

**A new context for agroecology: establishing the foundation in the southeastern US
considering the implications of climate change**

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Abstract

Agroecology is grounded in indigenous knowledge. Current agroecological research is primarily focused on Latin America, reflecting an area where substantial indigenous populations actively practice it. This project aimed to examine agroecology in the southeastern US as a possible practice given the forecasted climate change. A list of plant species used by the Siouan peoples was compiled from archaeobotanical records of Hillsborough, North Carolina. For three of these species (maize, nightshade, and sunflower), changes in the timing of key phenological stages were computed using Julian Day and growing-degree-days between 1950-2099 based on meteorological records and climatic model projections. Records indicate the use of 37 species that were cultivated and foraged. All three species showed decreases of 1.6-2.2 days/decade in the number of days required to reach maturation, which ranged from 137.7 to 227.7 days. Corn and nightshade showed similar decreases in total number of days to reach flowering, decreasing 1.6 days/decade and 1.5 days/decade respectively. However, sunflower had a 1.5 days/decade increase to reach flowering. This increase reflected that sunflower was beginning growth earlier but progressing slower, thus requiring a longer time to reach flowering. The indigenous knowledge of this region has potential to expand and challenge the dominant idea of local agriculture. However, the results indicate that the exact ways in which plants were cultivated and foraged cannot be replicated given the dramatic changes that will alter plant phenology timing within this century. Instead, this project highlights novel local plants that could be incorporated into diet and underscores the need for further research on plant response to climate change.

Introduction

Problems with the current food system

Today's capitalist economic regime is driven by the underlying imperatives to maximize production in order to maximize profit (Nilsson 2017). The food system that developed within this regime is one that has become industrialized to meet these imperatives (Giménez and Shattuck 2011). Industrial agriculture today is characterized by seven main tenets: intensive tillage, monocultures, synthetic fertilizers, irrigation, chemical weed and pest control, manipulated genomes, and factory farming (Gliessman 2014). Together, these tenets have devastating effects on the environment and society.

The main tenets of industrial agriculture impact the environment in a myriad of ways. Intensive cultivation requires more nutrients than the soil can along provide, thus creating a need to apply fertilizer (Tilman *et al.* 2002). Petroleum-based fertilizers tend to be applied in excess and runoff into waterways (Tilman *et al.* 2002). Fertilizer runoff from the Midwest has culminated into the creation of a 8,776 square mile dead zone in the Gulf of New Mexico during the summer of 2017 (NOAA 2017). If the usage of fertilizers continues along its predicted trajectory there will be an expected 2.4-2.7 increase in eutrophication caused by nitrogen and phosphorus runoff in terrestrial, freshwater, and near-shore marine ecosystems by 2050 (Tilman *et al.* 2001). Overtime intensive tillage causes soil degradation, as the large machinery compacts the soil and the repeated soil disturbance reduces soil fertility (Jakab *et al.* 2017). Furthermore, monocropping used to maximize production has dramatically reduced genetic biodiversity. Today 90% of food comes from only 15 plants and 8 animal species, even though there are over 300,000 known edible plants (FAO 2004). The reliance on a few species makes farmers, and consequently consumers, more vulnerable to the threat of diseases and natural disasters (Reusch *et al.* 2005). In addition, monocultures create a need for pesticides because they do not create a suitable environment for naturally occurring pest-repelling plants or beneficial insects (Hooper *et al.* 2005). The widespread application of pesticides has allowed some pests to become resistant to current pesticides, creating the need to develop a stronger formula and forcing those farmers applying pesticides to become caught in a 'pesticide treadmill' (Bakker *et al.* 2017). Animal factory farms also have detrimental impacts on the environment and livestock production is a significant contributor to climate change (Steinfeld *et al.* 2006). What is described above is just a snapshot of the extensive environmental degradation associated with conventional agriculture.

Industrial agriculture has extensive negative social impacts. By 2015, 51% of U.S. farm production came from operations exceeding \$1 million in sales (MacDonald *et al.* 2018). Farm consolidation has created an oligopoly of business that retain the bulk of profits from food sales and leverages all of the risks of agriculture on farmers (Perfecto *et al.* 2009). This consolidation reduces the local economic multiplier, the amount of money that would circulate in the local economy as a result of the business with the farm, ultimately extracting wealth from communities where farms are situated (Hardesty *et al.* 2016). There are additionally a multitude of health issues associated with industrial agriculture. Respiratory health effects are associated with being employed by or living near CAFOS (Essen and Auvermann 2005); acute poisoning and declining neuropsychological and cognitive functioning are associated with farmworker exposure to pesticides (Muñoz-Quezada *et al.* 2016); foodborne outbreaks in humans have been linked to antimicrobial resistance in livestock (McCrackin *et al.* 2016). Furthermore, innumerable health risks exist within the processing and consumption areas of the industrial food system that are beyond the scope of this paper.

The industrial agriculture production system is a significant driver of climate change. In 2007, the production of food and beverages for Americans accounted for 13.6% of US CO₂ fossil fuel emissions (Canning *et al.* 2017). Furthermore, the animal agriculture sector alone is responsible for 35–40% of annual anthropogenic methane emissions and 9% of total CO₂ emissions (Steinfeld *et al.* 2006). These emissions from the agricultural sector have significantly contributed to intensifying climate change.

Climate Change

Climate is not stagnant and over time oscillates between warmer and colder periods. Two recent historic oscillations were the Medieval Warming Period (MWP), which occurred between approximately 650-1050 AD. The MWP was followed by the Little Ice Age (LIA), when the climate began cooling at 1450 AD and was in full effect between 1550-1850 AD (Viau *et al.* 2012). These climatic changes were driven by environmental factors, including atmospheric circulation and continental ice sheets. However, along with natural forces, humans have increasingly influenced the climate since the advent of the industrial revolution. Since 1895 the average U.S. temperature has increased increased by 0.72°C to 1.06°C, with the majority of this increase occurring after 1970 (USGCRP 2014). The rising temperature is significant when compared to historical temperatures. For example, pollen-based paleoclimate reconstructions in North America show that a base period of 1960-1990 was significantly warmer than the MWP (Viau *et al.* 2012). These increases are projected to continue. The IPCC projects a mean increase of 2°C in North America within the next century, with the later half of the century exceeding 4°C in most land areas (Romero-Lankao *et al.* 2014).

Climate change's impact on temperature is important, given that temperature is a key driver of plant phenology (Rawson and Macpherson 2000). The progression of plant development often is limited by energy availability in the form of heat. Ambient air must be above a certain temperature, called the base temperature, for a plant to surpass key developmental stages (Battel 2017). So temperature can be used to estimate the length of time required for a plant to reach maturation. Many plants are also limited by critical temperature thresholds and climate change may also jeopardize a plant's ability to complete growth without being damaged by extreme

temperature. Phenologies of several species have already been affected by climate change. For example, according to the Spring Indices, from 1955 to 2002 the first leaf dates began 1.2 days earlier per decade for the Northern Hemisphere (Cleland *et al.* 2007).

While agriculture is a major driver of climate change, it also has, and will continue to be affected by climate change. The IPCC asserts with high confidence that climate change will make food production more vulnerable to “climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires” (2014). Climate change will further affect the food system in countless ways: shifting growing regions, reducing the amount of arable land, disrupting water supplies (IPCC 2014). The effects of extreme events related to climate change will have on agriculture are nearly impossible to predict for a specific location, thus making it imperative identify agricultural methods that are extremely adaptable.

Addressing the problem: The case for agroecology

It is obvious that a new agricultural production paradigm is needed - one that does not perpetuate the devastating effects of industrial agriculture, can adapt to and mitigate the effects of climate change, and facilitates socially, environmentally, and economically just and resilient forms of agriculture. Several alternative agriculture methods have arisen, such as organic farming, permaculture, biodynamic agriculture, and sustainable intensification. Organic agriculture in the US is a set of farming practices that was established and are regulated by the USDA. Biodynamic agriculture follows similar practices as organic agriculture, while emphasizing the ways in which agriculture can be ecologically healing and focusing more on being adaptable than adhering to a strict set of methods and techniques (King 2008). These methods dramatically reduce the amount

of synthetic fertilizers and pesticides applied to crops, which is an improvement from the environmentally damaging inputs used in conventional agricultural.

Organic agriculture has become the most widely used out of all of the alternatives. As of 2015, organic farming was practiced on 50.9 million hectares of land in 179 different countries (Willer and Lernoud 2017). Driven by a growing consumer demand for organic food in the US, large food manufacturers, such as General Mills, Kellogg's, and Dean Foods, have entered the organic market by acquiring smaller organic companies and developing their own lines of organic products, commonly adopting the USDA Organic certification as proof of their sustainable agricultural practices (Greene *et al.* 2009). However, the USDA Organic certification does not necessarily equate to sustainable food production. Organic certifications are not economically sustainable because the cost burden of transitioning to sustainable agriculture is often placed on the farmers, who do not have the capacity to sell organic produce at a lower price before they are eligible to receive a premium from the organic certification (Koohafkan *et al.* 2012). Such standards likewise are not environmentally sustainable, as farmers still must conform to uniform, 'grade A' produce criteria (ie. such as identical size and shape of produce) in order to sell in the market (Koohafkan *et al.* 2012). Furthermore, while USDA Organic certification bans harmful synthetic fertilizers and pesticides, it does not ban other ecologically harmful practices, such as intensive tillage (Obach 2007). Companies driving the scaling up on organic agriculture have proven to prioritize intensification at the expense of the resilience of agroecosystems and farmers, thus simply perpetuating the same issues of the agroindustrial model.

Organic monocultures require the use of commodified 'alternative' inputs, similar to the system of external inputs used in conventional agriculture (Altieri and Nicholls 2012). Farmers

using these inputs become trapped in an “organic treadmill”, where the inputs they apply create new problems, which require more inputs to be used (Altieri *et al.* 2017). For example, organic grape farmers in California began applying sulfur dust to control the grape’s foliar diseases, an approved USDA organic input. However, the farmers found that the sulfur dust kills off beneficial predators of grape pests, thus creating an additional reliance on an input to control grape pests (Guthman 2004). Furthermore, sulfur dust became the leading agricultural input causing worker injuries in California following its usage in organic grape vineyards (Guthman 2004). Organic agriculture’s dependence on external inputs ultimately has failed to create a resilient form of agriculture that fosters sovereignty in farming practices and markets.

The underlying issue of organic agriculture is that it operates within a capitalistic economic framework that mandates profitability as the bottom line for all farmers at the expense of environmental and social protection (Altieri *et al.* 2017, Obach 2007). Perfecto *et al.* 2009 contends that operating inside this system will inherently fail, explaining that, “in a capitalist economy, where growth is an imperative of any business, organic agriculture is bound to follow this imperative. Ironically, the success of organic agriculture could become the seed of its own destruction”. The co-opting of organic agriculture by the agroindustry is already apparent, from the creation of an organic input market and the pressure on organic farmers to monocrop, to the large number of conventional farmers transitioning to organic while making few fundamental changes to their operations.

Agroecology is distinct from organic agriculture in that it serves to achieve sustainability on all fronts: economic, social, and ecological. Like other alternative agricultural methods, such as biodynamic, agroecology emphasizes principles of biodiversity, recycling on-farm nutrients, and

sustaining the entire agroecosystem, and prevents the use of external inputs and discourages intensification of one crop (Gliessman 2014). Beyond ecological sustainability, agroecology is grounded in indigenous knowledge and champions localized ownership of the food system over high yields and profits, hence promoting social and economic longevity (Altieri *et al.* 2017). Because of its ability to uphold all three pillars of sustainability, agroecology has the greatest potential for a new agricultural paradigm, rather than other alternative agricultural forms.

Defining Agroecology

Agroecology currently does not have an agreed-upon definition, which poses a challenge in its usage. The term ‘agroecology’ has been used since the 1930s but has become more frequently used in studies beginning in the 1980s and especially since the mid-2000s (Wezel and Soldat 2009). Agroecology originates from the combination of two classic disciplines: agronomy and ecology. Initially, agronomy influenced the agroecology more and early agroecology research was mostly conducted at the plot scale. As the ecology discipline became more integrated there was a shift to an agroecosystems approach. Recently more attention has been given to the holistic food systems approach as agroecology has become differentiated from other agriculture paradigms by its incorporation of socio-political context. For this thesis, I will use the definition: agroecology facilitates socially, environmentally, and economically just and resilient forms of agriculture.

Because agroecology is multidisciplinary in nature, a variety of stakeholders engage with it, especially scientific institutions, social movements, government, and educational institutions (Norder *et al.* 2016). Within scientific institutions, researchers have adopted a variety of approaches to study and engage with agroecology. Norder *et al.* 2016 categorized these numerous approaches into three general areas: ethno-ecology, eclectic, and universality. Ethno-ecology

focuses on how rural agroecology movement result in ecological improvements; eclectic focuses on specific practices and proposals that enable sustainable agriculture; universality focuses on the possibilities and limitations of different agroecosystems and their associated farming practices (Norder *et al.* 2016). My thesis research aligns primarily with the universality approach, though research conducted using the ethno-ecology and eclectic approaches also heavily inform this project.

Agroecology in a new context: The Southeastern US

The contextualized nature of agroecology is location-specific, which implies that agroecological research would be occurring throughout the globe. However, today the majority of energy around agroecology is focused on the global South, particularly South America. This focus is unsurprising given over 50% of the 1.5 billion smallholder farmers still follow agroecological agricultural practices (Altieri and Toledo 2011). Many of these smallholders practice farming that is grounded in indigenous knowledge and agriculture practices. These indigenous practices have developed over generations often in ways that reflect and enhance the biosphere they are cultivating within (Altieri *et al.* 2017). While not all practices are sustainable and many are often justified by unscientific explanations, their agricultural history serves as an immense placed-based collection of knowledge. This extensive knowledge base held by the smallholders who have retained their historical practices logically has made areas where these farmers reside the epicenter of agroecology.

The emphasis on the Global South reflects a pattern of colonial knowledge in academia. The majority of researchers and affiliated research institutions are from industrialized countries, while the majority of research is completed in non-industrialized countries. Gomez *et al.* 2013

conducting a literature review found that the most studied countries were Brazil, Cuba, Nigeria, Bangladesh, and Venezuela yet the majority of articles were published by authors from Western Europe. The authors explain that, “this syncs with a trend of mainstream environmentalism deeply rooted in colonial logic and modern constructions of nature where the latter is seen as something external to the Western world or confined to uninhabited wild areas” (Gomez *et al.* 2013).

The concentration of subsistence farmers in the Global South and intentional separation between western scientists and their study areas has resulted in minimal knowledge generation about agroecology in the Western world. While some techniques and practices are universal, how these methods function together as an agro-ecosystem is inherently specific to local areas (Giménez and Shattuck 2011). The southeastern US, the focus of this thesis, has an environment quite different from the tropics of the global South. Thus, agroecological knowledge founded from studies in the tropics is not always applicable to the region. For example, the soil of the South American tropics has poor fertility and consequently many farmers practice slash-and-burn as a way to increase the fertility of the soil (Perfecto *et al.* 2009). On the contrary, the southeastern US has rich soil fertility and such a technique is not beneficial to the agroecosystem. This lack of understanding about how the area’s ecology informs agricultural practices prevents agroecology from becoming a dominant paradigm in the region. Ironically, areas where less research is focused also are areas where there is a critical need to transform the current agricultural landscape into a more socially and environmentally sustainable paradigm.

Missing Foundation: The Case for Agroecology in the Southeastern US

Leaders in agroecology assert that training and dissemination of knowledge is a central part of a transformation to agroecology (Altieri and Toledo 2011). However this component

cannot be engaged if the agroecological knowledge for an area is unknown. The success of an agroecological revolution hinges on the existence of this knowledge. For many areas this expertise has been cultivated by the indigenous peoples of the area and the focus of agroecology movements has been to rediscover, uplift, and disseminate this information (Perfecto *et al* 2009). However, the southeastern US no longer has a substantial indigenous population practicing traditional agriculture and much of their heritage has been erased. This poses a challenge in establishing a basis for agroecology without the identification of this knowledge. For this reason, I have chosen to study the indigenous practices of the southeastern US in order to elevate the region's agroecological knowledge.

Within this region, two sites in the Central Piedmont of North Carolina were chosen to study in-depth. These two sites, referred to as Wall and Jenrette, are part of an area occupied for approximately 700 years by a group that is broadly referred to as the Siouan. The Piedmont Siouan were linguistically and culturally group distinct from three major groups (the Algonkian, Tuscarora, and Cherokee) who inhabited North Carolina's other major physiographic regions: the Coastal Plain and mountains (Ward and Davis 1999). The Wall Site was inhabited during the late Woodland Period between A.D. 1400-1600 (Melton 2014). The site is considered a strong example of the Piedmont Village Tradition, specifically the Hillsboro Phase, which was characterized by "compact, nucleated villages with relatively large populations" (Ward and Davis 1999). Wall site is estimated to have been populated by 100-150 people for less than twenty years. The Jenrette site was inhabited during the early Contact Period between A.D. 1650-1680 (Davis 2002). The site is immediately adjacent to Fredricks site, which is believed to have been the Occaneechi village visited by Lawson in 1701 (Ward and Davis 1999). The Jenrette site is

believed to have been inhabited by descendents of Hillsboro phase and to have possibly been the Shakori people visited by John Lederer in 1670 (Davis 2002).

Prior to European contact, indigenous populations began to inhabit the fertile land near floodplains throughout the southeast US as cultivated plants became a mainstay of diet (Doolittle 2004, Ferguson and Green 1984). While indigenous agriculture in this area has never been categorized as agroecology, there is evidence to support that agroecological practices were engaged in that are similar to practices in Latin America. Most notably, is the similarity in land usage that supports a robust ecosystem.

In *Nature's Matrix*, the authors contextualize agroecology within the field of conservation, arguing that maintaining high-quality agroecosystems is a key factor in conserving biodiversity (Perfecto *et al.* 2009). They explain that metapopulations consist of numerous localized populations. While some localized populations periodically go extinct, the metapopulation does not because members of one local population have the ability to migrate and establish a new local population, therefore continuing the existence of multiple local populations. The authors assert that ensuring the ability of species to immigrate and create new local populations is crucial to maintaining the metapopulations. To immigrate, a species must move through what the authors refer as a 'matrix', a space which can or cannot be conducive for species migration. The authors emphasize that today, and historically, much of the matrix that species move through is agricultural land, thus encouraging agricultural systems that promote species migration is a central factor in maintaining biodiversity.

Nature's Matrix is almost explicitly focused on examples in South America of farmers practicing agroecology in a way that supports a 'healthy' matrix. Interestingly, in North Carolina

land surrounding indigenous settlements has also been described as matrix (Melton 2014).

Gremillion 2003 explains how indigenous agriculture and foraging practices produced, “a mosaic of vegetation types occupying the continuum between the relatively closed, mature deciduous forest and open, recently disturbed heavily managed gardens and fields” (p. 22). This matrix consisted of corridors and buffer areas where nuts, fruits, and greens were foraged, in addition clearings where corn, squash, beans, and oil seeds were cultivated (Scarry 2003).

Archaeobotanical research provides insightful evidence to these group’s agricultural practices (Gremillion 1989, Melton 2014). With this information, an ecological lenses can be applied to refine this basis of knowledge and to ultimately form a strong foundation of agroecological practices for the area. This foundation can become the catalyst for an agroecological revolution in the southeastern US.

Question & Hypothesis

Q. (1) Using the historical reconstruction for Siouans in NC, how will plant species sustainably cultivated in the past be affected by climate change?

Q. (2) Specifically, how does the temperature associated with climate change impact the phenologies of plants that were consumed by Siouans?

Hyp. (1) Plant species would begin phenological growth earlier and would complete plant maturation in a shorter time frame.

Methods

Focus Site

Because there is much heterogeneity in the foodways of southeastern indigenous people in the US, the project's scope was focused on one study site. Potential study sites were first narrowed to North Carolina, the state where the author is from and attends school that offers an advantage in accessing state-specific resources. Using *Time Before History*, a comprehensive overview of North Carolina archaeology, a list of potential sites were compiled that were noted to have both ethnobotanical records and historical accounts (Ward and Davis 1999). From the list compiled, the Wall site (31Or11) and adjacent Jenrette site (31Or231a) were selected because they were associated with two ethnobotanical analyses and a historic account from John Lederer. The site's close proximity to one another, as illustrated in Figure 1, and their similar organization of "circular palisaded villages with house structures organized around open central plazas" enables them to be easily comparable (Melton 2014). Furthermore, archaeobotanical excavations have included both large and small fire pits, thus providing a representational sample of remains from communal eating events as well as household foodways (Melton 2014).

Located in the Hillsborough, NC the Jenrette and Wall sites are part of a group of four sites occupying a 25-acre space of land along an U-shaped dip in the Eno River (Ward and Davis 1999). The Wall Site cover 1.25 acres and the Jenrette site covers approximately half an acre. The soil of the two sites is primarily Congaree fine sandy loam that has a 0-2% slope and is noted to be frequently flooded (Web Soil Survey).

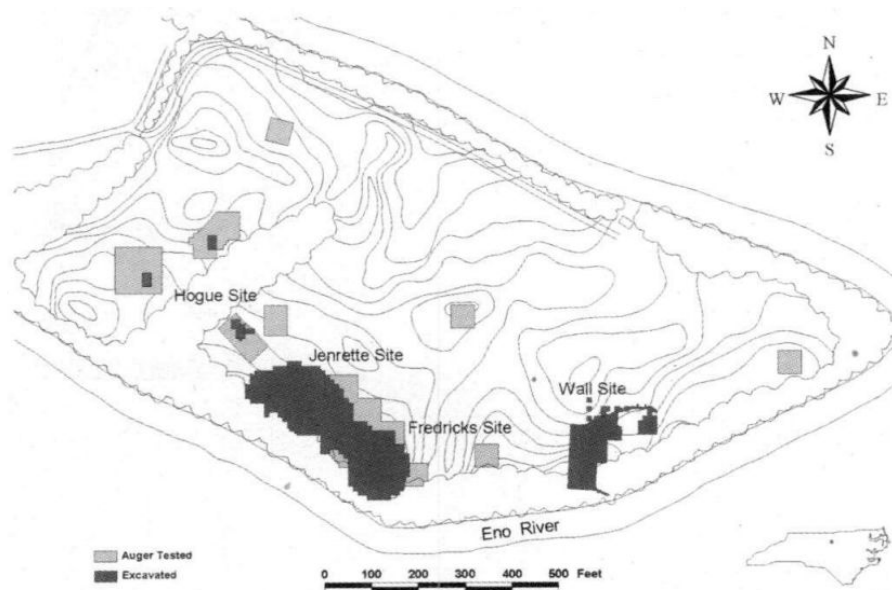


Figure 1. Map of area in Hillsborough, NC, that was inhabited by the Siouan during AD 1400-1680. Charred plant remains in fire pits excavated at these sites enabled the identification of plants used by Siouans. Created by R.P.S. Davis 2002

The search terms “ethnobotany” AND “Jenrette” were used to identify literature about the sites. There were two significant studies completed on the archaeobotanical remains in site fire pits. The first study was completed by Gremillion in 1989. A following study was completed by Melton in 2014 that expanded the scope of the first study by comparing Gremillion’s study of remains from the small and medium sized pits to remains from larger pits that were excavated following Gremillion’s publication (Melton 2014). A list of the charred plant species remains in fire pits identified by these two authors was compiled. From this list, three plants with sufficient phenological data pertaining to their growing degree days (corn, nightshade, and sunflower) were studied further.

Climate Data

Downscaled climate and hydrological projections were culled for the study site’s geographic location (latitude: 36.0715; longitude: -79.0903). This data was retrieved from the

World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project phase 3 multi-model dataset made available by the modeling groups, the Program for Climate Model Diagnosis and Intercomparison, and the WCRP's Working Group on Coupled Modelling (Reclamation 2011). The WCRP downscales climate and hydrological projections produced for the International Panel on Climate Change's Assessment Reports (PCMDI). The WCRP provided 97 projections of monthly maximum and minimum temperatures between 1950-2099 for the latitude bounds: (36.0, 36.125) and longitude bounds: (-79.125, -79.0), including an approximate area of 156 km² within the bounds with a resolution of 1/8 degree. The access1-0.1.rcp45 climate model was chosen as it was ranked by the WCRP as the most accurate for the area. The model was developed by the Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia (Brekke *et al.* 2014). The projections reported monthly maximum and minimum temperature for each year included in the model. The data was grouped into 10-year segments (ie. 1950-1959, 1960-1969, etc) and the monthly maximum and minimum temperatures were averaged for each decade and converted to degrees Fahrenheit to be comparable to GDD reported in degrees Fahrenheit.

WCRP average temperature and precipitation projections between 1950 and 2100 were plotted on the scPDSI index by decade. The scPDSI index was calculated using R studio Palmer Drought Severity Index (PDSI program) by Christian Zang. The modified scPDSI used to correct for bias in soil moisture from original PDSI Palmer (1965).

Annual precipitation data from 1950-2100 was retrieved from the NOAA's U.S. Climate Resilience Toolkit and Climate Explorer for Hillsborough. A linear regression of annual precipitation vs. time was completed using Microsoft Excel.

Determination of Growing Degree Days

Growing degree days (GDD) are one method to estimate the impact of temperature on plant development. GDD are not determined by a calendar day but instead are a measure of heat accumulation (Battel 2017). The number of GDD required for a plant to reach different phenological stages does not change, but the amount of time required varies depending on the minimum and maximum daily temperatures. Growing degrees were calculated by subtracting the average maximum (T_{max}) and minimum temperature (T_{min}) for a given day from the base temperature (T_{base}) of a plant (Eq. 1) (Battel 2017).

$$GDD = \left\{ \left[\frac{T_{max} - T_{min}}{2} \right] - T_{base} \right\} \quad (\text{Eq. 1})$$

Table 1. The base temperature and GDD required to reach each phenological stage for corn, nightshade, and sunflower. GDD listed are cumulative (ie. only 1300 days are required to progress between flowering and seed maturation in corn). GDD data for emergence was not available for nightshade. GDD information from Battel 2017, UC ANR, and Miller *et al.* 2001

Stage	Base Temp	Emergence	Flowering	Seed Maturation
Corn	50 °F	200	1400	2700
Nightshade	42.8 °F	NA	1080	1800
Sunflower	44 °F	206	1048	2310

The average GDD were calculated and then the value was multiplied by the number of days in a given month, adjusting the month of February for the number of leap years occurring in the decade (either 28.2 days or 28.3 days). The standard deviation for the average monthly minimum and maximum temperature (T_{avg}) per decade was determined and then the overall

monthly standard deviation computed (Eq. 2). From the standard deviation, the standard error was then computed.

$$(1/\sqrt{n}) * \sqrt{((\frac{1}{2})^2 * (\sigma_{min})^2) + ((\frac{1}{2})^2 * (\sigma_{max})^2)} \quad (\text{Eq. 2})$$

The Julian Days (JD), a uniform count of calendar days, required for the plants to reach two or three major phenological stages were computed, which is illustrated in Figure 2 (Jefferys 1998). The phenological stages varied by plant species but were typically emergence, initial reproductive stage, and seed maturity (Table 1). GDD were refined only to the monthly scale, so the count for GDD began with the first month that had a positive average of GDD - indicating the beginning of heat accumulation. The change from one phenological stage to the next was determined as a percentage for each month that had positive GDD. If the number of GDD did not exceed the total GDD required to reach the next phenological stage, it was marked as a 1 (indicating 100% of the month falling into that one phenological stage). For months that did not fall within a single growth stage, the percentage of the month's days falling within the current stage and successive stage were calculated. Once the percentage of each month that fell within a phenological stage was computed, the number of JD for that stage was calculated by multiplying the percentage of a month falling within a specific stage by the number of days in the month and totaling all the months that the stage occurred within.

Translating Growing Degree Days (GDD) into Calendar Days

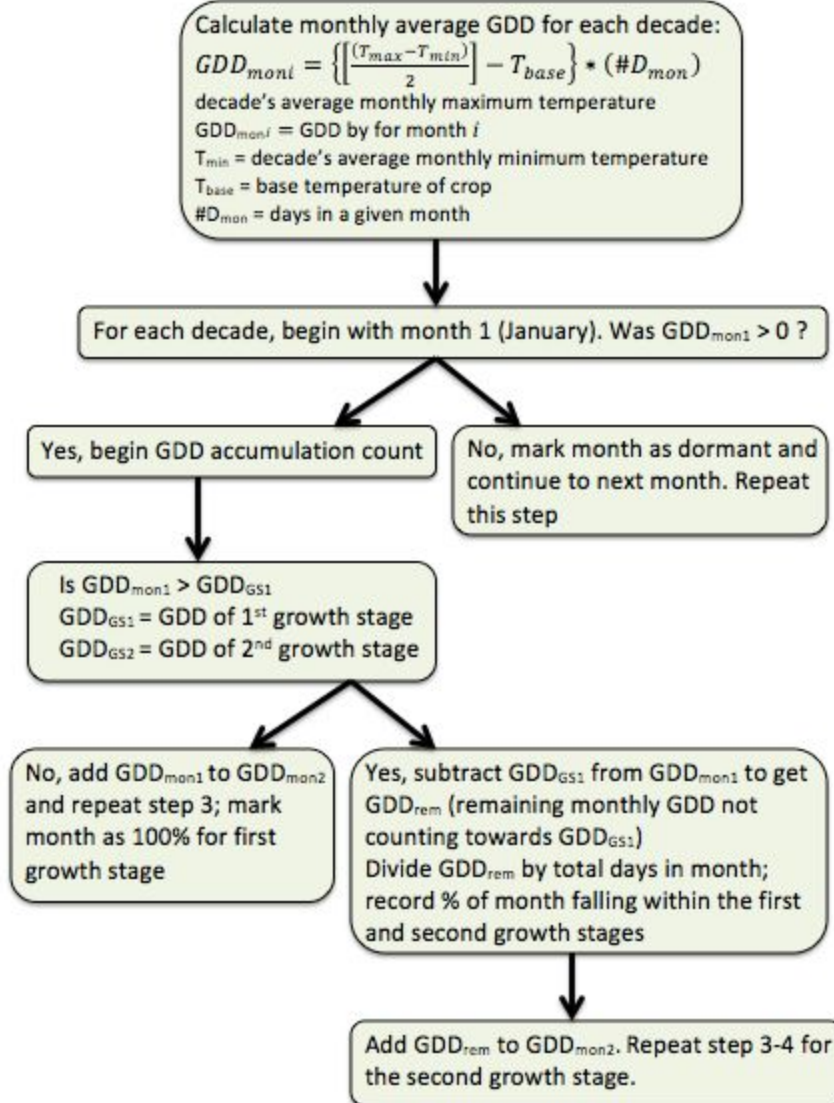


Figure 2. Schematic of methods used to convert GDD into JD

Analyzing Growing Degree Days

Time to Maturation: The change in total JD required to complete all main phenological phases through time was analyzed using a linear regression model in R studio.

Beginning GDD Accumulation: Analyzing the change in the length of the dormancy stage does not capture small changes in the start date of accumulation because the GDD accumulation

count always begins on the first day in a month. Instead the change in cumulative days required to complete the emergence stage was analyzed using a linear regression model

Individual Stage Change: The average number of days, standard deviation, and maximum and minimum length within each phenological stage were calculated. Linear regressions models were used to determine the change in the length of each individual stage over time.

Results

Thirty species and three families were identified by Gremillion (1989) and Melton (2014). These species represent charred remains identified in smaller fires pits associated with individual households as well as larger pits associated with communal meals (Melton 2014). Chenopod and knotweed were listed as both cultigens and greens, as their greens were harvested in the spring/summer and their fruit was then harvested later in the fall. Plants species whose use is categorized as cultigens were intentionally grown in prepared gardens or agriculture fields (Scarry 2003). The other nuts, greens, and fruits were harvested through foraging, though these non-cultigens may have been “planted, tended or protected” to some extent (Wagner 2003, p. 157).

Table 2. Plants identified in fire pit remains at Wall Site and Jenrette Sites in Hillsborough, NC Plants identified by Gremillion (1989) denoted with a ‘1’; plants identified by Melton (2014) denoted with a ‘2’; season information from Scarry (2003)

Plant Group	Common Name	Scientific Name	Season Available	Use	Wall Site	Jenrette Site
Annual	Bearsfoot	<i>Polymnia uvedalia</i>	late summer/ fall	cultigen	1	1
Annual	Maize	<i>Zea mays</i>	late summer/ fall	cultigen	1,2	1,2
Annual	Chenopod	<i>Chenopodium berlandieri</i>	spring/ summer; late summer/ fall	greens; cultigen	2	1
Annual	Knotweed	<i>Polygonum erectum</i>	summer; late summer/ fall	greens; cultigen	2	1
Annual	Squash	<i>Cucurbita sp.</i>	late summer/ fall	cultigen	NA	1

Annual	Sumpweed	<i>Iva annua</i>	later summer/ fall	cultigen	2	1,2
Annual	Sunflower	<i>Helianthus annuus</i>	later summer/ fall	cultigen	2	2
Annual	Common bean	<i>Phaseolus vulgaris</i>	NA	cultigen	1,2	1
Annual	Maypop	<i>Passiflora incarnata</i>	mid-summer/ fall	fruit	1,2	1,2
Annual	Nightshade	<i>Solanum</i> sp.	summer/fall	fruit	NA	1
Annual	Purslane	<i>Portulaca</i> sp.	spring/ fall	greens	2	NA
Annual	Bulrush	NA	NA	misc.	NA	1
Annual	Carpetweed	<i>Mollugo</i> sp.	NA	misc.	2	NA
Annual	Sedge	<i>Scirpus</i> sp.	NA	misc.	2	NA
Annual	Grass family	<i>Poaceae</i>	NA	misc.	2	NA
Annual	Legume family	<i>Fabaceae</i>	NA	misc.	1,2	2
Annual	Nightshade Family	<i>Solanaceae</i>	NA	misc.	1,2	1
Annual	Pink Family	<i>Caryophyllaceae</i>	NA	misc.	1	NA
Perennial	Hawthorn	<i>Crataegus</i> sp.	summer/fall	fruit	1	1
Perennial	Pokeweed	<i>Phytolacca americana</i>	spring/ summer	greens	1	1
Perennial tree	Peach	<i>Prunus persica</i>	NA	fruit	NA	1,2
Perennial tree	Persimmon	<i>Diospyros virginiana</i>	fall	fruit	1,2	1
Perennial tree	Plum/cherry	<i>Prunus</i> sp.	mid-summer/ fall	fruit	2	NA
Perennial tree	Acorn	<i>Quercus</i> sp	fall	nuts	2	NA
Perennial tree	Hickory	<i>Carya</i> sp.	fall	nuts	1,2	1,2
Perennial tree	Walnut (if Butternut)	<i>Juglans cinerea</i>	fall	nuts	1	1,2
Perennial tree	Walnut (Black walnut)	<i>Juglans nigra</i>	fall	nuts	1	1,2
Perennial tree	Beechnut	<i>Fagus grandifolia</i>	fall	nuts	2	NA
Perennial/ Annual Herb	Bedstraw	<i>Galium</i> sp.	NA	misc.	1,2	1,2
Perennial tree	Black gum	<i>Nyssa sylvatica</i>	NA	misc.	2	1
Perennial tree	Dogwood	<i>Cornus florida</i>	NA	misc.	1	NA
Shrub	Bramble	<i>Rubus</i> sp.	NA	fruit	NA	1,2
Vine	Grape	<i>Vitis</i> sp.	mid-summer/ fall	fruit	1,2	1,2

Climatic Changes

For the region of interest, the average maximum and minimum temperature increased over time from the 1950's to current years and projected from the climate model. The slope of the linear regression for maximum and minimum temperature showed an increase of 0.32°C per decade and 0.25°C per decade, respectively (Figure 3). The area's mean annual precipitation showed a slight increase in temperature between 1950-2100, though this change is not significant (Figure 4). The PSDI index of wet and dry conditions in Hillsborough, NC between 1950-2100 showed continuous oscillations that reflected seasonal variation (Figure 5). These oscillations became more augmented over time, especially after 2050. The 2060 decade notably exemplified the increasing extreme wet and dry periods of the later part of the century (Figure 6).

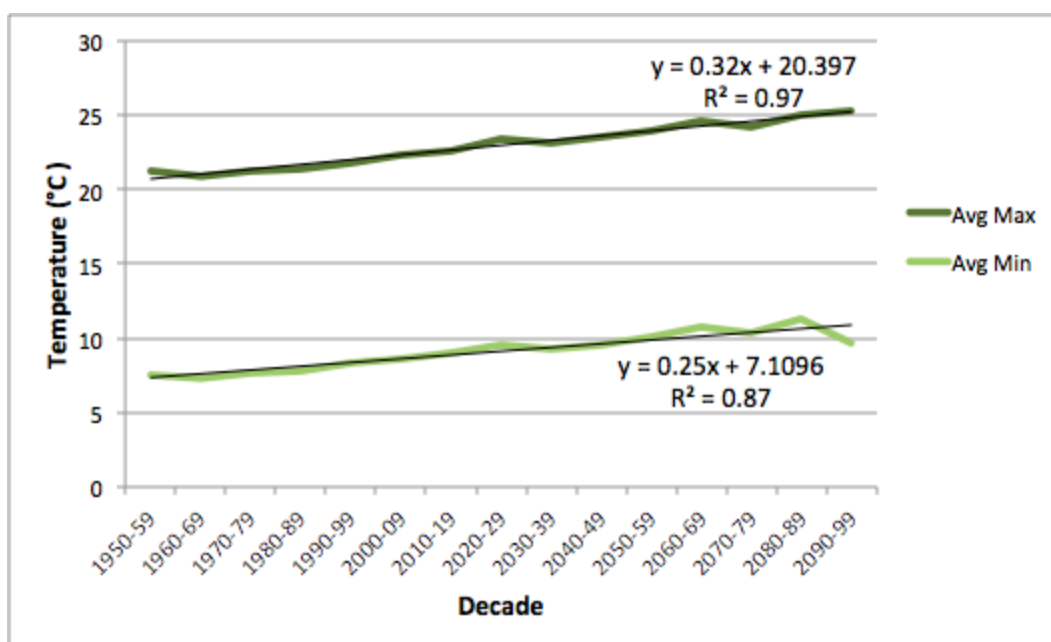


Figure 3. Average maximum and minimum temperature ($^{\circ}\text{C}$) by decade between 1950-2100; determined using climate data from Reclamation 2011; linear regressions completed using Microsoft Excel

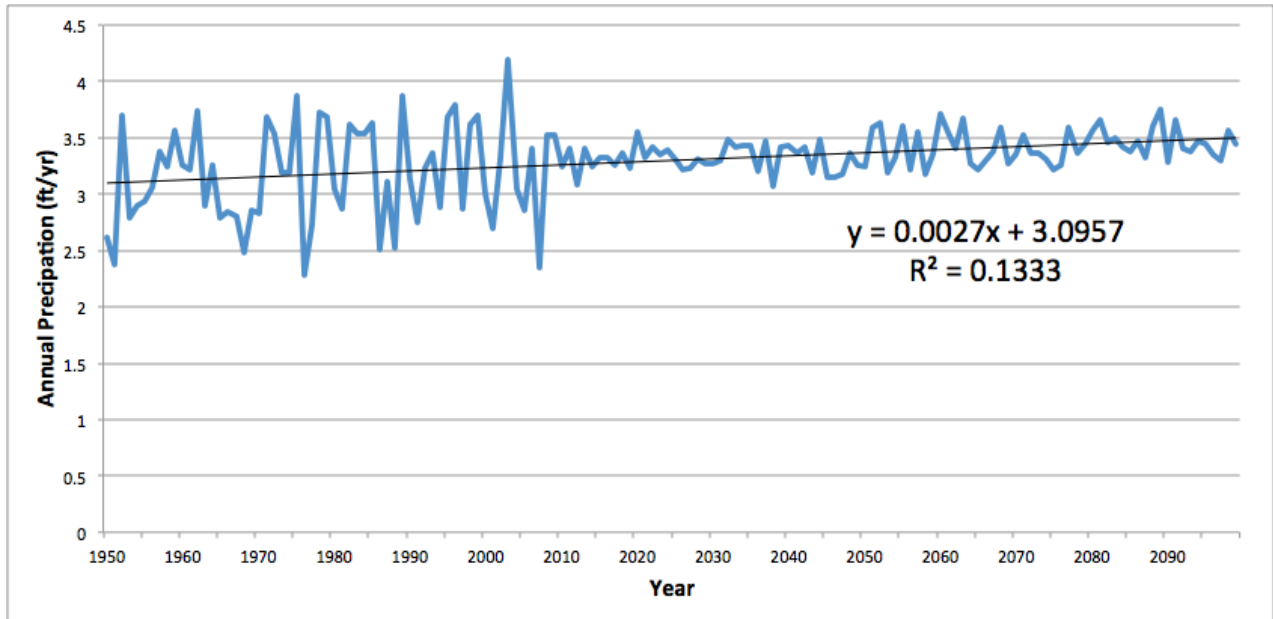


Figure 4. Change in annual precipitation (feet/year) from 1950-2099. Data from NOAA’s U.S. Climate Resilience Toolkit and Climate Explorer. Historical data is included from 1950-2010 and median climate projection is included from 2011-2099.

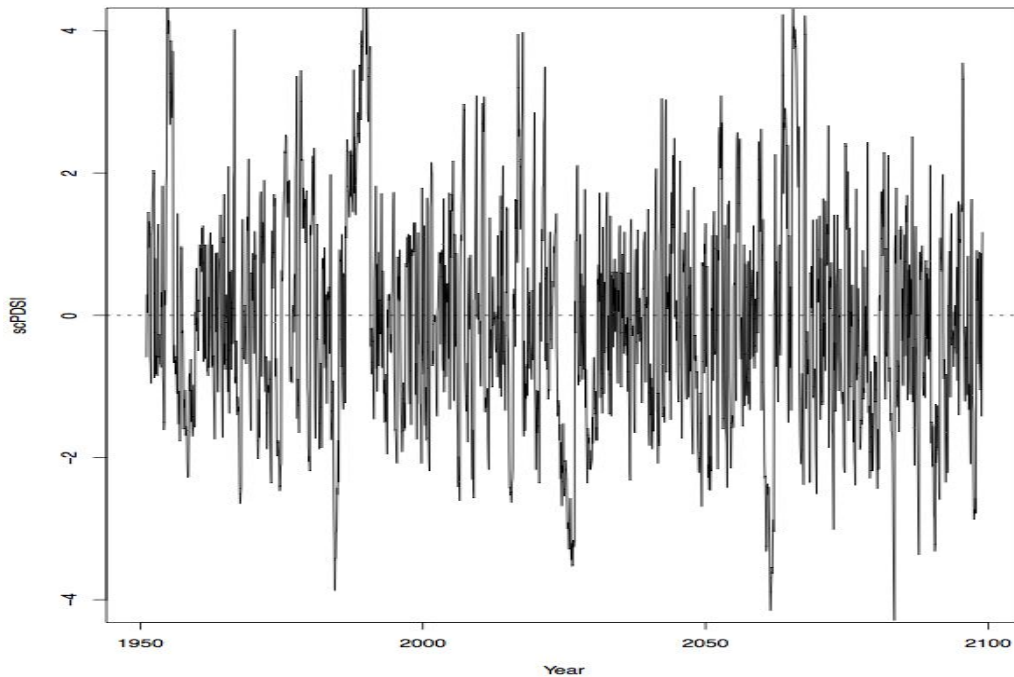


Figure 5. Change in wet/dry conditions from 1950-2100. Positive values represent wetter conditions and negative represent dryer conditions. Values of -2 to -2.9 represent a moderate drought; -3 to -3.9 represent a severe drought; and -4.0 or less represent a severe drought. Values of +2 to +2.9 is moderately moist; +3 to +3.9 is very moist; and +4 and higher is extremely moist. PSDI Index projections determined using temperature data from Reclamation 2011 and soil type from Web Soil Survey using the study site’s latitude and longitude

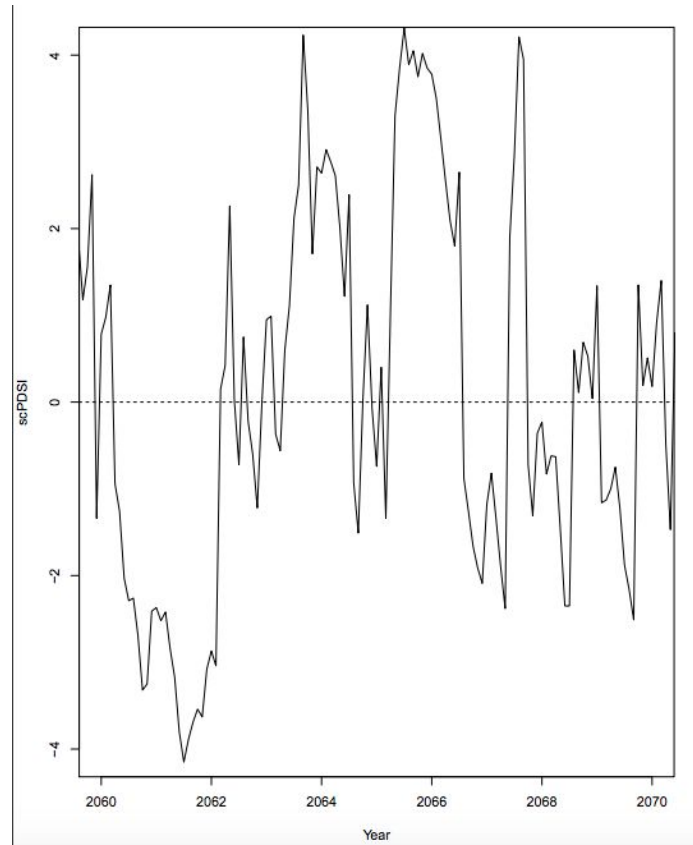


Figure 6. Change in wet/dry conditions from 2060-2069. Negative values represent wetter conditions and positive represent dryer conditions. Values of -2 to -2.9 represent a moderate drought; -3 to -3.9 represent a severe drought; and -4.0 or less represent a severe drought. Values of +2 to +2.9 is moderately moist; +3 to +3.9 is very moist; and +4 and higher is extremely moist. PSDI Index projections determined using temperature and precipitation data from Reclamation 2011

Corn

The average number of JD required for corn to reach seed maturity was $212.3 \text{ days} \pm 10.3$ days. This total number of days to complete growth ranged from 196.6 to 227.7 days, with the longest growing period in the 1970-79 decade and shortest period in the 2090-2099 decade (Figure 7). The cumulative number of days shortened overall by an average of 2.24 days/decade with a significant r^2 value of 0.95 (Figure 7). Within each phenological stage, emergence took an average 32.0 ± 12.6 days, silking took an average 60.7 ± 3.9 days, and maturation took an average $43.9 \pm$

3.3 days (Table 3). The length of all three individual phenological stages shortened over time, except for emergence. The slope of the maturation stage (-0.62 days/decade) was the only individual phenological stage whose slope was significant ($r^2 = 0.71$) (Table 3). Though only the individual maturation stage had significant change, corn still had an overall increasingly negative slope over time that began with -1.43 days/decade following emergence and ended with -2.24 days/decade following maturation. Furthermore, the cumulative decreases were associated with increasingly significant r^2 values (0.65-0.95) (Figure 7). This result indicates that slight, insignificant decreases in individual stages cumulated to have an overall significant decrease in days to complete maturation over time.

Table 3. Summary of linear regressions of cumulative change in JD over time and change in length within stage over time for corn, nightshade, and sunflower. Completed using R studio. *** = <0.001 ; ** = <0.01 ; * = <0.1

Stage	Plant	Average # of Days by Stage	Max/Min By Stage (Days)	Average Cumulative # of Days	Max/Min Cumulative (Days)	Cumulative Change (Days/Decade)	r^2	Change Within Stage (Days/Decade)	r^2
Dormancy	Corn	75.78	90.30/ 59.20	75.78	90.30/ 59.20	NA	NA	-1.55	0.19
	Nightshade	41.56	59.30/ 0	41.56	59.30/ 0	NA	NA	-2.67	0.20
	Sunflower	51.35	59.30/ 0	51.35	59.30/ 0	NA	NA	-2.37	0.25
Emergence	Corn	31.97	49.48/ 6.63	107.75	121.78/ 96.83	-1.43	0.65***	0.12	0.002
	Nightshade	NA	NA	NA	NA	NA	NA	NA	NA
	Sunflower	34.49	71.42/ 20.06	85.84	99.14/ 36.18	-1.78	0.26*	0.55	0.04
Flowering	Corn	60.70	68.74/ 55.98	168.45	181.95/ 156.03	-1.62	0.92***	-0.019	0.05
	Nightshade	89.37	130.72/ 68.23	130.93	144.49/ 111.65	-1.53	0.66***	1.15	0.05
	Sunflower	47.82	80.88/ 37.58	133.67	117.06/ 147.77	-1.50	0.73***	0.28	0.02
Maturation	Corn	43.88	49.33/ 39.82	212.33	227.74/ 196.60	-2.24	0.95***	-0.62	0.71***
	Nightshade	25.58	28.05/ 22.25	156.52	168.33/ 139.7	-1.56	0.74***	-0.04	0.01
	Sunflower	42.3	46.86/ 38.74	176.01	187.83/ 161.37	-1.72	0.87***	-0.22	0.19

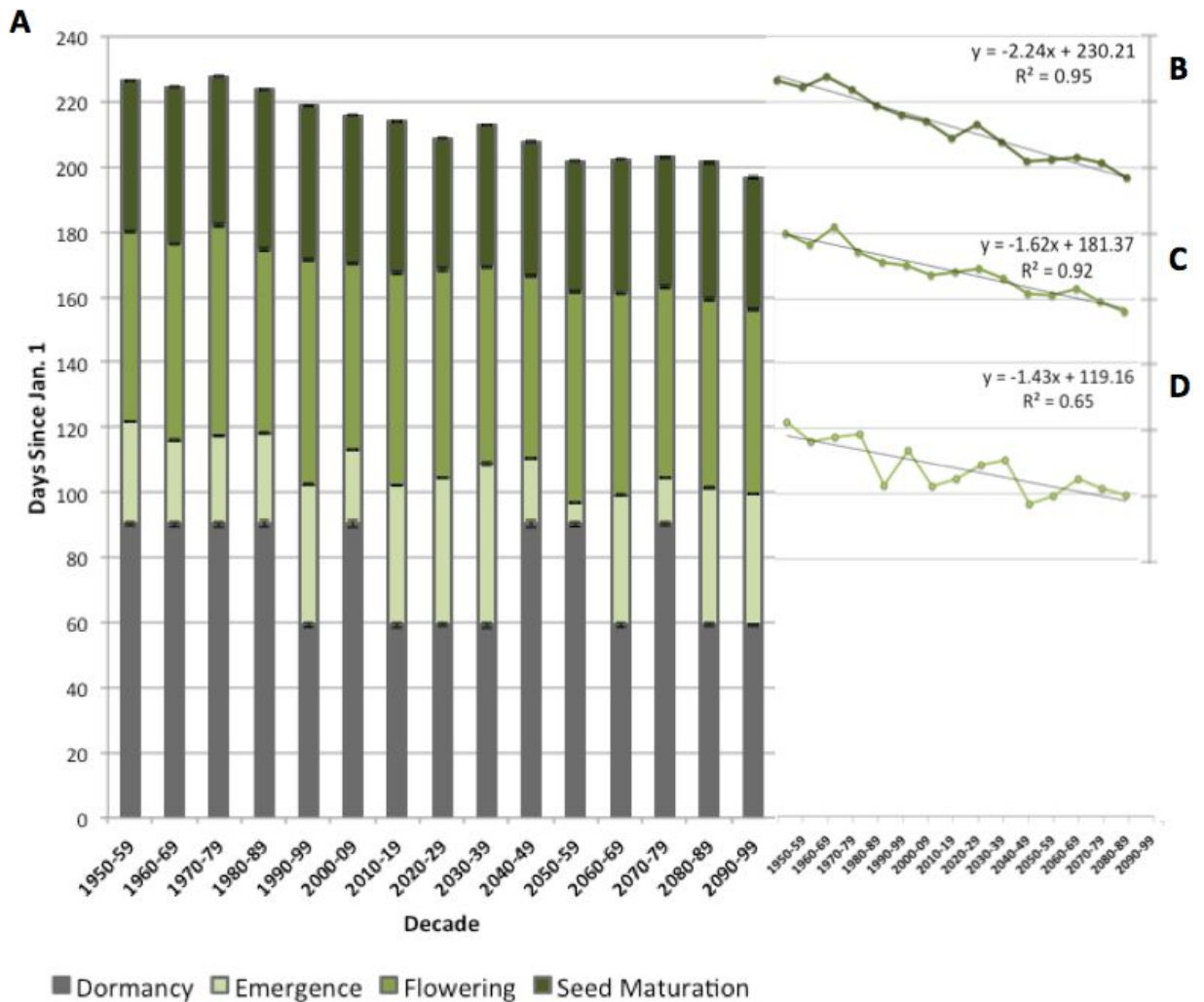


Figure 7. Change in corn phenological development through time. A) Trends for all stages (mean \pm s.e. JD). Development from one stage to the next is based on current growing degree-days requirements. B), C), and D) depict the cumulative change (Julian days/decade) in corn growth by stage (from top to bottom: B - maturation, C - flowering, and D - emergence); lines are linear regressions of sum of Julian days from dormancy through stage against decade

Sunflower

The average number of JD required for sunflower to reach seed maturity was 176.0 days \pm 8.2 days (Figure 8). The number of days to reach maturity ranged from 161.4 to 187.8 days, with the longest growing period in the 1950-59 decade and shortest period in the 2060-2069 decade (Figure 8). Within each phenological stage, emergence took an average 34.5 \pm 11.7 days,

flowering took an average 47.8 ± 10.1 days, and maturation took an average 43.9 ± 2.3 days (Table 3). The cumulative number of days shortened overall by an average of 1.72 days/decade with a significant r^2 value of 0.87 (Table 3). Within phenological stages, the length of the dormancy and maturation shortened over time and the length of the emergence and flowering stages increased over time. The dormancy stage had the greatest change over time of -2.37 days/decade. However, no individual stage had a significant r^2 value, which would indicate that, by stage, increases or decreases over time were insignificant. Interestingly, the cumulative change was consistently negative, and the flowering and maturation stages had significant r^2 values, 0.73 and 0.87 respectively (Figure 8).

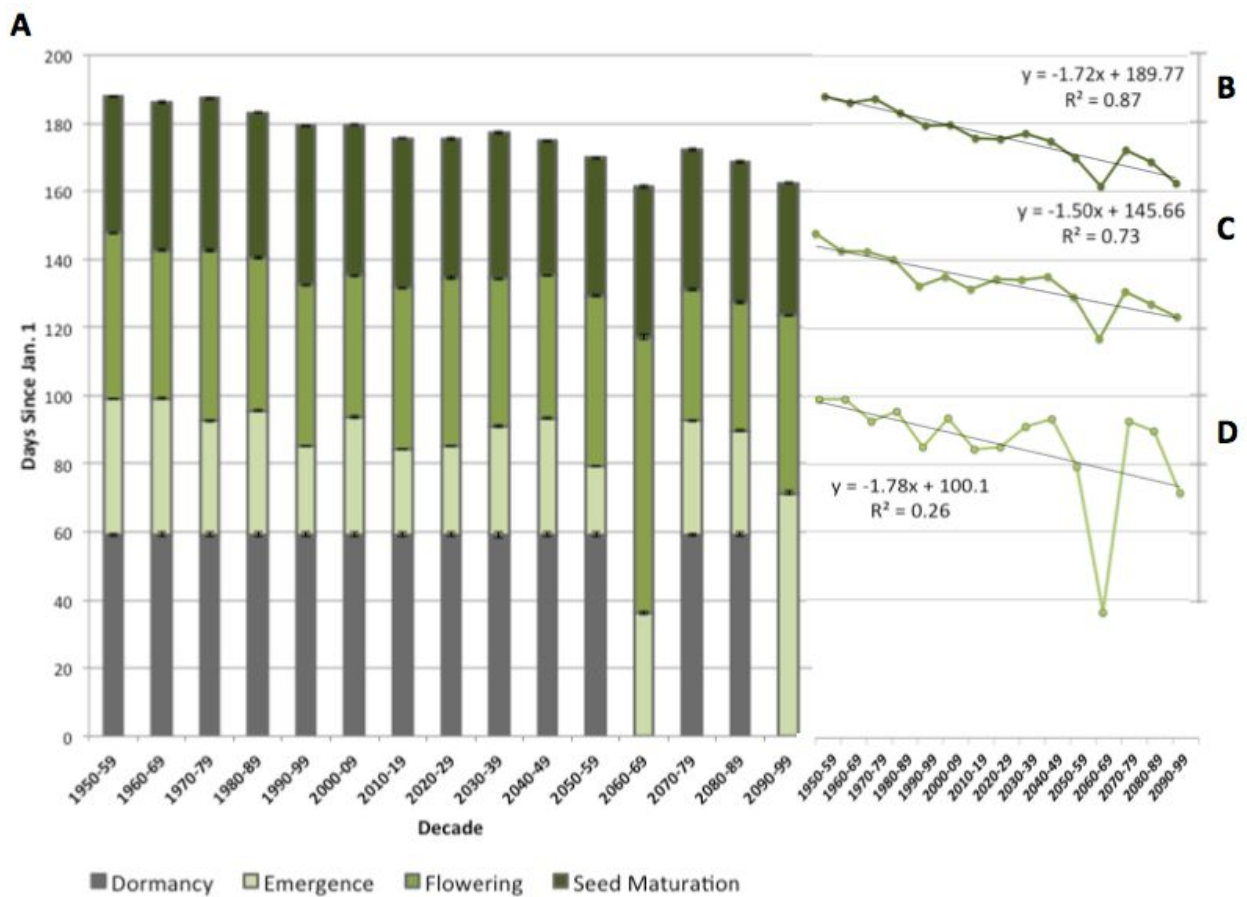


Figure 8. Change in sunflower phenological development through time. A) Trends for all stages (mean \pm s.e. JD). Development from one stage to the next is based on current growing degree-days requirements. B), C), and D) depict the cumulative change (days/decade) in sunflower growth by

stage (from top to bottom: B - maturation, C - flowering, and D - emergence); lines are linear regressions of sum of Julian days from dormancy through stage against decade

Nightshade

The average number of JD required for nightshade to reach physiological maturity was 156.5 days \pm 8.1 days. The total number of days to reach maturity ranged from 139.7 to 168.3 days, with the longest growing period in the 1950-59 decade and shortest period in the 2060-2069 decade (Figure 9). Within each phenological stage, flowering took an average 89.4 \pm 22.4 days and maturation took an average 25.6 \pm 1.8 days (Table 3). The cumulative number of days shortened overall by an average of 1.56 days/decade with a significant r^2 value of 0.74. The length of the dormancy and maturation stages shortened over time by, while the length of the flowering stage increased over time. Nightshade's dormancy stage had the greatest change over time of -2.67 days/decade however its r^2 value was insignificant. Similar to sunflower, no individual stage had a significant r^2 value while the cumulative change over time remained consistently negative with significant r^2 values (0.66 and 0.74) (Figure 9).

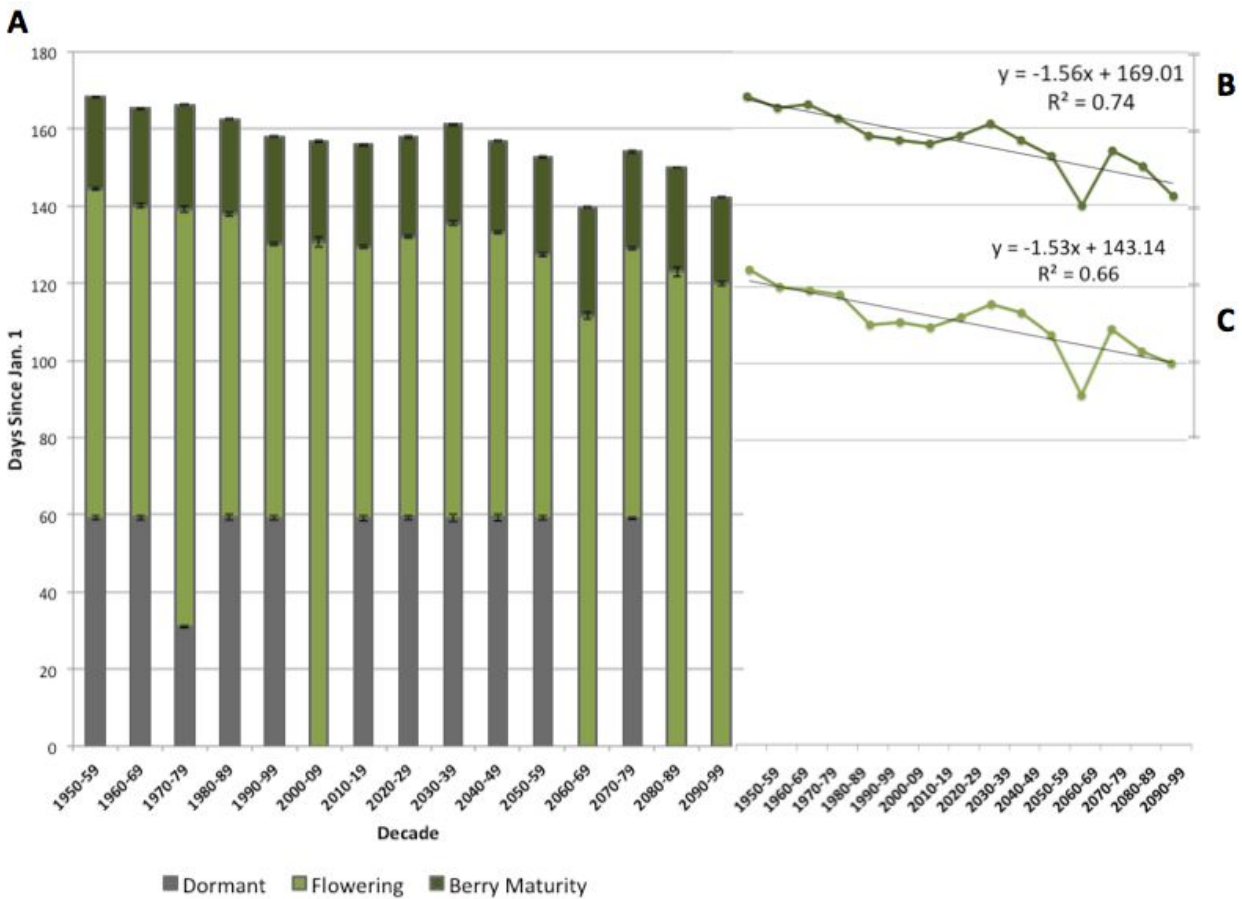


Figure 9. Change in nightshade phenological development through time. A) Trends for all stages (mean \pm s.e. JD). Development from one stage to the next is based on current growing degree-days requirements. B) and C) depict the cumulative change (days/decade) in nightshade growth by stage (from top to bottom: B - maturation C - emergence and flowering); lines are linear regressions of sum of Julian days from dormancy through stage against decade

Discussion

The objective of this research project was to identify plant species consumed by the Siouan and to discern how plant phenologies are impacted by past, present, and future climate conditions. This objective was situated within a broader goal of understanding how agroecology may have been practiced by the Siouan and how these practices could be utilized in the future to mitigate the impacts of climate change on agriculture. The results show that 1) a wide range of plant species were cultivated or foraged by the Siouans 2) temperature has been, and will continue to increase

and water availability will become more variable and 3) plant phenologies are significantly affected by temperature. This section provides further commentary on the results and discusses the interplay between climate, environment, and people and the implications these factors that have for agriculture.

Plant Species Remains

The plant remains in Table 2 are believed to represent species consumed by the Siouans. This interpretation is derived from the assumption that all the remains in the fire pits were remains from meals. The Cherokee utilized bearsfoot, bedstraw, black gum, dogwood, pokeweed, and members of the nightshade and pink family for their healing properties, so the presence of species that are unusual to consume, notably the species categorized as miscellaneous, may be explained by their usage for treating illness (Melton 2014). Furthermore, some archaeologists suggest that fire pits may also have been used as waste pits where other materials were deposited (Melton 2014). The plant species identified are biased towards species that are more easily preserved. Not captured in Table 2 are numerous roots, tubers and other greens that likely were part of Siouan diet, but that are not as easily preserved as the abundance of nutshells and seeds found in the fire pits (Scarry 2003). The presence of peach pits in the remains indicates that the sites were inhabited post-European contact, as peaches aren't native to the Americas (Scarry 2003). Interestingly, indigenous people were introduced to numerous European plant species, but only a limited number were integrated into indigenous foodways (Scarry 2003). The Siouans likely utilized peaches because the trees thrived within the regional ecosystem. The incorporation of peaches underscores that indigenous agricultural practices were not static and were constantly being shaped by the introduction of new plants species.

The Siouan worked within and changed the area's deciduous forest ecosystem (Gremillion 2003). The site's proximity to the Eno River indicates how their settlement location complemented their nutritional needs because riverbanks provide suitable environments for fruit trees and floodplains environments provide rich, moist soil conducive for agricultural cultivation (Melton 2014). At the same time, the Siouan were not neutral actors within this ecological system and disturbance is noted to have been "a major factor in creating and maintaining the mosaic character of vegetation" (Gremillion 2003). Disturbance of land impacts plant distributions, and consequently the amount and variety of plant species available for human consumption (Gremillion 2003). Scarry (2003) elaborates on the implications of disturbance, explaining that, "plants that produce fleshy fruit are most often found in forest clearings, along forest streams borders, and in anthropogenic habitats such as fallow and in-use garden plots, field edges, and other disturbed areas in and around settlements. Thus, intentionally or not, Native Americans enhanced the availability of fruit simply by pursuing everyday activities" (p. 68). Species in Table 2, including bramble, grape, hawthorn, maypop, and persimmon, are all plant species that thrive in disturbed edge areas that would have made up the matrix spaces surrounding Siouan settlements (Melton 2014). Furthermore, Wagner (2003) asserts that the nut trees in Table 2 were likely grown intentionally in groves in the matrix surrounding the two sites by using practices such as fire-induced coppicing or clearing surrounding vegetation to minimize the trees being shaded. The environment influenced Siouan agricultural decisions while at the same time the Siouan significantly influenced the environment. This duality underscores that this form of agriculture was grounded in "mutualistic human-plant relationships and management skills honed from

millennia of resource management” that are in sync with agroecological principles (Wagner 2003 p. 150)

Changing Climate Influencing Phenology

The hypothesis that corn, nightshade, and sunflower would reach the number of GDDs required for plant species maturation in a shorter time frame was confirmed. All three species showed significant overall decreases of 1.6-2.2 days/decade in the number of days required to reach maturation, with nightshade having the least change over time and corn having the greatest (Table 3). The decrease in total number of days to complete growth mirrors the consistent increase in temperature occurring over the same time period (Figure 3). This finding is supported by similar results from other studies. For example, a comprehensive review of phenological data in 21 European countries between 1971 and 2000 found that over 75% of the species studied had accelerated phenology over this time period (Cleland *et al.* 2007). A shortened window of phenological growth impacts plant yields. Ainsworth and Donald (2010) explain, “in annual crops, higher temperatures can drive shorter life cycles, resulting in less seasonal photosynthesis, shorter reproductive phase, and thus lower yield” (p. 528). Considering how sensitive plant phenology is to temperature, it is likely that the plant species experienced longer periods of growth when Siouan people inhabited the study site, because the Little Ice Age lowered regional temperatures during this time period thus lengthening the period of heat accumulation .

The cumulative number of days to complete emergence for both corn and sunflower shortened over time by -1.43 days/decade ($r^2 = 0.65$) and -1.78 days/decade ($r^2 = 0.26$) respectively. The cumulative change in flowering for nightshade, which serves as a proxy for its cumulative change in emergence, also shortened over time (UC ANR). These results support the

hypothesis that plant species have, and will continue to, begin accumulating GDD earlier between 1950 and 2100. The results reflect the increase in temperature observed between 1950-2100 (Figure 3). The results further reflect a global trend of earlier warming observed during the spring. Since 1950, spring phenologies have begun earlier, by 2.3 to 5.1 days per decade (Scheffers *et al.* 2016). Interestingly, this pattern was found to be less augmented among agriculture crops grown in Europe because farmers' were adapting their practices to the changing climate (Cleland *et al.* 2007). An earlier starting date has implications beyond plant phenological timing and progression. Notably, warmer spring months have been associated with delayed pollination and foliation, and reduced fruit yield and quality (Scheffers *et al.* 2016). In comparison to the trend of earlier emergence that has occurred since 1950, a prolonged emergence was a greater concern for the Siouan because the LIA extended the winter season (Viau *et al.* 2012). This prolonged dormancy was especially salient for the Siouan because they consumed substantial amounts of foraged materials and would have less ability to adapt to delayed plant growth of foraged foods than of crops that they cultivated

By individual phenological stage, dormancy and maturation had consistently negative slopes for all three species, though the r^2 was only significant for one slope (corn, maturation). Also for all three species, the dormancy stage had the greatest change over time, though there is no significant r^2 associated with this stage. The lack of significant r^2 values associated with the majority of individual stage change for any of the species suggest that no singular change in stage length is solely responsible for the cumulative decrease in time to reach maturation that was observed. The discrepancy between individual and cumulative change in corn and nightshade, along with emergence cumulative stage's insignificant r^2 value, may be due to a lengthened

emergence phase occurring following a shorter dormancy phase. When beginning growth earlier in the year the species may be accumulating heat at a slower rate, thus lengthening the span of the emergence phase while still having an overall shortened time. This result slightly reflects the increase in temperature, though it is not as clearly associated with temperature as the cumulative change.

As can be visually observed in Figures 4-6, there is greater variability in phenology length during the later decades, most notably during the 2060s. This variability reflects that the temperature is not only increasing due to climate change but also becoming less consistent. Climate change is predicted to increase the likelihood of extreme temperatures (IPCC 2014). High temperatures are a risk to plants during their sensitive development stages, as they may incur long-term tissue damage (Kole *et al.* 2015). Temperature extremes are somewhat captured in GDD because the model is an average of maximum and minimum temperature (Figure 3, Eq. 1). Sunflower and nightshade particularly reflect variability because of their lower base temperatures. Their low base temperature causes them to begin accumulating heat earlier and thus reflects more of the variability in the early months that is not captured in the corn results because it's still in the dormancy stage when sunflower and nightshade begin heat accumulation. Sunflower and nightshade's greater variability aligns with other studies that have found that the phenologies of early season species are accelerated the most by increasing temperature (Cleland *et al.* 2007).

Other Climatic Factors

Several other climatic factors influence plant phenology, including precipitation and drought. For Hillsborough, NC precipitation is projected to slightly increase over time, though the change is insignificant (Figure 4). While the precipitation is projected to increase, the effects of

additional rain are mediated by the dramatically increasing temperature. Precipitation and temperature both influence water availability. Between 1950 and 2100, water availability becomes more variable, which is shown by the increase of both flood and drought conditions (Figure 5). This variability becomes more extreme over time. For example, the decade of 2060 is projected to experience a dry period followed by three wet periods. The first event was rated as a 4 and the following events were rated as -4, which represent the most severe conditions on the PDSI index (Figure 6). The Siouan also experienced extreme climatic conditions, enduring a severe drought during the 1600s (Trouet *et al.* 2013). However, the extreme climatic conditions are only somewhat comparable because the Siouan experienced a sustained period of severe drought, whereas the area in the future is predicted to experience shorter, sporadic periods of both extreme wet and dry conditions.

Limitations & Future Research

The most significant limitation of the climate projection model used was that it only reported temperature by month instead of by day. Because climate data was refined to a monthly level, the daily GDD value for a given month was the same and the start day for heat accumulation always began on the first day of a month. This limitation caused the start day to shift abruptly by approximately 30 days for what could be a minor change in monthly average temperature. Thus, the beginning date of emergence was not an accurate metric for supporting or refuting the second hypothesis that species would begin accumulating GDDs earlier. Even though the cumulative change of the emergence stage was considered instead, it is unclear to what extent the abrupt change in the dormancy stage's length influenced the cumulative decrease observed. This limitation is particularly important given that the overall change over time amounted to a 24-33

day decrease. The daily minimum and maximum temperatures can fluctuate dramatically throughout a month, especially during months of seasonal change. For example, in Chapel Hill (which is 12 miles south of the study site) the daily maximum temperature increased by 5.3°C and the daily minimum temperature increased by 4.7°C during the month of March, a common month for the three species to begin heat accumulation (US Climate Data). Daily data would have allowed an exact start date for accumulations to be established, consequently reducing the error associated with the blunt 30 day jump between starting months.

Beyond not capturing daily temperature variation within each month, this project's methodology was further limited by not accounting for extreme temperature. As the results indicate, a sustained temperature increase throughout a growing season will affect the duration of growth. Yet, regardless of significant changes in mean temperature, a short episode of high temperature lasting only a few days during critical phenological stages will have drastic impacts on plant yield (Challinor *et al.* 2007). For example, corn is particularly sensitive to extreme heat between its anthesis and silking stages and can experience flower abortion if it experiences heat stress during this point in growth (Lobell *et al.* 2013). So, if the increase in maximum temperature observed in the climate data (Figure 3) is being driven by short periods of extremely high temperatures, then the impacts on the plants are not being accurately portrayed using the current methodology. Future methodology could compare the timeline of phenological growth with daily maximum and minimum temperatures to determine if the critical temperature threshold is exceeded before a phenological stage is complete. Furthermore, plant phenology is driven by photoperiod, the hours between first and last light each day, in addition to heat accumulation. For example, a longer photoperiod lengthens the time to flowering and tassel initiation in corn

(Warrington and Kanemasu). Therefore, the effect that temperature has on a plant's growth duration may be modified by the photoperiod.

Another limitation of the climate projection model is that the earliest data was from 1950. This model does not include historical data relating to when the Siouan would have actually inhabited the land. This consideration is especially relevant given that the Siouans inhabited the sites in Hillsborough, NC during the Little Ice Age, a period of lower temperatures in the area (Viau *et al.* 2012). Moreover, the eastern coast of North America experienced a mega-drought during the 16th century (Trouet *et al.* 2013). These two climatic events would have strongly influenced agriculture practices in the area. Even if another another climate model had been included which extrapolated temperature to AD 1400-1700, this data could not be completely comparable to the current and future data used because it would be based off a model that was informed by different baseline assumptions. Future climate projections are useful given that agroecology is being considered as an agricultural method that could be implemented in the future as one way to mitigate climate change. Nevertheless, the lack of historical climate data is a critical knowledge gap in fully understanding indigenous agricultural practices.

More generally, this project was limited by bias in research that has only determined the GDD for a handful of common conventionally grown crops, such as corn, soybeans, tomatoes, and peppers. While there is some information pertaining to the general season in which the plants species of Table 2 begin growing or are available to harvest, there is little phenological data as specific as GDD. More detailed phenology data would enable the methodology of this study to be expanded. Incorporating additional climate variables, such as maximum daily temperature, daily

precipitation, evapotranspiration, soil type etc., into project methodology would improve the accuracy of the projections.

Conclusion

Siouan agriculture challenges conventional conceptions of agriculture. The wide variety of plant species utilized by the Siouan expands what is typically considered ‘food’. Many of the plants species consumed by the Siouan species are currently viewed as weeds rather than food, which is evident by the species’ common names (ie. pokewood, knotweed, sumpweed, etc.). Utilizing a wide range of plant species increased the Siouan’s food security. The failure of one species would not significantly impact their ability to eat because there were numerous other species to consume in its place. Because of their reliance on a wide range of plant species, the Siouan supported both within-species and between-species diversity as they encouraged plants to grow in the matrix surrounding their settlement. Conventional agriculture would benefit in a shift from monocropping to a similar Siouan farming model that fosters biodiversity, especially considering that biodiverse systems are more resilient to climate change (Romero-Lankao *et al.* 2014).

Siouan agriculture further challenges the concept of separation between humans and nature that is manifested in conventional agriculture’s paradigm. Conventional agriculture ideology frames agriculture fields as spaces of human-domination and influence, in contrast to forests and other ‘wild’ spaces dominated by nature. Yet, the Siouan’s the extensive foraging in the ‘matrix’ problematizes this concept. Scarry (2003) comments on the blurred lines between human-dominated and nature-dominated space, explaining that “those who exploit wild resources do not simply let nature take its course, but rather, take steps that enhance the yield and reliability

of the plant on which they depend. We can make a distinction between plants that are deliberately planted in a prepared field or garden bed, and those that are tended or otherwise encouraged. But we must recognize that so-called wild-plants may be and often are manipulated by people” (p. 51). The Siouan’s use and influence on the matrix surrounding their settlement can serve to expand our current conceptualization of agriculture beyond annual row crops to less conspicuous forms, such as silviculture. Additionally, intentionally developing a robust matrix is a practice in climate change mitigation because the matrix facilitates species migration - movement that will occur more frequently and become more critical to species survival as climate change drives species from their current habitats (Perfecto *et al.* 2009).

There is much room for improvement with current food production system in the southeast US and agroecology serves as a potential avenue through which to enact positive change. This project hopes to shed light on how indigenous knowledge can inform agroecology for this region. Furthermore, this project particularly serves as an entry point for considering the ways in which agriculture can be adapted mitigate the impacts of climate change.

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