e., dried food, food, staple, etc.).

After compiling the lists, I downloaded modern location data for the geophytes, narrowed down to the United States, from the Global Biodiversity Information Facility (GBIF) of listed geophytes. The genus, species, subspecies, and varieties from the consumable geophytes list were only downloaded from GBIF if their scientific names (i.e., Hook, Pursh, Nutt., etc.) match two-thirds, or one half, of the entries listed on the Native American Ethnology Database (Moerman 2003); this includes geophytes that have multiple names, or synonyms, only the ones that were specifically named on the database had their data downloaded. The number of Excel rows, for the all geophyte list, totals around 1.29 million. The number of Excel rows, for the consumable geophyte list, is smaller, numbering around 328,000 rows. Following this, I clipped the data (only kept bare minimum data for location and scientific name) in Excel to a document that is projected (WGS_1984) into ArcGIS on a basemap. Then, I merged the two different geophyte Excel documents into one and then projected it using the same projection.

Historic environmental variables, for the United States, were also incorporated into this research. These variables are growing season precipitation, annual precipitation, and mean temperature. These data were incorporated because they could possibly impact a person's decision to adopt maize or intensify on geophytes. I expect a higher number of geophytes to correlate with a lower number of archaeological sites containing maize during, both, high and low precipitation years and growing seasons and in cool and warm environments.

Data for these variables were downloaded as ASCII files from the PRISM Database (Northwest Alliance for Computational Science and Engineering 2020). The data were then added to a base map in ArcGIS. Maps depicting these independent variables, compared to the dependent variable, are found below along with the methods utilized to create them. A 2.5 by 2.5 decimal degree grid was created over the United States to systematically divide the space and the variables located within them (growing season precipitation, total annual rainfall, temperature, geophyte richness of all/general geophytes, geophyte richness for consumable geophytes, and archaeological sites containing maize).

Mapping Independent Variables

The first map created was the Frequency of All Geophyte Species in a Grid Cell Map. Following the steps mentioned above, I then created a grid using the "Grid Feature

Index” tool based on the merged All Geophyte Data where species is the field and the cell size is 2.5 by 2.5 decimal degrees. Then I utilized the “Tabulate Intersect” tool where the input zone is the grid that was created based on page name and the input feature class is the merged All Geophyte Data based on species. The resulting table shows a species within a grid cell (Page name), the number of points of that species in that grid cell, and the percentage of the points that make up the total number of species in that grid cell. However, there are multiple species present in each grid cell. To count the number of times each grid cell (Page Name) is named (one grid cell is named per species present), I used the “Frequency” tool. This would show how many different species are present in the table by counting the instances that grid cell (Page name) comes up. From there, the resulting table was symbolized by going to “Properties” of that table and then clicked on “Symbology”. Next, I went to “Quantities”, “Graduated Colors”, the “Value” was changed to the frequency (the number of geophyte species in each grid cell) and then the classification was changed to “Natural Breaks” and into 9 categories. This same process was utilized to calculate and map the number of consumable geophytes in a grid cell.

Figure 7 illustrates the number of all geophyte species (n = 1,293,168) compared to known archaeological sites in the United States that contains maize (n = 463). Also present in this map is a map of the continental United States, states are outlined in black, which was obtained from ArcGIS Online. This component was included in the map to show where the grid cells are located within the country. This set of maps is included in this analysis because they provide us with the opportunity to see the productivity of geophytes in the area which is one of the variables in the regression equation found on page eleven. The first map (Figure 6) shows the map with a legend for context.

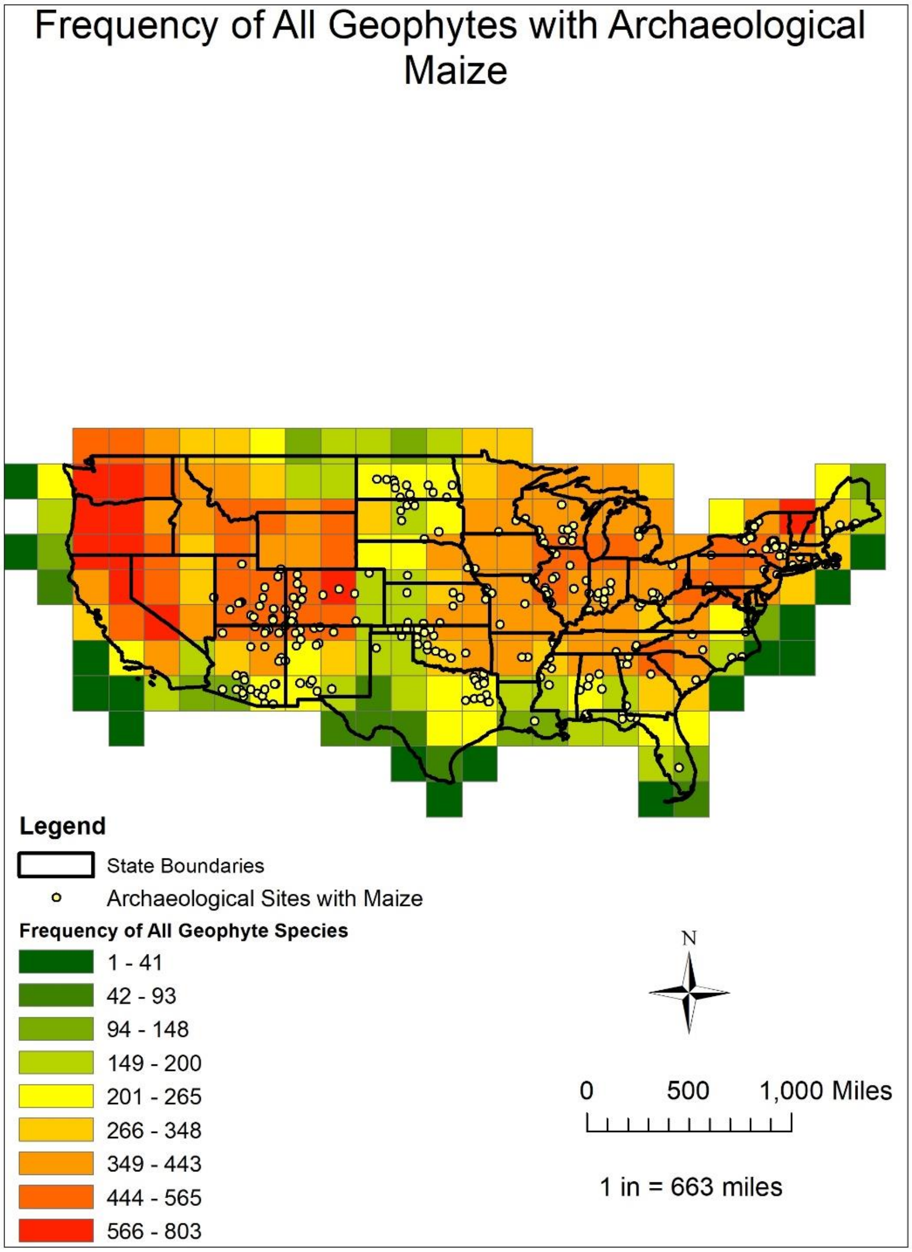


Figure 7 depicts the frequency of all geophyte species within a grid cell. As we can see, most archaeological sites with maize occur in grid cells that contain a mid to high number of geophyte species.

The map above illustrates the relationships between archaeological instances of maize and the number of all geophyte species present in grid cells. Grid cells are colored to represent the number of all geophyte species present; within the context of this visual analysis, the grid cells are divided into lower (1-41, 42-93, 94-148), middle (149-200, 201-265, 266-348), and high (349-443, 444-565, 566-803) categories. There are few grids in the lower frequency range that contain maize (n = 4). Most of the grids (n = 71) that contain archaeological sites with maize fall into the middle (n = 30) and high (n = 41) categories of number of species present.

The next map (Figure 8) depicts the frequency of consumable geophyte species (n = 328,285) present in a grid cell. The steps that were utilized to create the previous map were used here, as well.

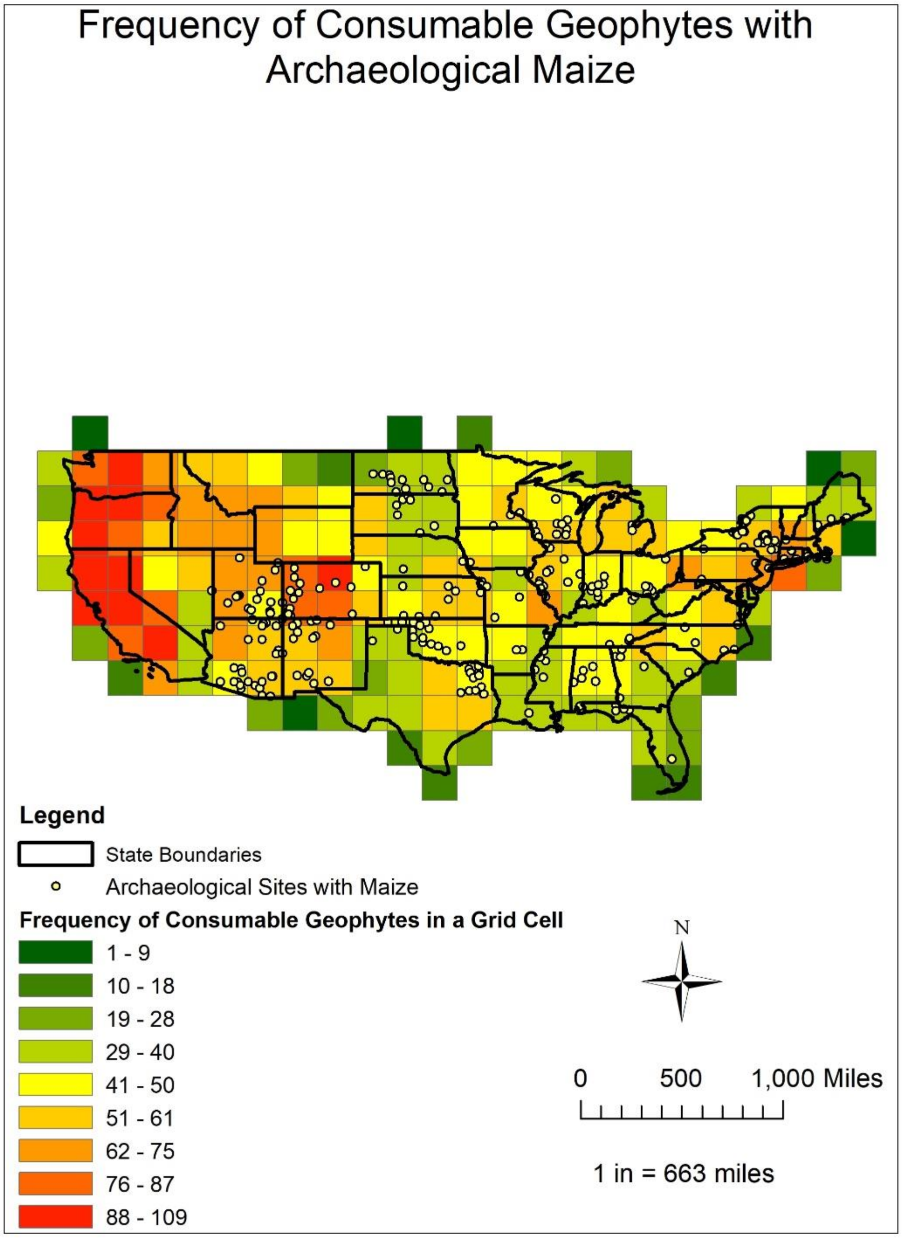


Figure 8 shows the frequency of consumable geophyte species within a grid cell. Most of the cells containing maize are categorized as lower to mid-high numbers. The outlier being the red cell on the border between Wyoming and Colorado.

The categories for consumable geophyte species present in a grid cell are different. The low category consists of the groupings 1-9, 10-18 and 19-28. The middle category is composed of the groupings 29-40, 41-50 and 51-61. The high category is made up of the groupings 62-75, 76-87 and 88-109. The map above, Figure 7, depicts much of the same pattern seen in Figure 6 where most (n = 76) of the grid cells containing maize sites fall into the middle (n = 63) to higher (n = 13) range of frequency of consumable geophytes and few grid cells (n = 2) contain maize that are in the lower category for species present. However, most of the grid cells containing maize fall into the true middle category, colored yellow and darker yellow. There are fewer outliers to this statement than the map before this one. There are, both, fewer low range grid cells and fewer high range grid cells containing archaeological maize than in the previous map.

From Figure 3, we predicted that precipitation levels were linked to the productivity of maize and is shown in the equation previously stated on page 11, hence the reason for its inclusion. The data were accessed through the PRISM database (Northwest Access for Computation Science and Engineering 2021a) by clicking on the "Historical Past" tab on the website and clicking on the bubble next to the "Precipitation" option for the years 1895 to, and including, 1950. Then, I downloaded the data as ASCII files through the "Download All Data For Year (asc)" button. Following this, I dragged the appropriate .asc files for each year into ArcGIS. From here, individual maps were created based on their respective environmental variable; methods for creating those maps are discussed below.

To make the Total Mean Precipitation map, depicted below (Figure 9), I imported into the files into ArcGIS for each year rather than each month of the year. After this, I used the “Cell Statistics” tool and chose every year’s file and used the “MEAN” calculation option.

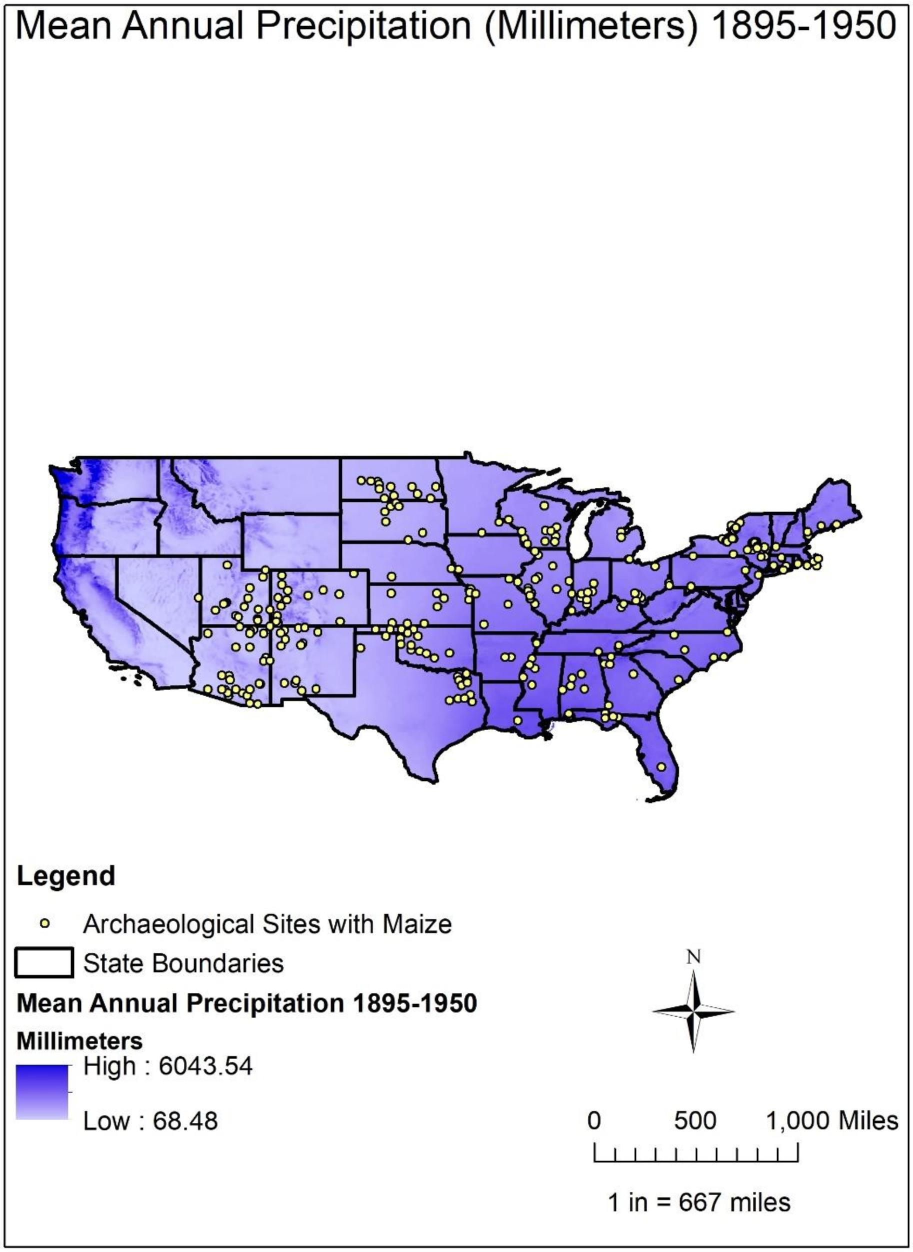


Figure 9 shows the mean annual precipitation for the years 1895 to 1950 in millimeters.

To make the Mean Growing Season Precipitation map, depicted below (Figure 10), I imported the precipitation files for the months of April, May, June, July, August, and September (04-09) into ArcGIS. Following this, I combined the months of each year by using the “Cell Statistics” tool with the calculation option set to “SUM”. Once that was achieved for each year (from 1895 to 1950), those year files were then combined using “Cell Statistics” tool with the calculation option set to “MEAN”. The resulting map depicts the mean growing precipitation for the years of 1895 to, and including, 1950.

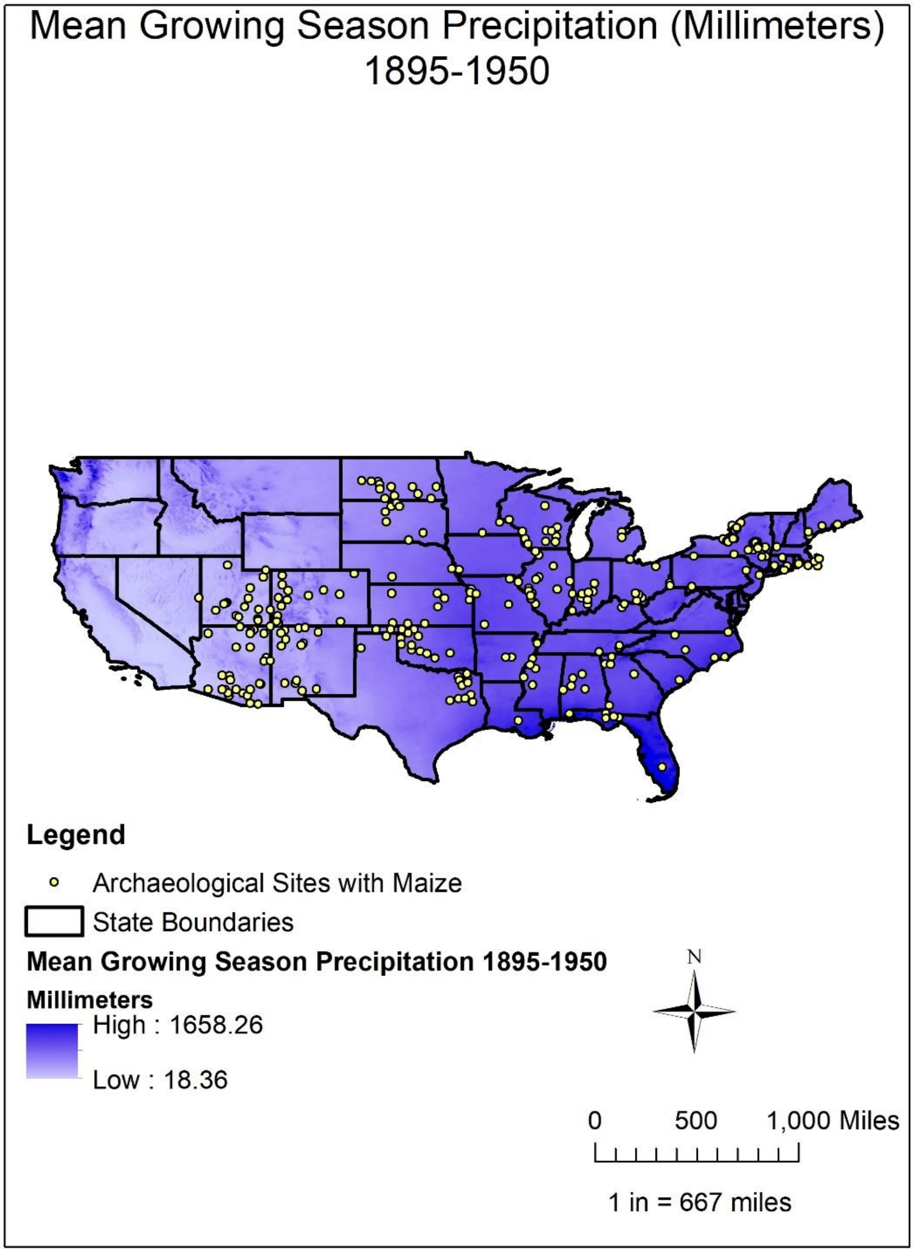


Figure 10 shows the mean precipitation levels during the growing season between the years 1895 and 1950 compared to archaeological sites containing maize.

The same steps that are listed above for the precipitation maps were utilized to obtain mean temperature data from the PRISM website (Northwest Access for Computation Science and Engineering 2021b). The only difference between that process and this one was clicking the option “Mean Temperature”. Everything else was conducted in the same manner. After downloading the .asc files for each year, I dragged the year files into ArcGIS, not the individual months, and used the “Cell Statistic” tool with the calculation set to “MEAN”. The resulting map (Figure 11) depicts the mean temperature in the United States from the year 1895 to 1950 (Northwest Access for Computation Science and Engineering 2021b).

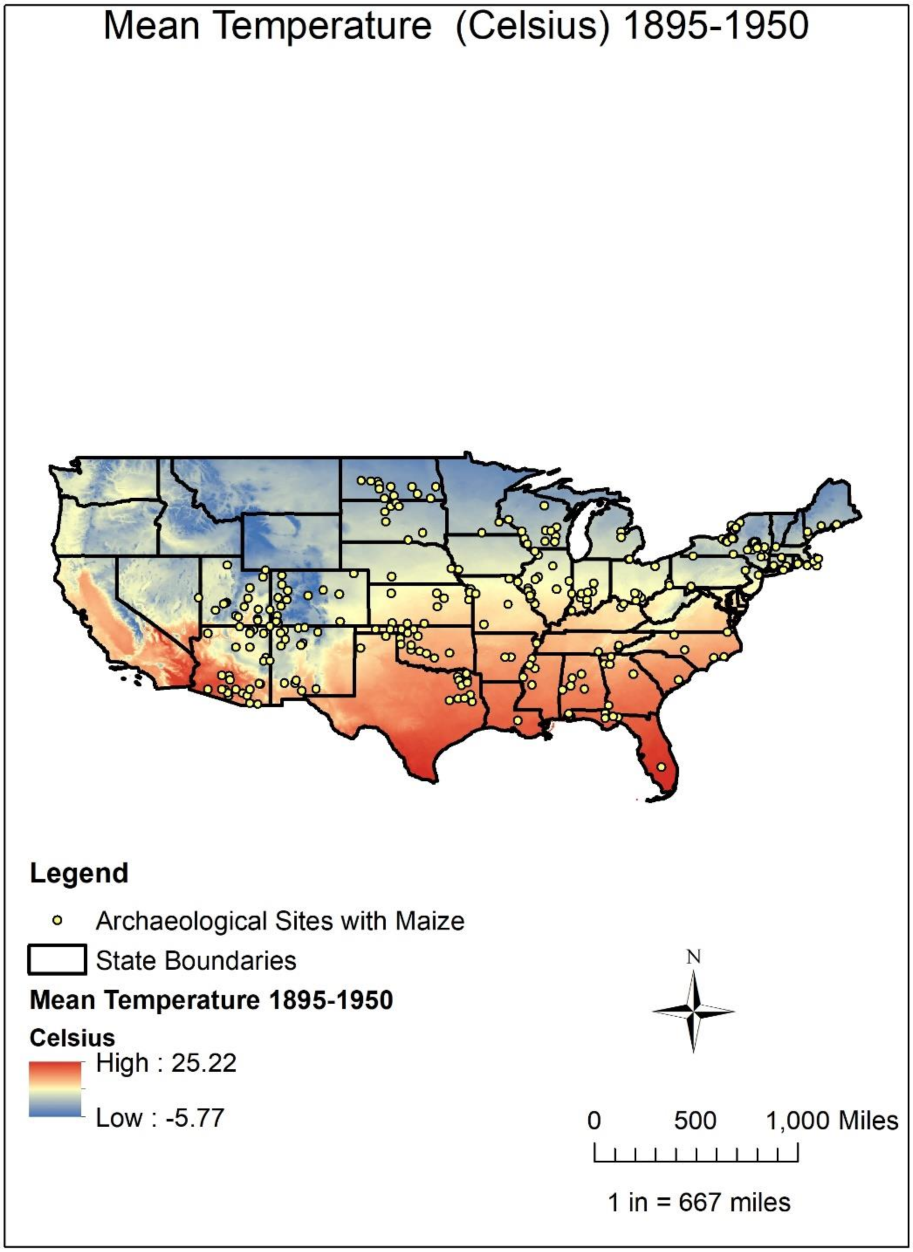


Figure 11 illustrates the mean temperature, in Celsius, for the years 1895 to 1950.

When referring to all three maps, an interesting pattern emerges. They show a curious grouping of archaeological sites containing maize in the West compared to the Midwest and Northeast. In the West, archaeological sites with maize are, predominantly, more scattered around each other with some overlap occurring. However, in the Midwest and Northeast there is more overlapping of sites compared to the scatter pattern. Possible explanations for this pattern could include varying access to reliable water sources, difference in available land, differing demographic pressures, and differing biases in archaeological excavation and reporting.

Final Data

To incorporate the "Historical Precipitation" and "Historical Mean Temperature", the "Project Raster" tool needed to be used to turn it into the "WGS_1984" geographic coordinate system. Then, the "Int" tool was utilized to turn it into an integer type of data rather than its original format (floating point). Following this, I used the "Build Raster Attribute Table" tool for the datasets. Lastly, the "Raster to Polygon" tool was utilized in order to make the data easier to work with when joining them with other data. All of the historical environmental data were put through the same process to put the data in the same data table. The environmental data was reported at a much finer resolution and were combined to calculate a number that accurately represented the 2.5 by 2.5 decimal degree grid cell.

To calculate the Total Annual Precipitation, I started by importing into ArcGIS the files for each year, rather than each month of the year. After this, I used the "Cell Statistics" tool and chose every year's file and used the "SUM" calculation option. The

“All Geophyte” dataset was imported to create a grid using the “Grid Index Feature” tool with, both, the height and width of the cell set at 2.5 decimal degrees. The resulting grid table was utilized as the input zone, based on page name, when using the “Tabulate Intersection” tool with the resulting summed values (from the “Cell Statistics” tool) as the input feature class, based on grid code. The resulting table shows multiple values (precipitation readings) assigned to grid cells. Next, I ran the “Summary Statistics” tool to obtain the mean of the summed values for each grid cell. Following this, I exported the data into a spreadsheet and then divided those sums by fifty-five in order to find the total precipitation mean for the years spanning 1895 through 1950.

To calculate the precipitation levels for Mean Growing Season Precipitation, I dragged the precipitation files for the months of April, May, June, July, August, and September (04-09) into ArcGIS. Following this, I combined the months of each year by using the “Cell Statistics” tool with the calculation option set to “SUM”. Once that was achieved for each year (from 1895 to 1950), those year files were then combined using the same methods listed above. Then, I imported a grid index based on the all geophyte data wherein the cells are 2.5 by 2.5 decimal degrees. Subsequently, I put that result into the “Tabulate Intersection” tool as the input zone, based on page name, while the summed precipitation level layer was utilized as the input feature, based on grid code. The resulting table was then put into the “Summary Statistics” tool wherein the grid code was utilized to calculate the mean level of those previously summed precipitation levels while the page name was the input for the case field to get the mean growing precipitation for the years of 1895 to, and including, 1950. Following this, the rows were selected and exported into an Excel sheet and then divided by 6 (the number of months per year) and then fifty-five (the number of years over which these data were collected and calculated). The concentration of precipitation during the growing season is simply the mean growing season precipitation divided by total precipitation.

The same steps that are listed above for Mean Precipitation Maps were utilized to obtain mean temperature data from the PRISM website (2021b). The only difference between that process and this one was clicking the option “Mean Temperature”. Everything else was conducted in the same manner. After downloading the .asc files for each year, I dragged the year files into ArcGIS, not the individual months, and used the “Cell Statistic” tool with the calculation set to “SUM”. Then I utilized the “Int” tool again. Following this, the “Project” tool was used to change the coordinate system to “GCS_WGS_1984”. A grid index was created from the same geophyte dataset that created a grid for the total precipitation map (merged all geophyte dataset) using the “Grid Index Tool” with the cell width and height set at 2.5 decimal degrees. Next, the resulting grid index was utilized as the zone field, based on page name, for the “Tabulate Intersection” tool with the resulting dataset from the “Project tool” as the feature class based on grid code to assign those values to grid cells. The resulting table shows multiple values tied to every grid cell. From here, the table was joined with the grid index that was created. Then, the “Summary Statistics” tool was utilized to get the mean of those summed values in the grid cell. The resulting table was then exported and turned into an Excel spreadsheet. From there, the data were divided by fifty-five in order to show the mean temperature in the United States from the years 1895-1950 (Northwest Access for Computation Science and Engineering 2021b).

Next, I imported the “Consumable Geophyte” point data in addition to the “All Geophyte” data. Following this, I added a grid by using the “Grid Index Features” tool with the dimensions of the output polygon measuring at 2.5 by 2.5 decimal degrees. Then, I added the maize database data (Archaeological Sites with Maize) to the resulting grid by joining them based on spatial location.

To calculate the number of geophyte species for each 2.5 x 2.5 decimal degree grid square, I had to use the “Tabulate Intersection” on the consumable geophyte data based on the category “specific epithet” (the species category) and on the all geophyte data based on the category “species”. The results split up the geophyte species into which grid cell they fell in. Next, I utilized the “Frequency” tool on the results of the “Tabulate Intersection” based on the page name (which is the grid cell name). This means that the “Frequency” tool counted how many geophyte species fell into a grid cell based on the occurrence of that grid cell name in the “Tabulate Intersection” results (the resulting table from the Tabulate tool shows a grid cell name, geophyte species, how many points of that species occur in that grid, as well as the percentage that species makes up in the total number of species in that cell). After this, I did a join based on the table for both results of the “Frequency” (“Consumable Geophyte” and “All Geophyte” data) so that ArcGIS would include in the spreadsheet the number of occurrences in each grid cell. When all categories were combined, I opened the attribute table and clicked on “Select All” then exported them as a text file with .csv at the end of the name of the table. Within the Excel spreadsheet, information not pertaining to the specific data was omitted. Lastly, about two dozen grid cells were omitted from the spreadsheet utilized for the analysis in R due to lower numbers in geophytes resulting from most of, if not the entire, grid cell being located over water (touches land or shoreline) or touches a land border.

Chapter 4: Results

In this chapter, I will discuss the results of my analysis. My results provide partial support for my predictions. I first provide a reminder of the main predictions of my model, then a summary of results and, finally, a description of the tables and figures that illustrate the results.

In chapter 2, I predicted the possible importance of precipitation concentration (as a variable that impacts the productivity of maize) and its interaction with geophyte abundances in a given area (Figure 3). I predicted that in environments where high maize and high geophyte productivity are present, people will intensify on maize. However, in environments where maize productivity is lower (lower concentration of growing season moisture) and geophyte productivity is high, people will intensify on geophytes. Lastly, in environments where maize and geophyte productivity are low, people will most likely intensify on maize.

In summary, I find that (1) temperature, the concentration of precipitation, and geophyte richness all have statistically significant (at $p<0.05$) effects when regressed on the number of maize sites among geographic areas. (2) The direction of effects, in part, are consistent with my model. For example, as temperature increases, the number of maize sites increases. Holding the richness of geophytes constant at a high value, a low concentration of precipitation during the growing season predicts more maize sites. Holding geophytes constant at low richness, maize sites are predicted to be more abundant in environments with a lower concentration of precipitation. However, where geophyte abundance is low and the centration of precipitation is high, few maize sites are predicted, which contradicts my prediction. Finally, when we control for spatial autocorrelation, the direction of all of the above effects still hold, however, the statistical significance of the predictor variables is marginal (i.e., not less than the arbitrary value of p=0.05). Overall, the results of the spatial regression indicate that some unaccounted-for spatial process has an important effect on the number of maize sites.

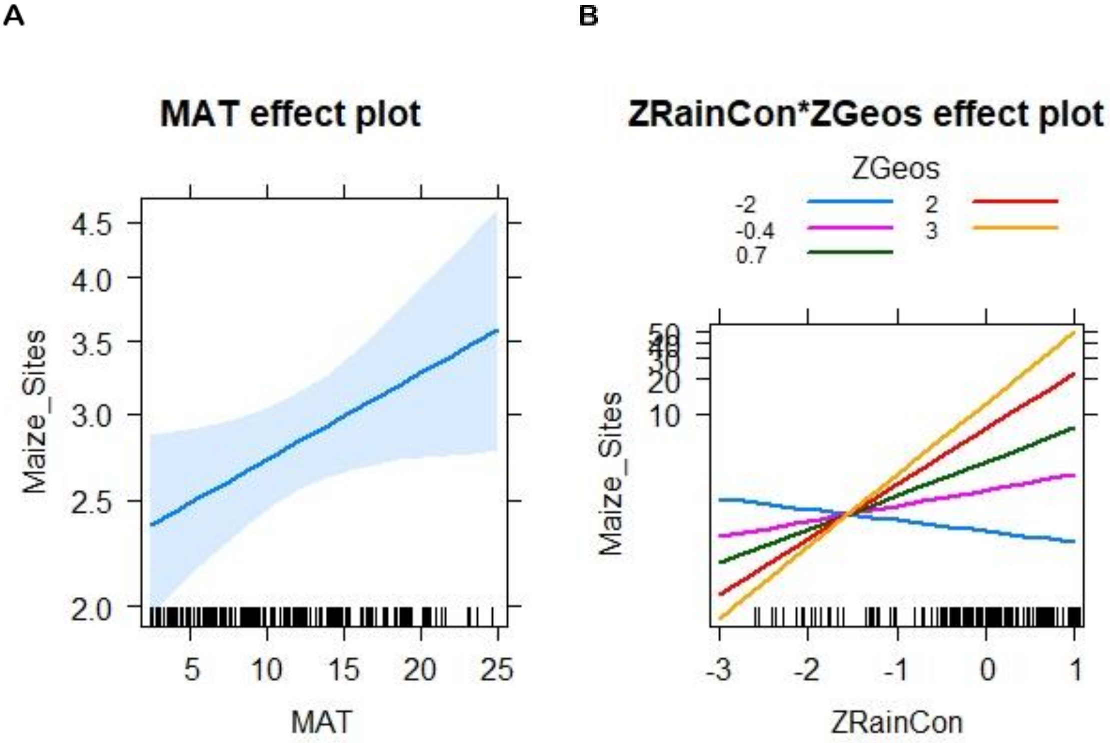


Figure 12A shows the relationship between the occurrence of archaeological sites with maize (Maize_Sites) and mean annual temperature for the years 1895-1950 (MAT). Figure 12B depicts the relationship between the concentration of precipitation during the growing season (ZRainCon) and the occurrence of archaeological maize sites (Maize_Sites) with various geophyte frequencies being held level (lines of differing colors). The differing colors represent their number of standard deviations from the mean.

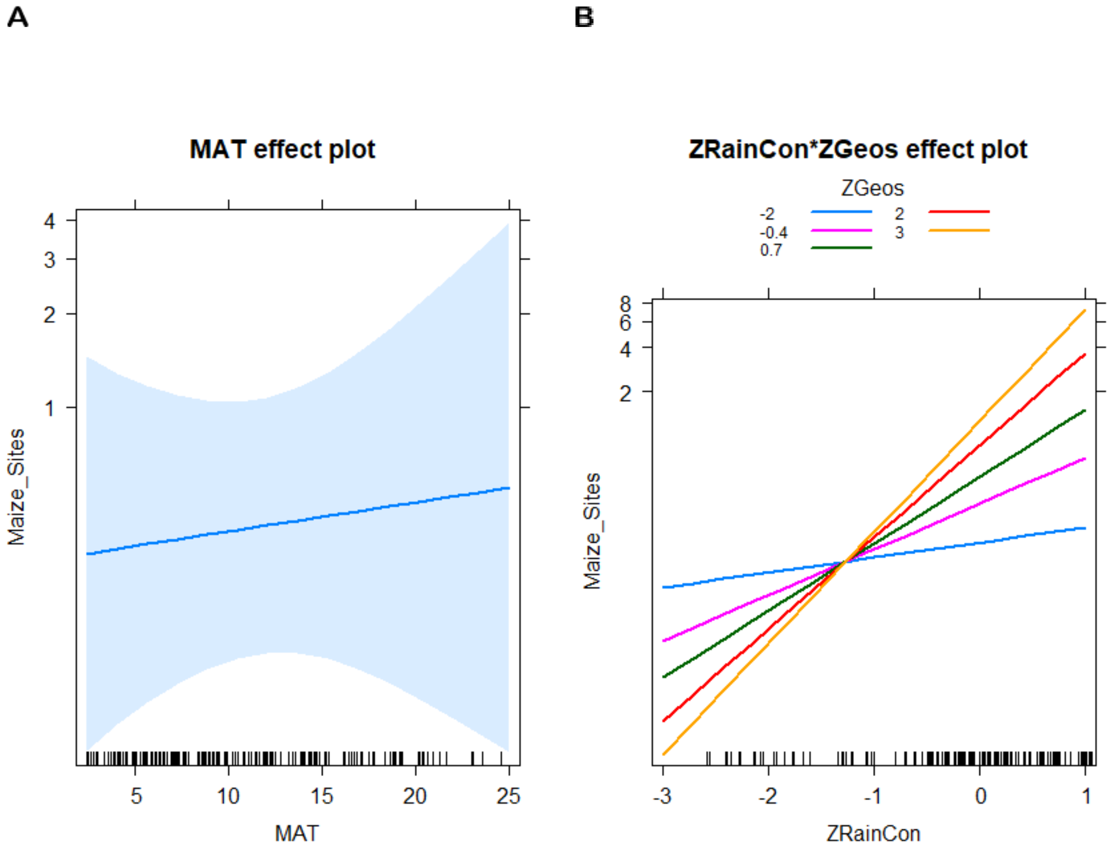
Table 2 provides calculations for each of the coefficients listed. The intercept is the point where all geophyte standard deviations converge. The coefficient ZRainCon is the z-score for growing season precipitation. MAT is the mean annual temperature. Z Geos represent the z-score for the frequency of all geophytes. ZRainCon and ZGeos are the combined variables defined above.

Variable	Coeff. Estimate	Std. Error	Z value	Pr(>|z|)
Intercept	0.820507	0.116426	7.047	<0.05
ZRainCon	0.435732	0.061196	7.120	<0.05
MAT	0.018256	0.008919	2.047	<0.05
ZGeos	0.499183	0.051300	9.731	<0.05
ZRainCon:ZGeos	0.323358	0.052052	6.212	<0.05

Figure 12 and Table 2 present the results of a general linear model (equation 1) that regresses the number of maize sites on temperature and the interaction of geophyte richness and rainfall concentration. Figure 12A visually presents the effect of temperature on the number of archaeological sites containing maize. Basically, it shows that when temperature goes up, so does the number of archaeological sites that contain maize. Figure 12B depicts the relationship between precipitation concentration during the growing season and archaeological sites containing maize when geophyte levels are held constant. The gold line represents grid cells containing the highest frequency of geophytes (3 standard deviations above the mean of all grid cells). As we can see from the graph, where geophyte richness is high and rainfall concentration low, very few maize sites are predicted by the model. However, where geophyte richness is high and rainfall concentration is high, maize sites are abundant. This result is consistent with my model predictions. The blue line, in the same graph, represents grid cells that contain the lowest frequencies of geophytes (-2 standard deviations from the mean). In environments with a low concentration of precipitation, these geophyte depauperate environments are predicted to have few maize sites. In such environments, as the concentration of precipitation during the growing season increases, fewer maize sites are predicted. This result is inconsistent with my model and predictions.

Figure 12B displays patterns consistent with the idea that where there is less rainfall during the growing season in an environment that possesses an abundance of geophytes, people will intensify on geophytes limiting the number of archaeological sites created containing maize. Figure 12B also shows that if the growing season contains a greater concentration of precipitation, with abundant geophytes, then people will intensify on maize. However, in dry growing season environments, if geophytes are less abundant then people are more likely to intensify on maize; thus, increasing the number of archaeological sites containing maize. Finally, where there is a smaller number of geophytes and a high concentration of precipitation during the growing season, people will intensify on geophytes.

Although Table 2 and Figure 12 illustrate patterns consistent with some of my predictions, this analysis does not take into account the potential for spatial autocorrelation of the residual deviances (errors) in the predicted abundance of maize sites. This potentially biases the coefficients of a model. In this case, I used a global Moran’s I test of spatial autocorrelation on the residual deviances and found a Moran’s I of 0.018 compared to a simulated expected value of -0.006 ($p<0.05$). This indicates that errors in the number of predicted maize sites weakly correlate in space (i.e., cluster together).



Figures 13A and 13B depict the same data but factors in the spatial component. Figure 13A illustrates the relationship between archaeological sites containing maize (Maize_Sites) and mean annual temperature for the years 1895-1950 (MAT) effect plot shows an increase in the confidence level range, the light blue area surrounding the blue line. Figure 12B depicts the relationship between the concentration of rainfall during the growing season ZRainCon) and the occurrence of archaeological maize sites (Maize_Sites) with various geophyte frequencies being held level (lines of differing colors). The differing colors represent their number of standard deviations from the mean.

Table 3 provides calculations for each of the coefficients listed. The intercept is the point where all geophyte standard deviations converge. The coefficient ZRainCon is the z-score for growing season precipitation. MAT is the mean annual temperature. Z Geos represent the z-score for the frequency of all geophytes. ZRainCon and ZGeos are the combined variables defined above.

Variable	Coeff. Estimate	Cond. SE	t-value
Intercept	-1.13768	0.86744	-1.3115
ZRainCon	0.83178	0.43965	1.8919
MAT	0.02166	0.06397	0.3386
ZGeos	0.37815	0.23191	1.6306
ZRainCon:ZGeos	0.29922	0.26627	1.1238

Figure 13 and Table 3 depict the results of a mixed effects regression model that include latitude and longitude as a random predictor of differences in the number of maize sites. Controlling for this variation in the spatial distribution of maize sites explains a significant amount of the variation in the number of maize sites among grid cells. Figure 13A and Figure 13B, depict the same data as Figure 12A and Figure 12B, but are calculated factoring in the spatial component (latitude and longitude). Figure 13A shows the significance between temperature and archaeological maize when factoring in the spatial clustering of data points. The line in Figure 13A is less steep but still has a gradual upwards trajectory and a much wider confidence range. It shows that the relationship between temperature and number of maize sites is now very nearly random. Figure 13B replicates the effects shown in Figure 12B.

Table 3 illustrates that the coefficients associated with the concentration of precipitation and the number of geophyte species are now marginally significant. Their lower estimates cross zero at the 95% confidence level, thus, at that level of confidence, we cannot rule out that the coefficients in the table are due to chance. A Moran’s I test on the residual deviances indicates a value of -0.02 against an expected value of -0.006 (p=0.07). This indicates that the spatial autocorrelation of the residual deviances is marginally significant.

Chapter 5: Discussion and Conclusion

In this final chapter, I restate the question that guided my research and then the predictions. Following this, I discuss the results and limitations of my data. Lastly, I state why my research is important and future avenues of research resulting from my thesis.

In the beginning of this thesis, I asked if regions of N. America where geophytes are more diverse, and (in theory) abundant, display less evidence of prehistoric agriculture than places where such resources were less abundant? Answering this question furthers our understanding of when, or under which environmental conditions, people will adopt or reject maize agriculture thereby enhancing our knowledge on the transition to agriculture. I predicted that a higher productivity of geophytes, in any given area, would correspond with a lower occurrence of archaeological maize sites while an area with lower geophyte productivity would correspond with more occurrences of archaeological maize. Furthermore, in high maize and high geophyte productivity environments, I expected people to increase their dependence on maize; while in lower maize productivity (due to lower concentration of growing season precipitation) and high geophyte productivity environments, I expected people would intensify their exploitation of geophytes. However, in areas where there is, both, low maize productivity and geophyte productivity, people would intensify their efforts in maize agriculture.

The results show that the productivity of geophytes, alone, may not matter much. However, the importance of the concentration of rainfall during the growing season does seem important. It appears that the concentration of precipitation during the growing season, in interaction with geophyte richness, impacts the presence of maize agriculture.

One of the greatest limitations within this study is the need to use modern data for both the identification of geophytes potentially consumed by prehistoric populations and location data for the geophyte occurrences. The modern data for identification of geophytes utilized for consumption comes from a book whereby the author draws from Native American knowledge that has been handed down through generations. The modern data for identifying geophyte occurrences comes from a database that identifies where people have seen this species or if it is a preserved specimen. Since technology for identifying traces of geophyte species has only recently developed within the past few years, there has not been enough time, nor money, to run these tests on multiple archaeological sites within the United States. It is possible that there are names of geophyte species, that were consumed throughout prehistory, that are not on the list due being forgotten over several generations or less to no access to them.

Another limitation on the data, specifically the maize database data, is that Google scholar was utilized to find most of the archaeological sites that contain maize. The reason for this is to make this study as accessible as possible. There could be biases in the reports and articles collated by Google Scholar (systemic exclusion of gray literature in some areas but not others) that could contribute to the patterns and correlations we see in the data presented above. However, if we collected maize data from all archaeological sites that have maize, in the United States, then the patterns seen in that data would more accurately depict trends.

Yet another limitation on this data is the use of species richness as a proxy for productivity. In my thesis, I assumed that species richness was a proxy for productivity since there was a precedent for this set by ecological researchers (Isbell and colleagues 2013). However, there is a possibility that they could be weakly linked.

This research could be used as a foundation for many research projects in the future. This research could model other, additional, variables in future studies regarding the adoption of maize agriculture in the United States to better understand the biogeographical conditions under which the switch occurs from a hunter-gatherer diet to a maize dependent diet. This research could also prove valuable for its ability to predict other possible archaeological sites containing maize in addition to task-oriented sites focused on processing geophytes.

Furthermore, the research could be expanded upon in the future when more archaeological sites containing maize in the United States are found. We could also expand the list of geophytes as the technology for identifying geophyte traces is utilized on sites and their artifacts more consistently in the future.

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Appendices

Appendix A

```
#READ FINAL
DATA###################################################################

#Set working directory to the directory with your data

#########################################################################

######Spatial Regression and testing for spatial autocorrelation

library(geoR)
library(viridis)
library(tidyverse)
library(gridExtra)
library(NLMR)
library(DHARMa)
library(spaMM)
library(ape)
library(pgirmess)
library(glpkAPI)
library(maps)
library(ggplot2)
library(effects)


##Load US State map

MainStates <- map_data("state")


###Read in your data

keep3<-read.csv(file="Thesis_Data_V5.csv", header=T)


###Plot in space the presence of maize.

  ggplot(keep3, aes(Long, Lat, colour = Maize_Sites)) +

  geom_point(size = 3)+

  scale_color_gradient2(low = "yellow", high = "darkgreen", na.value = NA) +

  theme_bw() +

  theme(axis.text.x = element_text(size=28, colour = "black"),
axis.title.x=element_text(size=24),
```

```
        axis.title.y=element_text(size=24), axis.text.y = element_text(
          size=28))+
  geom_polygon( data=MainStates, aes(x=long, y=lat, group=group),
              color="gray70", fill="NA" )

  ###Histogram of Maize Sites
hist((keep3$Maize_Sites), breaks=15)

#Step #1: Run GLM regression for count data on maize Poisson distribution
##mrean centered rainfall and geophyte variables

mylogit <- glm(Maize_Sites~ZRainCon+MAT+ZGeos+ZRainCon*ZGeos, data = keep3,
family =  "poisson")
summary(mylogit)
plot(allEffects(mylogit), multiline=TRUE)

###Check spatial autocrrelation of residuals at different spatial scales
nbc <- 20
cor_r <- pgirmess::correlog(coords=keep3[,c("Long", "Lat")],
                            z=mylogit$residuals,
                            method="Moran", nbclass=nbc)
cor_r
correlograms <- as.data.frame(cor_r)
correlograms$variable <- "mylogit$residuals"

# Plot correlogram of residual correlation at various distances
ggplot(subset(correlograms, variable=="mylogit$residuals"), aes(dist.class, coef)) +
  geom_hline(yintercept = 0, col="grey") +
```

```
  geom_line(col="steelblue") +
  geom_point(col="steelblue") +
  xlab("distance") +
  ylab("Moran's coefficient")+
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),
        panel.background = element_blank(), axis.line = element_line(colour = "black"))

##Conduct moran's I on residuals (not pooled by distance)
#Create distance matrix
GeophyteSpace<- as.matrix(dist(cbind(keep3$Long, keep3$Lat)))
#3Inverse distance matrix
GeophyteSpace.inv <- 1/GeophyteSpace
#3Set diagonals to 0
diag(GeophyteSpace.inv) <- 0
##Check matrix
GeophyteSpace.inv[1:5, 1:5]

###Claculate Moran's I for the residuals of mylogit
GeophyteResid<-resid(mylogit)
Moran.I(GeophyteResid, GeophyteSpace.inv)

###Plot Residuals of mylogit in space
keep3$mylogit_residuals <- residuals(mylogit)

ggplot(keep3, aes(Long, Lat, colour = mylogit_residuals)) +
  theme_bw() +
  theme(axis.text.x = element_text(size=28, colour = "black"),
axis.title.x=element_text(size=24),
```

```
        axis.title.y=element_text(size=24), axis.text.y = element_text(
          size=28))+
  scale_color_gradient2() +
  geom_point(size = 3)+
  geom_polygon( data=MainStates, aes(x=long, y=lat, group=group),
               color="gray70", fill="NA" )

# There is significant spatial autocorrelation at p<0.05, thus we run a spatial regression
model


###Poisson family model of environmental factors on number of maize sites
m_spamm2 <- fitme(Maize_Sites~ZRainCon+MAT+ZGeos+ZRainCon*ZGeos +
Matern(1 |Lat + Long), data = keep3, poisson(link = "log")) # this may take a bit of time
# model summary
summary(m_spamm2)
##Plot the marginal effects of the spatial model
plot(allEffects(m_spamm2), multiline=TRUE)


###Test the residuals of the spatial model for spatial autocorrelation
GeophyteResid2<-resid(m_spamm2)
Moran.I(GeophyteResid2, GeophyteSpace.inv)


###Plot correlation as a function of distance
dd <- dist(keep3[,c("Lat","Long")])
mm <- MaternCorr(dd, nu = 2.21, rho = 1.14)
plot(as.numeric(dd), as.numeric(mm), xlab = "Distance between pairs of location", ylab =
"Estimated correlation")


###Plot confidence intervals for coeffs in spatial model
```

```
coefs <- as.data.frame(summary(m_spamm2)$beta_table)
row <- row.names(coefs) %in% c('ZRainCon:ZGeos')
lower <- coefs[row,'Estimate'] - 1.96*coefs[row, 'Cond. SE']
upper <- coefs[row,'Estimate'] + 1.96*coefs[row, 'Cond. SE']
c(lower, upper)

coefs <- as.data.frame(summary(m_spamm2)$beta_table)
row <- row.names(coefs) %in% c('ZRainCon')
lower <- coefs[row,'Estimate'] - 1.96*coefs[row, 'Cond. SE']
upper <- coefs[row,'Estimate'] + 1.96*coefs[row, 'Cond. SE']
c(lower, upper)

coefs <- as.data.frame(summary(m_spamm2)$beta_table)
row <- row.names(coefs) %in% c('ZGeos')
lower <- coefs[row,'Estimate'] - 1.96*coefs[row, 'Cond. SE']
upper <- coefs[row,'Estimate'] + 1.96*coefs[row, 'Cond. SE']
c(lower, upper)

coefs <- as.data.frame(summary(m_spamm2)$beta_table)
row <- row.names(coefs) %in% c('MAT')
lower <- coefs[row,'Estimate'] - 1.96*coefs[row, 'Cond. SE']
upper <- coefs[row,'Estimate'] + 1.96*coefs[row, 'Cond. SE']
c(lower, upper)


###map predicted values from the spatial model

#save fitted values
```

```
m_spamm2_fitted <- fitted(m_spamm2)


#plot the fitted values
ggplot(keep3, aes(Long, Lat, colour = m_spamm2_fitted)) +
  theme_bw() +
  theme(axis.text.x = element_text(size=28, colour = "black"), axis.title.x=element_text(size=24),
        axis.title.y=element_text(size=24), axis.text.y = element_text(
          size=28))+
  scale_color_gradient2(low = "yellow", high = "darkgreen", na.value = NA) +
  geom_point(size = 3)+
  geom_polygon( data=MainStates, aes(x=long, y=lat, group=group),
               color="gray70", fill="NA" )
```

Appendix B

This appendix lists the sources from which archaeological sites containing maize were collected. Most sources were collected from Google Scholar using the steps listed in the “Dependent Variables” section in the Workflow Table. However, other sources utilized were the Ancient Maize Map, CARD Database, and Utah State University’s online academic library (peer-reviewed journal articles). Sources, and their information, were collected if the article mentions the terms (maize) pollen, corn cob, corn cupule, corn, maize, or osteological remains that show maize was part of the diet.

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Appendix C

Global Biodiversity Information Facility

2019 Occurrence Data. GBIF Backbone Taxonomy. Web page, Occurrence search (gbif.org), accessed January 29, 2020.

List of All Geophyte Genera:

Allium L.

Apios Fabr.

Asclepias L.

Astragalus L.

Asyneuma Griseb. & Schenk

Athyrium Roth.

Balsamorhiza Hook.

Bloomeria Kellogg

Boschniakia C.A.Mey. ex Bong.

Brodiaea Sm.

Caesalpinia L.

Calochortus Pursh

Camassia Lindl.

Cardamine L.

Carex L.

Chamaesyce Rafinesque

Chlorogalum Kunth

Cirsium Mill.

Claytonia L.

Colocasia Schott

Conioselinum Fisch. ex Hoffm.

Cucumis L.

Cymopterus Raf.

Cynoglossum L.

Cyperus L.

Dalea L.

Dasylirion Zucc.

Daucus L.

Dichelostemma Kunth

Dioscorea Plum. ex L.

Dodecatheon L.

Dryopteris Adans.

Equisetum L.

Eriogonum Michx.

Eriophorum L.

Erythronium L.

Ferula L.

Frasera Walter

Fritillaria L.

Gaura L.

Glycyrrhiza L.

Hedysarum L.

Helianthus L.

Hesperocallis A.Gray

Hoffmannseggia Cav.

Hydrophyllum L.

Ipomoea L.

Juncus L.

Lathyrus L.

Leucocrinum Nutt. ex A.Gray

Lewisia Pursh

Liatris Schreb.

Ligusticum L.

Lilium L.

Lithospermum L.

Lomatium Raf.

Lupinus L.

Lycopus L.

Maianthemum F.H.Wigg.

Melica L.

Menyanthes L.

Monolepis Schrad.

Musineon Raf.

Myriophyllum L.

Nuphar Sibth. & Sm.

Oenothera L.

Orobanche L.

Osmorhiza Raf.

Oxalis L.

Oxypolis Raf.

Oxytropis DC.

Parrya R.Br.

Parthenocissus Planch.

Pedicularis L.

Pediomelum Rydb.

Peniocereus (A.Berger) Britton & Rose

Perideridia Rchb.

Peucedanum L.

Phegopteris (C.Presl) Fee

Pholisma Nutt. ex Hook.

Phyllospadix Hook.

Physocarpus (Cambess.) Raf.

Piperia Rydb.

Pluchea Cass.

Polypodium L.

Polystichum Roth

Pteridium Gleditsch.

Pyrrhopappus A.Rich.

Ranunculus L.

Rumex L.

Sabal Adans.

Sagittaria Rupp. ex L.

Scirpus L.

Sedum L.

Silene L.

Sium L.

Smilax L.

Solanum L.

Solidago L.

Sophora L.

Sphaeralcea A.St.-Hil.

Strophostyles L.

Trifolium L.

Triteleia Douglas ex Lindl.

Typha L.

Valeriana L.

Wyethia Nutt.

Yucca L.

Zigadenus Michx.

Zostera L.

Appendix D

Global Biodiversity Information Facility

2019 Occurrence Data. GBIF Backbone Taxonomy. Web page, Occurrence search (gbif.org), accessed November 19, 2020.

List of Consumable Geophyte Species, Subspecies, and Varieties:

Allium acuminatum Hook.

Allium anceps Kellogg

Allium bisceptrum S.Watson

Allium bisceptrum var. *palmeri* (S.Watson) Cronquist

Allium bolanderi S.Watson

Allium canadense L.

Allium canadense var. *mobilense* (Regel) Ownbey

Allium cepa L.

Allium cernuum Roth

Allium cernuum var. *obtusum* Cockerell ex J.F.Macbr.

Allium dichlamydeum Greene.

Allium douglasii Hook.

Allium drummondii Regel

Allium geyeri S.Watson

Allium macropetalum Rydb.

Allium parvum Kellogg.

Allium platycaule S.Watson

Allium schoenoprasum L.

Allium schoenoprasum var. *sibiricum* (L.) Hartm.

Allium textile A.Nelson & J.F.Macbr.

Allium tricoccum Aiton

Allium unifolium Kellogg

Allium validum S.Watson

Allium vineale L.

Apios americana Medik.

Argentina anserina Rydb.

Argentina egedii subsp. *egedii* (Wormsk.) Rydb.

Arisaema triphyllum (L.) Schott

Astragalus australis (L.) Lam.

Astragalus canadensis L.

Astragalus canadensis var. *canadensis*

Astragalus cyaneus A.Gray

Asyneuma prenanthoides (Durand) McVaugh

Athyrium filix-femina (L.) Roth.

Balsamorhiza hookeri Nutt.

Balsamorhiza incana Nutt.

Balsamorhiza sagittata (Pursh) Nutt.

Balsamorhiza terebinthacea (Hook.) Nutt.

Bloomeria crocea var. *aurea* (Kellogg) J.W.Ingram

Boschniakia hookeri Walp.

Brodiaea coronaria (Salisb.) Engl.

Brodiaea elegans subsp. *hooveri* T.F.Niehaus

Brodiaea minor S.Watson

Caesalpinia jamesii (Torr. & A.Gray) Fisher

Calochortus amabilis Purdy

Calochortus aureus S.Watson.

Calochortus catalinae S.Watson

Calochortus concolor Purdy

Calochortus flexuosus S.Watson

Calochortus gunnisonii S.Watson

Calochortus leichtlinii Hook.f.

Calochortus luteus Douglas ex Lindl.

Calochortus macrocarpus Dougl.

Calochortus nuttallii Torr. & A.Gray

Calochortus palmeri S.Watson

Calochortus tolmiei Hook. & Arn.

Calochortus venustus Douglas ex Benth.

Camassia quamash (Pursh) Greene

Camassia scilloides (Raf.) Cory

Cardamine concatenata (Michx.) O.Schwarz

Cardamine diphylla (Michx.) Alph.Wood

Cardamine maxima Wood

Carex rostrata Stokes

Chamaesyce serpillifolia subsp. *serpillifolia* (Persoon) Small

Chlorogalum parviflorum S.Watson

Chlorogalum pomeridianum Kunth

Cirsium brevistylum Cronquist

Cirsium edule Nutt.

Cirsium hookerianum Nutt.

Cirsium ochrocentrum A.Gray

Cirsium scariosum Nutt.

Cirsium undulatum Spreng.

Cirsium vulgare (Savi) Ten.

Claytonia caroliniana Michx.

Claytonia lanceolata Pall. ex Pursh

Claytonia umbellata S.Watson

Claytonia virginica L.

Colocasia esculenta (L.) Schott

Cymopterus acaulis Raf.

Cymopterus acaulis var. *fendleri* (A.Gray) S.Goodrich

Cymopterus bulbosus A.Nels.

Cymopterus montanus (Nutt.) Torr. & Gray

Cymopterus multinervatus (Coult. & Rose) Tidestr.

Pseudocymopterus montanus (A.Gray) Coult. & Rose

Cynoglossum grande Dougl. ex Lehm.

Cyperus esculentus L.

Cyperus fendlerianus Boeckeler

Cyperus odoratus L.

Cyperus rotundus L.

Cyperus squarrosus L.

Dalea candida var. *candida*

Dalea candida var. *oligophylla* (Torr.) Shinners

Daucus carota L.

Daucus pusillus Michx.

Dichelostemma capitatum subsp. *capitatum*

Dichelostemma multiflorum A.Heller

Dichelostemma volubile (Kellogg) A.Heller *Dioscorea pentaphylla* L.

Dodecatheon hendersonii A.Gray

Dryopteris arguta (Kaulf.) Watt

Dryopteris campyloptera (Kunze) Clarkson

Dryopteris expansa (C.Presl) Fraser-Jenk. & Jermy

Dryopteris filix-mas (L.) Schott.

Equisetum arvense L.

Equisetum hyemale L.

Equisetum laevigatum A.Braun

Equisetum pratense Ehrh.

Equisetum telmateia Ehrh.

Eriogonum alatum Torr.

Eriogonum flavum Nutt.

Eriogonum longifolium Nutt.

Eriophorum angustifolium Honck.

Erythronium grandiflorum Pursh

Erythronium grandiflorum subsp. *grandiflorum*

Erythronium oregonum Applegate

Erythronium revolutum Sm.

Frasera speciosa Douglas ex Griseb.

Fritillaria affinis var. *affinis*

Fritillaria camtschatcensis (L.) Ker Gawl.

Fritillaria pudica (Pursh) Spreng.

Fritillaria recurva Benth.

Gaura mollis E.James

Glycyrrhiza lepidota Pursh

Hedysarum alpinum L.

Hedysarum boreale Nutt.

Hedysarum boreale subsp. *mackenzii* (Richardson) S.L.Welsh

Helianthus annuus L.

Helianthus cusickii A.Gray

Helianthus maximiliani Schrad.

Helianthus tuberosus L.

Hesperocallis undulata A.Gray

Hydrophyllum tenuipes A.Heller

Ipomoea batatas (L.) Lam.

Ipomoea cairica (L.) Sweet

Ipomoea leptophylla Torr.

Ipomoea pandurata (L.) G.F.W.Mey.

Juncus ensifolius Wikstr.

Lathyrus ochroleucus Hook.

Leucocrinum montanum Nutt. ex A.Gray

Lewisia columbiana (Howell) B.L.Rob.

Lewisia rediviva Pursh

Liatris punctata Hook.

Liatris punctata var. *punctata*

Ligusticum californicum J.M.Coult. & Rose

Lilium canadense L.

Lilium occidentale Purdy

Lilium pardalinum Kellogg

Lilium parvum Kellogg

Lilium philadelphicum L.

Lithospermum incisum Lehm.

Lomatium bicolor var. *leptocarpum* (Torr. & A.Gray) Schlessman

Lomatium californicum (Nutt. ex Torr. & A.Gray) Mathias & Constance

Lomatium canbyi J.M.Coult. & Rose

Lomatium cous J.M.Coult. & Rose

Lomatium dissectum (Nutt. ex Torr. & A.Gray) Mathias & Constance

Lomatium farinosum (Geyer ex Hook.) J.M.Coult. & Rose

Lomatium geyeri J.M.Coult. & Rose

Lomatium grayi J.M.Coult. & Rose

Lomatium nevadense J.M.Coult. & Rose

Lomatium orientale J.M.Coult. & Rose

Lomatium piperi J.M.Coult. & Rose

Lomatium simplex var. *leptophyllum* (Hook.) Mathias

Lomatium simplex var. *simplex*

Lomatium triternatum J.M.Coult. & Rose

Lomatium watsonii J.M.Coult. & Rose

Lupinus nootkatensis Donn ex Sims

Lupinus nootkatensis var. *nootkatensis*

Lupinus nootkatensis var. *fruticosus* Sims

Lupinus polyphyllus Lindl.

Lycopus uniflorus Michx.

Maianthemum racemosum subsp. *racemosum*

Melica bulbosa Porter & J.M.Coult.

Menyanthes trifoliata L.

Monolepis nuttalliana (Roemer & Schult.) Greene

Musineon divaricatum var. *divaricatum*

Musineon divaricatum var. *hookeri* Torr. & A.Gray

Myriophyllum spicatum L.

Nuphar lutea subsp. *polysepala* (Engelm.) E.O.Beal

Nuphar lutea subsp. *variegata* (Engelm. ex Durand) E.O.Beal

Oenothera biennis L.

Oenothera triloba Nutt.

Orobanche cooperi (Gray) A.A.Heller

Osmorhiza berteroi DC.

Oxalis violacea L.

Oxypolis rigidior (L.) Raf.

Oxytropis maydelliana Trautv.

Oxytropis nigrescens Fisch. ex DC.

Parthenocissus quinquefolia (L.) Planch.

Pedicularis kanei Dur.

Pedicularis kanei subsp. *kanei* Durland

Pediomelum esculentum (Pursh) Rydb.

Pediomelum hypogaeum var. *hypogaeum*

Perideridia bolanderi A.Nelson & J.F.Macbr.

Perideridia gairdneri (Hook. & Arn.) Mathias

Perideridia gairdneri subsp. *gairdneri*

Perideridia kelloggii (A.Gray) Mathias

Perideridia pringlei (J.M.Coult. & Rose) A.Nelson & J.F.Macbr.

Pholisma sonorae (Torr. ex A.Gray) Yatsk.

Phyllospadix scouleri Hook.

Phyllospadix serrulatus Rupr. ex Asch.

Phyllospadix torreyi S.Watson

Piperia elegans (Lindl.) Rydb.

Piperia unalascensis (Spreng.) Rydb.

Polypodium virginianum L.

Polystichum munitum (Kaulf.) C.Presl

Pteridium aquilinum (L.) Kuhn

Pteridium aquilinum var. *pubescens* Underw.

Ranunculus flammula var. *filiformis* (Michx.) Hook.

Ranunculus inamoenus Greene

Ranunculus pallasii Schlecht.

Rumex crispus L.

Sagittaria cuneata E.Sheld.

Sagittaria latifolia Willd.

Scirpus nevadensis S.Watson

Silene acaulis var. *exscapa* (All.) DC.

Smilax glauca Walter

Smilax herbacea L.

Smilax pseudochina L.

Smilax rotundifolia L.

Solanum fendleri A.Gray ex Torr.

Solanum jamesii Torr.

Solanum tuberosum L.

Solidago canadensis L.

Sphaeralcea coccinea var. *coccinea*

Strophostyles helvula (L.) Elliott

Tacca leontopetaloides (L.) Kuntze

Trifolium wormskioldii Lehm.

Triteleia grandiflora Lindl.

Triteleia laxa Benth.

Triteleia peduncularis Lindl.

Typha domingensis Pers.

Typha latifolia L.

Valeriana edulis Torr. & Gray

Wyethia amplexicaulis Nutt.

Zigadenus paniculatus (Nutt.) S.Watson

Zigadenus venenosus S.Watson

Zostera marina L.

Appendix E

The following references were referenced when discussing how coordinates were found and collected. The website, Lat-Long.com, was utilized to provide coordinates to archaeological sites containing maize in order to keep the location secret (to protect the site from vandalism) when the site was not known by the public (county, township, city). In cases where the archaeological site is promoted and widely known, the more precise coordinates are utilized (for example if the site has a museum) when available on the website. If the site was located within a state forest, national forest, state park, national park, national monument, national wildlife refuge, recreation area (lake, pond, or reservoir), or a canyon then those coordinates were recorded. Furthermore, if the site was located closer to a city, or town, than the civil seat of the county then that city's coordinates were recorded.

2020 Lat-Long.com, Latitude Longitude Search - Maps of More Than 2 Million GPS Coordinates (lat-long.com), accessed April 4, 2020.

http://www.lat-long.com/Latitude-Longitude-161526-Alabama-Autauga_County.html

http://www.lat-long.com/Latitude-Longitude-161527-Alabama-Baldwin_County.html

http://www.lat-long.com/Latitude-Longitude-161558-Alabama-Hale_County.html

http://www.lat-long.com/Latitude-Longitude-153402-Alabama-Shelby_Lakes.html

http://www.lat-long.com/Latitude-Longitude-161585-Alabama-Sumter_County.html

http://www.lat-long.com/Latitude-Longitude-161588-Alabama-Tuscaloosa_County.html

http://www.lat-long.com/Latitude-Longitude-27632-Arizona-Cienega_Creek.html

http://www.lat-long.com/Latitude-Longitude-3068-Arizona-Cochise.html http://www.lat-long.com/dynamic-map-25298-Arizona-Graham.html

http://www.lat-long.com/Latitude-Longitude-2418954-Arizona-Gu_Achi_District.html

http://www.lat-long.com/Latitude-Longitude-6627-Arizona-Kayenta.html

http://www.lat-long.com/Latitude-Longitude-7539-Arizona-Lukachukai.html

http://www.lat-long.com/Latitude-Longitude-37026-Arizona-Maricopa_County.html

http://www.lat-long.com/Latitude-Longitude-7725-Arizona-Marsh_Pass.html

http://www.lat-long.com/Latitude-Longitude-9433-Arizona-Pima.html

http://www.lat-long.com/Latitude-Longitude-25446-Arizona-Pima_County.html

http://www.lat-long.com/Latitude-Longitude-14958-Arizona-Pueblo_Grande_Museum.html

http://www.lat-long.com/Latitude-Longitude-9922-Arizona-Rainbow_Plateau.html

http://www.lat-long.com/Latitude-Longitude-24621-Arizona-Snaketown.html

http://www.lat-long.com/Latitude-Longitude-12842-Arizona-Tumamoc_Hill.html

http://www.lat-long.com/Latitude-Longitude-13212-Arizona-Ventana.html

http://www.lat-long.com/Latitude-Longitude-69164-Arkansas-Lonoke_County.html

http://www.lat-long.com/Latitude-Longitude-69899-Arkansas-Mississippi_County.html

http://www.lat-long.com/Latitude-Longitude-69177-Arkansas-Pulaski_County.html

http://www.lat-long.com/Latitude-Longitude-198133-Colorado-Douglas_County.html

http://www.lat-long.com/Latitude-Longitude-2410947-Colorado-City_of_Rifle.html

http://www.lat-long.com/Latitude-Longitude-178793-Colorado-Crow_Canyon.html

http://www.lat-long.com/Latitude-Longitude-196483-Colorado-McPhee_Reservoir.html http://www.lat-long.com/Latitude-Longitude-179042-Colorado-Mesa_Verde_National_Park.html

http://www.lat-long.com/Latitude-Longitude-183932-Colorado-Trimble.html

http://www.lat-long.com/Latitude-Longitude-2378290-Connecticut-City_of_Shelton.html

http://www.lat-long.com/Latitude-Longitude-213509-Connecticut-Town_of_South_Windsor.html

http://www.lat-long.com/Latitude-Longitude-295743-Florida-Glades_County.html

http://www.lat-long.com/Latitude-Longitude-306916-Florida-Leon_County.html

http://www.lat-long.com/Latitude-Longitude-351604-Georgia-Bartow_County.html

http://www.lat-long.com/Latitude-Longitude-348672-Georgia-Greene_County.html

http://www.lat-long.com/Latitude-Longitude-353662-Georgia-The_Flat_Woods.html

http://www.lat-long.com/Latitude-Longitude-465253-Iowa-Mills_County.html

https://www.latlong.net/place/cahokia-il-usa-4791.html

http://www.lat-long.com/Latitude-Longitude-424209-Illinois-Carroll_County.html

http://www.lat-long.com/Latitude-Longitude-424232-Illinois-Greene_County.html

http://www.lat-long.com/Latitude-Longitude-424244-Illinois-Jo_Daviess_County.html

http://www.lat-long.com/Latitude-Longitude-422247-Illinois-LaSalle_County.html

http://www.lat-long.com/Latitude-Longitude-413862-Illinois-Morton.html

http://www.lat-long.com/Latitude-Longitude-1784885-Illinois-Moultrie_County.html

http://www.lat-long.com/Latitude-Longitude-415490-Illinois-Pearl.html

http://www.lat-long.com/Latitude-Longitude-428633-Illinois-Township_of_Banner.html http://www.lat-long.com/Latitude-Longitude-415547-Illinois-Pere_Marquette_State_Park.html

http://www.lat-long.com/Latitude-Longitude-2400038-Illinois-Village_of_Valley_City.html

http://www.lat-long.com/Latitude-Longitude-451676-Indiana-Greene_County.html

http://www.lat-long.com/Latitude-Longitude-450356-Indiana-Hamilton_County.html

http://www.lat-long.com/Latitude-Longitude-450365-Indiana-Johnson_County.html

http://www.lat-long.com/Latitude-Longitude-451703-Indiana-Lawrence_County.html

http://www.lat-long.com/Latitude-Longitude-450375-Indiana-Morgan_County.html

http://www.lat-long.com/Latitude-Longitude-451681-Indiana-Orange_County.html

http://www.lat-long.com/Latitude-Longitude-450379-Indiana-Owen_County.html

http://www.lat-long.com/Latitude-Longitude-450396-Indiana-Vanderburgh_County.html

http://www.lat-long.com/Latitude-Longitude-484983-Kansas-Clay_County.html

http://www.lat-long.com/Latitude-Longitude-484986-Kansas-Comanche_County.html

http://www.lat-long.com/Latitude-Longitude-484999-Kansas-Geary_County.html

http://www.lat-long.com/Latitude-Longitude-485004-Kansas-Harper_County.html

http://www.lat-long.com/Latitude-Longitude-485010-Kansas-Johnson_County.html

http://www.lat-long.com/Latitude-Longitude-485022-Kansas-Marion_County.html

http://www.lat-long.com/Latitude-Longitude-485024-Kansas-Meade_County.html

http://www.lat-long.com/Latitude-Longitude-485052-Kansas-Sheridan_County.html http://www.lat-long.com/Latitude-Longitude-488935-Kentucky-Carlisle.html

http://www.lat-long.com/Latitude-Longitude-558582-Louisiana-Iberville_Parish.html

http://www.lat-long.com/Latitude-Longitude-606930-Massachusetts-Dukes_County.html

http://www.lat-long.com/Latitude-Longitude-606936-Massachusetts-Nantucket_County.html

http://www.lat-long.com/Latitude-Longitude-618249-Massachusetts-Town_of_Brewster.html

http://www.lat-long.com/Latitude-Longitude-581293-Maine-Lincoln_County.html

http://www.lat-long.com/Latitude-Longitude-581301-Maine-York_County.html

http://www.lat-long.com/Latitude-Longitude-1622951-Michigan-Bay_County.html

http://www.lat-long.com/Latitude-Longitude-1623015-Michigan-Saginaw_County.html

http://www.lat-long.com/Latitude-Longitude-659467-Minnesota-Faribault_County.html

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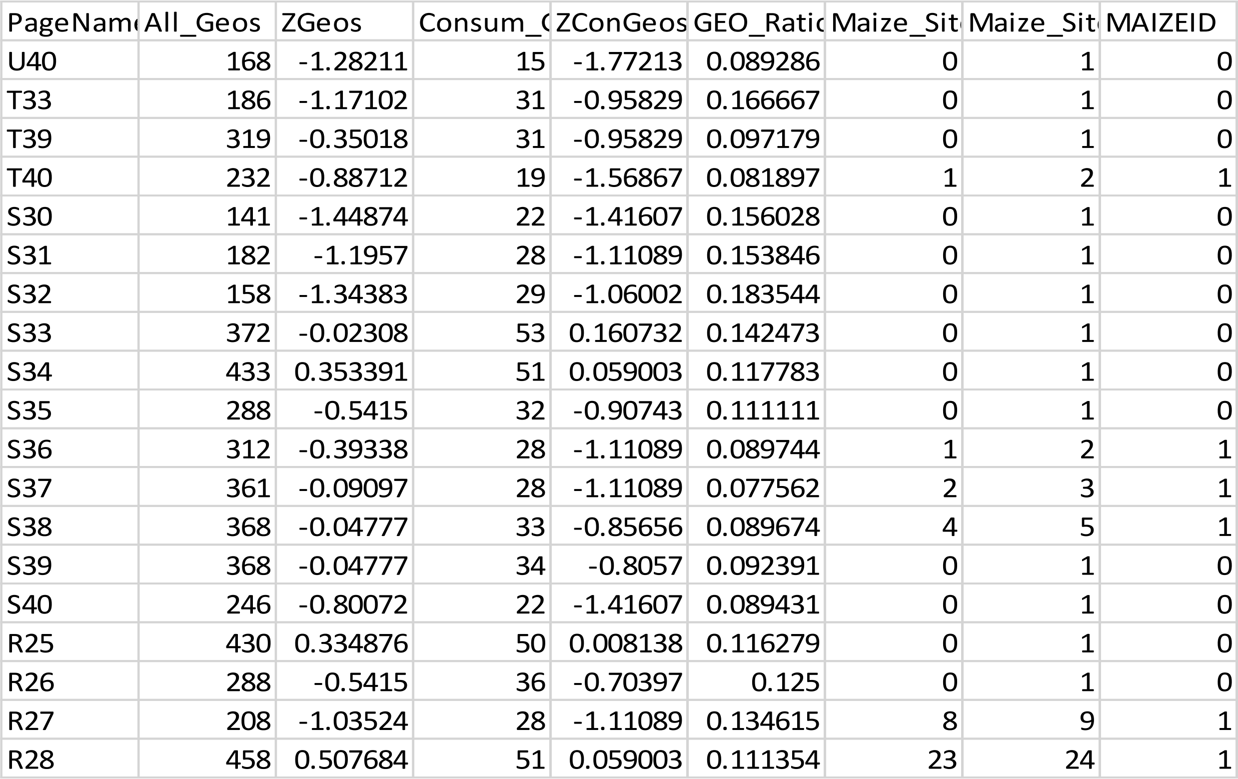
Appendix F

Attached in this appendix is the Excel sheet utilized to run the analyses in R. More specifically, this Excel sheet was created using the methods from the “Final Data” section of chapter 3. Grid cells containing so few numbers (double and single digit data points) of geophytes, both all and consumable, skewed the results and were, therefore, removed from the analysis.



PageNam	All_Geos	ZGeos	Consum_	ZConGeos	GEO_Rati	Maize_Sit	Maize_Sit	MAIZEID
U40	168	-1.28211	15	-1.77213	0.089286	0	1	0
T33	186	-1.17102	31	-0.95829	0.166667	0	1	0
T39	319	-0.35018	31	-0.95829	0.097179	0	1	0
T40	232	-0.88712	19	-1.56867	0.081897	1	2	1
S30	141	-1.44874	22	-1.41607	0.156028	0	1	0
S31	182	-1.1957	28	-1.11089	0.153846	0	1	0
S32	158	-1.34383	29	-1.06002	0.183544	0	1	0
S33	372	-0.02308	53	0.160732	0.142473	0	1	0
S34	433	0.353391	51	0.059003	0.117783	0	1	0
S35	288	-0.5415	32	-0.90743	0.111111	0	1	0
S36	312	-0.39338	28	-1.11089	0.089744	1	2	1
S37	361	-0.09097	28	-1.11089	0.077562	2	3	1
S38	368	-0.04777	33	-0.85656	0.089674	4	5	1
S39	368	-0.04777	34	-0.8057	0.092391	0	1	0
S40	246	-0.80072	22	-1.41607	0.089431	0	1	0
R25	430	0.334876	50	0.008138	0.116279	0	1	0
R26	288	-0.5415	36	-0.70397	0.125	0	1	0
R27	208	-1.03524	28	-1.11089	0.134615	8	9	1
R28	458	0.507684	51	0.059003	0.111354	23	24	1

Appendix G

Figure 14A depicts the relationship between two variables: archaeological sites containing maize (Maize_Sites) and mean annual temperature (MAT). The figure, 14A, shows a drastic upward trajectory with a narrower confidence interval. This shows a significant positive relationship between temperature and the number of maize sites. Figure 14B examines the relationship between archaeological sites containing maize (Maize_Sites) the z-score of the mean growing season rainfall (ZMGSR) while holding consumable geophyte level (ZConGeos).

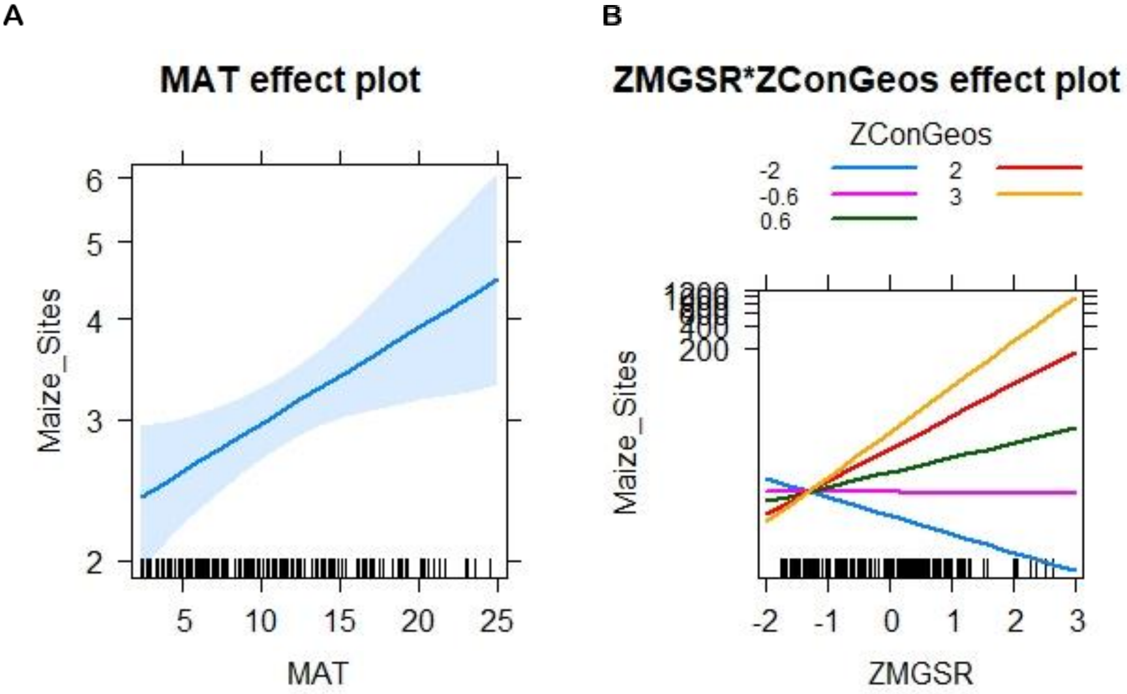


Figure 14A shows the relationship between mean annual temperature (MAT) and the frequency of archaeological sites containing maize (Maize_Sites). Figure 14B illustrates the relationship between archaeological maize sites (Maize_Sites) and z-scores for the mean growing season rainfall (ZMGSR) while keeping the z-scores for consumable geophytes (ZConGeos) level.

Table 4 provides calculations for each of the coefficients listed. The intercept is the point where all geophyte standard deviations converge. The coefficient ZMGSR is the z-score for mean growing season precipitation. MAT is the mean annual temperature. ZConGeos represent the z-score for the frequency of consumable geophytes. ZMGSR and ZConGeos are the combined variables defined above.

Variable	Coeff. Estimate	Std. Error	Z value	Pr(>|z|)
Intercept	0.81000	0.12683	6.386	<0.05
ZMGSR	0.21816	0.05598	3.897	<0.05
MAT	0.02760	0.01053	2.621	<0.05
ZConGeos	0.52162	0.05952	8.764	<0.05
ZMGSR:ZConGeos	0.39523	0.05649	6.997	<0.05

Figure 14 and Table 4 depict the results of a general linear model (equation 1) that regresses the number of maize sites on temperature and the interaction of geophyte richness and rainfall concentration. Figure 14A plots the effect of temperature on the number of archaeological sites containing maize. Furthermore, it illustrates a positive relationship between temperature and the presence of archaeological sites containing maize. In other words, as temperature increases so does the number of maize sites. The figure beside it, Figure 14B, depicts the relationship between mean precipitation concentration during the growing season and maize sites when geophyte levels are held level. In Figure 14B, the gold line signifies grid cells containing the highest frequency of geophytes (3 standard deviations above the mean) while the blue line signifies grid cells containing the lowest frequency of geophytes (-2 standard deviations from the mean).

The graph, Figure 14B, depicts a strong positive relationship between the mean growing season precipitation (ZMGSR) and the two highest standard deviations (gold and red lines) for consumable geophytes (ZConGeo). This means that in an area where there is a high abundance of geophytes and is rather rainy (higher concentration of growing season precipitation), maize sites are more likely to be present. However, in an environment where geophyte frequency is low and the summer is drier (lower concentration of growing season precipitation), people are less likely to adopt maize (lowering the number of maize sites in that area). The next set of graphs depicts the same data as above but considers the significance of data points based on their spatial clustering.

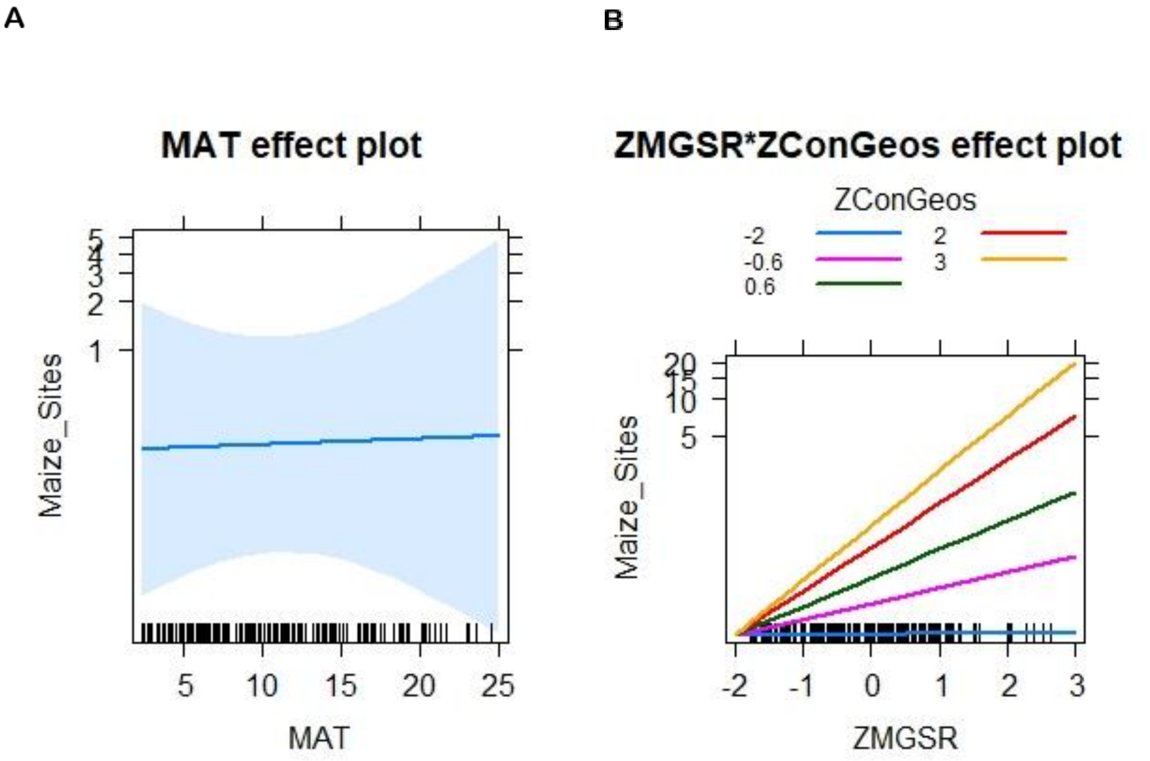


Figure 15A shows the relationship between mean annual temperature (MAT) and the frequency of archaeological sites containing maize (Maize_Sites). Figure 15B illustrates the relationship between archaeological maize sites (Maize_Sites) and z-scores for the mean growing season rainfall (ZMGSR) while keeping the z-scores for consumable geophytes (ZConGeos) level.

Table 5 provides calculations for each of the coefficients listed. The intercept is the point where all geophyte standard deviations converge. The coefficient ZMGSR is the z-score for mean growing season precipitation. MAT is the mean annual temperature. Z ConGeos represent the z-score for the frequency of consumable geophytes. ZMGSR and ZConGeos are the combined variables defined above.

Variable	Coeff. Estimate	Cond. SE	t-value
Intercept	-1.454235	1.23114	-1.18121
ZMGSR	0.422383	0.55535	0.76058
MAT	0.008297	0.08621	0.09624
ZConGeos	0.417019	0.25706	1.62227
ZMGSR:ZConGeos	0.206149	0.26548	.77652

Figure 15 and Table 5 depict the results of a mixed effects regression model that incorporate latitude and longitude as a random predictor of differences in the number of maize sites. Significant amounts of the variation in the number of maize sites among grid cells can be explained when controlled for the variation in spatial distribution of maize sites. Figure 15A and Figure 15B, depict the same data as the figures, Figure 14A and Figure 14B, before but is calculated utilizing the spatial component (latitude and longitude). Figure 15A shows the significance between temperature and archaeological maize when factoring in the spatial clustering of data points. The line in Figure 15A is level and possesses a much wider confidence range. It shows that there is now, possibly, no relationship between the two meaning that their relationship is very nearly random. Figure 15B, also, displays the same information as Figure 14B but factors in the significance of spatial distribution of data points. We can see the Figure 15B exhibits the same effects shown in Figure 14B but distributed a bit differently. Essentially, the figure (Figure 15B) shows that in areas with higher abundances of geophytes with a higher concentration of growing season rainfall, people will intensify on maize. However, in areas with a low frequency of geophytes and a lower concentration of growing season rainfall, people will intensify on geophytes (lowering the number of archaeological sites containing maize present in that area).

Table 5 states the coefficients associated with the concentration of growing season precipitation and the standard deviances of consumable geophyte species plot (Figure 14B). The calculations lead me to reject the null hypothesis. However, I cannot reject the alternative hypothesis. This means that there is a possibility of significant clustering. A Moran's I test on the residual deviances indicates a Moran's I, or observed, value of -0.02 against an expected value of -0.006 ($p=0.04$). The presence of a negative z-score, resulting from this, indicates more clustering than can be realistically attributed to chance alone.