University of Utah
UNDERGRADUATE RESEARCH JOURNAL

UNDERSTANDING THE DISTRIBUTION OF ANCIENT MAIZE AGRICULTURE IN UTAH'S THREE PHYSIOGRAPHIC PROVINCES

Ishmael Medina (Faculty Mentor: Brian Codding)
Department of Anthropology

Abstract

Maize (*zea mays*) was one of the most widespread and oldest domesticated plants in the Americas before the arrival of Europeans (Huanca-Mamani et al., 2015). Despite its widespread distribution, explaining how and why maize farming spread remains a central research question in archaeology (Boyd & Surette, 2010; Hart & Lovis, 2013), as does understanding the societal impact maize agriculture had on ancestral populations (Kohler & Higgins, 2016). For my Undergraduate Research Opportunity Program (UROP) research, conducted in the spring of 2020, I examined spread of maize across Utah's Intermountain Plateaus region. This region is comprised of three major physiographic provinces, which include the Basin and Range, the Middle Rocky Mountains, and the Colorado Plateau (see Figure 3) (Utah Geological Survey, 2019). Each province is characterized by different geologic formations and environments, which should impact how well maize can grow in each province and may have different societal impacts.

These provinces are rich in ancient maize remnants and abundant in artifacts associated with maize, such as ground stone, pottery, pit houses, cliff dwellings, defense structures, and granaries (Madsen & Simms, 1998; Matson, 2016; McCool & Yaworsky, 2019). The introduction of maize agriculture into these regions had significant effects on the people living there but affected each of these provinces differently (Madsen & Simms, 1998). Before the introduction and movement of maize agriculture into these regions people lived in highly mobile, small, bands and relied on foraging as a means of subsistence. The introduction of maize agriculture gave way to many changes in these peoples' lifeways and some groups began to transition to more sedentary and semi-sedentary lifestyles by aggregating into larger communities based around maize agriculture, or horticulture, and opportunistic foraging (McCool & Yaworsky, 2019); a prominent example of this would be the Ancestral Puebloan archaeological site at Chaco Canyon, located in the Four Corners region (Dorshow, 2012).

In this paper I will analyze the distribution of maize within Utah's three physiographic provinces, using spatial analysis, via ArcGIS Pro2 (Esri Inc., 2019), and statistical analysis, via RStudio (RStudio Team, 2019). I am using a subset of maize samples from a database of all the radiocarbon dates in Utah, which has recently been created by the faculty and students at the University of Utah's Archaeological Center (Codding et al., in review). I am using these maize samples as potential maize agriculture sites because a majority of the sites are in either granaries, middens, or near sedentary structures (pit houses/ villages); these sedentary features are usually near cultivation sites (Barlow, 2002).

Assuming that the Ideal Free Distribution model (Fretwell & Lucas, 1969) is correct, I expect the earliest farmers to settle in the best locations, only moving to less suitable locations later in time due to increasing competition. This model suggests that "habitat suitability varies across the landscape, that individuals have perfect knowledge of their environment and are free

(i.e., not excluded by competitors) to settle where they choose, and that habitat suitability is characterized by negative density dependence" (Yaworsky & Codding, 2018). To predict the most suitable locations for ancient maize agriculture in Utah I have selected a modern moisture index (Yaworsky, 2016), assuming the moisture index of Utah has stayed relatively the same over the last three thousand years, and elevation as the ecological factors that influence an ancient maize farmers site choice. I will then try to use a Generalized Additive Model (GAM) to demonstrate how the Ideal Free Distribution model can also be applied to understanding the dissemination of ancient maize in Utah.

Datasets and Methods

I was able to obtain access to a database, with help from Dr. Brian Codding, that has been constructed by the faculty and Ph.D. students at the University of Utah Archaeological Center, which is projected to contain all the radiocarbon dates in the state of Utah (Codding et al., in review). The data I am using is a subset of maize samples, known as "ancient maize" (meaning maize older than ~400 BP). This data set is equipped with raw and calibrated radiocarbon dates, elevation (ft), coordinates, site descriptions, site numbers, and much more useful information for the 433 maize samples present.

A high-resolution spatial raster dataset of Utah's Moisture Index (MI) was created by a University of Utah Ph.D. student, Peter Yaworsky (2016), using methods from Ramankutty et al. (2002) where:

MI = annual actual evapotranspiration (ETact)/ potential evapotranspiration (PET)

Evapotranspiration (Shaw, 1988) is an important variable to look at when analyzing potential maize agriculture sites, as "evapotranspiration determines the water budget of the field" (Boomgarden et al., 2019). This data was collected between 2000 to 2013 and the "Moisture Index (MI) was created to compare the suitability of settlement locations throughout Utah to explain initial Euro-American settlement of the region" (Yaworksy, 2016). The data uses a zero to one raster value, where zero indicates poor agricultural suitability and one indicates ideal agricultural suitability. I was able to import this data into ArcGIS Pro 2 (Esri Inc., 2019) where I assigned it to a map of Utah and added my maize agricultural sites to the map (see Figure 5) by using the NAD 1983 UTM Zone 12N coordinates. I then extracted the raster values that coincide with the appropriate maize agricultural site and exported a Microsoft Excel file to run the statistical models via RStudio (R Core Team, 2019).

Utah's 3 Physiographic Provinces

As previously mentioned, Utah's Intermountain Plateaus region is home to 3 unique physiographic provinces: the Basin and Range, the Middle Rocky Mountains, and the Colorado Plateau (see Figure 3) (Utah Geological Survey, 2019). Using the radiocarbon data for maize samples, I was able to create a Chi-square test by separating the data by province and accounting for the spatial portions (mi^2) in the state of Utah. The Chi-square test residual results indicate that there are more maize agriculture sites than expected in the Colorado Plateaus province, and less maize agriculture sites than expected in the Middle Rocky Mountains and Basin and Range provinces (see Figure 1). I have also created a bar graph (see Figure 2) to illustrate how the number of maize agricultural sites differ between each province. It seems people are doing a lot more farming in the Colorado Plateau province than expected when compared to the Basin and Range and Middle Rocky Mountains provinces. To make sure this test and observation is correct, I have created a map with ArcGIS Pro 2 (Esri Inc., 2019) to see if the statistical analysis matches the spatial analysis (see Figure 3).

```
PROVINCE
       BASIN AND RANGE      COLORADO PLATEAUS MIDDLE ROCKY MOUNTAINS
             -4.512979               5.961119              -4.160129
```

Figure 1: These values are the residuals that indicate that there were fewer samples in Basin and Range (-4.512979) and Middle Rocky Mountains (-4.160129) provinces than expected, and more samples than expected in the Colorado Plateau province (5.961119) (RStudio Team, 2019).

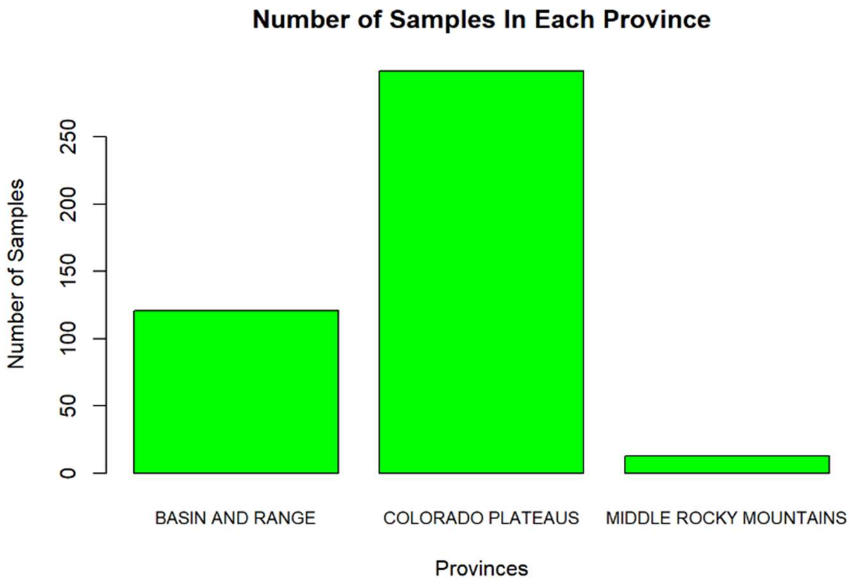

Figure 2: This bar graph illustrates the number of maize samples, or potential agricultural sites, in each province. Made via RStudio (RStudio Team, 2019).

Figure 3 uses the United States Geological Survey (USGS, 2019) data to indicate the three different physiographic provinces. I then added the locations and ages (BP) of maize agricultural sites. According to this map, the Colorado Plateau has the most maize agriculture as well as the oldest sites. Figure 3 does seem to resemble the Chi-Square test in that I would expect to see that the Colorado Plateau has the most maize agriculture sites. Since maize is native to central Mexico and first arrived in the American Southwest approximately 4,000 BP and the Colorado Plateau takes up a majority of Southern and Central Utah, it is no surprise that this is where a majority of the oldest maize samples are located (Merrill, 2009; Madsen & Simms, 1998). However, this does not explain why the Colorado Plateau is so abundant in ancient maize agriculture sites compared to the other two provinces. I will now try to use a Generalized Additive Model with implications from the Ideal Free Distribution model to explain this difference between provinces, as well as identify what variables are deemed favorable by past maize farmers in Utah.

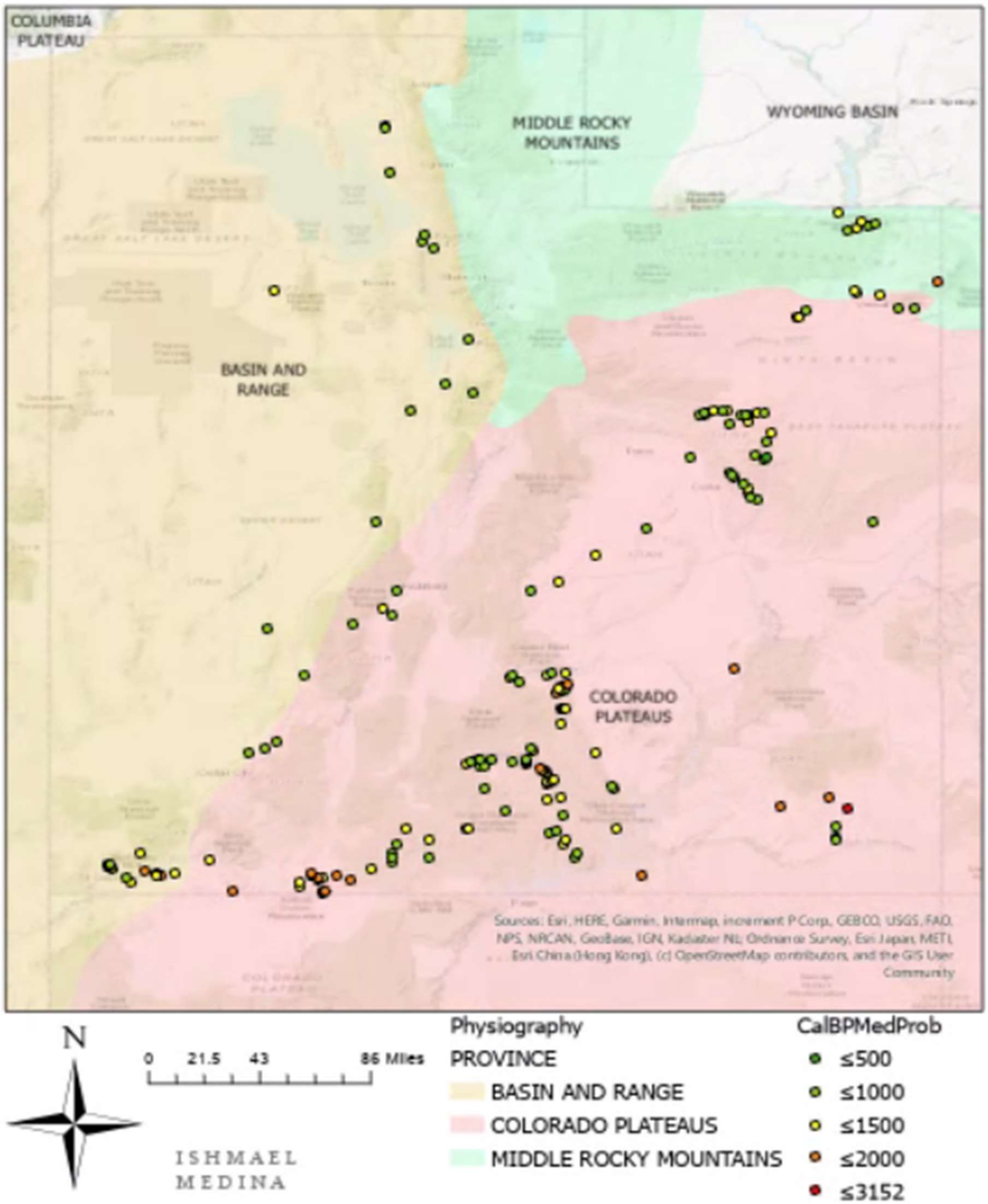

Figure 3: This map is using graduated colors to show the age of the samples. "CalBPMedProb" is the median calibrate radiocarbon date (age) and each color is separated into bands with unique colors. This map indicates that the oldest samples/ potential maize agricultural sites are located in the Colorado Plateaus province. Province data provided by https://water.usgs.gov/GIS/dsdl/physio_shp.zip.

Results

Of the 433 maize samples tested, the median MI value is 0.097 and has an interquartile range (IQR) of 0.072 to 0.116 and a median elevation of 5250 ft and an IQR of 4720 to 5880 ft. In order to see when and where people are choosing to grow cultigens, I have created a General Additive Model (GAM) to see if I can explain why there are so many maize agriculture sites in the Colorado Plateau compared to the two provinces by using ecological variables. For the GAM I have selected the calibrated median date, as my dependent variable to help reconstruct where the first farmers began to grow maize and what areas were desirable for farming over time. Moisture Index and elevation are the dependent variables, as these two variables tend to be codependent.

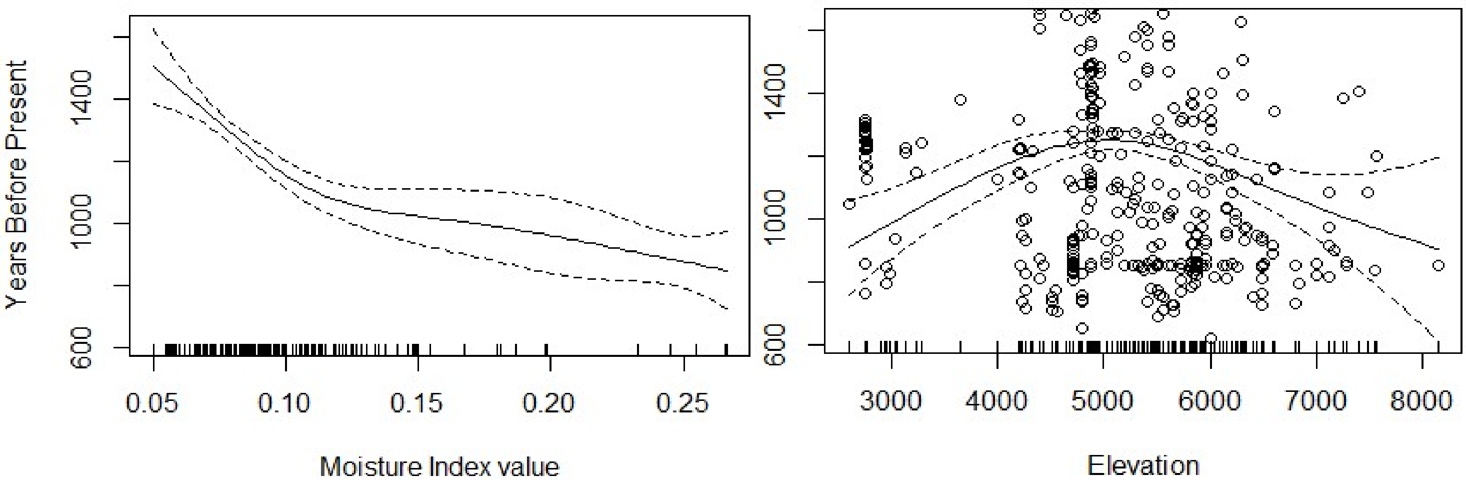

Figure 4: a) GAM plot for MI (Yaworsky, 2016) showing a negative trend, that was not expected. b) GAM plot for Elevation (R Core Team, 2019), indicating there is a favorable elevation range around the IQR (4720 to 5880 ft).

After running the GAM I obtained two significant p-values, less than 0.05, for both elevation and Moisture Index value, indicating people were choosing where to farm based on these two variables. I obtained a deviance explained value of 20.7% and the residuals are dispersed and skewed to the right. Despite these significant results, the MI GAM plot (see Figure 4a) seems to contradict what I expected. According to the Ideal Free Distribution model (Fretwell & Lucas, 1969; Yaworsky & Codding, 2018), I would expect early settlers to take up the best farming land, areas with higher MI values, first and through time we would begin to see people settling into harsher farming land. However, the model I obtained (see Figure 4a) appears to show that the early maize farmers were choosing the land with the poorest agricultural conditions first and as time progressed farmers began to grow maize in more suitable areas. If we refer to Figure 5, we can see that people were farming in dryer climates, rather than wet climates. As previously mentioned, elevation and MI covary; meaning as there is an increase in elevation there is also an increase in potential and actual evapotranspiration (MI) (see Figure 5). We can see that the areas with higher MI values seem to be on mountain ranges (e.g., the Wasatch Range and the Uinta Mountains; see Figure 5) where the agriculture of maize is almost impossible. The GAM for elevation (see Figure 4b) seems to match the IQR, 4720 to 5880 feet above sea level, and this elevation range is the most favorable for maize agriculture and can help explain why we do not see maize agriculture sites on tall mountain ranges (ex. the Wasatch Range).

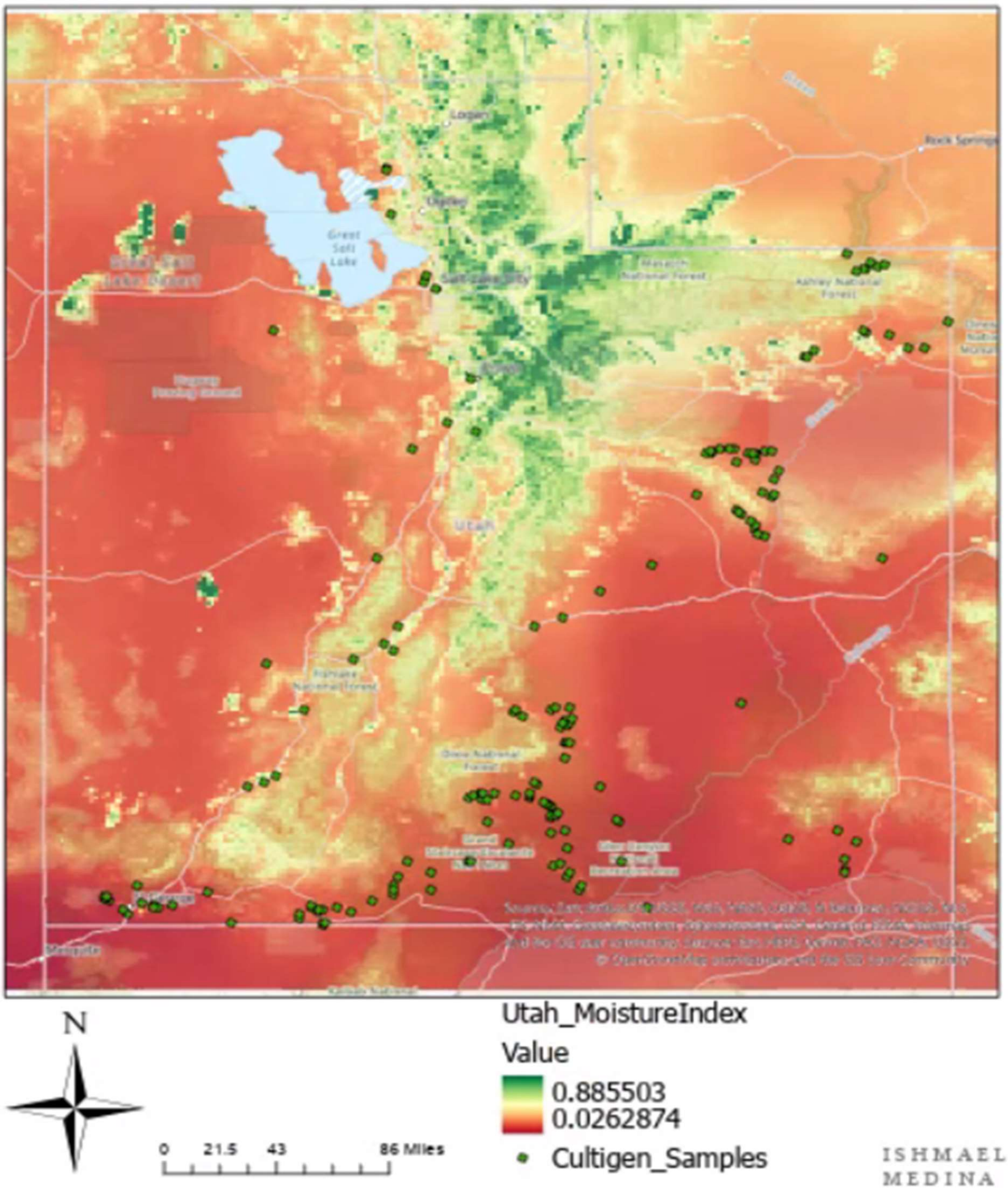

Figure 5: This a map of Utah's Moisture Index (MI) (Yaworsky, 2016) and the maize samples, or potential agricultural sites. Created via ArcGIS Pro2 (Esri Inc., 2019).

Discussion and Conclusion

In this study, I tried to understand the distribution and difference of potential maize agriculture sites between Utah's three physiographic provinces by utilizing the Ideal Free Distribution model (Fretwell & Lucas, 1969; Yaworsky & Codding, 2018). Unfortunately, the

GAMs for elevation and MI in this research did not match what I would expect while using the Ideal Free Distribution model. However, this does not mean we should not use this IFD model for this archaeological application, but alternative and/or additional variables may be a better fit for the models.

A major issue in this study was the use of a modern Moisture Index (Yaworsky, 2016) and assuming it has been relatively the same for the past three thousand years that maize has been present in Utah. Actual and potential evapotranspiration (MI) vary from year to year and assuming it has been steady over a short period of time can help analyze more recent archeological settlements (Yaworsky & Codding, 2018), but assuming it has been the same for three millenniums discounts the natural variability that come along with changing global and local environments in this extended period of time. Periods of severe droughts, floods, natural disasters, and other natural phenomena were not considered by using this modern MI. Though predictions of evapotranspiration are important for understanding crop growth, it would be a daunting task to try and predict MI levels over the past several thousand years. Thus, by using other similar variables and understanding ancient irrigation systems (Boomgarden et al., 2019) a future model can be constructed to understand the dissemination of ancient maize and agriculture tactics in Utah.

Though the GAMs for elevation and MI in this study did not match what I would expect while using the Ideal Free Distribution model to explain the distribution of maize in Utah's physiographic provinces, I am hopeful that future models can be constructed to explain this distribution. However, the Chi-square test and map (see Figure 3) do indicate a significant difference between provinces and that past maize farmers favor the Colorado Plateau. There are still additional variables and models waiting to be explored. This study should not devalue the use of the Ideal Free Distribution model (Fretwell & Lucas, 1969; Yaworsky & Codding, 2018) for understanding the distribution of ancient maize agriculture, but additional models, like suitability and irrigation models (Boomgarden et al., 2019; Yaworsky & Codding, 2018), should be used together to better understand this distribution.

Work Cited

Barlow, K. R. (2002). Predicting maize agriculture among the Fremont: An economic comparison of farming and foraging in the American Southwest. *American antiquity*, 65-88.

Boomgarden, S., Metcalfe, D., & Simons, E. (2019). An Optimal Irrigation Model: Theory, Experimental Results, and Implications for Future Research. *American Antiquity, 84*(2), 252-273. doi:10.1017/aaq.2018.90

Boyd, M., & Surette, C. (2010). Northernmost precontact maize in North America. *American Antiquity*, *75*(1), 117-133.

Codding, Brian F., Joan Brenner Coltrain, Lisbeth Louderback, Kenneth Blake Vernon, Peter M. Yaworsky, Simon C. Brewer, and Jerry D. Spangler (in review) Socioecological Dynamics Structuring the Spread of Farming in the North American Basin-Plateau Region. Environmental Archaeology.

Dorshow, W. B. (2012). Modeling agricultural potential in Chaco Canyon during the Bonito phase: a predictive geospatial approach. *Journal of Archaeological Science*, *39*(7), 2098-2115.

Esri Inc. (2019). *ArcGIS Pro* (Version 2.4.2). Esri Inc. https://www.esri.com/en-us/arcgis/products/arcgis-pro/.

Fretwell, Stephen Dewitt, and Lucas, Henry L. 1969 On Territorial Behavior and Other Factors Influencing Habitat Distribution in Birds. *Acta Biotheoretica* 19 (1):37–44.

Hart, J. P., & Lovis, W. A. (2013). Reevaluating what we know about the histories of maize in northeastern North America: a review of current evidence. *Journal of Archaeological Research*, *21*(2), 175-216.

Hirst, K. Kris. (2018, October 1). BP: How Do Archaeologists Count Backward Into the Past? Retrieved from https://www.thoughtco.com/bp-how-do-archaeologists-count-backward-170250

Huanca-Mamani, W., Muñoz, I., Laime, D., & Bastías, E. (2015). Genetic Analysis of Archaeological Maize from the Site of San Lorenzo (Azapa, Chile): A Contribution to the Maize Problem / Análisis Genético de Maíces Arqueológicos del Sito San Lorenzo (Azapa, Chile): *Chungara: Revista De Antropología Chilena, 47*(4), 565-573. Retrieved from http://www.jstor.org/stable/24916528

Kohler, T. A., & Higgins, R. (2016). Quantifying household inequality in early Pueblo villages. *Current Anthropology*, *57*(5), 690-697.

Madsen, D. B., & Simms, S. R. (1998). The Fremont complex: a behavioral perspective. *Journal of World Prehistory*, *12*(3), 255-336.

Matson, R. G. (2016). *The origins of southwestern agriculture*. University of Arizona Press. 191-193

McCool, W. C., & Yaworsky, P. M. (2019). Fight or flight: An assessment of Fremont territoriality in Nine Mile Canyon, Utah. *Quaternary International*, *518*, 111-121.

Merrill, W. L., Hard, R. J., Mabry, J. B., Fritz, G. J., Adams, K. R., Roney, J. R., & MacWilliams, A. C. (2009). The diffusion of maize to the southwestern United States and its impact. *Proceedings of the National Academy of Sciences*, *106*(50), 21019-21026.

R Core Team (2019). R: A language and environment for statistical computing. Vienna, Austria.

Shaw, Roger H. 1988 Climate Requirement. In *Corn and Corn Improvement*, 3rd edition, edited by Sprague, G. F. and Dudley, J. W., pp. 609–638. American Society of Agronomy, Madison, Wisconsin.

Utah Geological Survey (2019) State of Utah. geology.utah.gov.

Yaworsky, Peter, 2016, "A Raster of Remotely Sensed Agricultural Suitability as a Function of Moisture Index (MI) in Utah, U.S.A.", https://doi.org/10.7910/DVN/9HS0Q7, Harvard Dataverse, V1

Yaworsky, P. M., & Codding, B. F. (2018). The ideal distribution of farmers: Explaining the Euro-American settlement of Utah. *American Antiquity*, *83*(1), 75