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Neogene Climate Change in Eastern North America: A Quantitative Reconstruction

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Neogene Climate Change in Eastern North America: A Quantitative Reconstruction

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by

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ABSTRACT

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Though much is known of the global paleoclimate during the Neogene, little is understood about eastern North America at that time. During the Neogene the global paleoclimate was transitioning from the warm temperatures and higher levels of precipitation of the Paleogene to the cooler temperatures and lower levels of precipitation during the Pleistocene. Eleven fossil sites from Neogene eastern North America were analyzed using the Coexistence Approach: Pollack Farm, Brandon Lignite, Legler Lignite, Alum Bluff, Bryn Mawr, Big Creek on Sicily Island, Brandywine, Gray Fossil Site, Citronelle, Peace Creek, and Ohoopee River Dune Field. Analyses showed a general trend that early and middle Miocene sites were warmer than the area today, while middle and late Miocene sites were comparable to the area today, and Pliocene sites were comparable to or cooler than the area today. However, there is no clear trend of increased precipitation during the Neogene.

DEDICATION

This thesis is dedicated to my friends and family, who supported me throughout this endeavor. It is also dedicated to Dr. K.C. Lohmann at the University of Michigan for renewing my passion for paleontology.

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CHAPTER 1

INTRODUCTION

Unlike many other parts of the world from the time, Neogene eastern North America is still in the process of being understood. The discovery of fossil sites in recent years has helped expand existing knowledge of the region, but analysis has been limited to individual fossil sites. Though limited comparisons have been made between sites with respect to the presence or absence of fossil taxa, comparisons of paleoclimate across time and space have not been published.

Neogene Global Climate

The Neogene was a time of great climatic, floral, and faunal changes across the globe. Stable isotope analyses of benthic foraminifera indicate that the early Cenozoic was the beginning of a transitional period of global cooling that was evident throughout the Paleogene and Neogene (Zachos et al. 2008). In central Europe the mean annual temperature dropped between 15°-20° C from the Paleocene to the Pleistocene and continued to drop approximately another 10° C during the Pleistocene (Anderson and Borns 1997). During the Neogene (Miocene and Pliocene) mean global temperatures were higher (Zachos et al. 2001) and the global climate was wetter than today (Retallack 2007). Ice sheets covered some, if not all, of Antarctica and were beginning to appear in the northernmost regions of North America (Steppuhn et al. 2006). Across the globe the meridional temperature gradient was much weaker than it is today due to higher polar temperatures (Micheels et al. 2010) and CO_2 levels of approximately 360-440 ppm (Raymo et al. 1996). Studies of fossil leaf stomata have suggested that late Neogene CO_2 levels fluctuated between about 280-370 ppm (Van Der Burgh et al. 1993).

In North America C_4 grasslands expanded across the continent, typically at the expense of the existing woodlands (Retallack 2001; McInerney et al. 2011). In eastern North America there is paleontological evidence of forest refugia of relict populations from these grasslands (Wallace and Wang 2004). This grassland expansion occurred between 8-5 Ma, during the driest part of the Miocene-Pliocene transition, and was accompanied by drastic faunal turnover (Graham 1993; Cerling et al. 1997, 1998). Numerous modern faunal orders originated during the Neogene, as well as many with a strong Eurasian connection (DeSantis and Wallace 2008). Tiffney (1985b) asserted that the Miocene was one of 5 periods of floristic exchange between eastern North America and eastern Asia. Plant elements from North America and Eurasia were exchanged via the North Atlantic Land Bridge into the Miocene and via the Bering Strait into the late Miocene and Pliocene (Raven and Axelrod 1974; Tiffney 1985a, 1985b; Xiang et al. 2000). During the Paleogene and early Neogene a continuous mixed mesophytic forest occurred across the Northern Hemisphere but was subsequently extirpated in western Europe and western North America due to climatic and geological changes during the late Neogene and Quaternary (Graham 1993; Manchester 1999). The paleogeomorphology of North America was very similar to today, including the position of continents and ocean bathymetry (Crowley 1996). However, the presence of Bering Land Bridge and the North Atlantic Land Bridge are in stark contrast to modern coastlines (Figs. 1, 2).

Figure 1: Paleogeographic map of Early Miocene North America, courtesy of Ron Blakey, Colorado Plateau Geosystems, Arizona USA.

Figure 2: Paleogeographic map of Early Pliocene North America, courtesy of Ron Blakey, Colorado Plateau Geosystems, Arizona USA.

In North America the Neogene fossil record is biased toward the mid-latitudes of the western half of the continent (Wallace and Wang 2004). In eastern North America there are few fossil sites of that age, particularly in the interior of the continent. Of the presently known

Neogene fossil sites in eastern North America, many are predominately floral, with relatively high proportions consisting solely of pollen.

Scientists may be able to use an understanding of the global climate during the Neogene to predict the future trajectory of anthropogenic climate change (Salzmann et al. 2009). A study by Haywood et al. (2001) indicated that the late Pliocene in North America was probably 2°- 4° C warmer annually than today, with increased precipitation and less seasonality, and some regions, such as the current Great Plains, did not experience winter freezes. If global temperatures continue to rise at the current rate, the future global climate might resemble that of the middle Pliocene. However, due to the relative scarcity of Neogene fossil sites in eastern North America, this model is likely not representative of all of the continent. Neogene paleoclimate data from eastern North America would be a beneficial addition to the geological history of the continent.

Fossil paleoclimate data come from 2 primary sources: terrestrial data and marine data. Fossil data from marine invertebrates are relatively consistent: marine invertebrate remains are constantly being deposited on the ocean floor, which means that there are continuous climate data throughout geologic time (Zachos et al. 2001). However, these data are best used as a global average. They are not as sensitive to minute fluctuations in temperature and instead show broad trends. In addition, marine invertebrate fossil data can only give information about global temperature patterns; the bottom of the ocean is minimally impacted by changes in precipitation.

The terrestrial climate can be reconstructed in a variety of ways, such as the study of floral and faunal fossils, the study of geochemistry, or the study of sedimentology (Hickson et al 2010; Utescher et al. 2011). Paleosols are abundant and can reconstruct both temperature and precipitation as well as give an idea of the paleoenvironment (Sheldon et al. 2002; Retallack, 2004, 2005). Stable isotope analyses can provide a variety of paleoclimatic and paleoenvironmental information; carbon isotope variation can reconstruct the vegetation and the atmospheric CO_2, oxygen isotope variation can tentatively reconstruct temperature, and nitrogen isotope variation can be used as a proxy for rainfall abundance (Koch 1998; Kohn and Cerling 2002). With respect to terrestrial fossils, floral fossils are among the most widely used climatic and environmental indicators (Uhl et al. 2006). In general, floral data are restricted to terrestrial regions and are limited to the availability of fossil sites. However, where fossils are present, the climate information from floral data is relatively precise because it only pertains to a particular region and can give data on temperature as well as precipitation (Mosbrugger and Utescher 1997). Comparing fossil data, isotopic analyses or paleosols data with marine invertebrate data demonstrate how regional climate variation fits into global climate trends.

CHAPTER 2

MATERIALS AND METHODS

The Neogene is relatively unknown period in the history of eastern North America, but it is well-studied throughout the rest of the continent and the world. The fossil sites of eastern North America are remarkably important for reconstructing the paleoclimate across the region throughout the Neogene. I intend to (1) use floral fossils to reconstruct the climate of eastern North America during the Neogene, (2) describe general paleoclimate trends across eastern North America during the Neogene, and (3) compare the reconstructions to those estimated with different paleoclimate reconstructions, such as Zachos et al. (2001, 2008).

Fossil Material

There are few Neogene fossil sites in eastern North America and even fewer with enough data to perform a quantitative paleoclimate analyses. Therefore, only fossil sites with at least 15 fossil taxa were considered. This analysis included 11 Neogene fossil sites: the Alum Bluff site in Florida (Corbett 2004; Jarzen et al. 2010), the Big Creek on Sicily Island site in Louisiana (Wrenn et al. 2003), the Brandon Lignite in Vermont (Tiffney 1994; Traverse 1994), the Brandywine Formation in Maryland (McCartan et al. 1990), the Bryn Mawr Formation in Maryland (Pazzaglia et al. 1997), the Citronelle Formation in Alabama (Stults 2003; Stults and Axsmith 2009; Stults et al. 2010; Stults and Axsmith 2011b), the Gray Fossil Site in Tennessee (Wallace and Wang 2004; Gong et al. 2010; Liu and Jacques 2010; Ochoa et al. 2012), the Legler Lignite in New Jersey (Rachele 1976), the Ohoopee River Dune Field in Georgia (Rich et al. 2002), the Peace Creek Formation in Florida (Hansen et al. 2001), and the Pollack Farm Site in Delaware (Groot 1992). These fossil sites vary in age, location, and primary fossil composition (Table 1).

Table 1. Neogene fossil sites, their ages, and possible paleoclimate reconstruction methods

Fossil Site	Location	Age	Reconstruction Method
Pollack Farm	Delaware	Early Miocene	CA
Brandon Lignite	Vermont	Early Miocene	CA
Legler Lignite	New Jersey	Middle Miocene	CA
Alum Bluff	Florida	Middle Miocene	CA
Bryn Mawr Formation	Maryland	Middle/Late Miocene	CA
Big Creek on Sicily Island	Louisiana	Late Miocene	CA
Brandywine Formation	Maryland	Late Miocene	CA
Gray Fossil Site	Tennessee	Late Miocene/Early Pliocene	CA
Citronelle Formation	Alabama	Middle Pliocene	CA and LMA
Peace Creek Formation	Florida	Late Pliocene	CA
Ohoopee River Dune Field	Georgia	Middle Miocene/Late Pliocene	CA

Fossil Sites

In North America the Neogene fossil record is biased toward the mid-latitudes of western half of the continent (Wallace and Wang 2004) (Fig. 3). In eastern North America, there are few fossil sites of that age, particularly in the interior of the continent.

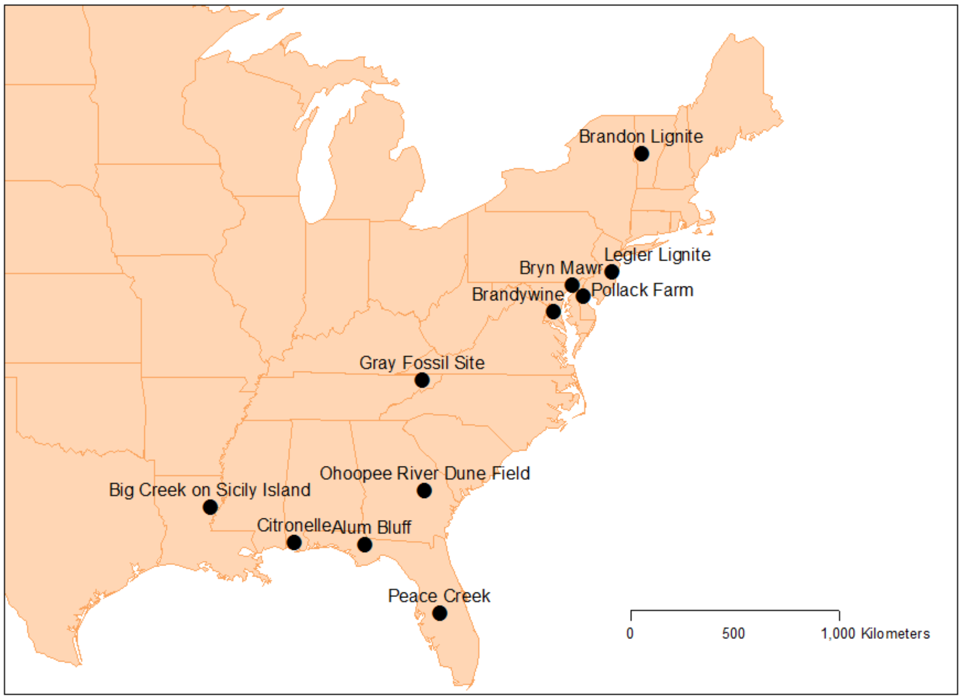

Figure 3. Location of Neogene floral fossil sites across eastern North America.

Pollack Farm. The Pollack Farm Site is an Early Miocene fossil site (19.2-17.3 Ma) in central Delaware, near Cheswold, and is currently the oldest known Neogene site in eastern North America (Groot 1998). Excavation took place on an exposed portion of the lower Miocene Cheswold Sands of the Calvert Formation from shallow sea deposits of the Late Oligocene to Early to Middle Miocene. The site was dated using siliceous microfossils (Benson et al. 1985). The pollen at this site does not appear extensively reworked; however, individual grains of *Casuarinidites* and *Thomsonipollis* were probably reworked from Upper Cretaceous or Paleogene deposits (Groot 1992). From the palynological assemblage, over 50 different taxa have been identified. *Quercus*, *Carya*, and *Pinus* dominated the vegetation, but many exotic species were also present, including *Momipites* (*Engelhardia* type), *Manilkara*, *Planera*, and palms that are now native to tropical and subtropical, moist environments such as eastern Asia, Florida and Central America (Groot 1992). The presence of *Momipites* is complicated: it possibly represents *Engelhardia*, which today lives mainly in the mountains of the tropics and subtropics. However, during the Paleocene it spread throughout lowland peat swamps of Europe as well as North and Central America. Groot (1992) suggested that *Momipites* at this site represented upland vegetation.

The majority of the palynomorphs found from this site were produced by taxa that grow in the coastal plain of Delaware today. According to Groot (1992), the presence of *Quercus*, *Pinus*, and *Carya* in eastern North American during the Late Oligocene and Miocene as well as at present indicated the persistence of the taxa, with the exception of disruptions during Pleistocene glaciations. The presence of subtropical and tropical taxa and the relative absence of cold-climate indicator taxa suggest that the paleoclimate of the modern coastal plain of Delaware was likely warm-temperate to subtropical and moist, similar to present day coastal Georgia and northern Florida. The abundance of pollen from trees and shrubs coupled with the relative absence of pollen from herbaceous plants indicates that a thick forest dominated by *Quercus*, *Pinus*, and *Carya* grew all the way to the east coast (Groot 1998). Today, the mean annual temperature (MAT) for the area is 12.2° C and the mean annual precipitation (MAP) is 1106 mm (NOAA-NCDC 2014).

Brandon Lignite. The Brandon Lignite in west-central Vermont is Early Miocene in age (Traverse 1994) and is the northernmost Neogene fossil site in this study. It is located about 7 km east of Brandon in the Green Mountains near Forestdale, Vermont (latitude 43° 50' N, longitude 73° 03' W) (Tiffney 1994). The deposit was discovered in 1848 while mining for iron and was rediscovered in 1901 while mining for clay (Barghoorn and Spackman, Jr. 1949). The Brandon Lignite deposit is composed of fossiliferous lignite and organic-rich clays and is difficult to date for 2 primary reasons (Tiffney 1994). Firstly, it is underlain by Cambrian formations and overlain by Pleistocene drift. The internal stratigraphy has been deformed by the passage of Pleistocene ice sheets, which limits paleomagnetic assessment. Secondly, there are no available radiometric indicators or vertebrate fossils. Therefore, the age can only be determined by floral fossils. Its relative isolation from other fossil sites of the same age makes dating even more difficult.

The fossil assemblage consisted of 98 taxa, including both micro-fossils and mega-fossils. Many of these fossils were from extinct species known primarily from the Eurasian fossil record (Tiffney 1994). Twenty-two of the remaining genera currently survive in warm-temperate and temperate regions of North America: 14 genera survive in eastern North America today primarily along the Gulf of Mexico, and 7 genera are still present in Vermont. The fossil taxa present in the Brandon Lignite suggest that it was a closed forest environment and conservative estimates suggest that the floral composition was half evergreen and half deciduous (Tiffney 1994). The phenology was determined by comparing that of the nearest living relatives; however, the phenology of modern cognates does not necessarily reflect that of the fossil taxa. Global paleoclimate estimates indicate that the Miocene was warmer, wetter, and less seasonal than the modern climate. Therefore, it is probable that the flora of the Brandon Lignite consisted of a higher proportion of evergreen taxa than predicted by observing modern cognates. Tiffney (1994) argued that the flora was predominately evergreen, suggesting a warm-temperate or subtropical climate with infrequent freezes. Some evergreen taxa included *Nyssa*, *Quercus*, and *Magnolia*.

Comparisons to the modern climate of the North American Gulf Coast, the highlands of Veracruz, Mexico, and middle elevations of Taiwan and the Sichuan Province of China estimated that the Brandon flora had a MAT of 17.1° C and a mean annual range of temperatures (MART) of 17° C. The MAP was about 1600 mm and fluctuated throughout the year with a summer high and a winter low (Tiffney 1994). The deciduous composition of the forest was likely in response to the seasonal fluctuation in temperature, not changes in precipitation. Today, the MAT of the area is 6.8° C and the MAP is 987 mm (NOAA-NCDC 2014).

Legler Lignite. The Legler Lignite is a Middle Miocene site (approximately 11 Ma) in central New Jersey (Rachele 1976; Greller and Rachele 1983). The site is an open pit ilmenite mine of the Glidden-Durkee Division of SCM Corporation located about 3.2 km north of Lakehurst, near Legler, New Jersey (latitude 40° 2’ 3” N, 74° 20’ 00” W) (Rachele 1976). The pit is a section of lignite in the Cohansey Formation and was the first palynological study of the formation. The age of the site was determined by the Cohansey Formation’s stratigraphic relationship to other geologic formations of known ages. The Cohansey Formation overlies the Kirkwood Formation, which Owens and Minard (1979) considered equivalent to the upper part of the Calvert Formation of Maryland. Ward and Blackwelder (1980) dated the upper Calvert at 13.3 Ma. Owens and Minard (1979) also observed that Cohansey Formation is overlain by the Bridgeton Formation, which is overlain by the Pensauken Formation. They considered the Pensauken Formation to be greater than 5 Ma. Greller and Rachele (1983) used this stratigraphy to date the Legler Lignite at approximately 11 Ma.

To date only fossil pollen has been recovered at this site (Groot et al. 1990). Many of the fossil taxa found at the site are still found in coastal New Jersey today, with some marked exceptions. Today, *Cyathea* and *Podocarpus* are native to the mountains of Mexico and the Antilles, *Engelhardia* is native to the mountains of tropical Mexico and Central America, and *Pterocarya* is native to eastern Asia (Greller and Rachele 1983). The dominance of *Quercus*, *Pinus*, *Carya*, and other warm-temperate genera suggested that the paleoclimate was warmer and wetter than in the region today (Rachele 1976). The paleoclimate was likely similar to, or slightly warmer than, that of modern southeastern North America due to the presence of taxa that are restricted to subtropical and tropical regions today. The paleoenvironment was mostly composed of marshes and swamp forests. Rachele (1976) predicted that the MAP of the Legler Lignite was about 1270 mm, with an average January temperature of 6° C and average July temperature of 24° C. Today, the MAT in the area is 12° C and the MAP is 1074 mm (NOAA-NCDC 2014).

Alum Bluff. Alum Bluff is a Middle Miocene site in the western panhandle of Florida (18-15 Ma) (Corbett 2004; Jarzen et al. 2010). The site is located about 3.2 km north of the town of Bristol, Florida (latitude 30° 28’ 08” N, longitude 84° 59’ 10” W). The Alum Bluff site is a steep river cut bluff exposure along the Apalachicola River on property owned by the Nature Conservancy known as Apalachicola Bluffs and Ravines Preserve (Corbett 2004).

The Alum Bluff group is found throughout the western and central regions of the Florida panhandle and include the Miocene Chipola Formation, the Miocene Oak Grove Sand, the Miocene Shoal River Formation, the Miocene Choctawhatchee Formation, and the Pliocene Jackson Bluff Formation (Scott 2002). The floral fossils were found in the upper levels of the group in unnamed beds underlain by the Early Miocene Chipola Formation and overlain by the Pliocene Jackson Bluff Formation and are estimated to be Middle Miocene in age based on the presence of Late Hemingfordian or Early Barstovian mammal fossils (Bryant et al. 1992; Scott 1997). The fossil bearing beds are gray to yellow and white clayey sands (Schmidt 1986). These clayey sands, coupled with some cross bedding, could indicate deltaic or prodeltaic sediments (Schmidt 1986; Means 2002). According to Jarzen et al. (2010), the sandy matrix and the presence of *Sabalites* trunks suggested a high energy riverine depositional environment, as does the lack of megaspores from heterosporous ferns.

Berry (1916a) first studied the Alum Bluff site and used 12 plant species and 1 fungal species to determine that the flora was tropical to subtropical. However, Manchester (1999) identified the temperate Eurasian genus *Paliurus* that is extinct in North America today, which suggested a cooler paleoclimate. Fossil ferns recovered from the site were comparable to a number of extant genera; *Azolla*, *Lygodium*, and *Acrostichum* are commonly found in mangrove backwaters, *Ceratopteris* is found in slow moving still waters in the tropics, and *Pityrogramma* is found in warm and tropical regions (Jarzen et al. 2010). Floral remains from this site also included temperate taxa such as *Carya*, *Quercus*, *Ulmus*, *Ilex*, *Juglans*, and *Liquidambar* (Corbett 2004; Jarzen et al. 2010). A cursory leaf margin analysis by Corbett (2004) observed that the leaves from the Alum Bluff site were small and serrated, as would be expected from a temperate paleoclimate. Corbett (2004) interpreted the paleoclimate as warm-temperate similar to the modern Florida Gulf Coast, with elm-hickory-palmetto forest near an oak and pine dominated landscape. The paleoenvironment was likely an upland forest flanking a river in a floodplain (Jarzen et al. 2010). Today the MAT of the area is 19.6° C and the MAP is 1512 mm (NOAA-NCDC 2014).

<u>Bryn Mawr.</u> The Bryn Mawr Formation palynoflora is a Middle to Late Miocene fossil site in northeastern Maryland near the Chesapeake Bay (Pazzaglia et al. 1997). The site is located in Cecil County, Maryland at the York Building Products Belvidere gravel pit about 8.5 km northeast of Perryville, Maryland (latitude 39° 37’ N, longitude 76° 1’ W). The Bryn Mawr Formation is composed of quartzose, sandy gravel braided alluvial plain deposit, and is the thickest and most extensive at the head of the Chesapeake Bay, Maryland. The Bryn Mawr

Formation represents deposition from the Late Oligocene to Late Miocene. This age is based on the plant assemblages and factors such as the presence of extinct or exotic taxa and the relative abundance of certain modern taxa. The pollen does not appear to have been reworked (Pazzaglia et al. 1997).

The floral fossil assemblage included approximately 40 taxa and was dominated by *Quercus, Alnus*, *Carya*, *Taxodium, Liquidambar*, *Juglans, Pterocarya*-type, and *Pinus* (Pazzaglia et al. 1997). Many of the taxa found at the site are still present in the region today including *Quercus, Carya*, *Pinus*, *Ilex*, and *Betula*; however, exotic taxa were also present. The presence of *Sciadopitys*, *Engelhardia*, and *Pterocarya* indicated that the site must be older than Pleistocene. The prevalence of *Quercus*, *Carya*, *Engelhardia*, *Symplocos,* and *Cyrilla* indicated a warm-temperate to subtropical climate without extended annual cool periods. However, the presence of temperate gymnosperm pollen, such as *Tsuga* and *Picea*, suggested a cooler climate with more seasonality. Pazzaglia et al. (1997) suggested that the Middle to Late Miocene brought about a shift from thermophilic species and *Quercus-Carya* dominance to the more cold-adapted *Pinus* and *Picea.* Today the MAT of the area is 12.7° C and the MAP is 1095 mm (NOAA-NCDC 2014).

Big Creek on Sicily Island. Big Creek on Sicily Island is a Late Miocene fossil site (8.68 Ma) in eastern Louisiana (Wrenn et al. 2003). The site is an exposure of lignitic shale on the western side of Sicily Island, Louisiana and is part of the Catahoula Formation, which was originally considered part of the Grand Gulf Sandstone but it was later renamed to mitigate confusion. Geologic formations along the Gulf Coast use the biostratigraphy of marine mollusks and microfossils for dating, but the Catahoula Formation lacks marine fossils, which makes the age of this formation up for interpretation. Attempts to date the formation using terrestrial floral remains or freshwater mollusks have been largely disregarded because they cannot be correlated to Gulf Coast marine markers and zonations. The Catahoula Formation was subsequently dated using its stratigraphic position, which resulted in 2 differing interpretations. Matson (1917) and Berry (1917) concluded that the Catahoula Formation is Oligocene in age because it interfingers with the Vicksburg Group. On the other hand, Howe (1933), Chawner (1936), and Murray (1961) concluded that the Catahoula Formation is Miocene in age because it unconformably overlies the Vicksburg Group. Howe (1933) went on to correlate the Catahoula Formation with the freshwater Chattahoochee Formation and the marine Tampa Limestone in Florida, both of which are Miocene in age.

Wrenn et al. (2003) used palynomorph assemblages in the lignite to date the formation. The Louisiana Geological Survey demonstrated that palynomorphs could be used as the terrestrial equivalents of marine calcareous oozes with regard to fossil abundance (Wrenn et al. 2003). These palynomorphs included pteridophyte spores, pollen, and freshwater algal remains, as well as fungal debris. The assemblage was assigned to the Paly24 marker horizon of the Shell Offshore Inc. Cenozoic pollen zonation, indicating a Late Miocene age (Wrenn et al. 2003). The presence of rare specimens including ambrosid and helianthid pollen distinguished that the Catahoula Formation is Miocene rather than Oligocene. The absence of *Artemisia* pollen as well as the paucity and lack of diversity of ambrosid pollen precluded a younger late Miocene or Pliocene age, while the absence of Eocene and Oligocene marker taxa precluded a pre-Miocene age (Wrenn et al. 2003).

More than half of the pollen from Big Creek on Sicily Island came from ferns, many of which came from freshwater floating and climbing ferns (Wrenn et al. 2003). The presence of pollen from warm climate seed plants including palm and mangrove, coupled with the fern spores, indicated that the paleoclimate of the Catahoula Formation at Big Creek on Sicily Island was tropical to subtropical. According to Wrenn et al. (2003), the site was most likely a bayou, a quiet fluvial backwater, or the uppermost reaches of a tidal channel or estuary. Today the MAT of the area is 19.3 °C and the MAP is 1539 mm (NOAA-NCDC 2014).

Brandywine. Brandywine is a Late Miocene fossil site (11.2-6.5 Ma) in southern Maryland (McCartan et al. 1990) The site is near Brandywine, Maryland and is about 20 km southeast of Washington D.C. The Brandywine site was found in a clay lens (about 30 m wide, 90 m long, and 6 m thick) that occupied an irregular channel remnant in an alluvial plain composed of quartzose sand and gravel. The fossiliferous clay was found in the deepest part of the channel and did not appear to have evidence of deformation (McCartan et al. 1990). McCartan et al. (1990) dated the site as late Miocene based on the diverse flora.

Approximately 49 fossil taxa were unearthed from the site (McCartan et al. 1990). The fossils included pollen, seeds, fruit, and leaves, as well as wood from *Taxodium.* The vegetation was dominated by vines and deciduous trees. Of the identified fossil taxa found at this site, only one (*Mneme*) is now extinct. Only 4 of the taxa are no longer native to North America but still survive in a temperate climate elsewhere. Of the remaining 44 genera, all but 2 still grow in Maryland: *Sophora* now grows west of the Appalachian Mountains and *Larix* only grows as far south as New Jersey.

The scarcity of terrestrial herbaceous plants and absence of grass pollen indicated a lack of open space near the site (McCartan et al. 1990). Groot (1991) suggested that the presence of *Taxodium*, *Pterocarya*, *Liquidambar*, and *Cyrilla* from this site indicated a warm-temperate or subtropical climate, while McCartan et al. (1990) suggested that the abundance of deciduous taxa and presence of taxa with high cold tolerance such as *Pinus*, *Smilax*, *Myrica*, and *Comptonia* indicated a temperate climate. Conservatively, the paleoclimate of the Brandywine formation was likely similar to that of present-day coastal North and South Carolina, with hot summers, mild winters without much frost, and consistent seasonal rainfall. The presence of *Taxodium distichum* and absence of drought-tolerant taxa suggested a high water table and adequate rainfall (McCartan et al. 1990). Today the MAT of the area is 13.4° C and the MAP is 1134 mm (NOAA-NCDC 2014).

Gray Fossil Site. The Gray Fossil Site in northeastern Tennessee is Late Miocene to Early Pliocene (7.0-4.5 Ma) in age (Wallace and Wang 2004; Shunk et al. 2006). The site is located in Johnson City, Tennessee (latitude 36° 22' 13" N, longitude 82° 29' 49" W). The Gray Fossil Site was a sinkhole lake that was up to 39 m deep and approximately 2 ha in size (Wallace and Wang 2004; Shunk et al. 2006). This sinkhole lake was likely composed of 11 different sinkholes within the oxidized subaerial chert-rich gravels, muds, and sands of the Knox Group carbonates that disconformably overlays the lacustrine sequence (Clark et al. 2005; Shunk et al. 2006; Whitelaw et al. 2008). This resulted in a deposit of finely laminated clays, silts, and fine sands intermixed with gravel lenses. Zobaa et al. (2011) suggested that the Gray Fossil Site basins consisted of a younger Late Miocene/Early Pliocene subbasin and an older Paleocene to Eocene subbasin. The age of the site was constrained biostratigraphically by using the temporal range of the short-faced bear *Plionarctos* and the rhinoceros *Teleoceras* (Parmalee et al. 2002; Wallace and Wang 2004).

Both floral and faunal fossils have been found at the Gray Fossil Site that indicate the site rarely experienced freezing temperatures and had limited seasonality (DeSantis and Wallace 2008; Liu and Jacques 2010). The faunal fossils present a unique combination of influence. Taxa such as *Alligator, Heloderma*, and *Tapirus* indicate a warm adapted southern influence, while taxa such as the badger *Arctomeles* and the red panda *Pristinailurus* indicate a cool adapted northern component (Wallace and Wang 2004; Mead et al. 2012). The presence of crocodilian fossils suggested that the Gray Fossil Site had a cold month mean temperature (CMMT) of warmer than 5.5° C (Shunk et al. 2006). A study by DeSantis and Wallace (2008) showed that stable isotope analyses of carbon and oxygen varied insignificantly and indicated that there were only minor differences in monthly temperature and precipitation between the modern climate of eastern Tennessee and the paleoclimate of the Gray Fossil Site in the Neogene, but the paleoclimate had less seasonality.

Both micro- and megafloral fossils have been found at the Gray Fossil Site, including wood, leaves, fruits, and seeds (Gong et al. 2010; Liu and Jacques 2010; Zobaa et al. 2011; Ochoa et al. 2012). The floral taxa were predominately genera native to North America such as *Quercus*, *Carya*, and *Pinus* but also from taxa with a strong east Asian correlation including *Pterocarya*, *Vitis*, and *Sinomenium* (Gong et al. 2010; Liu and Jacques 2010; Ochoa et al. 2012). The presence of *Sinomenium* suggests a CMMT of -7.3°-21°C (Liu and Jacques 2010). The paleoenvironment of the site closely resemble the modern North American mesophytic forest region and likely acted as a refugium for forest species from the expansion of grasslands across the continent (Ochoa et al. 2012). Fossil tapirs indicate a nearby forested paleoenvironment (DeSantis and Wallace 2008). The fossil data combined with the presence of charcoal suggests that the paleoclimate was warm and dry with periodic fire events (Zobaa et al. 2011). Today the MAT of the area is 13.9° C and the MAP is 1263 mm (NOAA-NCDC 2014).

<u>Citronelle.</u> The Citronelle Formation fossil sites in southwestern Alabama are Late Pliocene (3.4-2.7 Ma) in age (Stults et al. 2002). The date was originally estimated as Pliocene (Berry 1916b; Matson 1916) but has been debated for almost a century (Roy 1939; Stringfeld

and LaMoreaux 1957; Doering 1958; Isphording and Lamb 1971). Otvos (1997, 1998) estimated a Pliocene age based on evidence for higher sea level and intense subtropical/tropical weathering, as well as correlation with other regional formations. Recent work supports Berry's (1916b) Pliocene age estimation.

Floral fossils were found in peat deposits and rare, relatively unoxidized clay lenses (Stults 2003). They are located on the eastern shore of Perdido Bay in Baldwin County, Alabama (latitude 30° 24.05' N, longitude 87° 26.97' W), on the western shore of Perdido Bay on the Alabama-Florida border (latitude 30° 20.61' N, longitude 87° 29.12' W), in central Mobile County, Alabama (latitude 30° 43.74' N, longitude 88°8.57' W), and on the Scarborough School site on private property within the Mobile city limits (latitude 30° 43.74' N, longitude 88° 8.57' W and latitude 30° 43.7' N, longitude 88° 8.76' W) (Stults and Axsmith 2009, 2011b). Unfortunately, according to Stults and Axsmith (2011b), the fossiliferous layers at the Scarborough site are no longer accessible due to land reclamation efforts.

A variety of microfloral and megafloral fossils have been found, including pollen, leaves, fruits, and seeds (Stults et al. 2002; Stults 2003; Stults and Axsmith 2009; Stults et al. 2010; Stults and Axsmith 2011a, 2011b; Stults et al. 2011). The fossil taxa included native taxa such as *Liquidambar*, *Carpinus*, Cupressaceae, and *Pinus* (Stults et al. 2002; Stults and Axsmith 2009; Stults et al. 2010; Stults and Axsmith 2011b; Stults et al. 2011), as well as exotic taxa including *Pterocarya*, *Trapa*, Menispermaceae, *Gordonia*, and *Begonia* (Stults and Axsmith 2011a, 2011b). These fossils sites provided the earliest post-Eocene evidence of *Carpinus* in North America (Stults et al. 2002). The paleoenvironment was likely lacustrine wetlands. Leaf margin analysis of the sites by Stults (2003) gave a MAT of 17.6° C with a standard error of 2.7° C. The temperature in coastal Alabama during the Middle Pliocene was likely similar or slightly cooler than the current MAT for the region of 19.3° C (Stults and Axsmith 2011). Today the MAT of the area is 19.6° C and the MAP is 1597 mm (NOAA-NCDC 2014).

Peace Creek. The Peace Creek site is a Late Pliocene sinkhole locality (approximately 2.8 Ma) in central Florida located in the Polk Upland between Lakeland Ridge, Lake Wales Ridge, and Lake Henry Ridge (latitude 27°54'45.8" N, longitude 81°45'14.8" W) (Hansen et al. 2001). The site is within the Hawthorn Group, which consists of the Arcadia Formation (upper Oligocene-lower Miocene) near the Bone Valley Member of the Peace River Formation (upper Miocene-lower Pliocene) (Hansen et al. 2001). The Peace Creek sinkhole formed in a thick carbonate unit, likely the Suwannee or Ocala Limestones. High sea levels during the Miocene and middle Pliocene refute the possibility that the site is older than late Pliocene (Hansen et al. 2001).

Palynological remains from the Peace Creek site were dominated by *Pinus* (Hansen et al. 2001). However, wetland and aquatic taxa including *Taxodium*, *Cyrilla*, *Sagittaria*, and *Nuphar* made up a large component of the studied pollen. Native taxa such as *Quercus*, *Carya*, *Pinus*, *Liquidambar*, and *Myrica* were prevalent in the pollen assemblage, but exotic taxa including *Pterocarya*, *Sciadopitys*, cf. *Ginkgo*, and cf. *Dacrydium* were also observed. Sediments and the pollen assemblage from this site suggested that it was a shallow-water wetland and alternated between bay swamp, shrub bog, cypress pond, water lily marsh, flag marsh, and wet prairie (Hansen et al. 2001). The paleoclimate was similar to that of modern Florida. Today the MAT of the area is 22.4° C and the MAP is 1316 mm (NOAA-NCDC 2014).

Ohoopee River Dune Field. The Ohoopee River Dune Field site in Emanuel County, Georgia is difficult to date (Rich et al. 2002). It is underlain by the Middle Miocene Altamaha Formation and overlain by Pleistocene dunes; however, the site itself cannot be decisively dated

(Rich personal communication 2013). The site was discovered by a series of auger holes drilled into the Pleistocene dunes (Rich et al. 2002). Clayey, organic-rich sediments were encountered during the drilling process. Analysis of the clayey sediments produced abundant palynomorphs, as well as palygorskite that is common in Miocene strata (Weaver and Beck 1977). The presence of *Momipites* also suggested a pre-Quaternary age, but the number of pollen grains was too small to be a reliable indication (Rich et al. 2002).

Microfloral fossils produced 87 different taxa, mostly of herbaceous plants, shrubs, and trees that are native to modern southeastern North America including *Nyssa*, *Taxodium*, *Carya*, and *Quercus* (Rich et al. 2002). Four exotic fossil genera were also present: *Casuarinidites*, *Momipites*, *Pterocarya*, and *Sciadopitys*. All identified palynomorphs represent terrestrial or freshwater species (Rich et al. 2002). Ecologically, the paleoenvironment of this site was probably composed of warm coastal swamps and open, flooded marshlands. Today the MAT of the area is 17.7° C and the MAP is 1198 mm (NOAA-NCDC 2014).

Analytical Procedures

The available fossil data were sufficiently identified to use the Coexistence Approach, but lacked the level of leaf preservation to warrant CLAMP (Climate Leaf Margin Analysis). Leaf Margin Analysis (LMA) for the floral fossils of the Citronelle Formation in Alabama was performed by Stults (2003).

Coexistence Approach

The Coexistence Approach (CA) was developed by Mosbrugger and Utescher (1997) and is a largely computer-based method of quantitative paleoclimate reconstruction. It has been used to estimate paleoclimate parameters of Neogene Europe (Uhl et al. 2003; Uhl et al. 2006), as well as eastern Asia (Liang et al. 2003). CA uses the modern climatic requirements of a fossil taxon's nearest living relative (NLR). For a given climate parameter the estimated climatic interval is the range in which all, or most, NLRs can coexist. Analysis using CA requires a minimum of 10 taxa, the more taxa provide higher levels of resolution (Mosbrugger and Utescher 1997).

The floral fossils from 11 fossil sites were analyzed using the methods adapted from Mosbrugger and Utescher (1997) and Uhl et al. (2003). NLRs were determined to the genus level from the literature. For the extinct genera *Microdiptera* and *Mneme*, the extant genus *Decodon* was used as the nearest living relative (Graham 2013). NLR climatic parameters were obtained from the Palaeoflora Database (some parameters are available online at http://palaeoflora.de). From this analysis, the intervals for coexistence were calculated for mean annual temperature (MAT), cold month mean temperature (CMMT), warm month mean temperature (WMMT), mean annual precipitation (MAP), monthly maximum precipitation (MMaP), monthly minimum precipitation (MMiP), and warm month mean precipitation (WMMP). Comparison modern climate data were obtained from the National Oceanic and Atmospheric Administration National Climatic Data Center (NOAA-NCDC) website (http://ncdc.noaa.gov/cag).

GIS Reconstruction

Using the data from the CA analysis, the paleoclimate data for each fossil site were mapped on to a modern map of North America using ArcMap in ArcGIS 10.1. Two paleoclimate parameters were mapped: the mean annual temperature (MAT) and mean annual precipitation (MAP). Paleoclimate data were compared to modern climate data from the PRISM Climate Group at Oregon State University 30-Year Normals (http://prism.oregonstate.edu/normals/) to determine differences between the modern and paleoclimate. MAT and MAP were chosen so that paleoclimate and modern climate parameters were compared directly. The mean of estimated paleoclimatic intervals was used for comparison.

CHAPTER 3

RESULTS

Fossil Sites

Pollack Farm

During the Miocene, the Pollack Farm Site had a MAT that was higher than it is in the region today, but the modern MAP falls within the Miocene estimate (Table 2, Figs. 4, 5). Today the MAT of the Pollack Farm area is 12.9° C and the MAP is 1117 mm.

Table 2. Paleoclimate climatic intervals using the coexistence approach (CA) for 11 Neogene fossil sites for mean annual temperature (MAT), cold month mean temperature (CMMT), warm month mean temperature (WMMT), mean annual precipitation (MAP), monthly maximum precipitation (MMaP), monthly minimum precipitation (MMiP), and warm month mean precipitation (WMMP).

Fossil Site	**MAT**	**CMMT**	**WMMT**	**MAP**	**MMaP**	**MMiP**	**WMMP**
Pollack Farm Site	14.4-18.4	4.3-9.6	25.1-27.9	961-1520	109-196	42-56	108-175
Brandon Lignite	15.7-21.3	5.5-13.3	23.6-27.9	1096-1520	165-195	42-43	111-176
Legler Lignite	14.4-20.8	5.2-12.6	24-27.9	996-1347	204-293	52-56	99-142
Alum Bluff	20.4-21.7	13.3-14.8	26-27.9	823-932	204-241	29-45	108-176
Bryn Mawr	13.8-20.8	3.1-13.3	23.6-27.9	823-1613	204-245	9-59	79-180
Big Creek on Sicily Island	20.4-20.8	4.3-15.6	25-27.9	1122-1520	146-178	42-45	99-180
Brandywine	13.3-16.1	-0.1-7.8	23-25.6	735-1551	109-195	32-56	74-176
Gray Fossil Site	13.6-18.5	4.3-12.5	23.6-25.9	961-1167	109-151	42-56	99-176
Citronelle Formation	14.4-20.8	4.3-13.3	25.7-27.9	961-1355	113-195	42-43	94-163
Peace Creek Formation	14.4-21.9	4.3-13.6	23.6-27.9	961-1520	204-281	42-56	99-177
Ohoopee River Dune Field	14.4-20.8	1.8-13.3	23.6-27.9	823-1562	204-264	25-59	99-176

Brandon Lignite

The Brandon Lignite had a drastically warmer MAT during the Miocene (Table 2). Tiffney (1994) predicted that the Brandon Lignite had a MAT of 17.1° C with a mean annual range of temperature (MART) of 17° C. This differed dramatically from the MAT of the Brandon Lignite today of 7.6° C (Fig. 4). Tiffney (1994) also predicted that the MAP was about 1600 mm with seasonal fluctuations. This was slightly higher than the interval estimated by the CA (Fig. 5). The modern MAP of 953 mm is slightly lower than the Miocene MAP of 1096-1520 mm.

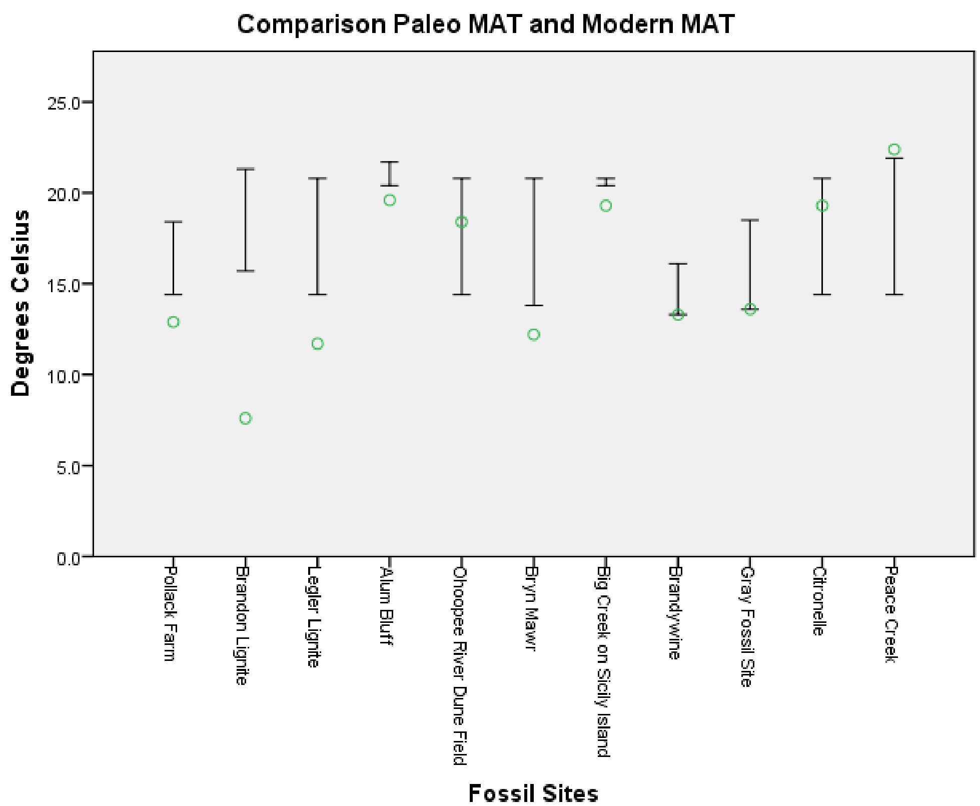

Figure 4. Comparison of the modern MAT (green dots) and the paleo MAT interval (whiskers) for 11 fossil sites

Legler Lignite

The Legler Lignite had a good deal warmer MAT during the Miocene than the region has today, but the modern MAP falls within the estimated Miocene range (Table 2, Figs. 4, 5). Rachele (1976) predicted that the MAP was about 1270 mm, with an average January temperature of 6° C and an average July temperature of 24° C. Today the Legler Lignite region has a MAT of 11.7° C and a MAP of 1211 mm.

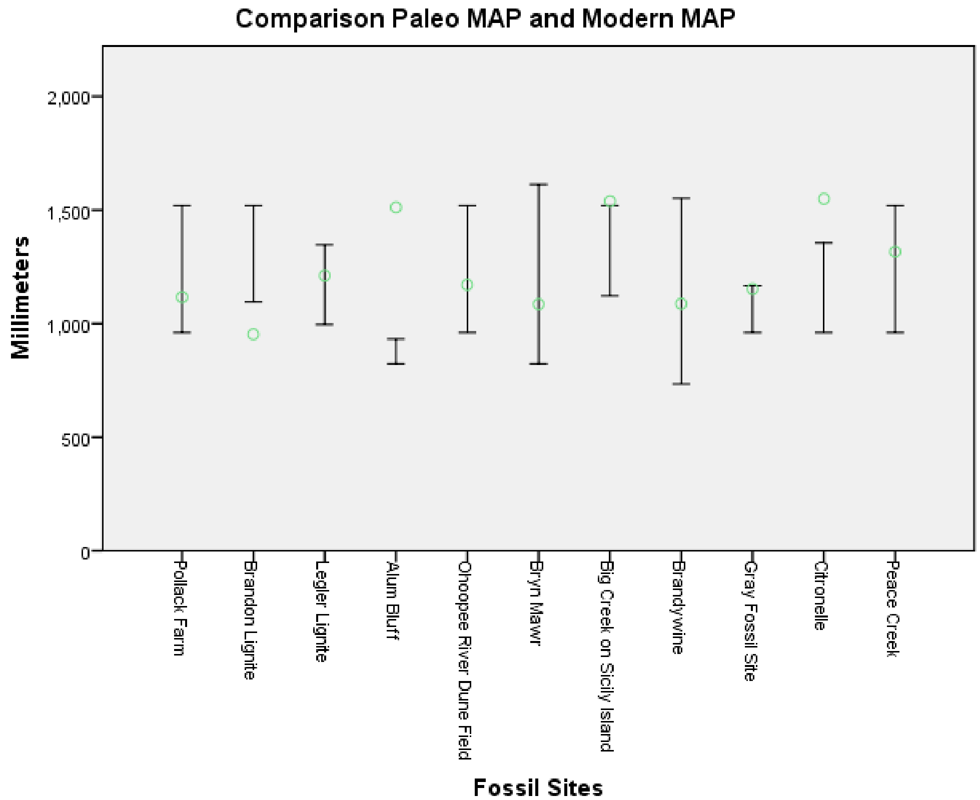

Figure 5. Comparison of the modern MAP (green dots) and the paleo MAP interval (whiskers) for 11 fossil sites

<u>Alum Bluff</u>

The Alum Bluff site was slightly warmer, but the modern MAP is higher than the estimated Miocene range (Table 2, Figs. 4, 5). Today Alum Bluff region has a MAT of 19.6° and a MAP of 1512 mm.

Bryn Mawr

During the Miocene the Bryn Mawr Site had a MAT that was slightly warmer than the region today, but the modern MAP falls within the expected Miocene range (Table 2, Figs. 4, 5). Today the Bryn Mawr region has a MAT of 12.2° C and a MAP of 1086 mm.

Big Creek on Sicily Island

The Big Creek on Sicily Island site had a MAT that was slightly warmer than today and a MAP that was slightly higher (Table 2, Figs. 4, 5). Today the MAT is 19.3° C and the MAP is 1539 mm. Overall, the climate does not appear to have changed much since the Miocene.

Brandywine

The Brandywine site had a similar MAT as the region today and a similar MAP (Table 2, Figs. 4, 5). Today the Brandywine area has a MAT of 13.3° C and a MAP of 1088 mm.

Gray Fossil Site

The Gray Fossil Site was probably warmer during the Neogene, and the modern MAP falls within the Neogene range (Table 2, Figs. 4, 5). Today the Gray Fossil Site has a MAT of 13.6° C and a MAP of 1153 mm. The presence of crocodilians at this site suggests that the CMMT was greater than 5.5° C (Shunk et al. 2006), while the presence of *Sinomenium* suggested a CMMT of -7.3°-21° C (Liu and Jacques 2010). Both of these estimates fall within or encompass the CA interval.

Citronelle

The Citronelle Formation had a comparable or cooler MAT during the Pliocene, while the MAP was lower than today (Table 2, Figs. 4, 5). Using LMA, Stults (2003) predicted a MAT of 17.6° C with a standard error of 2.7° C (14.9°-20.3° C). After including the standard error, both approaches yield similar results. The current MAT for the region is 19.3° C, suggesting that the paleoclimate was similar to or slightly cooler than in the region today (Stults 2003; Stults and Axsmith 2011). The modern MAP of 1550 mm is greater than the Miocene MAP of 961-1355 mm.

Peace Creek

The Peace Creek had a cooler MAT during the Pliocene than today, but the modern MAP falls within the Pliocene range (Table 2, Figs. 4, 5). Today the MAT of the Peace Creek site is 22.4° C and the MAP is 1316 mm.

Ohoopee River Dune Field

The Ohoopee River Dune Field had both a MAT and a MAP that are comparable to the modern values (Table 2, Figs. 4, 5). Today the MAT of Ohoopee River Dune Field is 18.4° C and the MAP is 1171 mm.

Overall Patterns

Throughout the Paleogene and Neogene there is an general pattern of decreasing temperature and precipitation. However, the analyzed fossil sites from Neogene eastern North America do not reflect this cooling and drying trend. Overall, there was a pattern of early and middle Miocene sites being warmer than today, the middle and late Miocene sites being comparable to today, and Pliocene sites being cooler than today (Figs. 4, 6). There was no clear pattern of precipitation (Figs. 5,7).

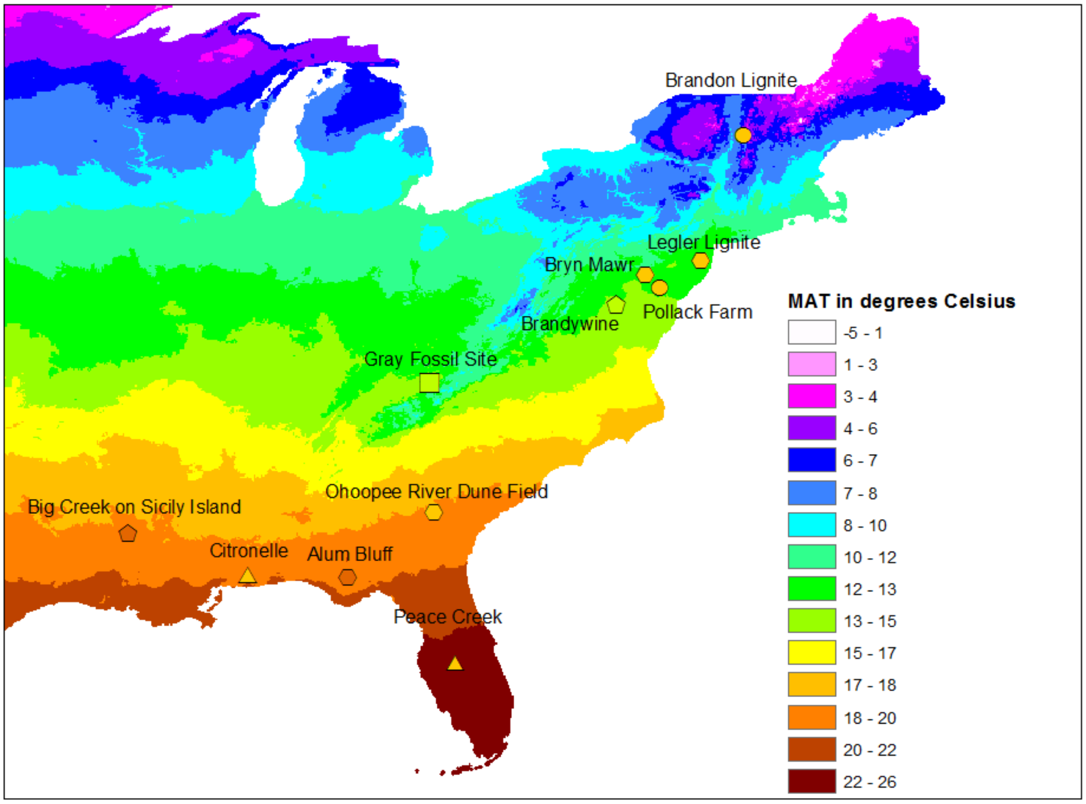

Figure 6. Comparison of modern MAT (base map) to estimated MAT (colored dots) of Neogene floral fossil sites in eastern North America. Modern MAT values are 30-year Normals from the PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Copyright © 2014, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu Map created 1/23/2014.

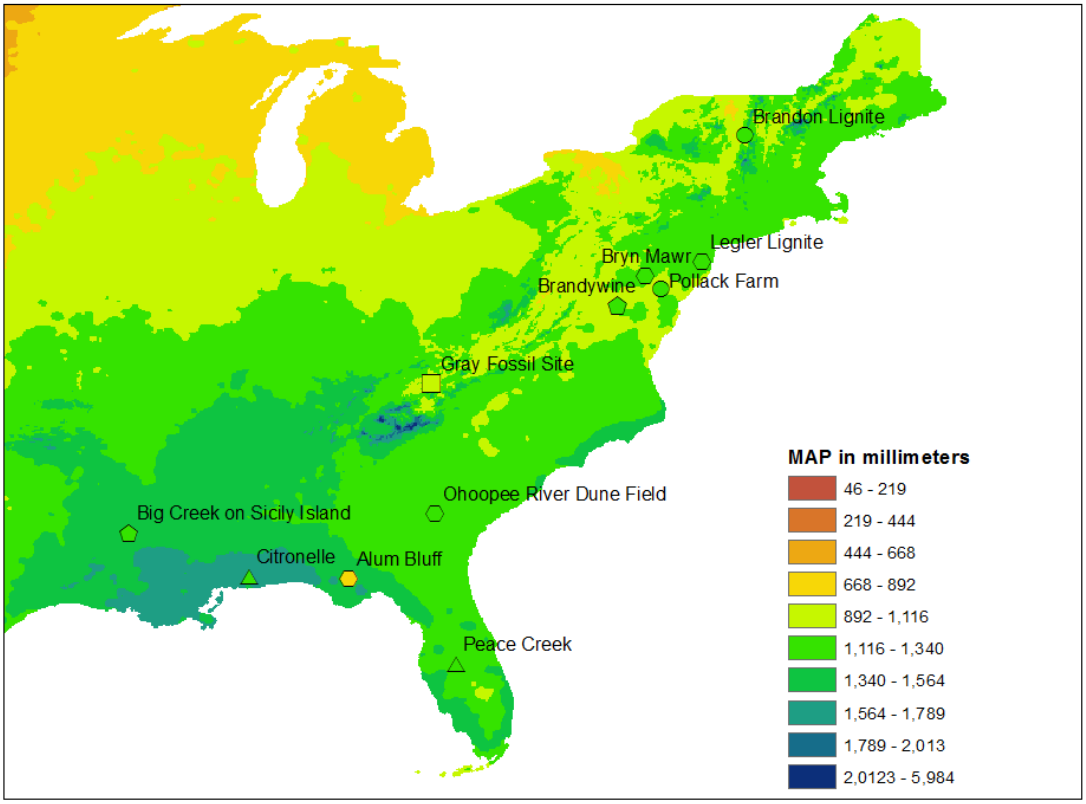

Figure 7. Comparison of modern MAP (base map) to estimated MAP (colored dots) of Neogene floral fossil sites in eastern North America. Modern MAP values are 30-year Normals from the PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Copyright © 2014, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu Map created 1/23/2014.

CHAPTER 4

DISCUSSION

Comparison of Methodologies

Only 4 of the fossil sites included in this analysis had previous paleoclimate reconstructions: the Brandon Lignite (Tiffney 1994), the Legler Lignite (Rachele 1976), the Gray Fossil Site (Shunk et al. 2006; Liu and Jacques 2010), and the Citronelle sites (Stults 2003). Tiffney (1994) estimated that the Brandon Lignite had a MAT of 17.1° C and a MART of 17° C, as well as a MAP of about 1600 mm. The coexistence approach gave the range 15.7° -21.3 ° C for the MAT. The MART can be inferred from the difference between the CMMT range (5.5°-13.3° C) and the WMMT range (23.6°-27.9° C). However, the difference of 22.4° should be interpreted cautiously because it was not obtained directly. The coexistence approach gave a range of 1096-1520 mm for the MAP. The Tiffney's MAT estimate falls in the middle of the coexistence approach range, while his MAP estimate is greater than the coexistence approach range.

Rachele (1976) estimated the Legler Lignite to have a MAP of about 1270 mm, a mean January temperature of 6° C, and a mean July temperature of 24°C. The coexistence approach gave the range 996-1347 mm for the MAP, the range 5.2°-12.6°C for the CMMT, and the range 24°-27.9° C for the WMMT. Rachele's MAP estimate falls within the coexistence approach range. Rachele's January mean temperature prediction seems reasonable with respect to the coexistence approach range for CMMT, but the July mean temperature prediction could be a little low.

Shunk et al. (2006) used the presence of crocodilian fossils to estimate that the Gray Fossil Site had a CMMT of > 5.5° C. The coexistence approach gave the range 4.3°-12.5° C for the CMMT. The previous estimate falls in the new range. Liu and Jacques (2010) suggested that the presence of *Sinomenium* indicated a CMMT of -7.3°-21° C. This is a large range and encompassed the CA estimate. Stults (2003) used LMA to estimate a MAT of 17.6° C with a standard error of ± 2.7° C (14.9°-20.3° C) at the Citronelle sites. This is nearly identical to the coexistence approach range of 14.4°-20.8°C.

Haywood et al. (2001) estimated that the Piacenzian stage of the Pliocene (2.6-3.6 Ma) in North America was between 2°-4° C warmer annually with higher levels of precipitation and less seasonality. Both the Citronelle sites (Stults et al. 2002) and the Peace Creek site (Hansen et al. 2001) fall in this time. For the Citronelle sites, the estimated MAT of 14.4°-20.8° is nearly identical to, if not slightly cooler than, the modern MAT of 19.3° C. Also, the estimated MAP of 961-1355 mm is less than the modern MAP of 1550 mm. This suggests the late Pliocene in the Gulf Coast of Alabama was actually cooler and drier than the region is today. The Peace Creek site, the only other Pliocene fossil site in this analysis, had an estimated MAT of 14.4°-21.9° C, which is cooler than the modern MAT of 22.4° at Peace Creek, while the Neogene estimated MAP of 961-1520 mm encompasses the modern MAP of 1316 mm.

However, these are only 2 Late Pliocene sites on the Gulf Coast and they are not necessarily representative of all of eastern North America at that time. However, this is unsurprising because Haywood et al. (2001) had difficulty simulating the climate of southern North America, which is where the Pliocene sites in this analysis were located. Haywood et al. (2001) and Salzmann et al. (2009) both asserted that the middle Pliocene can be used a ‘test bed’ for future global warning. However, these simulations will be incomplete without paleoclimate data from Neogene eastern North America, particularly from the Pliocene. Furthermore, a study by De Schepper et al. (2013) showed that during the early Late Pliocene (~3.3 Ma) a temporary

Northern Hemisphere glaciation caused by increased Pacific Ocean to Atlantic Ocean flow via the Central American Seaway cooled the high latitude oceans. A subsequent drop in sea level ceased Pacific Ocean inflow, leading to buildup of warm water in the Caribbean and the termination of the glaciation. This influx of cold water through the Central American Seaway could partially be the cause of the relatively cool temperatures estimated in the Gulf Coast during the late Pliocene.

The coexistence approach relies on climatic parameters of the nearest living relative from the Palaeoflora Database; therefore, it is vitally important that the database be accurate, up-to-date and inclusive. In my experience, this was not always the case. For example, in my own research I came across inaccurate genera: the genus *Toxicodendron* (poison ivy and poison sumac) was included in the genus *Rhus* (sumac), and *Engelhardia* was under the incorrect spelling of *Engelhardtia*. Also, while the Palaeoflora Database includes a large number of woody plant genera and a surprising number of ferns, it lacks herbaceous plants. This is likely due to the difficulty in identifying some herbaceous fossil taxa past the family level and the sheer number of species.

In order to verify the validity of the paleoclimate reconstruction method, Grimm and Denk (2012) used the coexistence approach to reconstruct modern flora using the MAT. They tested the resolution and reliability of the MAT interval on forests in North America, Georgia (Transcaucasia), China, and Japan using both the MAT given in the Palaeoflora Database as well as corrected values from Thompson (1999a, 1999b, 2001). Grimm and Denk (2012) stated that the CA should not be regarded as a quantitative method of reliably reconstructing mean annual temperatures with a high resolution. When the “corrected” MAT values were used for reconstructing coexistence intervals, the precision of the coexistence approach was no more than

5° C: differences of less than 2° C could not be resolved, and even differences of less than 5° C were hardly captured by reconstructed MAT intervals based on potential species-level NLRs (Grimm and Denk 2012). This strongly suggests that the assumed precision of 0.1° C of Mosbrugger and Utescher (1997) is not accurate.

Grimm and Denk (2012) also pointed out that 560 of the over 700 taxa in the Palaeoflora Database could potentially coexist at a MAT of 16° C. In other words, the majority of the taxa in the database could survive in modern North Carolina. For example, NLRs such as *Symplocos* and *Engelhardia* are frequently found in fossil assemblages, but their inaccurately warm climate intervals could lead to the incorrect elimination of other potential NLRs (Grimm and Denk 2012). Despite the apparent shortcomings of the coexistence approach, it is still relatively new and should not be entirely discounted.

In order to successfully, and carefully, implement the coexistence approach method in my research, I was conservative in my application. I mined the literature for floral lists and, if included, I used the authors' noted nearest living relatives. Also, even if the nearest living relative was identified to the species level, I ran the analysis at the genus level. However, this leads to a different set of problems. Genera generally have climatic ranges that are wider than that of individual species (Grimm and Denk 2012). This means that the coexistence intervals are much wider at fossil sites with fewer fossil taxa or in assemblages with many speciose genera. That meant that some sites had much wider coexistence intervals than others. Unfortunately, I was limited by the data in the literature, so if a fossil site had fewer than 15 unique fossil taxa I did not include it in this analysis. To combat bias in my analysis, I compared my coexistence approach results with that of Stults (2003) LMA from the Citronelle sites and other methods of quantitative paleoclimate reconstruction such as stable isotope analysis.

Grimm and Denk (2012) showed that relict taxa such as *Glyptostrobus*, *Engelhardia*, *Liquidambar*, *Taxodium*, and *Zelkova* determined MAT intervals in many studies. Many of my fossil sites' coexistence intervals were bookended by *Cyrilla* and *Sciadopitys*, two monotypic genera. Today *Cyrilla racemiflora* is distributed across the southeastern United States, while *Sciadopitys verticillata* is currently restricted to Japan. Unfortunately, *Sciadopitys* only had values for MAT in the Palaeoflora Database, so it could not be included in this study. The loss of *Sciadopitys* broadened the coexistence intervals, particularly for mean annual temperature.

While Grimm and Denk (2012) observed that "all roads lead to North Carolina"—meaning that many NLRs can coexist at a MAT of 16° C—I had a similar trend converging in South Carolina. It would appear that throughout the Neogene the climate in eastern North America was most like that of South Carolina. Grimm and Denk (2012) also demonstrated that lower limits of coexistence intervals could be more meaningful than the upper limit or the center value, which means that my wide, conservative coexistence intervals could still be meaningful.

The nearest living relative coexistence approach allows for much flexibility in analysis; the more taxa included and the lower the taxonomic level identified, the more precise the analysis. This has both positive and negative impacts on analyses. For example, analysis at the species level would have a narrower range of optimal values because the climatic ranges of the taxa are more narrow to begin with. However the older the taxa, the more subjective this identification becomes. With the exception of monotypic genera, the selection of a species as the nearest living relative already makes an assumption about the paleoclimate. On the other hand, identifying the taxa only to the family level assumes less about the climatic requirements of the taxa, but the range of values would be prohibitively large and may not provide any insight on the paleoclimate. Using the genus level finds the middle ground between the approaches. While some genera have remarkably large climatic intervals (*Quercus*, *Populus*, *Pinus*), others are not much larger than that of its respective species. However, it is important to remember that it was not until about 20 Ma that fossil angiosperms were referable to extant families and not until about 10 Ma that fossils were referable to extant genera (Traverse 1988).

Neogene Climate Patterns

The fossil sites in this analysis exhibited an unexpected pattern. There appeared to be a north/south age gradient among the fossil sites. The Brandon Lignite in Vermont is Early Miocene and is the northernmost site in this analysis (Fig. 8). Continuing south, the sites become younger and younger until the Pliocene Peace Creek site in Florida, which was the southernmost and youngest site. The Alum Bluff site (Middle Miocene) in Florida and the Big Creek on Sicily Island in Louisiana (Late Miocene) were exceptions to this pattern. Even the Ohoopee River Dune Field, which was difficult to date, appeared to follow this pattern. However, it is unclear whether this north-south age pattern is based on geology or coincidence. Unfortunately, that question is beyond the scope of this thesis but warrants future consideration.

Within the Neogene it is difficult to directly compare the Miocene and the Pliocene. First of all, the Miocene lasted from 23 Ma until 5.3 Ma (17.7 million years), while the Pliocene only lasted from 5.3 Ma until 2.6 Ma (2.7 million years). In other words, there is a greater time difference between the Early Miocene and the Late Miocene than between the Early Pliocene and the Late Pliocene. Secondly, this analysis of 11 sites included 8 Miocene sites, 1 Late Miocene or Early Pliocene site, and 2 Pliocene sites. This is not a balanced comparison.

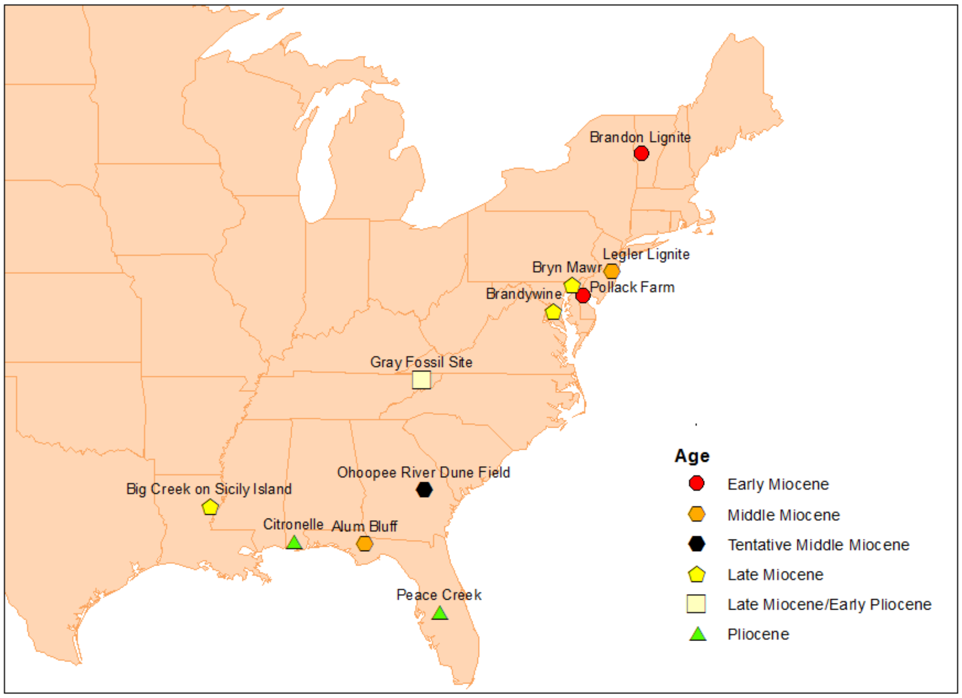

Figure 8. Ages of Neogene floral fossil sites in eastern North America used in this analysis

However, conservative comparisons were possible. In general, the earliest Miocene sites were the most warmer than the climate expected in those regions today. Later Miocene sites were virtually the same temperature as expected in those regions today. Pliocene sites were cooler than expected in those regions today. Overall, the reconstructed temperature parameters reflected the expected cooling trend, though to a higher degree than expected, throughout the Neogene. However, there does not appear to be a drying trend.

The Ohoopee River Dune Field was a difficult fossil site to date (Rich et al. 2002; Rich personal communication 2013). It is underlain by the Middle Miocene Altamaha Formation and overlain by Pleistocene dunes. For that reason it was unclear where the site should fall in this analysis. However, after performing the CA analysis, the Ohoopee River Dune Field site appeared to fit best in the Middle or Late Miocene. Of the sites in this analysis early Miocene sites (Brandon Lignite, Pollack Farm, Legler Lignite, Bryn Mawr) tended to be the most warmer than the current MAT, while middle and late Miocene sites (Alum Bluff, Big Creek on Sicily Island, Brandywine, Gray Fossil Site) tended to comparable to the current MAT, and Pliocene sites (Citronelle, Peace Creek) tended to be cooler than the current MAT. These patterns were not observable with respect to the MAP. Unlike temperature, which is primarily meridonially dependent, precipitation is primarily geologically dependent. However, it is problematic to use the age of fossil sites to describe patterns in paleoclimate and then use patterns in paleoclimate to predict the age of fossil sites. Therefore, this estimation should be taken cautiously.

Future Work

Unlike western North America with its abundance of Neogene sites and bounty of appropriately aged geological exposures, eastern North America does not have that bounty. Only 11 sites were included in this analysis and, of those sites, all but the Gray Fossil Site in Tennessee and the Brandon Lignite in Vermont were along the coast. Therefore, interpretations of paleoclimate must take into account the effects of the ocean. Though the Gray Fossil Site and the Brandon Lignite were not exposed to such forces, they do not form a representative sample, being separated by hundreds of kilometers and millions of years.

The Pipe Creek Sinkhole in Indiana could help to shine light on the question of paleoclimate (Farlow et al., 2001; Farlow and Argast 2006; Shunk et al. 2009). It is located well into the interior of the continent and could help to complete the paleoclimatic puzzle. Unfortunately, the site was discovered fairly recently and the initial investigation is still being published in the scientific literature. While the fauna of the site have been relatively well described, the flora are virtually unknown. Few floral identifications have been performed to the genus level; most floral fossils have only been identified to the family or even order. It appears that the site has a boon of floral fossils and it is vital that a paleobotanist study these fossils to fill out the picture of the site.

Furthermore, the paucity of Neogene sites in North America is exacerbated by the near absence of Pliocene sites. While the late Miocene/early Pliocene Gray Fossil Site does offer some insight, the late Pliocene Citronelle sites and the late Pliocene Peace Creek site take on the brunt of the analysis. It is not realistic to make conclusions about the paleoclimate of all of eastern North America based on the results of two Gulf Coast fossil sites. Future analyses would benefit from the inclusion of more Pliocene sites, particularly from further north and in the interior of the continent. However, at the time of this writing, those fossil sites do not exist.

CHAPTER 5

CONCLUSION

The Neogene a transitional period in Earth's history, with decreasing temperatures and precipitation across the globe, as well as changes in the paleoenvironment and floral and faunal makeup. However, in eastern North America there is a distinct lack of Neogene fossil sites. Of the 11 fossil sites with enough taxa to perform a coexistence approach analysis (Pollack Farm, Brandon Lignite, Legler Lignite, Alum Bluff, Bryn Mawr, Big Creek on Sicily Island, Brandywine, Gray Fossil Site, Citronelle, Peace Creek, Ohoopee River Dune Field), there were 2 primary broad patterns. Firstly, there was a general trend that early and middle Miocene sites were warmer than the area today, while middle and late Miocene sites were comparable to the area today, and Pliocene sites were similar to or cooler than the area today. This pattern of cool Pliocene sites along the Gulf Coast could be due to Northern Hemisphere glaciations during the middle Pliocene. However, there is no clear pattern of increased precipitation, as would be expected from global climate trends. Secondly, there is a rough pattern of early Neogene sites in the northern regions of eastern North America with younger sites further south. This pattern could be due to geology or be entirely coincidental.

Neogene paleoclimate data from eastern North America will have a great impact on the study of North America paleoclimate as well as future climate predictions. By including the paleoclimate of the entire continent in climate models, predictions will become more accurate.

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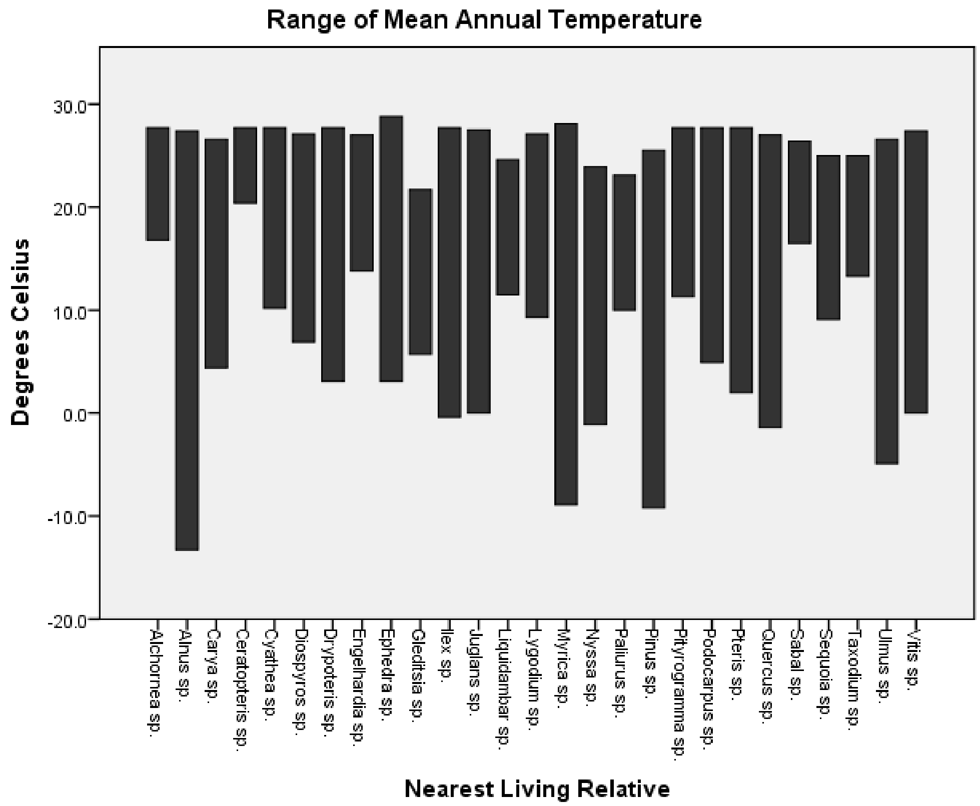
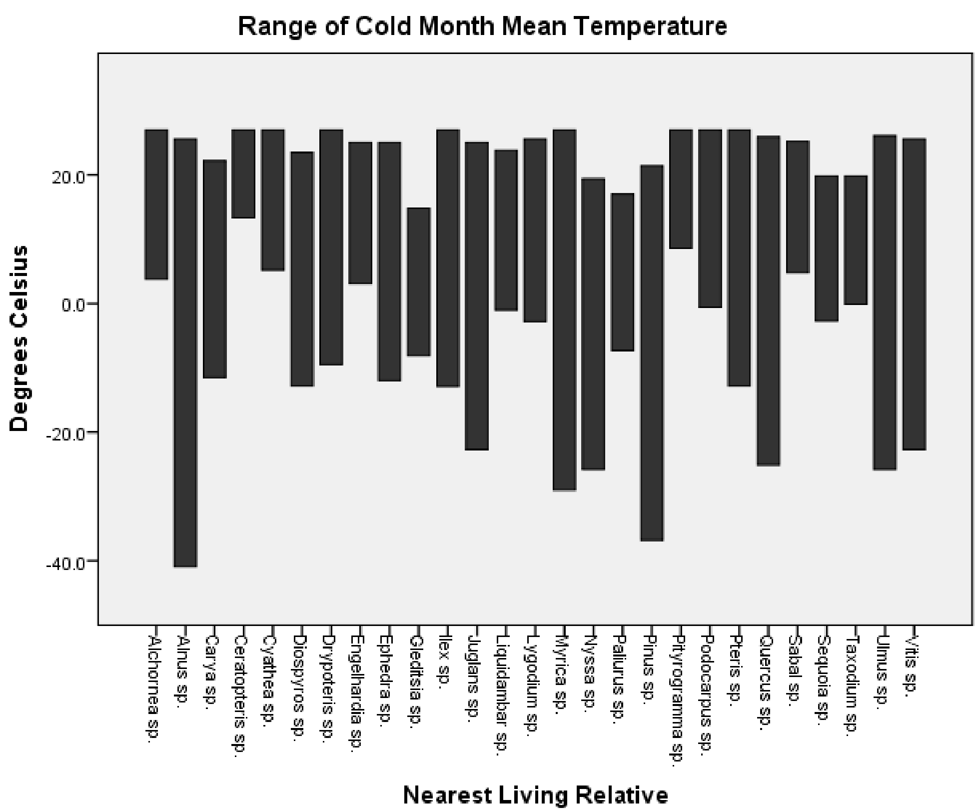
APPENDICES

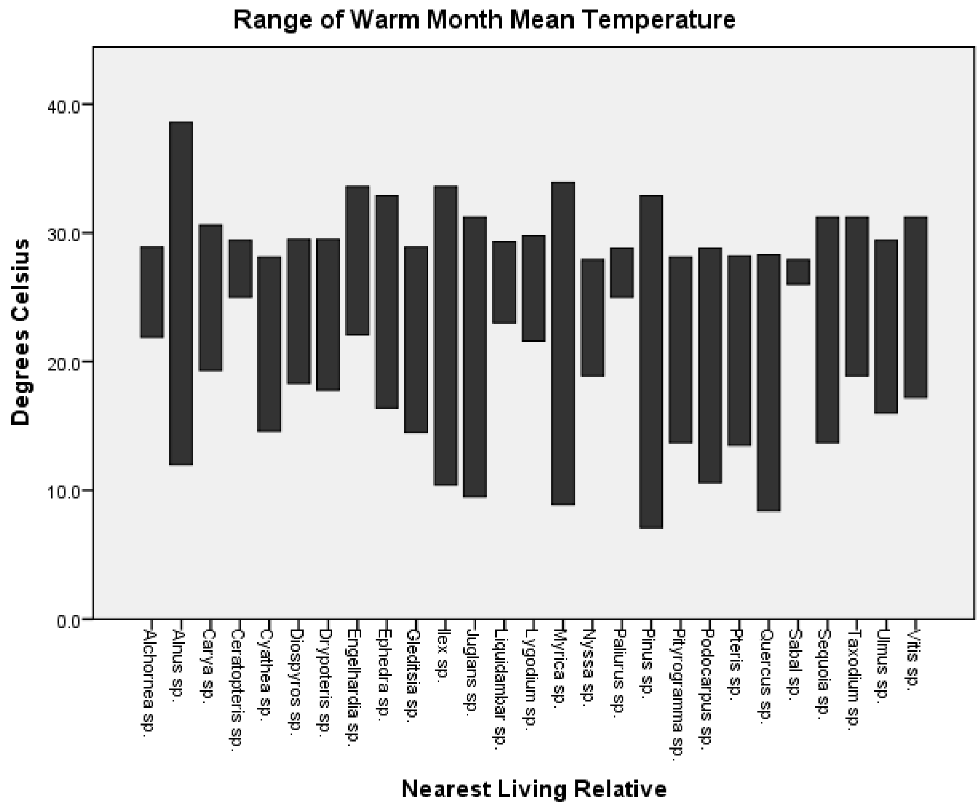
Appendix A

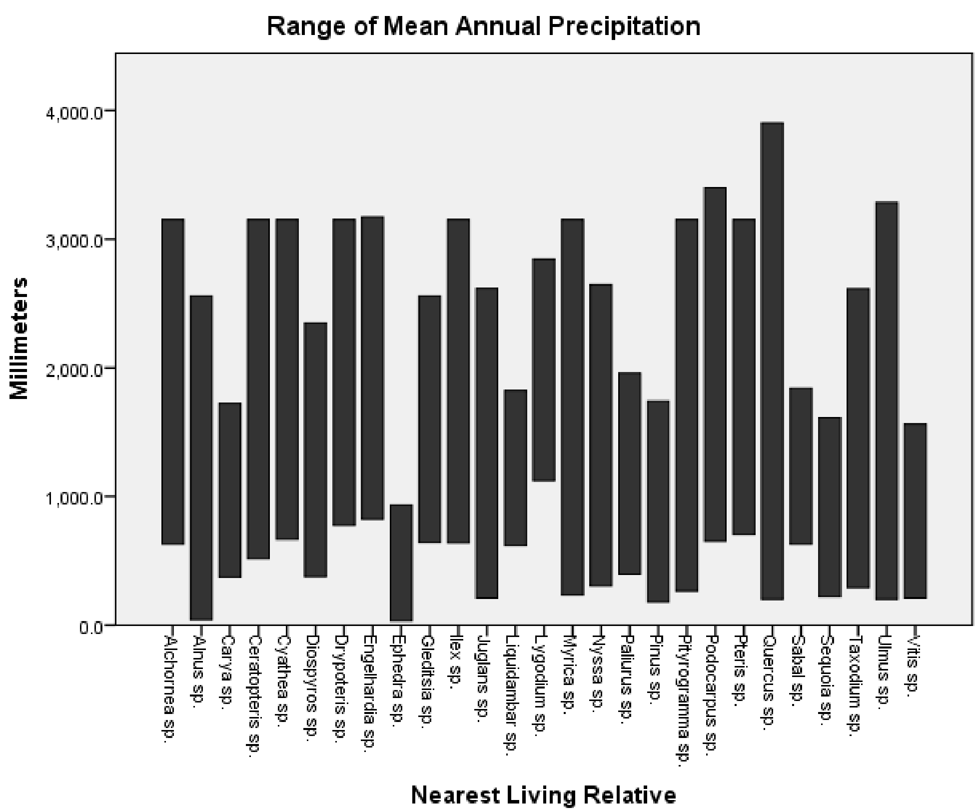
Alum Bluff Raw Results and Climate Intervals

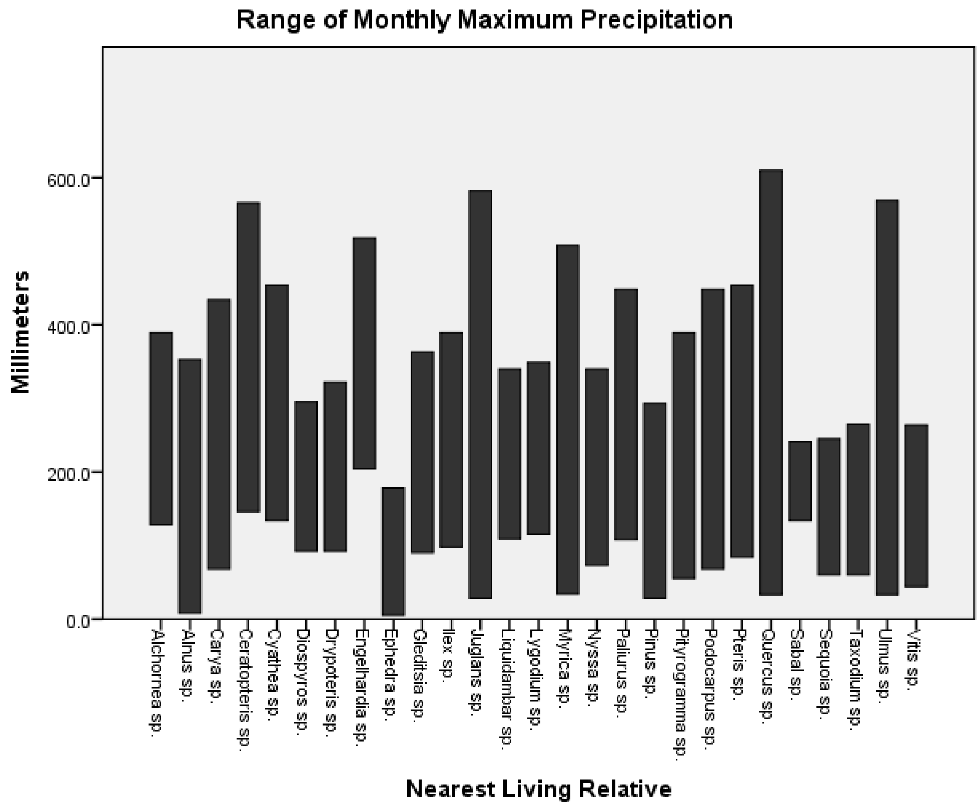
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP		MMaP	MMiP	WMMP
Pollen	*Ranunculacidites*	*Alchorea sp.*	16.8 - 27.7	3.8 - 27	21.9 - 28.9	629	3151	128 - 389	4 - 165	43 - 221
	Alnipollenites	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41	2559	8 - 353	0 - 135	8 - 207
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373	1724	68 - 434	8 - 93	45 - 258
	Magnastriatites	*Ceratopteris sp.*	20.4 - 27.7	13.3 - 27	25 - 29.4	517	3151	146 - 566	1 - 165	29 - 227
	Cyathea	*Cyathea sp.*	10.2 - 27.7	5.2 - 27	14.6 - 28.1	666	3151	134 - 454	12 - 165	93 - 224
	Diospyros	*Diospyros sp.*	6.9 - 27.1	-12.8 - 23.5	18.3 - 29.5	376	2348	92 - 295	1 - 83	58 - 185
	Dryopteris	*Dryopteris sp.*	3.1 - 27.7	-9.5 - 27	17.8 - 29.5	777	3151	92 - 322	29 - 165	92 - 312
	Momipites	*Engelhardia sp.*	13.8 - 27	3.1 - 25	22.1 - 33.6	823	3172	204 - 518	5 - 152	79 - 431
	Ephedripites	*Ephedra sp.*	3.1 - 28.8	-12 - 25	16.4 - 32.9	33	932	5 - 178	0 - 45	2 - 61
	Gleditsia	*Gleditsia sp.*	5.7 - 21.7	-8.1 - 14.8	14.5 - 28.9	644	2559	90 - 363	1 - 154	72 - 269
	Ilex	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641	3151	98 - 389	2 - 165	4 - 431
	Juglanspollenites	*Juglans sp.*	0 - 27.5	-22.7 - 25	9.5 - 31.2	210	2617	28 - 582	1 - 114	2 - 189
	Liquidambar	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619	1823	109 - 340	2 - 72	5 - 195
	Lygodiumsporites	*Lygodium sp.*	9.3- 27.1	-2.8 - 25.6	21.6 - 29.8	1122	2845	115 - 349	19 - 157	68 - 217
	Myrica	*Myrica sp.*	-8.9 - 28.1	-29 - 27	8.9 - 33.9	233	3151	34 - 508	0 - 165	0 - 221
	Nyssapollenites	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305	2645	73 - 340	0 - 122	55 - 246
	Paliurus	*Paliurus sp.*	10 - 23.1	-7.3 - 17	25 - 28.8	396	1958	108 - 448	4 - 70	108 - 431
	Nijssenosporites	*Pityrogramma sp.*	11.3 - 27.7	8.6 - 27	13.7 - 28.1	264	3151	55 - 389	0 - 165	2 - 221
	Pinus	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180	1741	28 - 293	0 - 94	0 - 304
	Podocarpidites	*Podocarpus sp.*	4.9 - 27.7	-0.6 - 27	10.6 - 28.8	652	3401	68 - 448	16 - 165	26 - 431
	Pteris	*Pteris sp.*	2 - 27.7	-12.8 - 27	13.5 - 28.2	705	3151	84 - 454	6 - 165	82 - 269
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201	3905	33 - 610	0 - 180	5 - 180
	Sabalites	*Sabal sp.*	16.5 - 26.4	4.8 - 25.2	26 - 27.9	629	1840	134 - 241	4 - 72	43 - 227
	Sequoiapollenites	*Sequoia sp.*	9.1 - 25	-2.7 - 19.8	13.7 - 31.2	222	1613	60 - 245	0 - 93	3 - 227
	Taxodium	*Taxodium sp.*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290	2615	60 - 265	0 - 93	19 - 227
	Ulmus	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201	3285	33 - 569	0 - 75	0 - 239
	Vitis	*Vitis sp.*	0 - 27.4	-22.7 - 25.6	17.2 - 31.2	210	1562	44 - 264	0 - 94	2 - 176

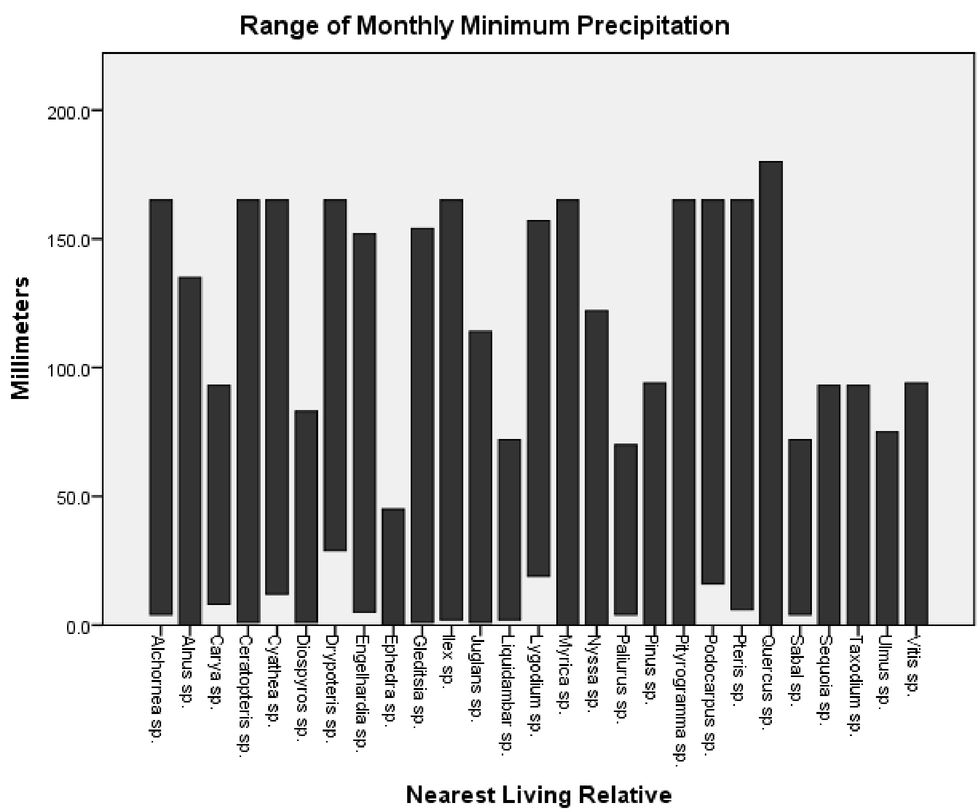

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Alchornea sp.
Alnus sp.
Carya sp.
Ceratopteris sp.
Cyathea sp.
Diospyros sp.
Drypoteris sp.
Engelhardia sp.
Ephedra sp.
Gleditsia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Nyssa sp.
Paliurus sp.
Pinus sp.
Pityrogramma sp.
Podocarpus sp.
Pteris sp.
Quercus sp.
Sabal sp.
Sequoia sp.
Taxodium sp.
Ulmus sp.
Vitis sp.
Nearest Living Relative

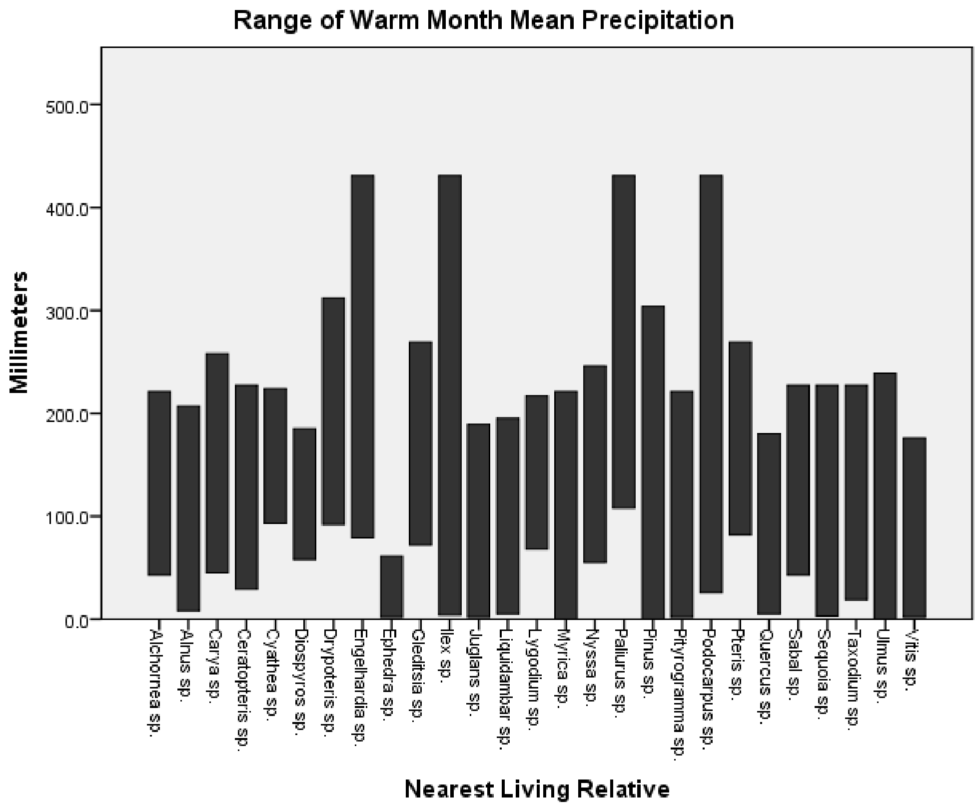

Range of Cold Month Mean Temperature
Degrees Celsius
20.0
0.0
-20.0
-40.0
Alchornea sp.
Alnus sp.
Carya sp.
Ceratopteris sp.
Cyathea sp.
Diospyros sp.
Drypoteris sp.
Engelhardia sp.
Ephedra sp.
Gleditsia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Nyssa sp.
Paliurus sp.
Pinus sp.
Pityrogramma sp.
Podocarpus sp.
Pteris sp.
Quercus sp.
Sabal sp.
Sequoia sp.
Taxodium sp.
Ulmus sp.
Vitis sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Alchornea sp.
Alnus sp.
Carya sp.
Ceratopteris sp.
Cyathea sp.
Diospyros sp.
Drypoteris sp.
Engelhardia sp.
Ephedra sp.
Gleditsia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Nyssa sp.
Paliurus sp.
Pinus sp.
Pityrogramma sp.
Podocarpus sp.
Pteris sp.
Quercus sp.
Sabal sp.
Sequoia sp.
Taxodium sp.
Ulmus sp.
Vitis sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Alchornea sp.
Alnus sp.
Carya sp.
Ceratopteris sp.
Cyathea sp.
Diospyros sp.
Drypoteris sp.
Engelhardia sp.
Ephedra sp.
Gleditsia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Nyssa sp.
Paliurus sp.
Pinus sp.
Pityrogramma sp.
Podocarpus sp.
Pteris sp.
Quercus sp.
Sabal sp.
Sequoia sp.
Taxodium sp.
Ulmus sp.
Vitis sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Alchornea sp.
Alnus sp.
Carya sp.
Ceratopteris sp.
Cyathea sp.
Diospyros sp.
Drypoteris sp.
Engelhardia sp.
Ephedra sp.
Gleditsia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Nyssa sp.
Paliurus sp.
Pinus sp.
Pityrogramma sp.
Podocarpus sp.
Pteris sp.
Quercus sp.
Sabal sp.
Sequoia sp.
Taxodium sp.
Ulmus sp.
Vitis sp.
Nearest Living Relative

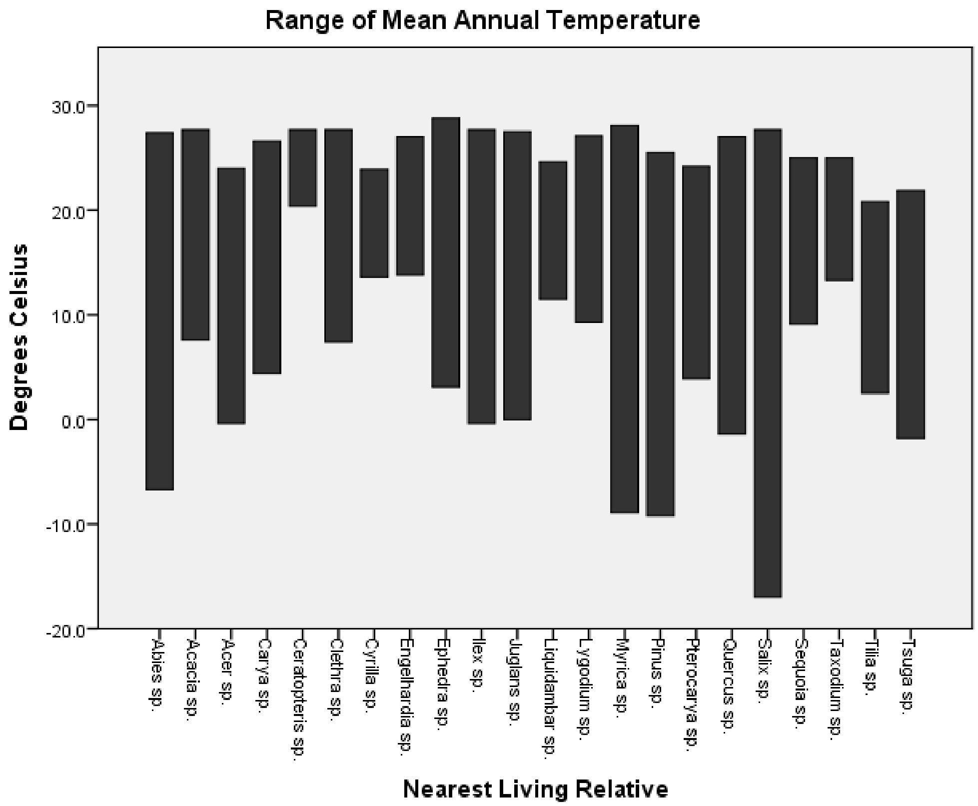

Range of Monthly Minimum Precipitation
Millimeters
200.0
150.0
100.0
50.0
0.0
Alchornea sp.
Alnus sp.
Carya sp.
Ceratopteris sp.
Cyathea sp.
Diospyros sp.
Drypoteris sp.
Engelhardia sp.
Ephedra sp.
Gleditsia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Nyssa sp.
Paliurus sp.
Pinus sp.
Pityrogramma sp.
Podocarpus sp.
Pteris sp.
Quercus sp.
Sabal sp.
Sequoia sp.
Taxodium sp.
Ulmus sp.
Vitis sp.
Nearest Living Relative

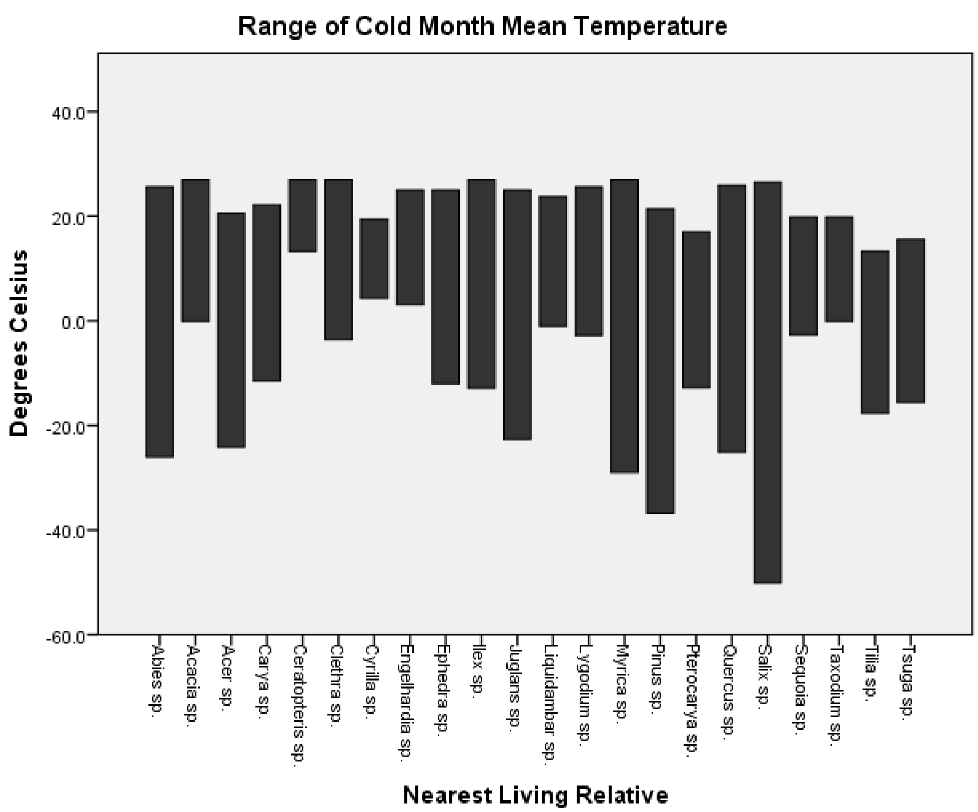

Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Alchornea sp.
Alnus sp.
Carya sp.
Ceratopteris sp.
Cyathea sp.
Diospyros sp.
Drypoteris sp.
Engelhardia sp.
Ephedra sp.
Gleditsia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Nyssa sp.
Paliurus sp.
Pinus sp.
Pityrogramma sp.
Podocarpus sp.
Pteris sp.
Quercus sp.
Sabal sp.
Sequoia sp.
Taxodium sp.
Ulmus sp.
Vitis sp.
Nearest Living Relative

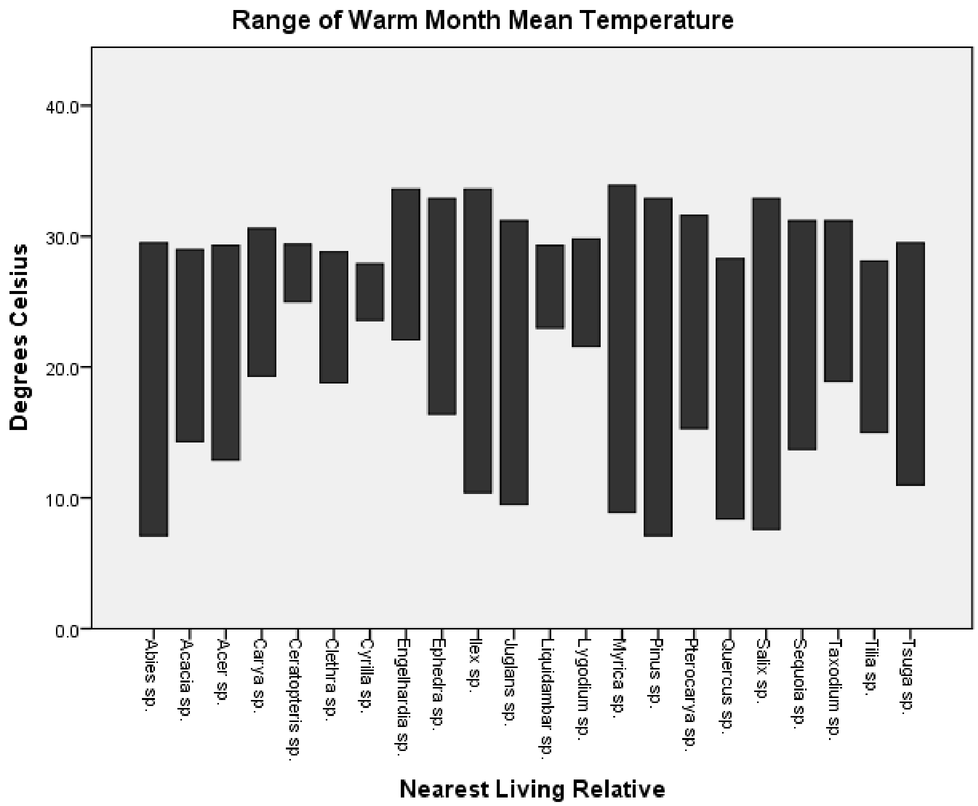
Appendix B

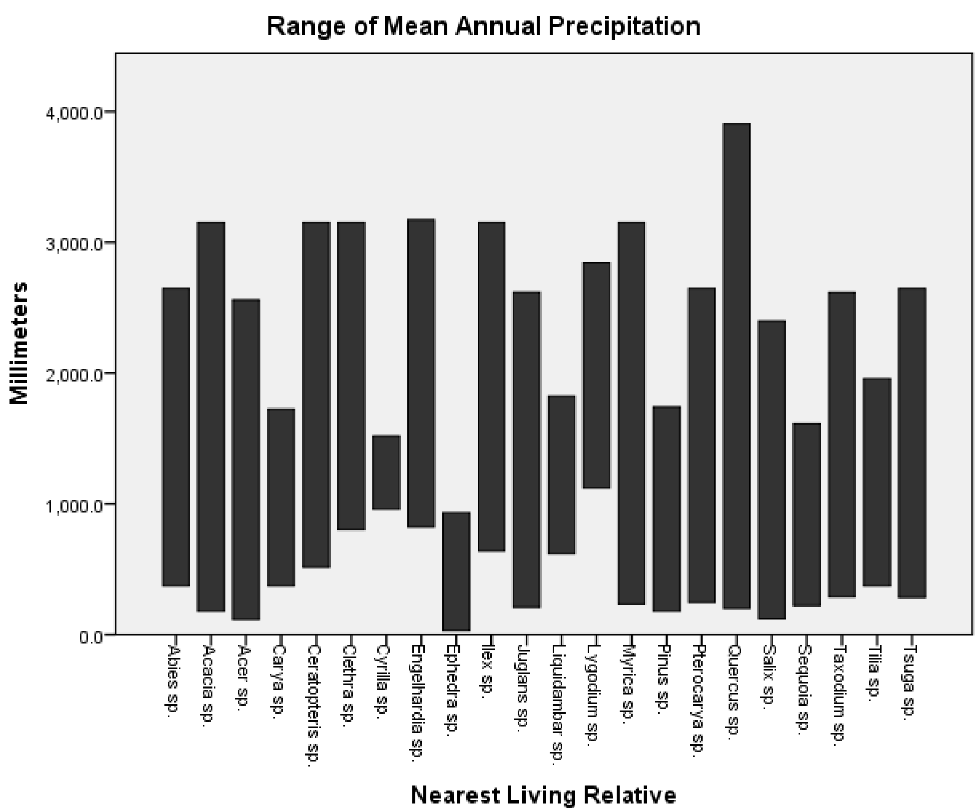
Big Creek on Sicily Island Raw Results and Climate Intervals

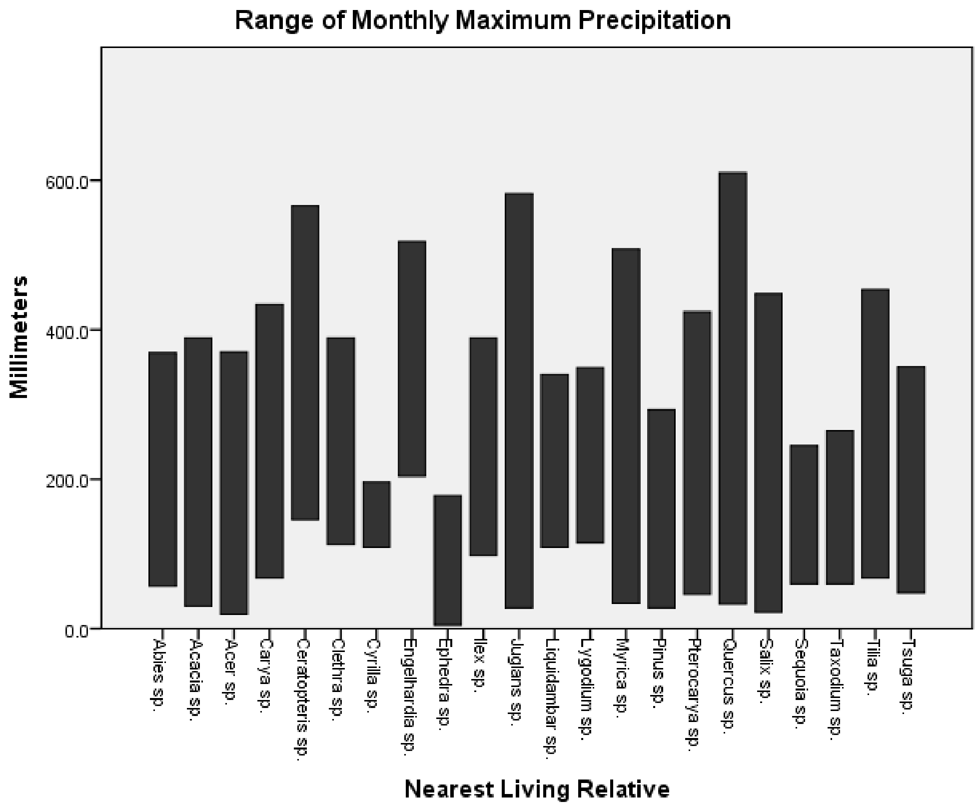
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Pollen	*Abies*	*Abies sp.*	-6.7 - 27.4	-26 - 25.6	7.1 - 29.5	373 - 2648	57 - 369	0 - 135	0 - 344
	Acacia	*Acacia sp.*	7.6 - 27.7	-0.1 - 27	14.3 - 29	180 - 3151	30 - 389	4 - 165	7 - 304
	Acer	*Acer sp.*	-0.4 - 24	-24.2 - 20.6	12.9 - 29.3	115 - 2559	19 - 370	1 - 135	1 - 366
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Clethra	*Clethra sp.*	7.4 - 27.7	-3.6 - 27	18.8 - 28.8	803 - 3151	113 - 389	1 - 165	94 - 229
	Ephedra	*Ephedra sp.*	3.1 - 28.8	-12 - 25	16.4 - 32.9	33 - 932	5 - 178	0 - 45	2 - 61
	Ilex	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Juglans	*Juglans sp.*	0 - 27.5	-22.7 - 25	9.5 - 31.2	210 - 2617	28 - 582	1 - 114	2 - 189
	Liquidambar	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	Momipites	*Engelhardia sp.*	13.8 - 27	3.1 - 25	22.1 - 33.6	823 - 3172	204 - 518	5 - 152	79 - 431
	Myrica	*Myrica sp.*	-8.9 - 28.1	-29 - 27	8.9 - 33.9	233 - 3151	34 - 508	0 - 165	0 - 221
	Pinus	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Pterocarya	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Salix	*Salix sp.*	-17 - 27.7	-50.1 - 26.5	7.6 - 32.9	122 - 2399	22 - 448	0 - 108	0 - 252
	Sequoiapollenites	*Sequoia sp.*	9.1 - 25	-2.7 - 19.8	13.7 - 31.2	222 - 1613	60 - 245	0 - 93	3 - 227
	Taxodium distichum	*Taxodium sp..*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290 - 2615	60 - 265	0 - 93	19 - 227
	Tiliapollenites	*Tilia sp.*	2.5 - 20.8	-17.7 - 13.3	15 - 28.1	373 - 1958	68 - 454	9 - 83	45 - 258
	Tsuga	*Tsuga sp.*	-1.8 - 21.9	-15.6 - 15.6	11 - 29.5	285 - 2648	48 - 350	0 - 108	0 - 344
	Cyrilla	*Cyrilla sp.*	13.6 - 23.9	4.3 - 19.4	23.6 - 27.9	961 - 1520	109 - 196	42 - 56	99 - 196
	Magnastriatites	*Ceratopteris sp.*	20.4 - 27.7	13.3 - 27	25 - 29.4	517 - 3151	146 - 566	1 - 165	29 - 227
	Lygodiumsporites	*Lygodium sp.*	9.3 - 27.1	-2.8 - 25.6	21.6 - 29.8	1122 - 2845	115 - 349	19 - 157	68 - 217

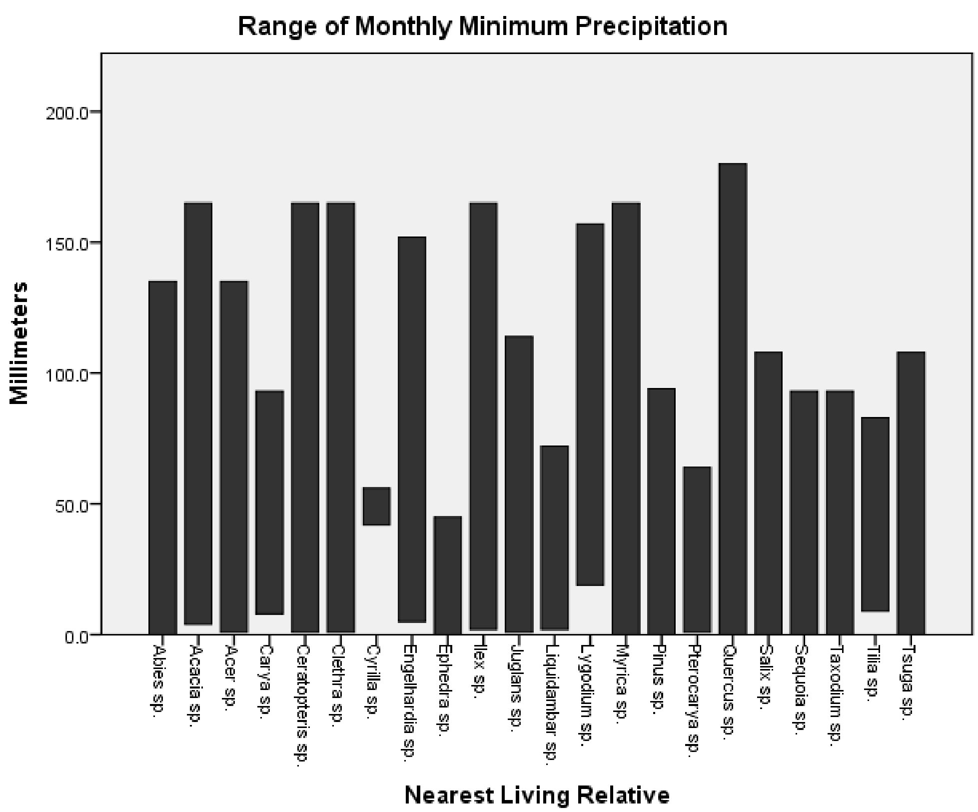

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Abies sp.
Acacia sp.
Acer sp.
Carya sp.
Ceratopteris sp.
Clethra sp.
Cyrilla sp.
Engelhardia sp.
Ephedra sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Nearest Living Relative

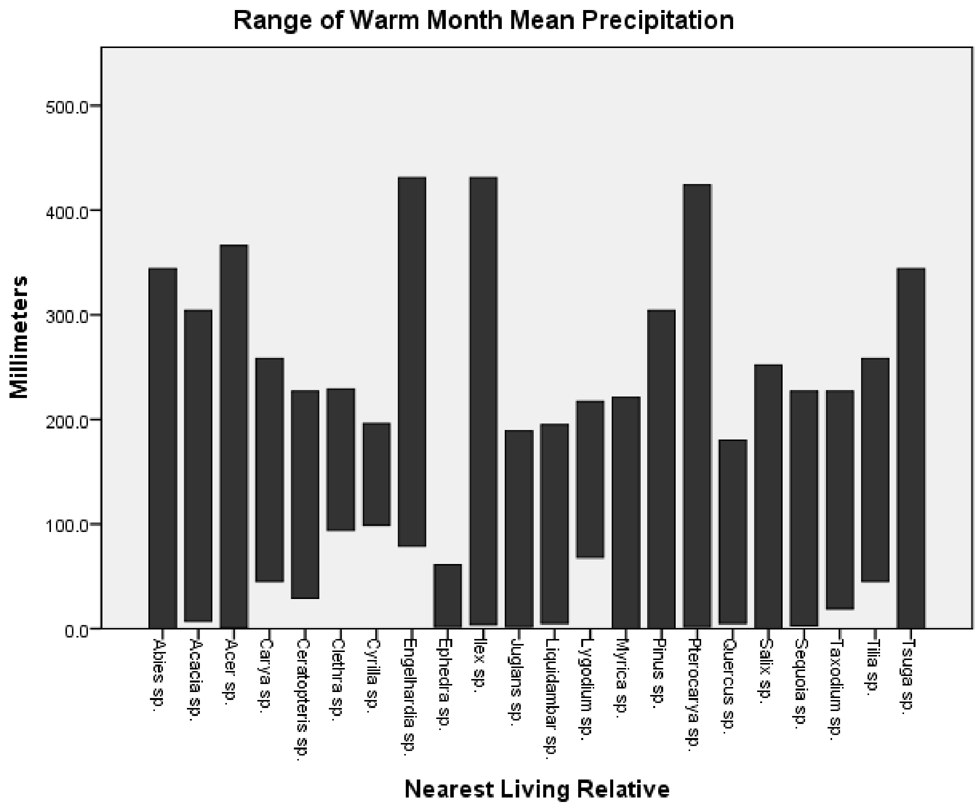

Range of Cold Month Mean Temperature
Degrees Celsius
40.0
20.0
0.0
-20.0
-40.0
-60.0
Abies sp.
Acacia sp.
Acer sp.
Carya sp.
Ceratopteris sp.
Clethra sp.
Cyrilla sp.
Engelhardia sp.
Ephedra sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Abies sp.
Acacia sp.
Acer sp.
Carya sp.
Ceratopteris sp.
Clethra sp.
Cyrilla sp.
Engelhardia sp.
Ephedra sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Abies sp.
Acacia sp.
Acer sp.
Carya sp.
Ceratopteris sp.
Clethra sp.
Cyrilla sp.
Engelhardia sp.
Ephedra sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Abies sp.
Acacia sp.
Acer sp.
Carya sp.
Ceratopteris sp.
Clethra sp.
Cyrilla sp.
Engelhardia sp.
Ephedra sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Nearest Living Relative


Range of Monthly Minimum Precipitation
Millimeters
200.0
150.0
100.0
50.0
0.0
Abies sp.
Acacia sp.
Acer sp.
Carya sp.
Ceratopteris sp.
Clethra sp.
Cyrilla sp.
Engelhardia sp.
Ephedra sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Nearest Living Relative



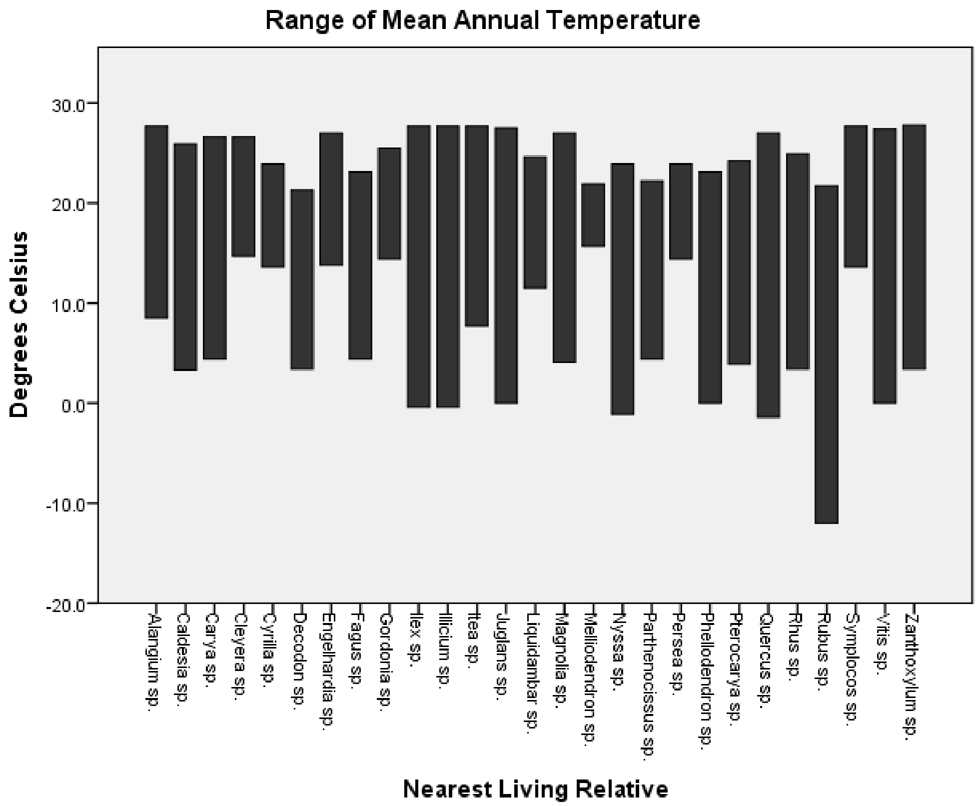
Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Abies sp.
Acacia sp.
Acer sp.
Carya sp.
Ceratopteris sp.
Clethra sp.
Cyrilla sp.
Engelhardia sp.
Ephedra sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Lygodium sp.
Myrica sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Nearest Living Relative

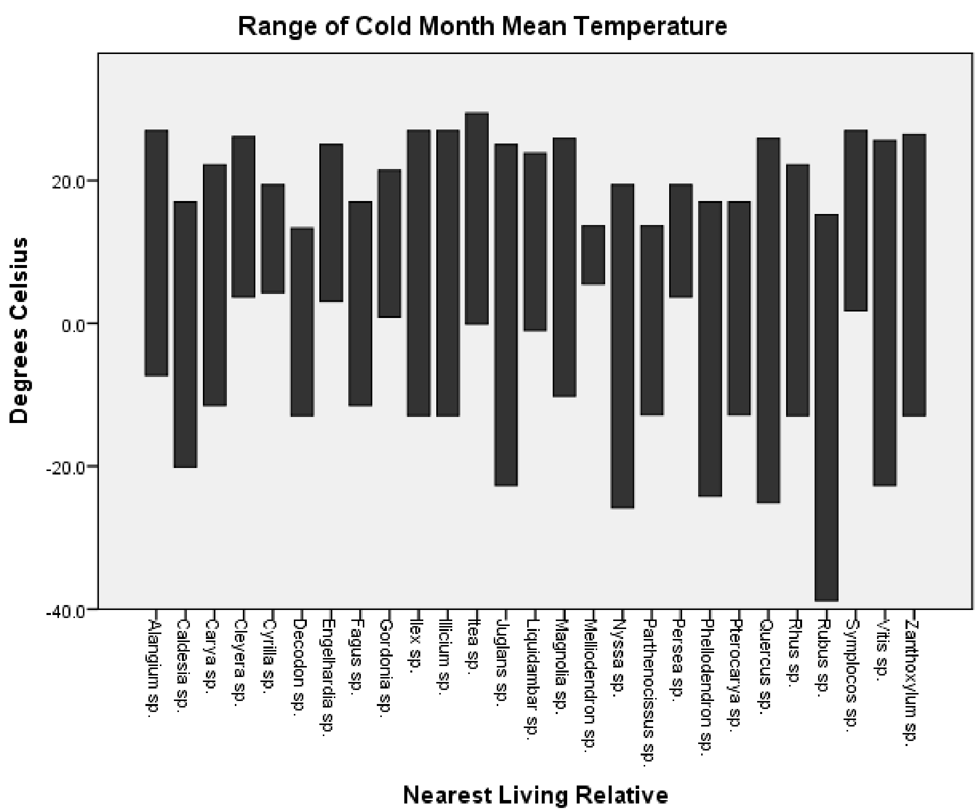
Appendix C

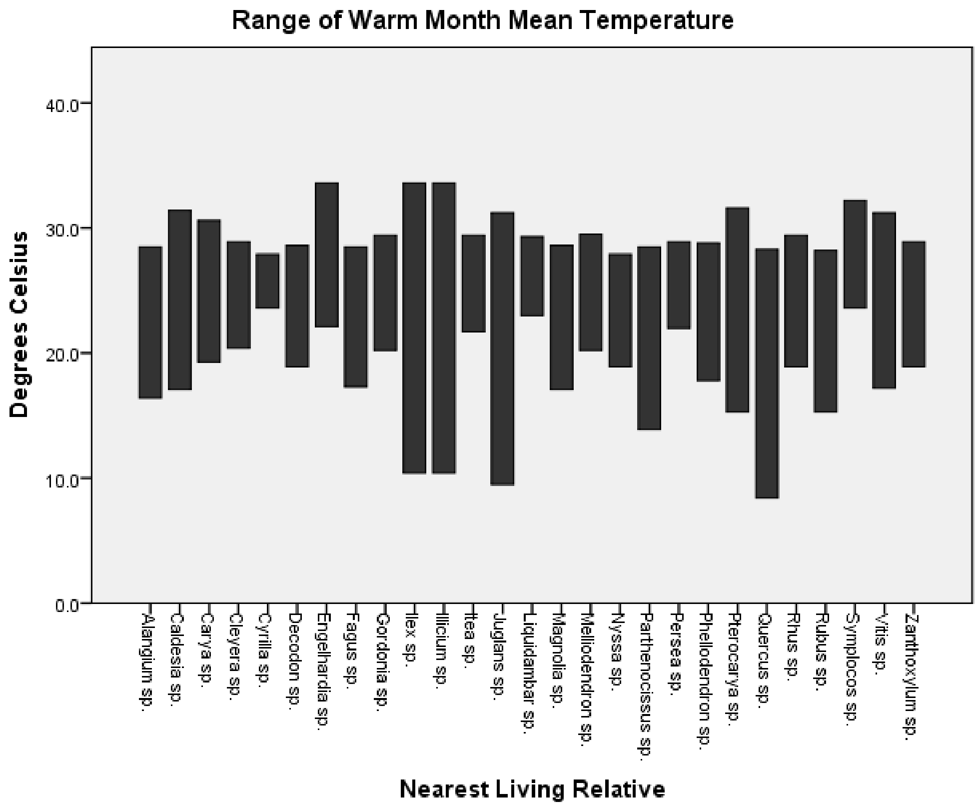
Brandon Lignite Raw Results and Climate Intervals

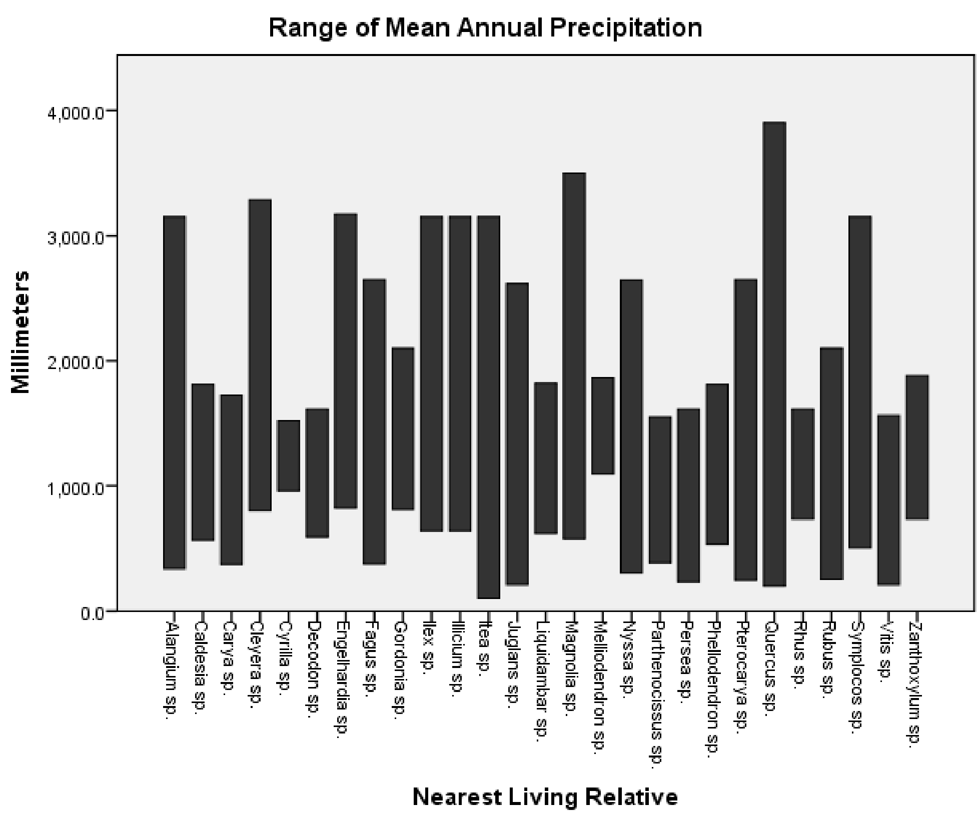
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Fruit	*Alangium*	*Alangium sp.*	8.5 - 27.7	-7.3 - 27	16.4 - 28.5	338 - 3151	92 - 389	1 - 165	66 - 221
	Caldesia	*Caldesia sp.*	3.3 - 25.9	-20.1 - 17	17.1 - 31.45	566 - 1812	78 - 448	2 - 43	78 - 431
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Gordonia	*Gordonia sp.*	14.4 - 25.5	0.9 - 21.4	20.2 - 29.4	810 - 2100	106 - 304	3 - 74	62 - 304
	Illicium	*Illicium sp.*	-0.4 - 27.7	-12.9 -27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	**Melliodendron*	*Melliodendron sp.*	15.7 - 21.9	5.5 - 13.6	20.2 - 29.5	1096 - 1864	220 - 304	3 - 55	111 - 304
	Nyssa	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Symplocos	*Symplocos sp.*	13.6 - 27.7	1.8 - 27	23.6 - 32.2	505 - 3151	109 - 436	3 - 208	43 - 208
Seed	*Cleyera*	*Cleyera sp.*	14.7 - 26.6	3.7 - 26.1	20.4 - 28.9	803 - 3285	161 - 569	1 - 53	105 - 227
	Ilex	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Magnolia	*Magnolia sp.*	4.1 - 27	-10.2 - 25.9	17.1 -28.6	578 - 3500	102 - 610	1 - 180	70 - 462
	**Microdiptera*	***Decodon sp.*	3.4 - 21.3	-12.9 - 13.3	18.9 - 28.6	592 - 1613	103 - 195	22 - 93	58 - 195
	Parthenocissus	*Parthenocissus sp.*	4.4 - 22.2	-12.8 - 13.6	13.9 - 28.5	385 - 1551	86 - 225	3 - 89	26 - 217
	Phellodendron	*Phellodendron sp.*	0 - 23.1	-24.2 - 17	17.8 - 28.8	534 - 1812	98 - 448	3 - 59	92 - 431
	Rubus	*Rubus sp.*	-12 - 21.7	-38.8 - 15.2	15.3 - 28.2	254 - 2100	34 - 322	4 - 71	5 - 269
	Vitis	*Vitis sp.*	0 - 27.4	-22.7 - 25.6	17.2 - 31.2	210 - 1562	44 - 264	0 - 94	2 - 176
	Zanthoxylum	*Zanthoxylum sp.*	3.4 - 27.8	-12.9 - 26.4	18.9 - 28.9	735 - 1882	83 - 366	5 - 59	78 - 366
Wood	**Cyrilla*	*Cyrilla sp.*	13.6 - 23.9	4.3 - 19.4	23.6 - 27.9	961 - 1520	109 - 196	42 - 56	99 - 196
	Persea	*Persea sp.*	14.4 - 23.9	3.7 - 19.4	22 - 28.9	223 - 1613	53 - 241	5 - 93	2 - 196
Pollen	**Momipites spackmanianus*	***Engelhardia sp.*	13.8 - 27	3.1 - 25	22.1 - 33.6	823 - 3172	204 - 518	5 - 152	79 - 431
	Pterocaryapollenites vermontensis	***Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	Juglanspollenites hornianus	***Juglans sp.*	0 - 27.5	-22.7 - 25	9.5 - 31.2	210 - 2617	28 - 582	1 - 114	2 - 189
	Iteapollis angustiporatus	***Itea sp.*	7.7 - 27.7	-0.1 -29.4	21.7 - 29.4	102 - 3151	49 - 389	25 - 165	13.5 - 221
	Faguspollenites parvifossilis	***Fagus sp.*	4.4 - 23.1	-11.5 - 17	17.3 - 28.5	376 - 2648	46 - 448	5 - 94	5 - 431
	Liquidambarpollenites brandonensis	***Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	**Rhuspollenites carbogenus*	***Rhus sp.*	3.4 - 24.9	-12.9 - 22.2	18.9 - 29.4	735 - 1613	73 - 195	18 - 93	49 - 195

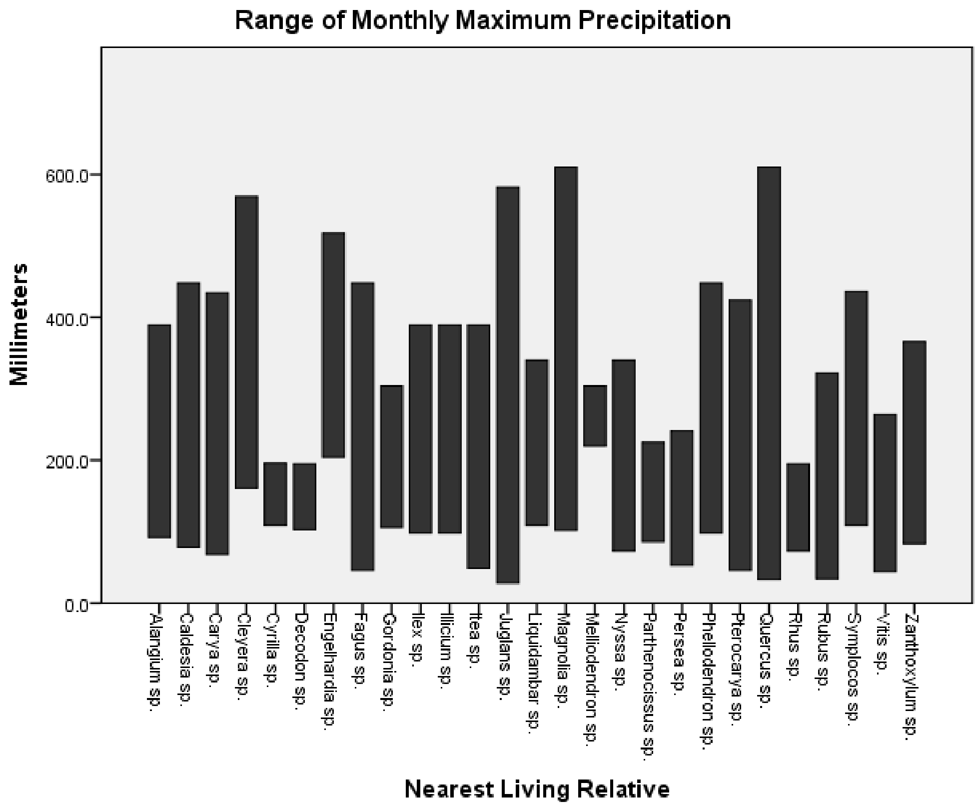
* Taxon is outlier in at least one climate interval
** Nearest Living Relative different genus than Fossil Taxon

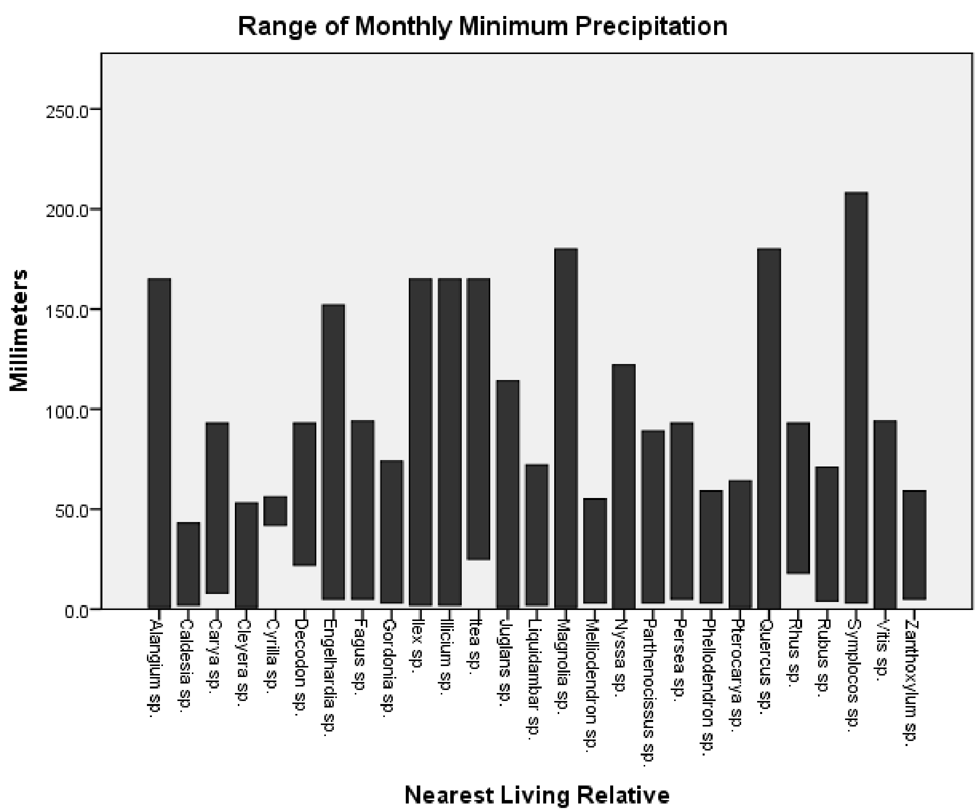

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Alangium sp.
Caldesia sp.
Carya sp.
Cleyera sp.
Cyrilla sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Illicium sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Mellodendron sp.
Nyssa sp.
Parthenocissus sp.
Persea sp.
Phellodendron sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Rubus sp.
Symplocos sp.
Vitis sp.
Zanthoxylum sp.
Nearest Living Relative

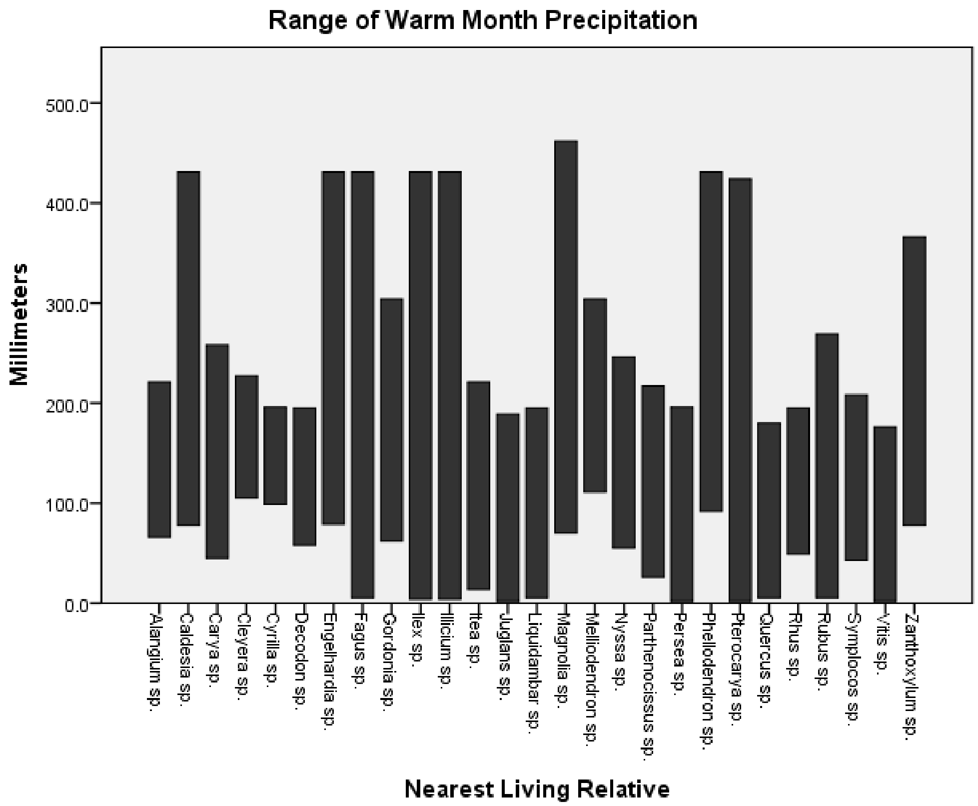

Range of Cold Month Mean Temperature
Degrees Celsius
20.0
0.0
-20.0
-40.0
Alangium sp.
Caldesia sp.
Carya sp.
Cleyera sp.
Cyrilla sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Illicium sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Mellodendron sp.
Nyssa sp.
Parthenocissus sp.
Persea sp.
Phellodendron sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Rubus sp.
Symplocos sp.
Vitis sp.
Zanthoxylum sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Alangium sp.
Caldesia sp.
Carya sp.
Cleyera sp.
Cyrilla sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Illicium sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Mellodendron sp.
Nyssa sp.
Parthenocissus sp.
Persea sp.
Phellodendron sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Rubus sp.
Symplocos sp.
Vitis sp.
Zanthoxylum sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Alangium sp.
Caldesia sp.
Carya sp.
Cleyera sp.
Cyrilla sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Illicium sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Mellodendron sp.
Nyssa sp.
Parthenocissus sp.
Persea sp.
Phellodendron sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Rubus sp.
Symplocos sp.
Vitis sp.
Zanthoxylum sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Alangium sp.
Caldesia sp.
Carya sp.
Cleyera sp.
Cyrilla sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Illicium sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Mellodendron sp.
Nyssa sp.
Parthenocissus sp.
Persea sp.
Phellodendron sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Rubus sp.
Symplocos sp.
Vitis sp.
Zanthoxylum sp.
Nearest Living Relative


Range of Monthly Minimum Precipitation
Millimeters
250.0
200.0
150.0
100.0
50.0
0.0
Alangium sp.
Caldesia sp.
Carya sp.
Cleyera sp.
Cyrilla sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Illicium sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Mellodendron sp.
Nyssa sp.
Parthenocissus sp.
Persea sp.
Phellodendron sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Rubus sp.
Symplocos sp.
Vitis sp.
Zanthoxylum sp.
Nearest Living Relative


Range of Warm Month Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Alangium sp.
Caldesia sp.
Carya sp.
Cleyera sp.
Cyrilla sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Illicium sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Mellodendron sp.
Nyssa sp.
Parthenocissus sp.
Persea sp.
Phellodendron sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Rubus sp.
Symplocos sp.
Vitis sp.
Zanthoxylum sp.
Nearest Living Relative

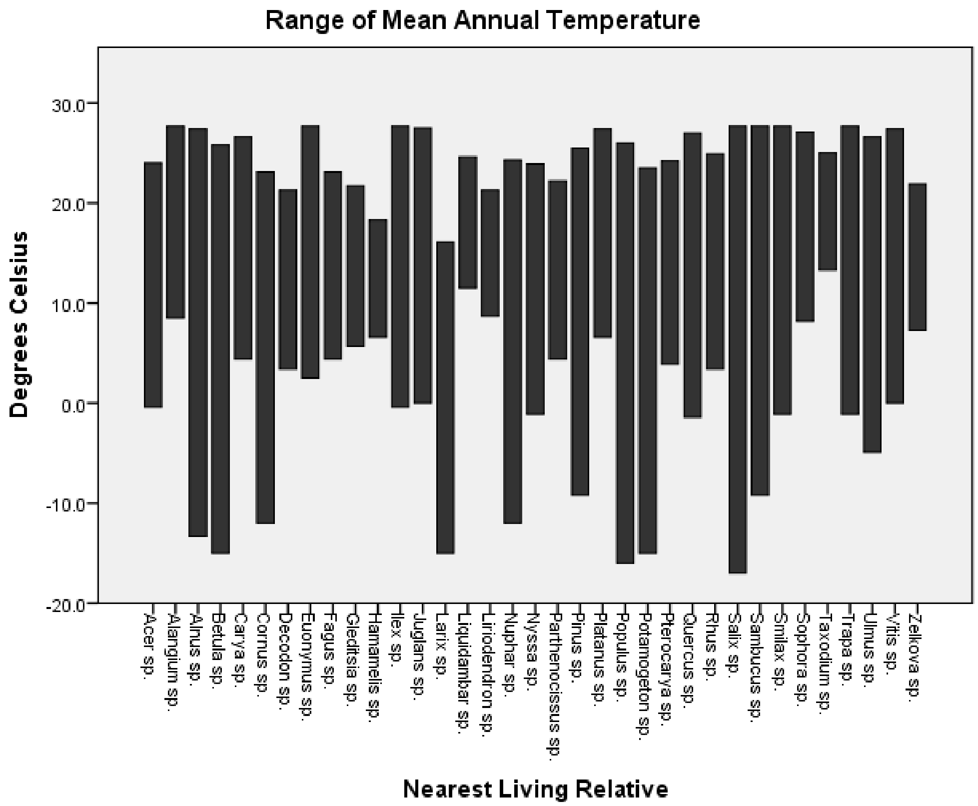
Appendix D

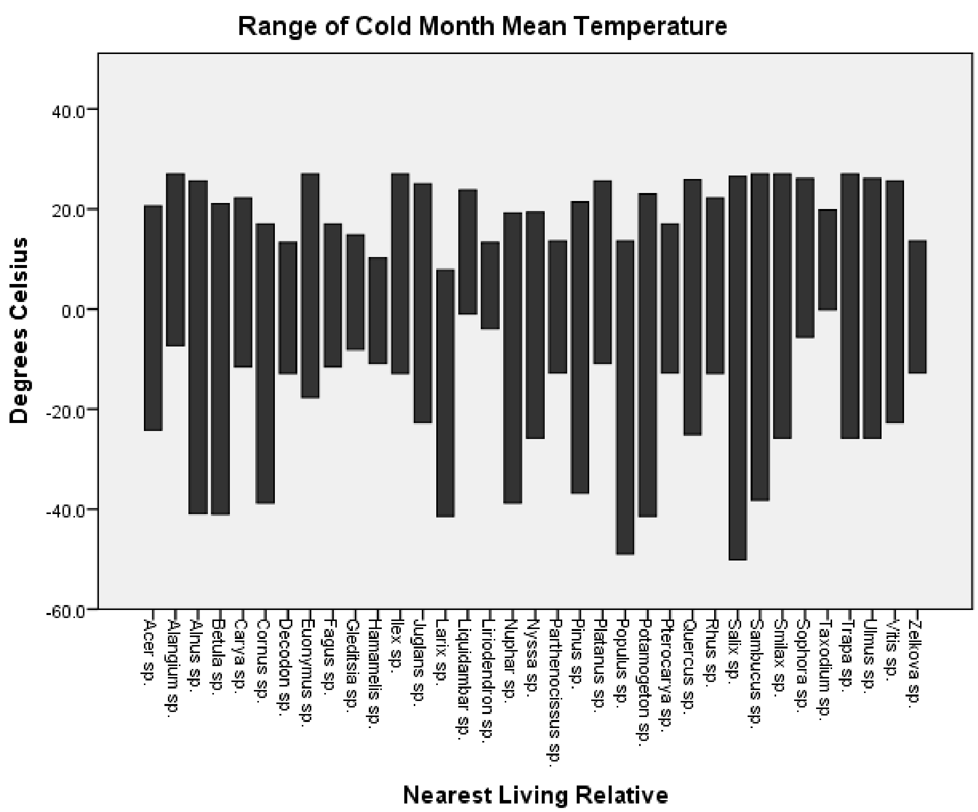
Brandywine Raw Results and Climate Intervals

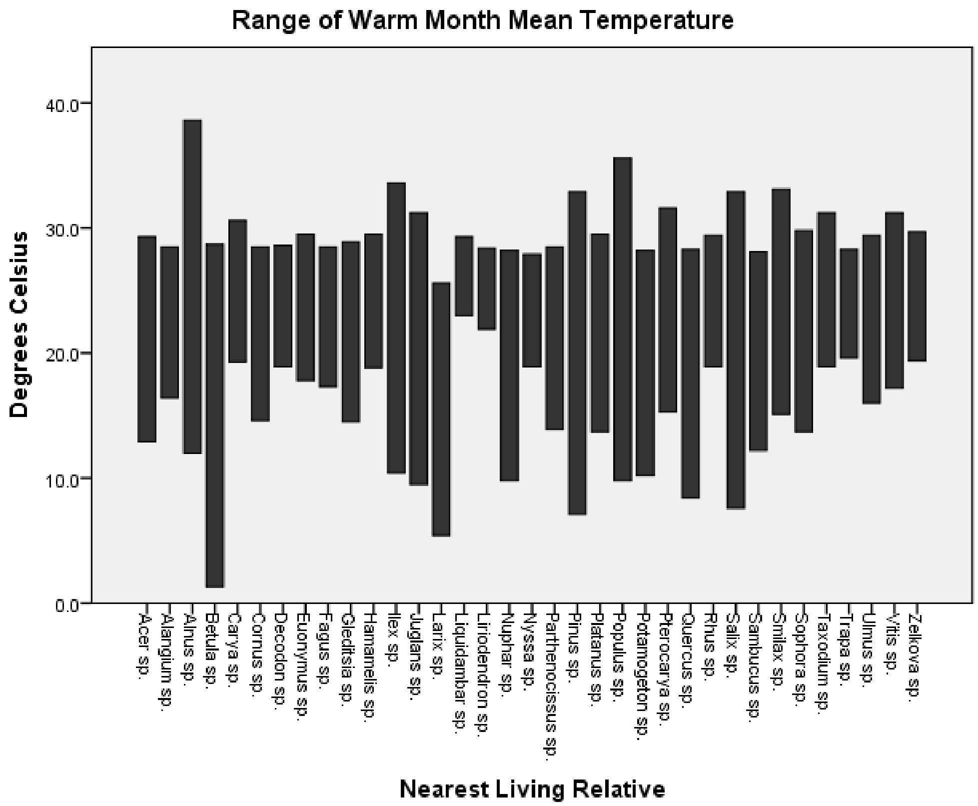
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Leaf	*Potamogeton*	*Potamogeton sp.*	-15 - 23.5	-41.4 - 23	10.2 - 28.2	114 - 2648	15 - 448	0 - 157	0 - 431
	Taxodium	*Taxodium sp.*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290 - 2615	60 - 265	0 - 93	19 - 227
	Nyssa	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Vitis	*Vitis sp.*	0 - 27.4	-22.7 - 25.6	17.2 - 31.2	210 - 1562	44 - 264	0 - 94	2 - 176
	Smilax	*Smilax sp.*	-1.1 - 27.7	-25.8 - 27	15.1 - 33.1	37 - 3151	8 - 389	0 - 165	0 - 221
	Salix	*Salix sp.*	-17 - 27.7	-50.1 - 26.5	7.6 - 32.9	122 - 2399	22 - 448	0 - 108	0 - 252
	Populus balsamifera/ P. heterophylla	*Populus sp.*	-16 - 26	-49 - 13.6	9.8 - 35.6	25 - 2559	8 - 358	0 - 93	0 - 224
	Ilex cornuta	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Platanus occidentalis	*Platanus sp.*	6.6 - 27.4	-10.9 - 25.6	13.7 - 29.5	399 - 2540	71 - 566	0 - 83	0 - 196
	Toxicodendron radicans	*Toxicodendron sp.*	3.4 - 24.9	-12.9 - 22.2	18.9 - 29.4	735 - 1613	73 - 195	18 - 93	49 - 195
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Alangium	*Alangium sp.*	8.5 - 27.7	-7.3 - 27	16.4 - 28.5	338 - 3151	92 - 389	1 - 165	66 - 221
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Pterocarya	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	Gleditsia triacanthos	*Gleditsia sp.*	5.7 - 21.7	-8.1 - 14.8	14.5 - 28.9	644 - 2559	90 - 363	1 - 154	72 - 269
	Sophora	*Sophora sp.*	8.2 - 27.1	-5.6 - 26.1	13.7 - 29.8	373 - 3285	74 - 569	3 - 56	3 - 312
	Ulmus	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
Fruit/Seed	*Trapa*	*Trapa sp.*	-1.1 - 27.7	-25.8 - 27	19.6 - 28.3	177 - 3151	27 - 389	2 - 165	27 - 221
	Mneme	***Decodon sp.*	3.4 - 21.3	-12.9 - 13.3	18.9 - 28.6	592 - 1613	103 - 195	22 - 93	58 - 195
	Hamamelis	*Hamamelis sp.*	6.6 - 18.3	-10.9 - 10.2	18.8 - 29.5	631 - 1864	74 - 295	18 - 94	74 - 196
	Parthenocissus	*Parthenocissus sp.*	4.4 - 22.2	-12.8 - 13.6	13.9 - 28.5	385 - 1551	86 - 225	3 - 89	26 - 217
	Acer	*Acer sp.*	-0.4 - 24	-24.2 - 20.6	12.9 - 29.3	115 - 2559	19 - 370	1 - 135	1 - 366
	Cornus	*Cornus sp.*	-12 - 23.1	-38.8 - 17	14.6 - 28.5	254 - 1958	52 - 448	0 - 93	0 - 431
	Sambucus	*Sambucus sp.*	-9.2 - 27.7	-38.2 - 27	12.2 - 28.1	226 - 3151	43 - 448	0 - 165	15 - 431
Pollen	*Nuphar*	*Nuphar sp.*	-12 - 24.3	-38.8 - 19.2	9.8 - 28.2	115 - 1958	19 - 281	4 - 83	11 - 177
	Liquidambar	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	Alnus	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41 - 2559	8 - 353	0 - 135	8 - 207
	Betula	*Betula sp.*	-15 - 25.8	-41 - 21.1	1.3 - 28.7	110 - 2559	23 - 353	0 - 135	2 - 312
	Euonymus	*Euonymus sp.*	2.5 - 27.7	-17.7 - 27	17.8 - 29.5	517 - 3151	81 - 398	0 - 165	10 - 221
	Fagus	*Fagus sp.*	4.4 - 23.1	-11.5 - 17	17.3 - 28.5	376 - 2648	46 - 448	5 - 94	5 - 431
	Liriodendron	*Liriodendron sp.*	8.7 - 21.3	-3.9 - 13.3	21.9 - 28.4	776 - 1967	75 - 370	32 - 93	74 - 236
	Juglans	*Juglans sp.*	0 - 27.5	-22.7 - 25	9.5 - 31.2	210 - 2617	28 - 582	1 - 114	2 - 189

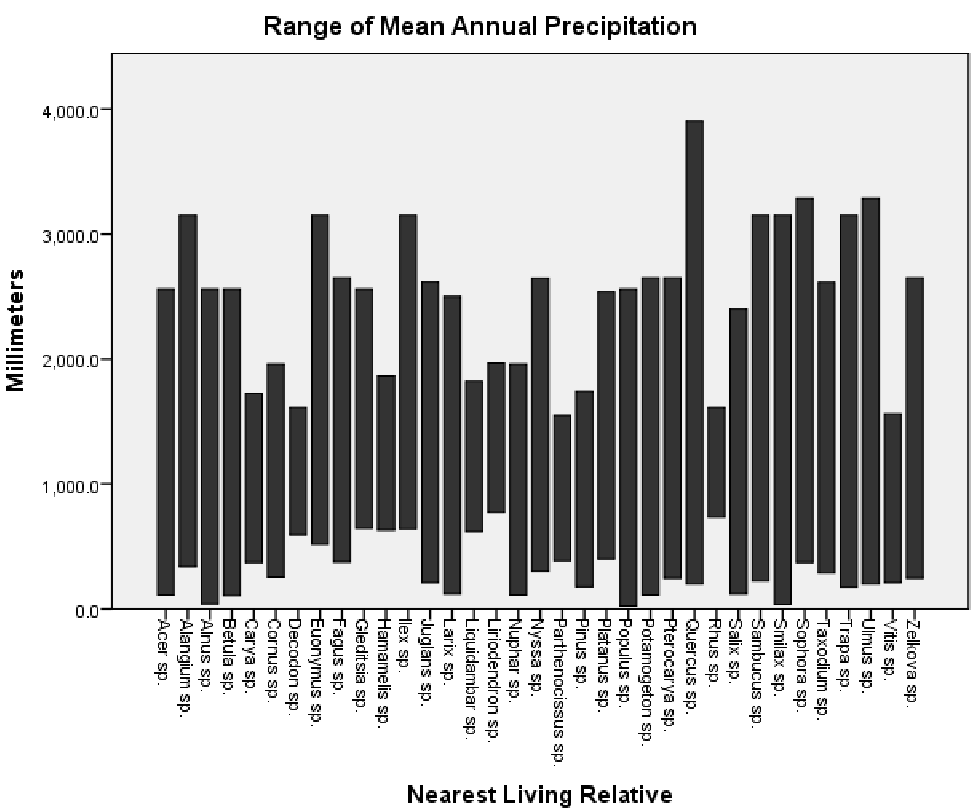
Zelkova-type	*Zelkova sp.*	7.3 - 21.9	-12.8 - 13.6	19.4 - 29.7	246 - 2648	46 - 369	3 - 59	3 - 344
Pinus	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
Larix	*Larix sp.*	-15 - 16.1	-41.4 - 7.8	5.4 - 25.6	122 - 2500	34 - 500	1 - 83	5 - 228

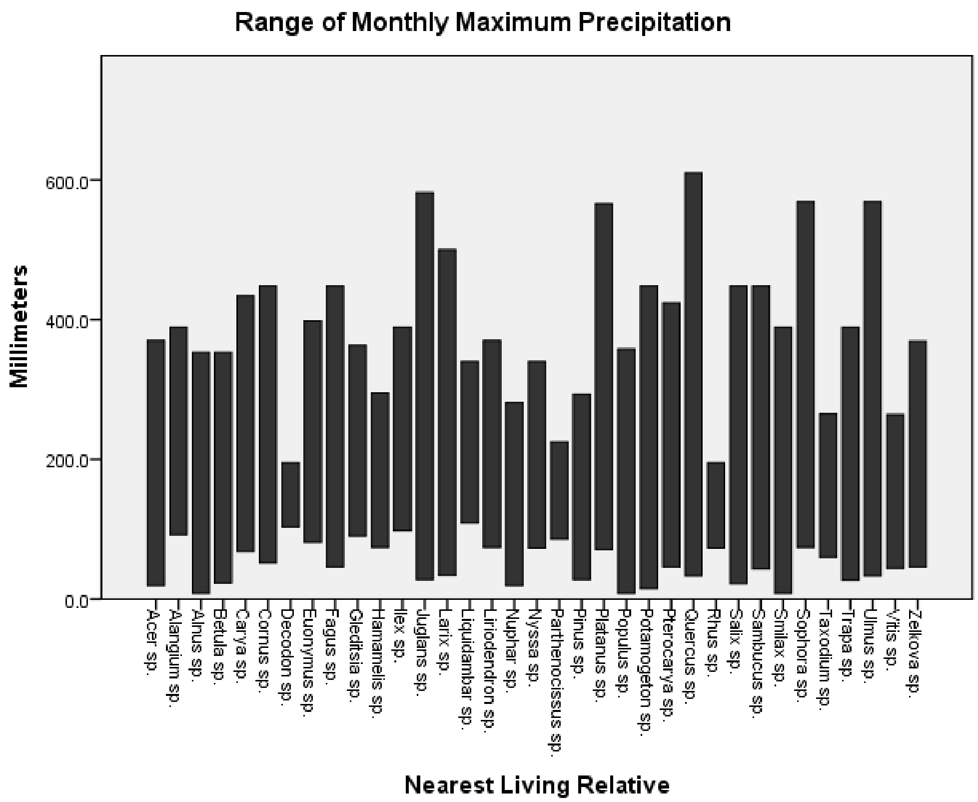
** Nearest Living Relative different genus than Fossil Taxon

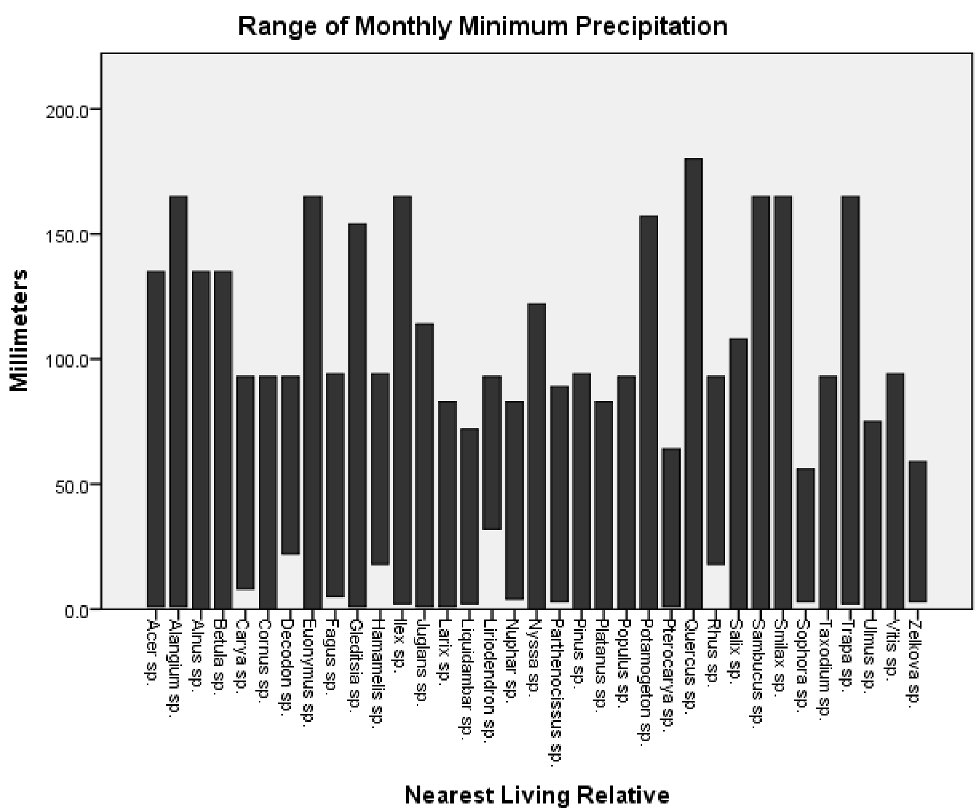

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Cornus sp.
Decodon sp.
Euonymus sp.
Fagus sp.
Gleditsia sp.
Hamamelis sp.
Ilex sp.
Juglans sp.
Larix sp.
Liquidambar sp.
Liriodendron sp.
Nuphar sp.
Nyssa sp.
Parthenocissus sp.
Pinus sp.
Platanus sp.
Populus sp.
Potamogeton sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Sambucus sp.
Smilax sp.
Sophora sp.
Taxodium sp.
Trapa sp.
Ulmus sp.
Vitis sp.
Zelkova sp.
Nearest Living Relative

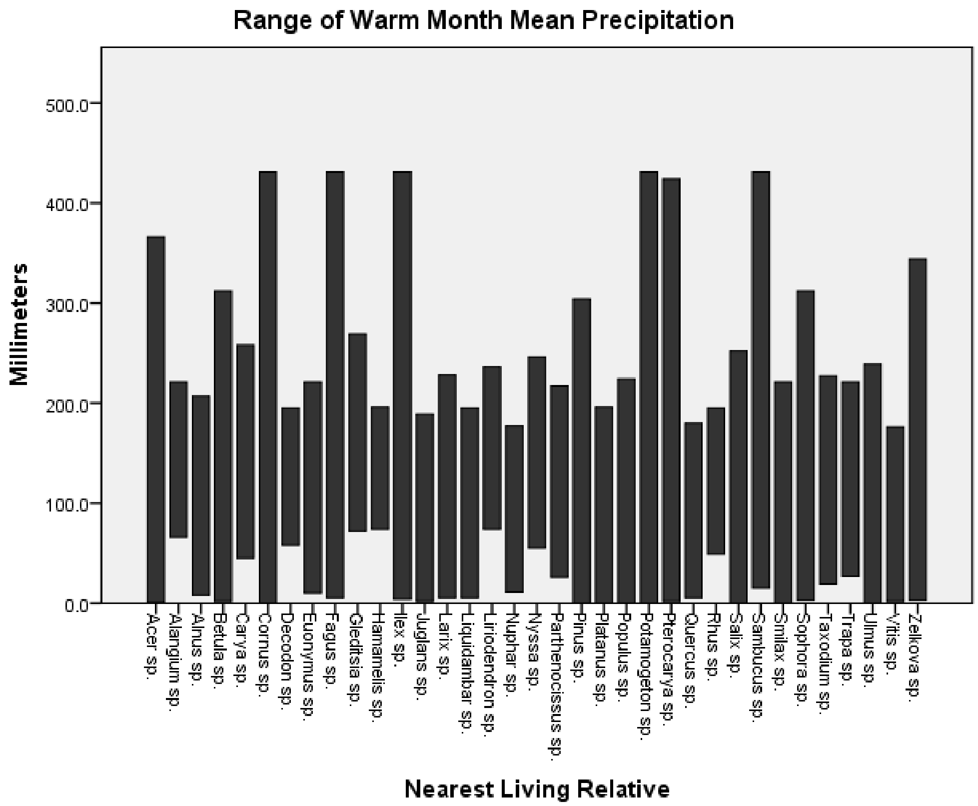

Range of Cold Month Mean Temperature
Degrees Celsius
40.0
20.0
0.0
-20.0
-40.0
-60.0
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Cornus sp.
Decodon sp.
Euonymus sp.
Fagus sp.
Gleditsia sp.
Hamamelis sp.
Ilex sp.
Juglans sp.
Larix sp.
Liquidambar sp.
Liriodendron sp.
Nuphar sp.
Nyssa sp.
Parthenocissus sp.
Pinus sp.
Platanus sp.
Populus sp.
Potamogeton sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Sambucus sp.
Smilax sp.
Sophora sp.
Taxodium sp.
Trapa sp.
Ulmus sp.
Vitis sp.
Zelkova sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Cornus sp.
Decodon sp.
Euonymus sp.
Fagus sp.
Gleditsia sp.
Hamamelis sp.
Ilex sp.
Juglans sp.
Larix sp.
Liquidambar sp.
Liriodendron sp.
Nuphar sp.
Nyssa sp.
Parthenocissus sp.
Pinus sp.
Platanus sp.
Populus sp.
Potamogeton sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Sambucus sp.
Smilax sp.
Sophora sp.
Taxodium sp.
Trapa sp.
Ulmus sp.
Vitis sp.
Zelkova sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Cornus sp.
Decodon sp.
Euonymus sp.
Fagus sp.
Gleditsia sp.
Hamamelis sp.
Ilex sp.
Juglans sp.
Larix sp.
Liquidambar sp.
Liriodendron sp.
Nuphar sp.
Nyssa sp.
Parthenocissus sp.
Pinus sp.
Platanus sp.
Populus sp.
Potamogeton sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Sambucus sp.
Smilax sp.
Sophora sp.
Taxodium sp.
Trapa sp.
Ulmus sp.
Vitis sp.
Zelkova sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Cornus sp.
Decodon sp.
Euonymus sp.
Fagus sp.
Gleditsia sp.
Hamamelis sp.
Ilex sp.
Juglans sp.
Larix sp.
Liquidambar sp.
Liriodendron sp.
Nuphar sp.
Nyssa sp.
Parthenocissus sp.
Pinus sp.
Platanus sp.
Populus sp.
Potamogeton sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Sambucus sp.
Smilax sp.
Sophora sp.
Taxodium sp.
Trapa sp.
Ulmus sp.
Vitis sp.
Zelkova sp.
Nearest Living Relative

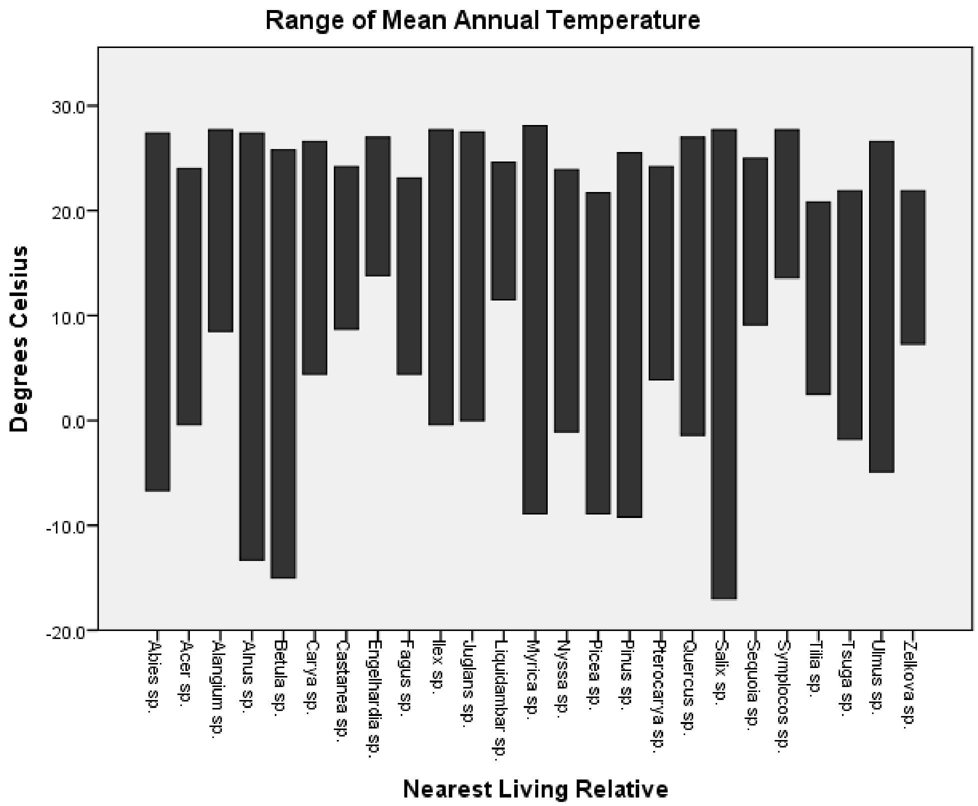

Range of Monthly Minimum Precipitation
Millimeters
200.0
150.0
100.0
50.0
0.0
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Cornus sp.
Decodon sp.
Euonymus sp.
Fagus sp.
Gleditsia sp.
Hamamelis sp.
Ilex sp.
Juglans sp.
Larix sp.
Liquidambar sp.
Liriodendron sp.
Nuphar sp.
Nyssa sp.
Parthenocissus sp.
Pinus sp.
Platanus sp.
Populus sp.
Potamogeton sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Sambucus sp.
Smilax sp.
Sophora sp.
Taxodium sp.
Trapa sp.
Ulmus sp.
Vitis sp.
Zelkova sp.
Nearest Living Relative

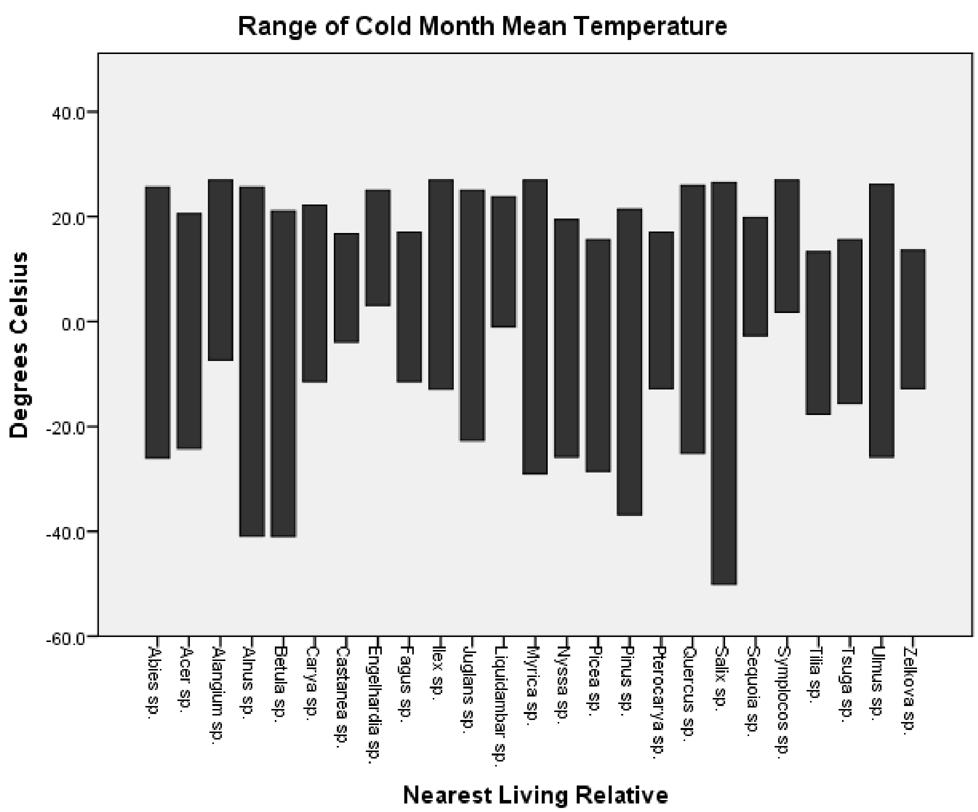

Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Cornus sp.
Decodon sp.
Euonymus sp.
Fagus sp.
Gleditsia sp.
Hamamelis sp.
Ilex sp.
Juglans sp.
Larix sp.
Liquidambar sp.
Liriodendron sp.
Nuphar sp.
Nyssa sp.
Parthenocissus sp.
Pinus sp.
Platanus sp.
Populus sp.
Potamogeton sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Sambucus sp.
Smilax sp.
Sophora sp.
Taxodium sp.
Trapa sp.
Ulmus sp.
Vitis sp.
Zelkova sp.
Nearest Living Relative

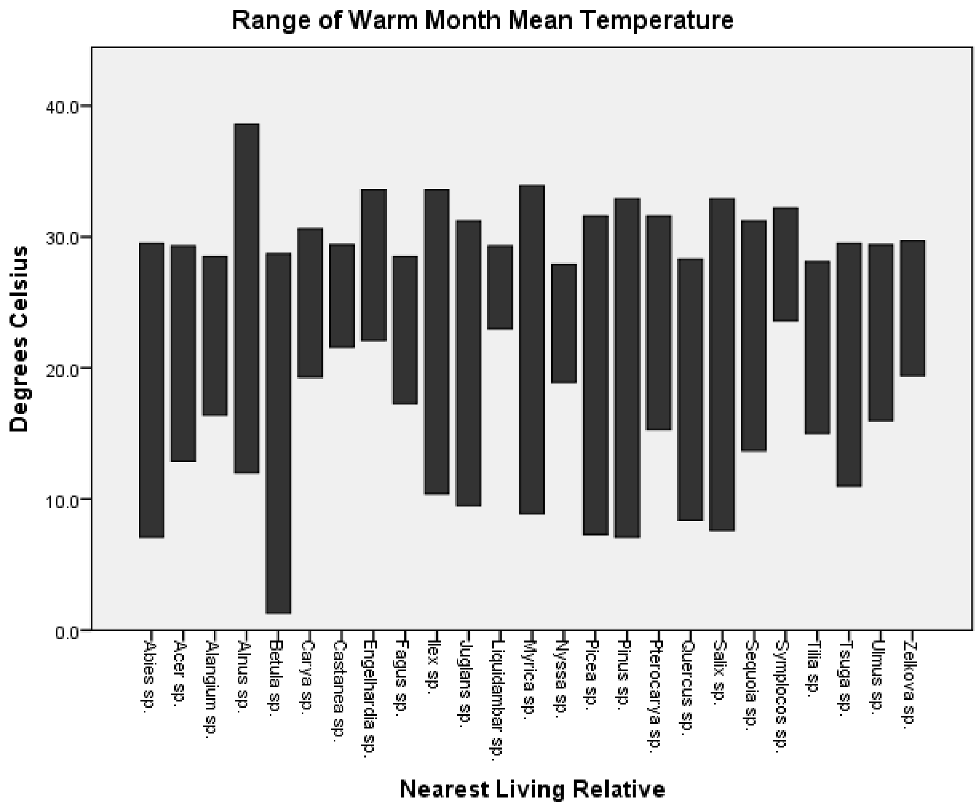
Appendix E

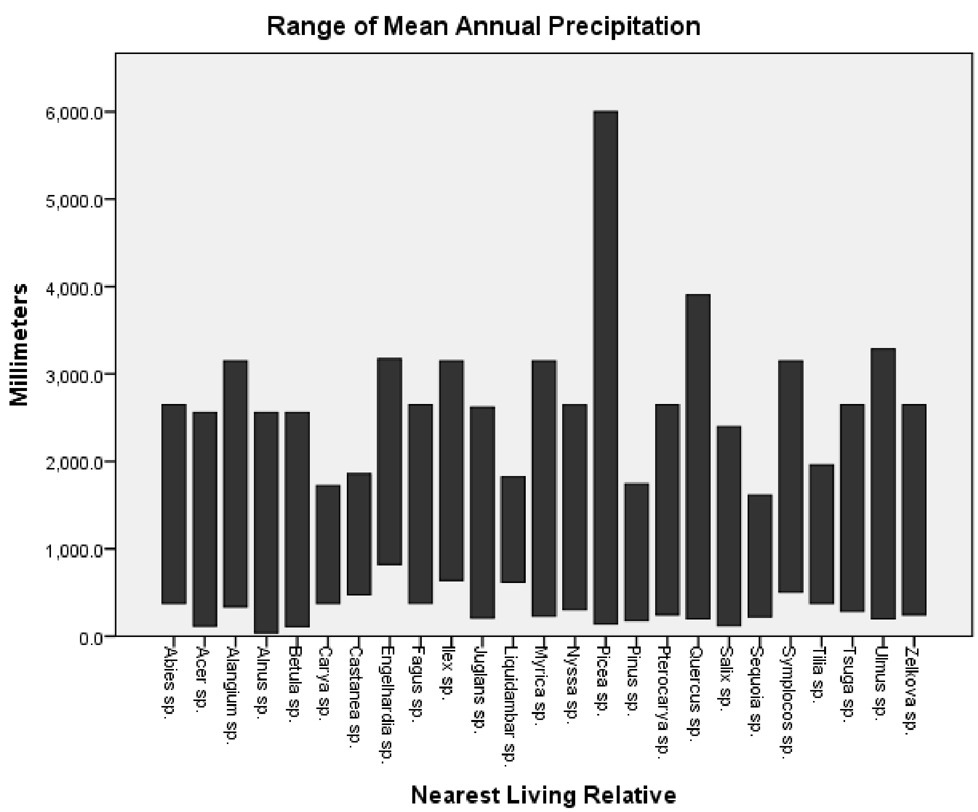
Bryn Mawr Raw Results and Climate Intervals

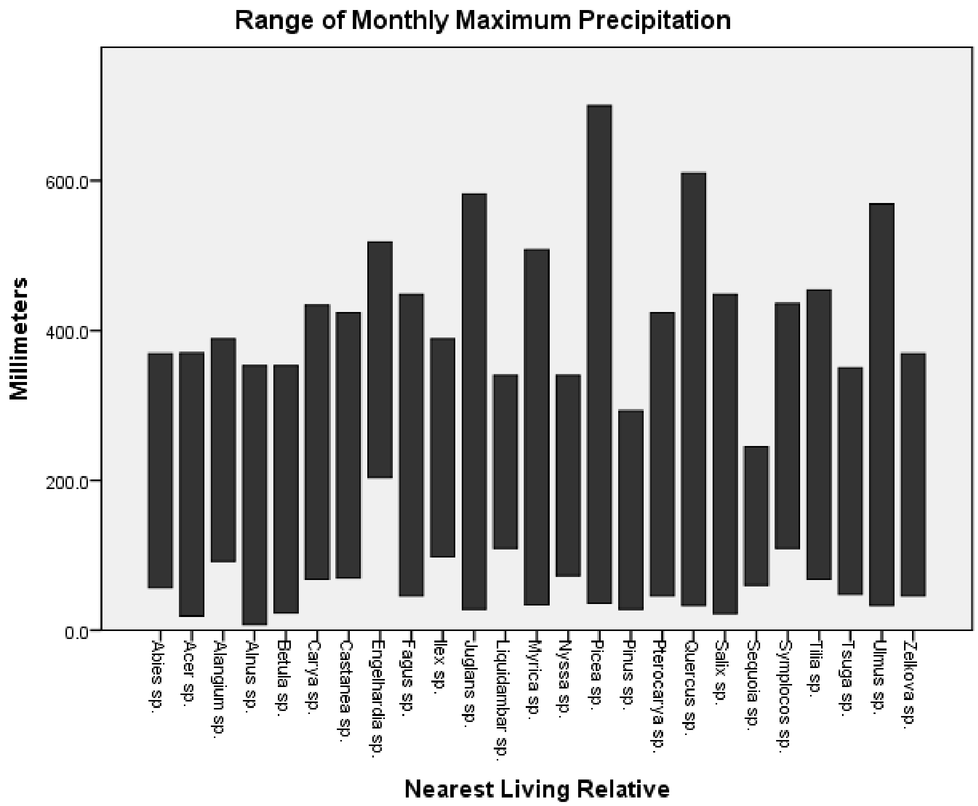
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Pollen	*Abies*	*Abies sp.*	-6.7 - 27.4	-26 - 25.6	7.1 - 29.5	373 - 2648	57 - 369	0 - 135	0 - 344
	Acer	*Acer sp.*	-0.4 - 24	-24.2 - 20.6	12.9 - 29.3	115 - 2559	19 - 370	1 - 135	1 - 366
	Alangium	*Alangium sp.*	8.5 - 27.7	-7.3 - 27	16.4 - 28.5	338 - 3151	92 - 389	1 - 165	66 - 221
	Alnus	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41 - 2559	8 - 353	0 - 135	8 - 207
	Betula	*Betula sp.*	-15 - 25.8	-41 - 21.1	1.3 - 28.7	110 - 2559	23 - 353	0 - 135	2 - 312
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Castanea?	*Castanea sp.*	8.7 - 24.2	-3.9 - 16.7	21.6 - 29.4	473 - 1857	70 - 424	3 - 88	3 - 239
	Engelhardia-type	*Engelhardia sp*	13.8 - 27	3.1 - 25	22.1 - 33.6	823 - 3172	204 - 518	5 - 152	79 - 431
	Fagus	*Fagus sp.*	4.4 - 23.1	-11.5 - 17	17.3 - 28.5	376 - 2648	46 - 448	5 - 94	5 - 431
	Ilex	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Juglans	*Juglans sp.*	0 - 27.5	-22.7 - 25	9.5 - 31.2	210 - 2617	28 - 582	1 - 114	2 - 189
	Liquidambar	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	Myrica	*Myrica sp.*	-8.9 - 28.1	-29 - 27	8.9 - 33.9	233 - 3151	34 - 508	0 - 165	0 - 221
	Nyssa	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Picea	*Picea sp.*	-8.9 - 21.7	-28.6 - 15.6	7.3 - 31.6	142 - 6000	36 - 700	2 - 400	2 - 400
	Pinus	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Pterocarya-type	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Salix	*Salix sp.*	-17 - 27.7	-50.1 - 26.5	7.6 - 32.9	122 - 2399	22 - 448	0 - 108	0 - 252
	Sequoia	*Sequoia sp.*	9.1 - 25	-2.7 - 19.8	13.7 - 31.2	222 - 1613	60 - 245	0 - 93	3 - 227
	Symplocos	*Symplocos sp.*	13.6 - 27.7	1.8 - 27	23.6 - 32.2	505 - 3151	109 - 436	3 - 208	43 - 208
	Tilia	*Tilia sp.*	2.5 - 20.8	-17.7 - 13.3	15 - 28.1	373 - 1958	68 - 454	9 - 83	45 - 258
	Tsuga	*Tsuga sp.*	-1.8 - 21.9	-15.6 - 15.6	11 - 29.5	285 - 2648	48 - 350	0 - 108	0 - 344
	Ulmus	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
	Zelkova-type	*Zelkova sp.*	7.3 - 21.9	-12.8 - 13.6	19.4 - 29.7	246 - 2648	46 - 369	3 - 59	3 - 344


Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Abies sp.
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Engelhardia sp.
Fagus sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Symplocos sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative

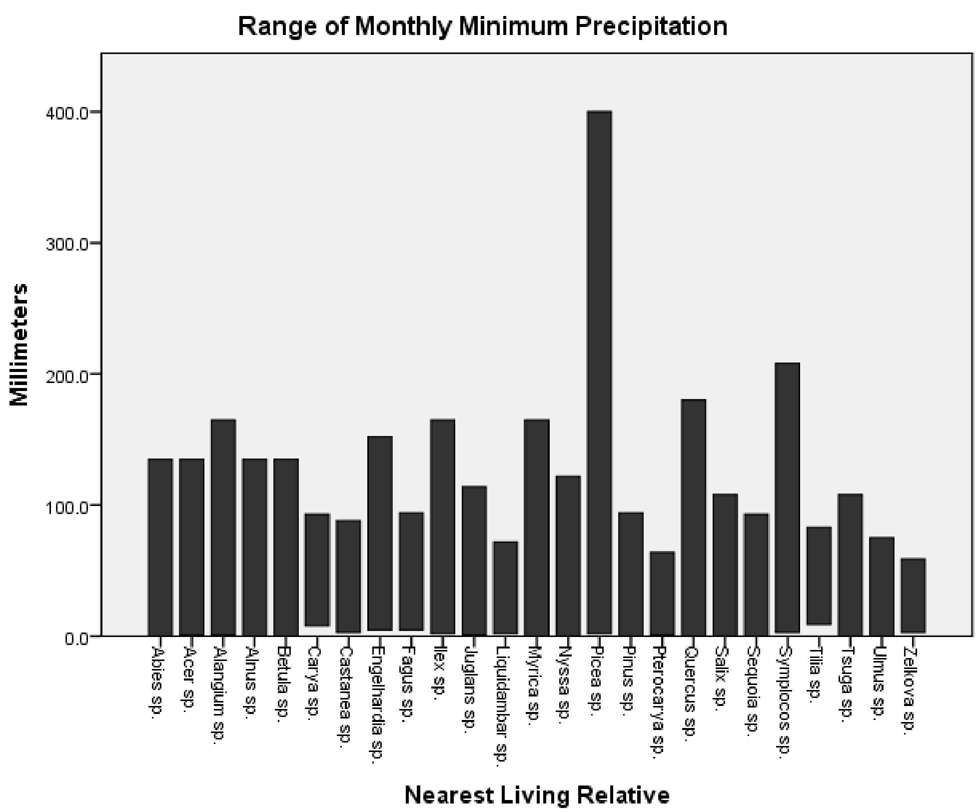

Range of Cold Month Mean Temperature
Degrees Celsius
40.0
20.0
0.0
-20.0
-40.0
-60.0
Abies sp.
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Engelhardia sp.
Fagus sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Symplocos sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Abies sp.
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Engelhardia sp.
Fagus sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Symplocos sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative

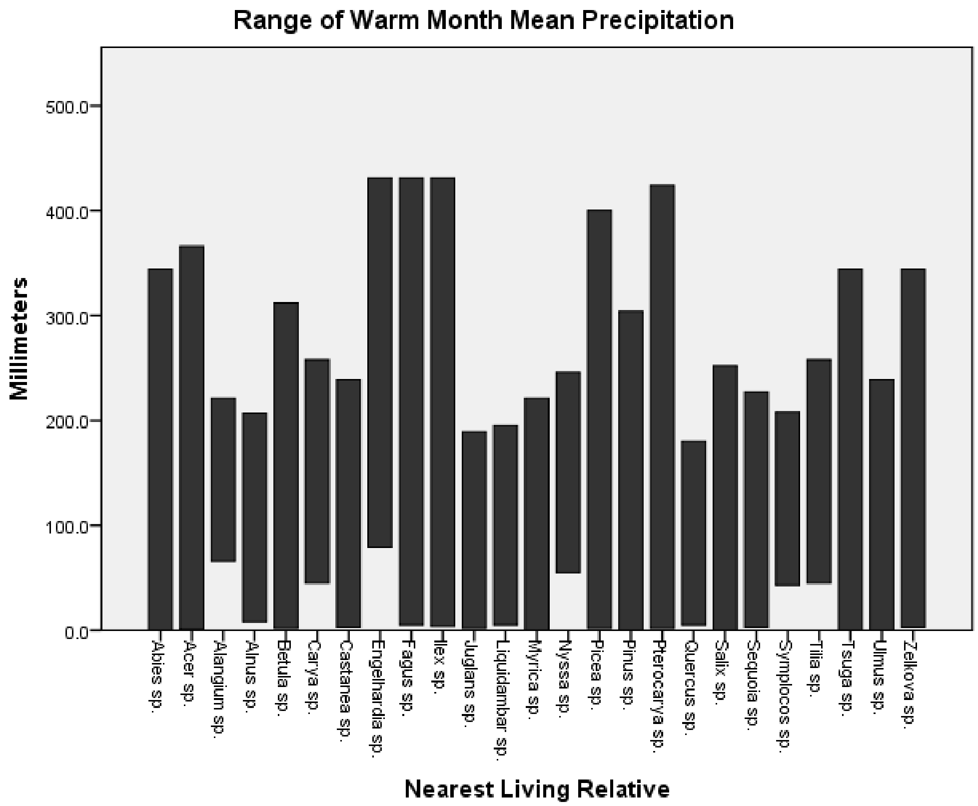

Range of Mean Annual Precipitation
Millimeters
6,000.0
5,000.0
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Abies sp.
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Engelhardia sp.
Fagus sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Symplocos sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative



Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Abies sp.
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Engelhardia sp.
Fagus sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Symplocos sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative



Range of Monthly Minimum Precipitation
Millimeters
400.0
300.0
200.0
100.0
0.0
Abies sp.
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Engelhardia sp.
Fagus sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Symplocos sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative

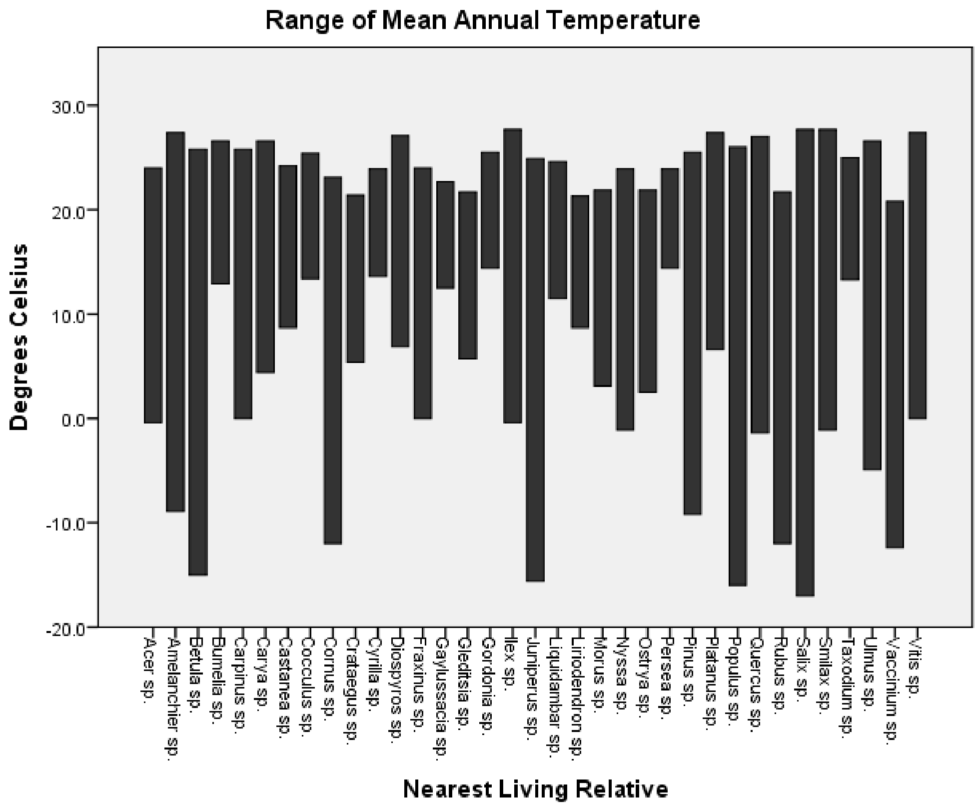

Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Abies sp.
Acer sp.
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Engelhardia sp.
Fagus sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Sequoia sp.
Symplocos sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative

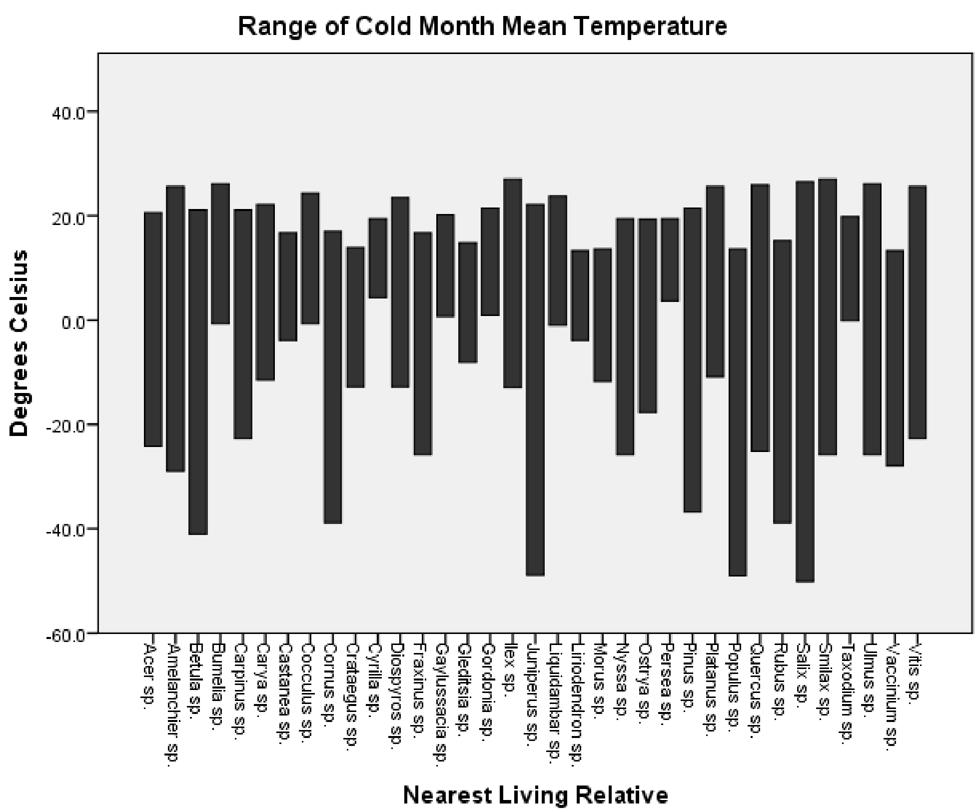
Appendix F

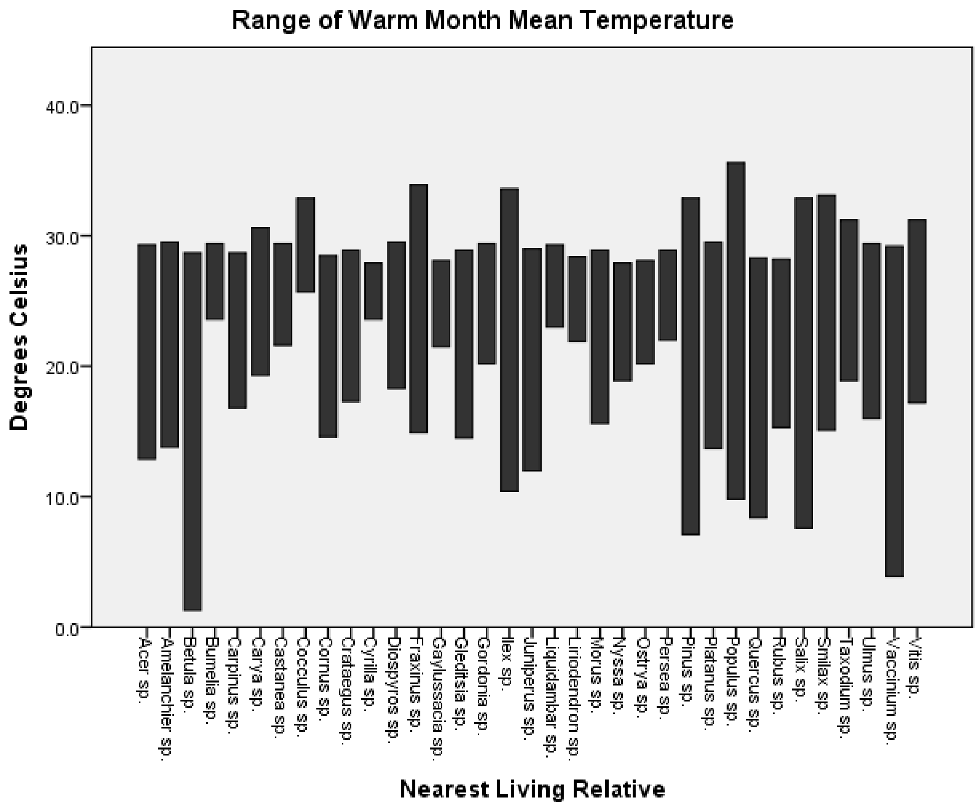
Citronelle Raw Results and Climate Intervals

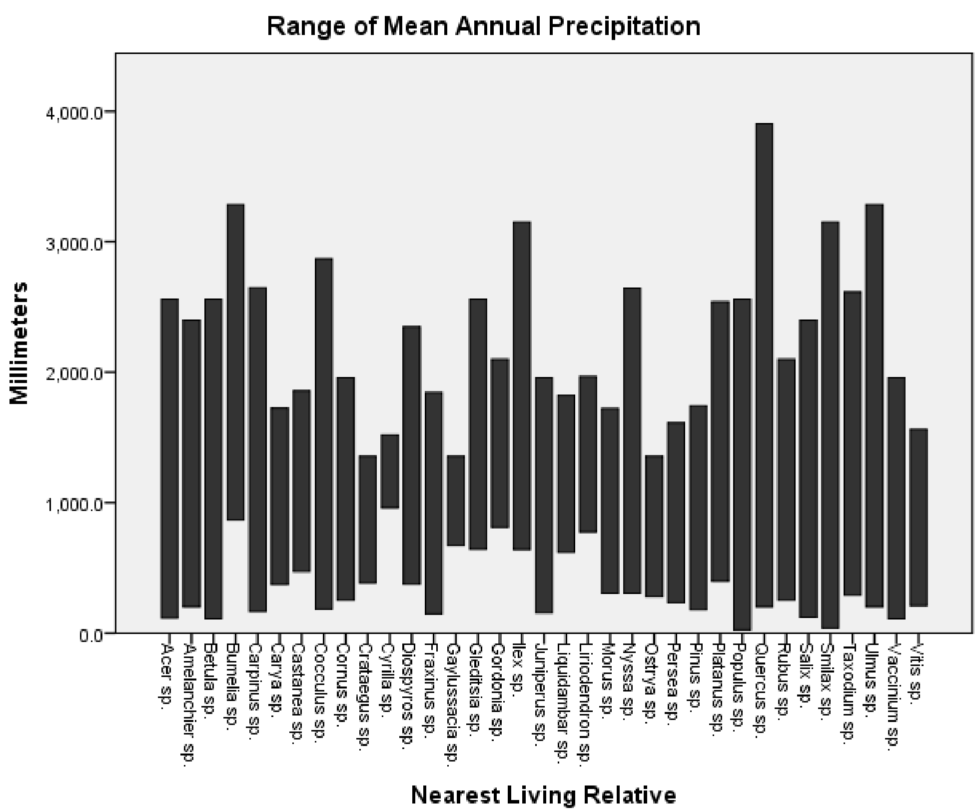
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Pollen	*Pinus strobus*	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Betula nigra	*Betula sp.*	-15 - 25.8	-41 - 21.1	1.3 - 28.7	110 - 2559	23 - 353	0 - 135	2 - 312
	Liquidambar styraciflua	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
Leaf	*Carpinus caroliniana*	*Carpinus sp.*	0 - 25.8	-22.7 - 21.1	16.8 - 28.7	164 - 2648	20 - 350	2 - 55	2 - 344
	Cornus sp.	*Cornus sp.*	-12 - 23.1	-38.8 - 17	14.6 - 28.5	254 - 1958	52 - 448	0 - 93	0 - 431
	Nyssa aquatica	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Cyrilla racemiflora	*Cyrilla sp.*	13.6 - 23.9	4.3 - 19.4	23.6 - 27.9	961 - 1520	109 - 196	42 - 56	99 - 196
	Cocculus carolinus	*Cocculus sp.*	13.4 - 25.4	-0.7 - 24.3	25.7 - 32.9	184 - 2869	22 - 329	2 - 160	20 - 261
	Populus deltoides	*Populus sp.*	-16 - 26	-49 - 13.6	9.8 - 35.6	25 - 2559	8 - 358	0 - 93	0 - 224
	Gordonia sp.	*Gordonia sp.*	14.4 - 25.5	0.9 - 21.4	20.2 - 29.4	810 - 2100	106 - 304	3 - 74	62 - 304
	Vitis rotundifolia	*Vitis sp.*	0 - 27.4	-22.7 - 25.6	17.2 - 31.2	210 - 1562	44 - 264	0 - 94	2 - 176
	Taxodium distichum	*Taxodium sp.*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290 - 2615	60 - 265	0 - 93	19 - 227
	Smilax walteri	*Smilax sp.*	-1.1 - 27.7	-25.8 - 27	15.1 - 33.1	37 - 3151	8 - 389	0 - 165	0 - 221
	Acer saccharinum	*Acer sp.*	-0.4 - 24	-24.2 - 20.6	12.9 - 29.3	115 - 2559	19 - 370	1 - 135	1 - 366
	A. negundo								
	A. rubrum								
	Ilex decidua	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Ostrya virginiana	*Ostrya sp.*	2.5 - 21.9	-17.7 - 19.3	20.2 - 28.1	279 - 1355	74 - 237	0 - 43	0 - 228
	Gaylussacia frondosa	*Gaylussacia sp.*	12.5 - 22.7	0.7 - 20.2	21.5 - 28.1	671 - 1355	113 - 195	2 - 74	94 - 195
	Vaccinium arboretum	*Vaccinium sp.*	-12.4 - 20.8	-27.9 - 13.3	3.9 - 29.2	110 - 1958	23 - 386	1 - 83	20 - 248
	V. corymbosum								
	Gleditsia triacanthos	*Gleditsia sp.*	5.7 - 21.7	-8.1 - 14.8	14.5 - 28.9	644 - 2559	90 - 363	1 - 154	72 - 269
	Castanea pumila	*Castanea sp.*	8.7 - 24.2	-3.9 - 16.7	21.6 - 29.4	473 - 1857	70 - 424	3 - 88	3 - 239
	C. dentata								
	Quercus falcata	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Q. laevis								
	Q. laurifolia								
	Q. nuttallii								
	Q. nigra								
	Q. virginiana								
	Carya aquatica	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	C. glabra								
	C. pallida								
	C. tomentosa								

	Persea palustris	*Persea sp.*	14.4 - 23.9	3.7 - 19.4	22 - 28.9	233 - 1613	53 - 241	5 - 93	2 - 196
	Fraxinus caroliniana	*Fraxinus sp.*	0 - 24	-25.8 - 16.7	14.9 - 33.9	148 - 1844	28 - 358	2 - 95	0 - 239
	Amelanchier arborea	*Amelanchier sp.*	-8.9 - 27.4	-29 - 25.6	13.8 - 29.5	201 - 2399	33 - 336	0 - 108	33 - 196
	Crataegus spathulata	*Crataegus sp.*	5.4 - 21.4	-12.8 - 13.9	17.3 - 28.9	385 - 1355	53 - 195	2 - 61	2 - 195
	Rubus argutus	*Rubus sp.*	-12 - 21.7	-38.8 - 15.2	15.3 - 28.2	254 - 2100	34 - 322	4 - 71	5 - 269
	Salix floridana	*Salix sp.*	-17 - 27.7	-50.1 - 26.5	7.6 - 32.9	122 - 2399	22 - 448	0 - 108	0 - 252
	Bumelia sp.	*Bumelia sp.*	12.9 - 26.6	-0.7 - 26.1	23.6 - 29.4	867 - 3285	106 - 569	32 - 93	49 - 163
	Ulmus alata	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
	Diospyros virginiana	*Diospyros sp.*	6.9 - 27.1	-12.8 - 23.5	18.3 - 29.5	376 - 2348	92 - 295	1 - 83	58 - 185
	Liriodendron tulipifera	*Liriodendron sp.*	8.7 - 21.3	-3.9 - 13.3	21.9 - 28.4	776 - 1967	74 - 370	32 - 93	74 - 236
	Morus rubra	*Morus sp.*	3.1 - 21.9	-11.8 - 13.6	15.6 - 28.9	305 - 1722	82 - 292	0 - 83	82 - 264
	Platanus occidentalis	*Platanus sp.*	6.6 - 27.4	-10.9 - 25.6	13.7 - 29.5	399 - 2540	71 - 566	0 - 83	0 - 196
Shoots	*Juniperus virginiana*	*Juniperus sp.*	-15.6 - 24.9	-48.9 - 22.2	12 - 29	155 - 1958	33 - 303	0 - 83	0 - 258

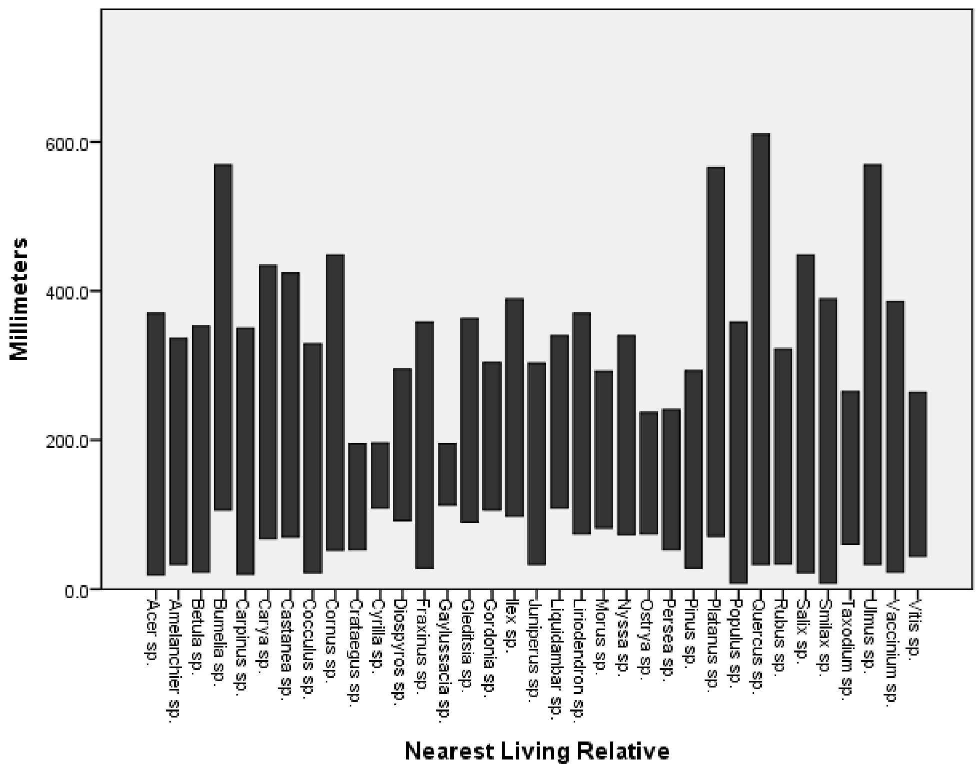

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Acer sp.
Amelanchier sp.
Betula sp.
Bumelia sp.
Carpinus sp.
Carya sp.
Castanea sp.
Cocculus sp.
Cornus sp.
Crataegus sp.
Cyrilla sp.
Diospyros sp.
Fraxinus sp.
Gaylussacia sp.
Gleditsia sp.
Gordonia sp.
Ilex sp.
Juniperus sp.
Liquidambar sp.
Liriodendron sp.
Morus sp.
Nyssa sp.
Ostrya sp.
Persea sp.
Pinus sp.
Platanus sp.
Populus sp.
Quercus sp.
Rubus sp.
Salix sp.
Smilax sp.
Taxodium sp.
Ulmus sp.
Vaccinium sp.
Vitis sp.
Nearest Living Relative


Range of Cold Month Mean Temperature
Degrees Celsius
40.0
20.0
0.0
-20.0
-40.0
-60.0
Acer sp.
Amelanchier sp.
Betula sp.
Bumelia sp.
Carpinus sp.
Carya sp.
Castanea sp.
Cocculus sp.
Cornus sp.
Crataegus sp.
Cyrilla sp.
Diospyros sp.
Fraxinus sp.
Gaylussacia sp.
Gleditsia sp.
Gordonia sp.
Ilex sp.
Juniperus sp.
Liquidambar sp.
Liriodendron sp.
Morus sp.
Nyssa sp.
Ostrya sp.
Persea sp.
Pinus sp.
Platanus sp.
Populus sp.
Quercus sp.
Rubus sp.
Salix sp.
Smilax sp.
Taxodium sp.
Ulmus sp.
Vaccinium sp.
Vitis sp.
Nearest Living Relative

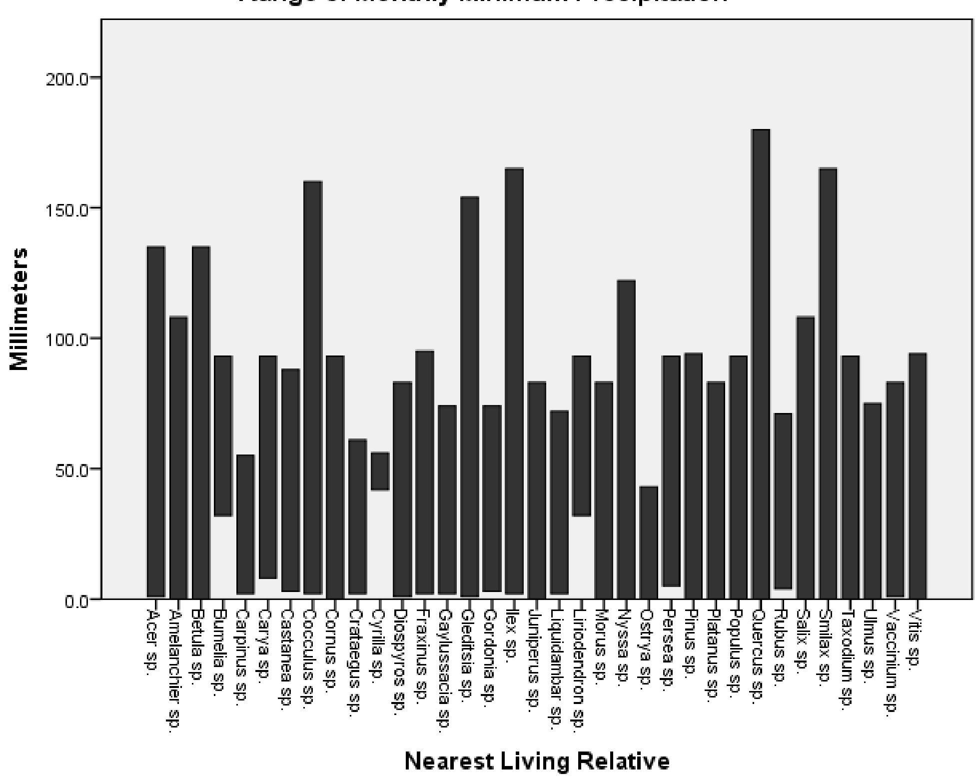

Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Acer sp.
Amelanchier sp.
Betula sp.
Bumelia sp.
Carpinus sp.
Carya sp.
Castanea sp.
Cocculus sp.
Cornus sp.
Crataegus sp.
Cyrilla sp.
Diospyros sp.
Fraxinus sp.
Gaylussacia sp.
Gleditsia sp.
Gordonia sp.
Ilex sp.
Juniperus sp.
Liquidambar sp.
Liriodendron sp.
Morus sp.
Nyssa sp.
Ostrya sp.
Persea sp.
Pinus sp.
Platanus sp.
Populus sp.
Quercus sp.
Rubus sp.
Salix sp.
Smilax sp.
Taxodium sp.
Ulmus sp.
Vaccinium sp.
Vitis sp.
Nearest Living Relative

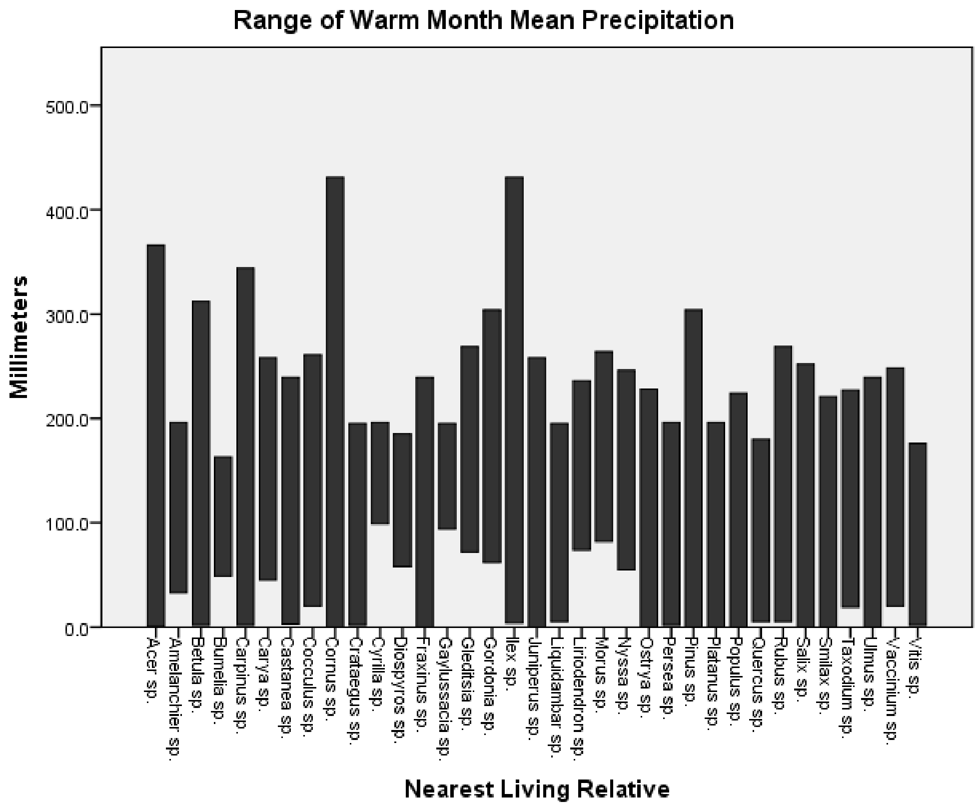

Range of Mean Annual Precipitation
Millimeters
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Acer sp.
Amelanchier sp.
Betula sp.
Bumelia sp.
Carpinus sp.
Carya sp.
Castanea sp.
Cocculus sp.
Cornus sp.
Crataegus sp.
Cyrilla sp.
Diospyros sp.
Fraxinus sp.
Gaylussacia sp.
Gleditsia sp.
Gordonia sp.
Ilex sp.
Juniperus sp.
Liquidambar sp.
Liriodendron sp.
Morus sp.
Nyssa sp.
Ostrya sp.
Persea sp.
Pinus sp.
Platanus sp.
Populus sp.
Quercus sp.
Rubus sp.
Salix sp.
Smilax sp.
Taxodium sp.
Ulmus sp.
Vaccinium sp.
Vitis sp.
Nearest Living Relative

Range of Monthly Maximum Precipitation



Range of Monthly Minimum Precipitation





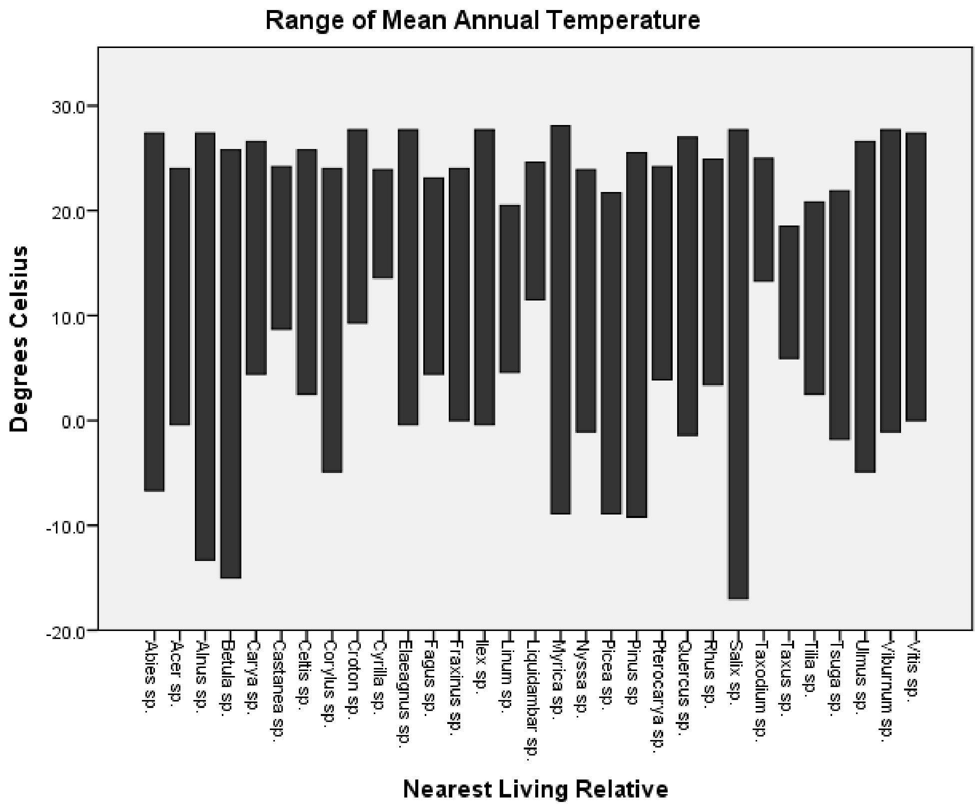
Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Acer sp.
Amelanchier sp.
Betula sp.
Bumelia sp.
Carpinus sp.
Carya sp.
Castanea sp.
Cocculus sp.
Cornus sp.
Crataegus sp.
Cyrilla sp.
Diospyros sp.
Fraxinus sp.
Gaylussacia sp.
Gleditsia sp.
Gordonia sp.
Ilex sp.
Juniperus sp.
Liquidambar sp.
Liriodendron sp.
Morus sp.
Nyssa sp.
Ostrya sp.
Persea sp.
Pinus sp.
Platanus sp.
Populus sp.
Quercus sp.
Rubus sp.
Salix sp.
Smilax sp.
Taxodium sp.
Ulmus sp.
Vaccinium sp.
Vitis sp.
Nearest Living Relative

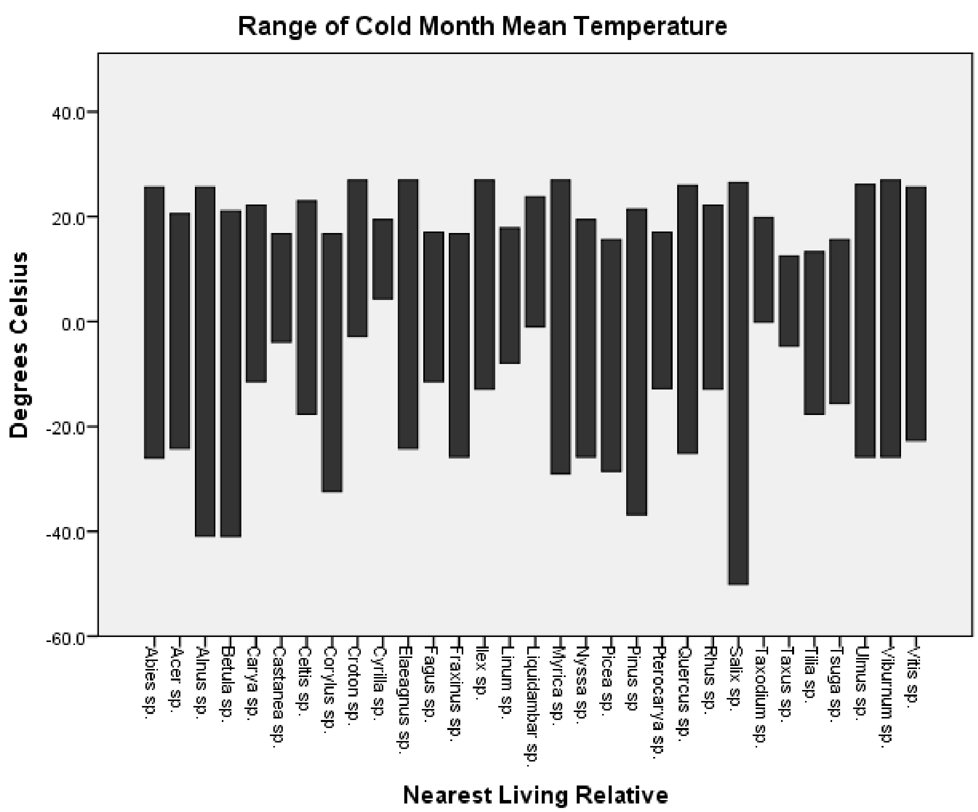
Appendix G

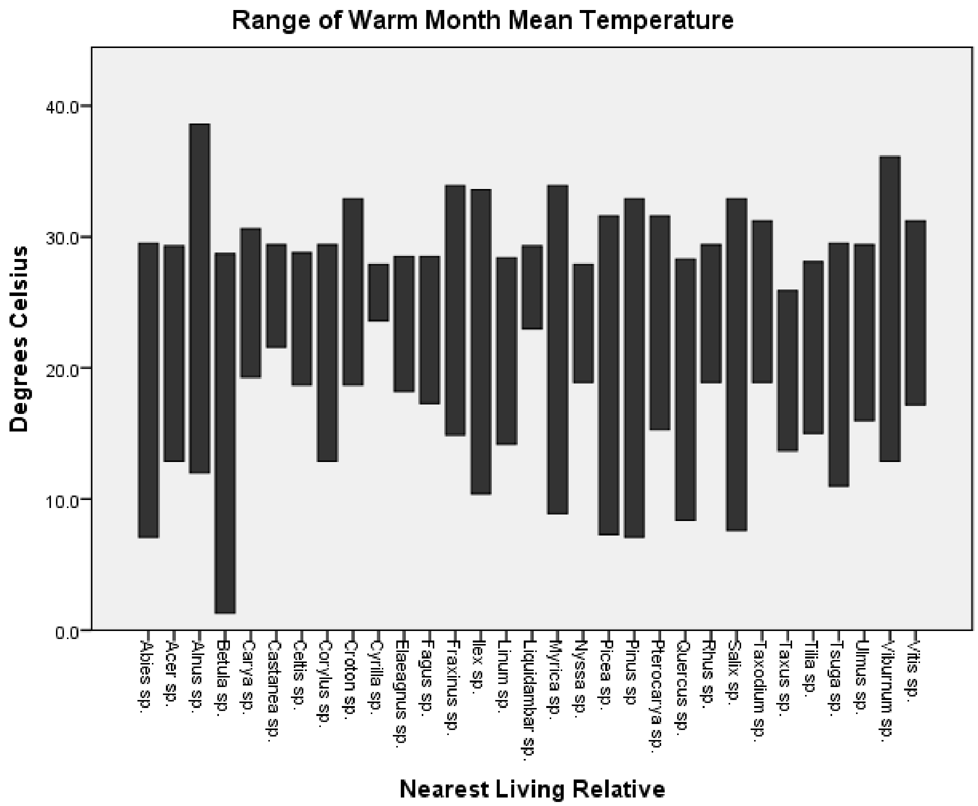
Gray Fossil Site Raw Results and Climate Intervals

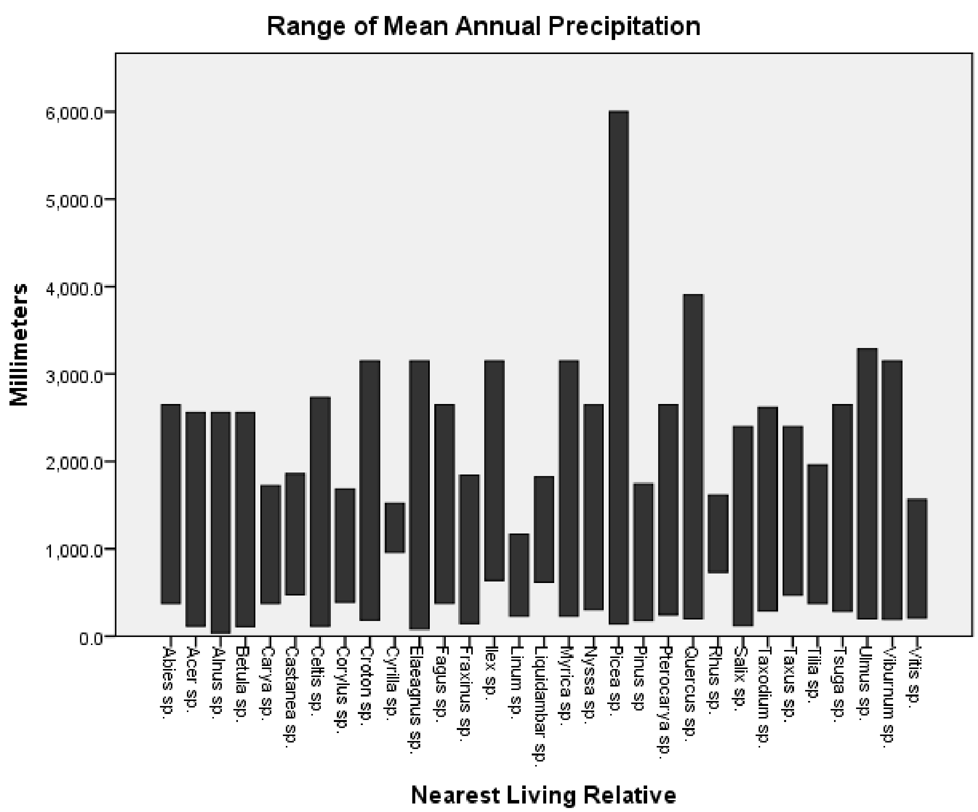
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Seed	*Vitis grayensis/ Vitis lanatoides/ Vitis latisculcata*	*Vitis sp.*	0 - 27.4	-22.7 - 25.6	17.2 - 31.2	210 - 1562	44 - 264	0 - 94	2 - 176
Pollen	*Abies*	*Abies sp.*	-6.7 - 27.4	-26 - 25.6	7.1 - 29.5	373 - 2648	57 - 369	0 - 135	0 - 344
	Acer	*Acer sp.*	-0.4 - 24	-24.2 - 20.6	12.9 - 29.3	115 - 2559	19 - 370	1 - 135	1 - 366
	Alnus	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41 - 2559	8 - 353	0 - 135	8 - 207
	Betula	*Betula sp.*	-15 - 25.8	-41 - 21.1	1.3 - 28.7	110 - 2559	23 - 353	0 - 135	2 - 312
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Castanea	*Castanea sp.*	8.7 - 24.2	-3.9 - 16.7	21.6 - 29.4	473 - 1857	70 - 424	3 - 88	3 - 239
	**Celtis*	*Celtis sp.*	2.5 - 25.8	-17.7 - 23	18.7 - 28.8	116 - 2730	25 - 597	0 - 24	2 - 533
	Corylus	*Corylus sp.*	-4.9 - 24	-32.4 - 16.7	12.9 - 29.4	389 - 1682	45 - 343	3 - 73	3 - 239
	Croton type	*Croton sp.*	9.3 - 27.7	-2.8 - 27	18.7 - 32.9	184 - 3151	28 - 389	2 - 165	2 - 221
	Cyrilla type	*Cyrilla sp.*	13.6 - 23.9	4.3 - 19.4	23.6 - 27.9	961 - 1520	109 - 196	42 - 56	99 - 196
	Elaeagnus	*Elaeagnus sp.*	-0.4 - 27.7	-24.2 - 27	18.2 - 28.5	84 - 3151	28 - 389	2 - 165	13 - 221
	Fagus	*Fagus sp.*	4.4 - 23.1	-11.5 - 17	17.3 - 28.5	376 - 2648	46 - 448	5 - 94	5 - 431
	Fraxinus	*Fraxinus sp.*	0 - 24	-25.8 - 16.7	14.9 - 33.9	148 - 1844	28 - 358	2 - 95	0 - 239
	Ilex vomitaria	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	**Linum*	*Linum sp.*	4.6 - 20.5	-7.9 - 17.8	14.2 - 28.4	233 - 1167	53 - 151	0 - 62	0 - 79
	Liquidambar styraciflua	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	Myrica	*Myrica sp.*	-8.9 - 28.1	-29 - 27	8.9 - 33.9	233 - 3151	34 - 508	0 - 165	0 - 221
	Nyssa	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Picea	*Picea sp.*	-8.9 - 21.7	-28.6 - 15.6	7.3 - 31.6	142 - 6000	36 - 700	2 - 400	2 - 400
	Pinus	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Pterocarya	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Rhus	*Rhus sp.*	3.4 - 24.9	-12.9 - 22.2	18.9 - 29.4	735 - 1613	73 - 195	18 - 93	49 - 195
	Salix	*Salix sp.*	-17 - 27.7	-50.1 - 26.5	7.6 - 32.9	122 - 2399	22 - 448	0 - 108	0 - 252
	Taxodium	*Taxodium sp.*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290 - 2615	60 - 265	0 - 93	19 - 227
	Tilia	*Tilia sp.*	2.5 - 20.8	-17.7 - 13.3	15 - 28.1	373 - 1958	68 - 454	9 - 83	45 - 258
	Tsuga canadensis	*Tsuga sp.*	-1.8 - 21.9	-15.6 - 15.6	11 - 29.5	285 - 2648	48 - 350	0 - 108	0 - 344
	Taxus	*Taxus sp.*	5.9 - 18.5	-4.7 - 12.5	13.7 - 25.9	470 - 2399	56 - 336	1 - 108	3 - 149
	Ulmus rubra	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
	Viburnum	*Viburnum sp.*	-1.1 - 27.7	-25.8 - 27	12.9 - 36.1	193 - 3151	46 - 389	0 - 165	0 - 226

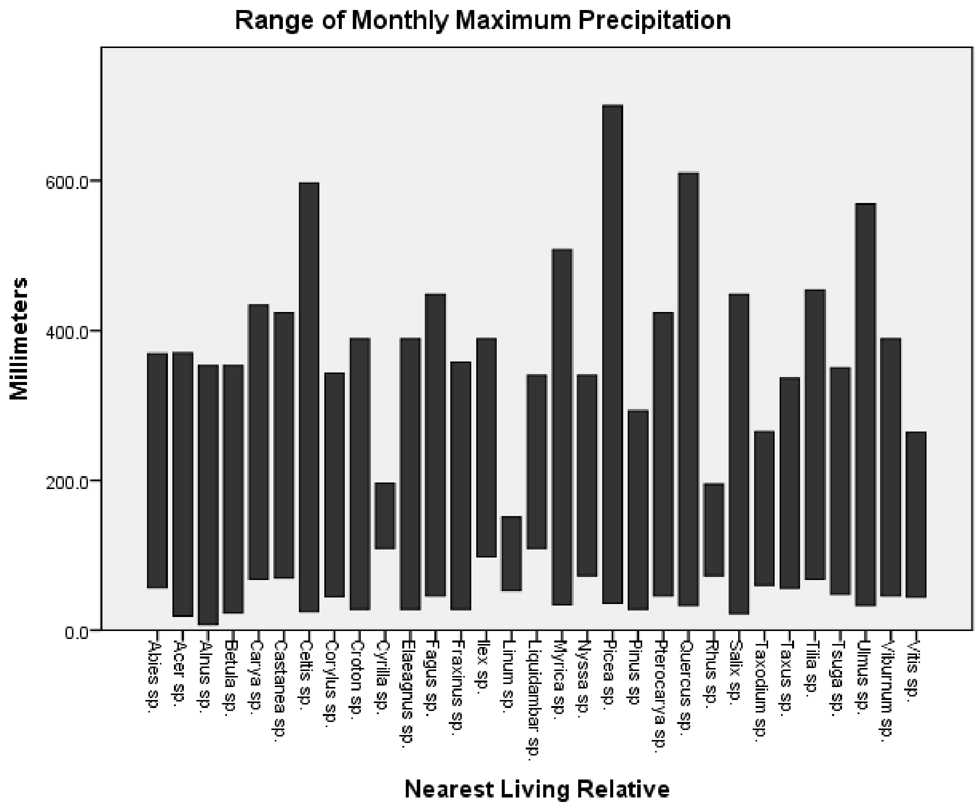
* Taxon is outlier in at least one climate interval

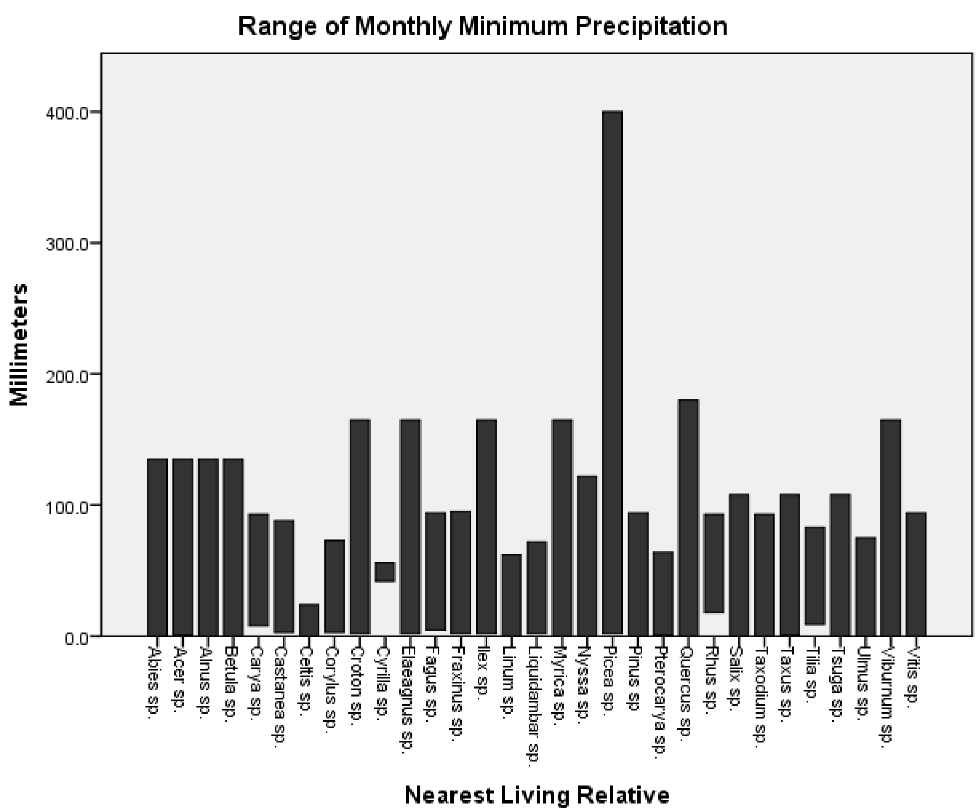

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Abies sp.
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Celtis sp.
Corylus sp.
Croton sp.
Cyrilla sp.
Elaeagnus sp.
Fagus sp.
Fraxinus sp.
Ilex sp.
Linum sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Taxodium sp.
Taxus sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

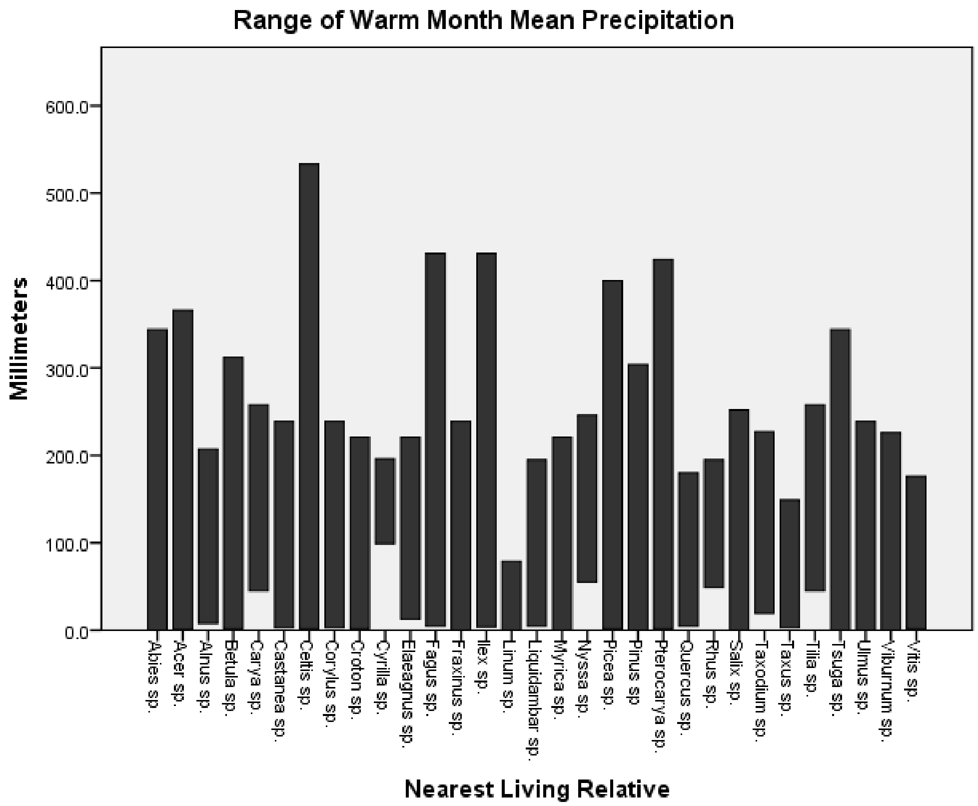

Range of Cold Month Mean Temperature
Degrees Celsius
40.0
20.0
0.0
-20.0
-40.0
-60.0
Abies sp.
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Celtis sp.
Corylus sp.
Croton sp.
Cyrilla sp.
Elaeagnus sp.
Fagus sp.
Fraxinus sp.
Ilex sp.
Linum sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Taxodium sp.
Taxus sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Abies sp.
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Celtis sp.
Corylus sp.
Croton sp.
Cyrilla sp.
Elaeagnus sp.
Fagus sp.
Fraxinus sp.
Ilex sp.
Linum sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Taxodium sp.
Taxus sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
6,000.0
5,000.0
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Abies sp.
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Celtis sp.
Corylus sp.
Croton sp.
Cyrilla sp.
Elaeagnus sp.
Fagus sp.
Fraxinus sp.
Ilex sp.
Linum sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Taxodium sp.
Taxus sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Abies sp.
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Celtis sp.
Corylus sp.
Croton sp.
Cyrilla sp.
Elaeagnus sp.
Fagus sp.
Fraxinus sp.
Ilex sp.
Linum sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Taxodium sp.
Taxus sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative


Range of Monthly Minimum Precipitation
Millimeters
400.0
300.0
200.0
100.0
0.0
Abies sp.
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Celtis sp.
Corylus sp.
Croton sp.
Cyrilla sp.
Elaeagnus sp.
Fagus sp.
Fraxinus sp.
Ilex sp.
Linum sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Taxodium sp.
Taxus sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

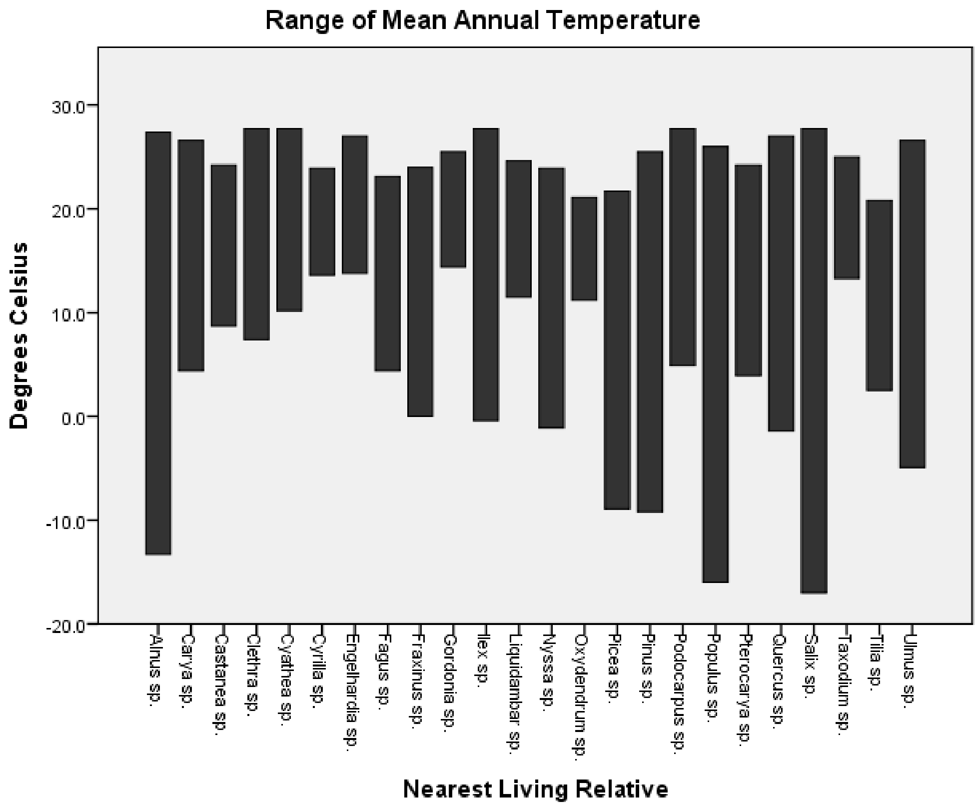

Range of Warm Month Mean Precipitation
Millimeters
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Abies sp.
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Celtis sp.
Corylus sp.
Croton sp.
Cyrilla sp.
Elaeagnus sp.
Fagus sp.
Fraxinus sp.
Ilex sp.
Linum sp.
Liquidambar sp.
Myrica sp.
Nyssa sp.
Picea sp.
Pinus sp
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Taxodium sp.
Taxus sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

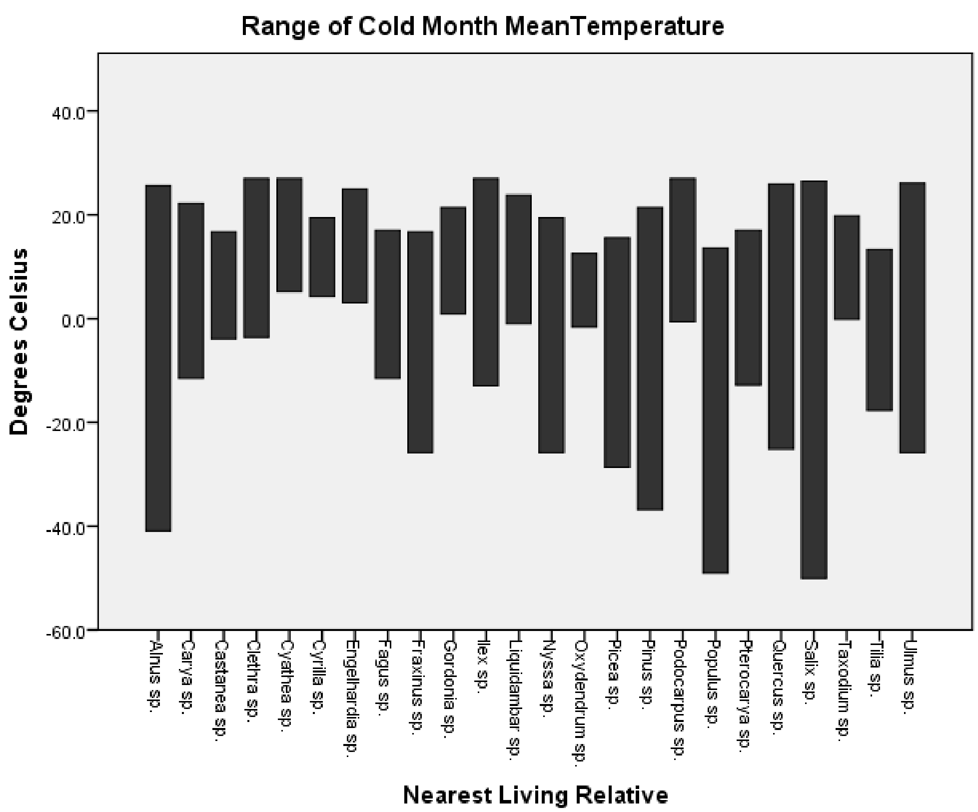
Appendix H

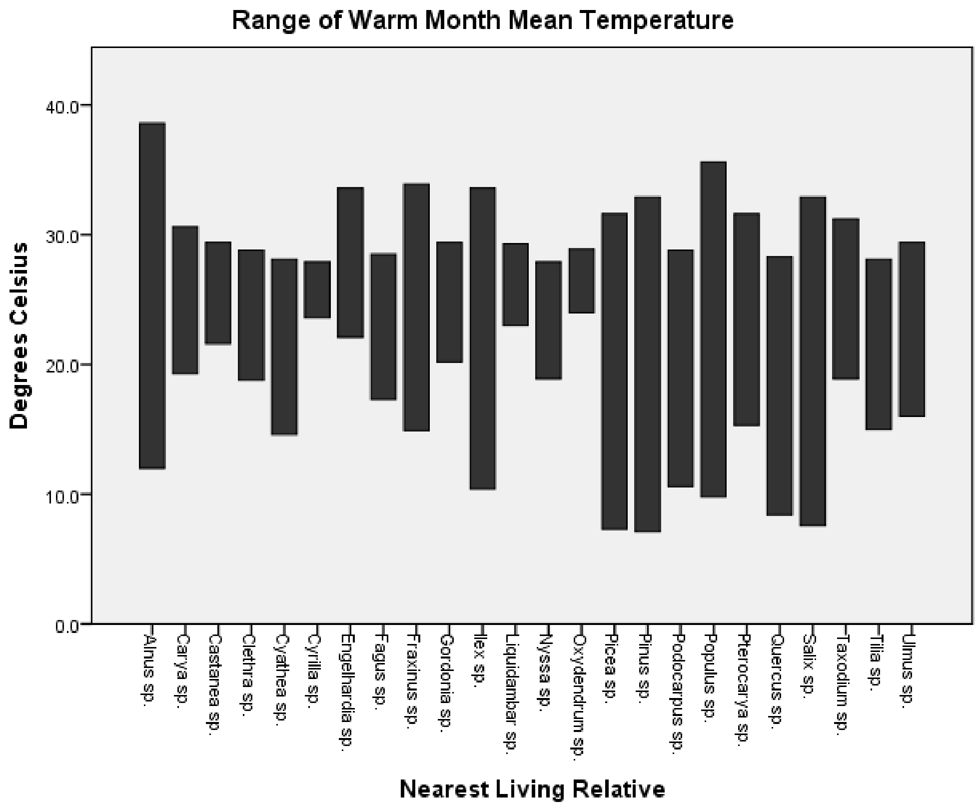
Legler Lignite Raw Results and Climate Intervals

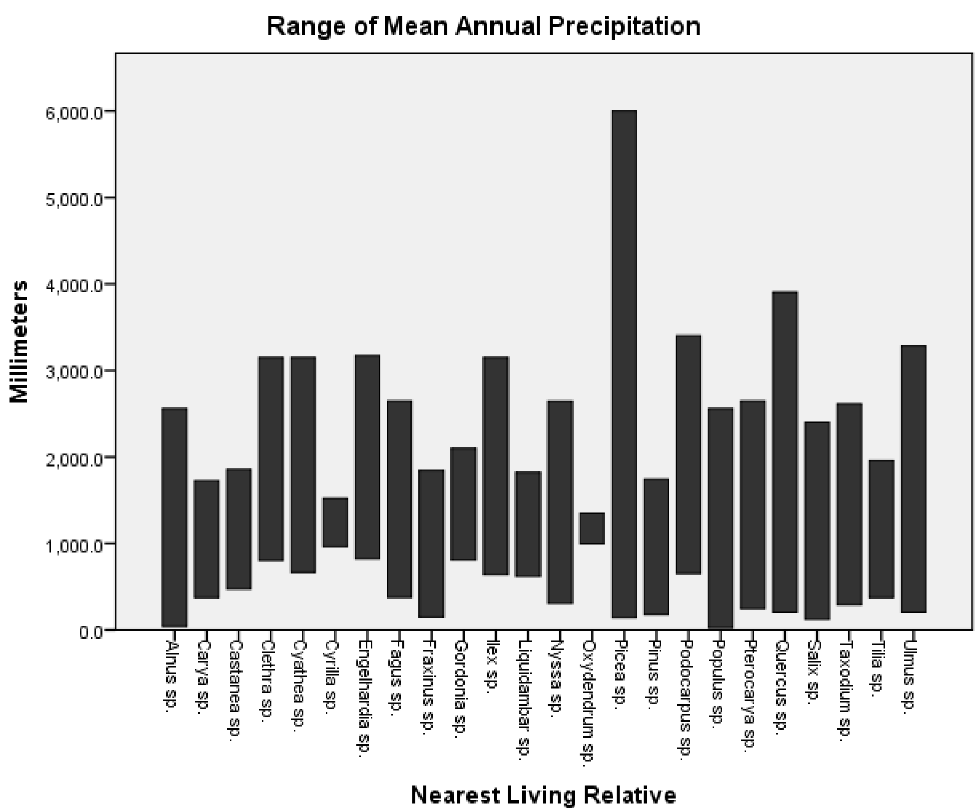
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Pollen	*Cyathea parvula*	*Cyathea sp.*	10.2 - 27.7	5.2 - 27	14.6 - 28.1	666 - 3151	134 - 454	12 - 165	93 - 224
	Pinus taeda	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Picea rubens	*Picea sp.*	-8.9 - 21.7	-28.6 - 15.6	7.3 - 31.6	142 - 6000	36 - 700	2 - 400	2 - 400
	Podocarpus nubigens	*Podocarpus sp.*	4.9 - 27.7	-0.6 - 27	10.6 - 28.8	652 - 3401	68 - 448	16 - 165	26 - 431
	Taxodium distichum	*Taxodium sp.*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290 - 2615	60 - 265	0 - 93	19 - 227
	Salix nigra	*Salix sp.*	-17 - 27.7	-50.1 - 26.5	7.6 - 32.9	122 - 2399	22 - 448	0 - 108	0 - 252
	Populus balsamifera	*Populus sp.*	-16 - 26	-49 - 13.6	9.8 - 35.6	25 - 2559	8 - 358	0 - 93	0 - 224
	Alnus serrulata	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41 - 2559	8 - 353	0 - 135	8 - 207
	Carya ovata	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Pterocarya stenoptera	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	**Engelhardia spicata*	*Engelhardia sp.*	13.8 - 27	3.1 - 25	22.1 - 33.6	823 - 3172	204 - 518	5 - 152	79 - 431
	Fagus grandifolia	*Fagus sp.*	4.4 - 23.1	-11.5 - 17	17.3 - 28.5	376 - 2648	46 - 448	5 - 94	5 - 431
	Castanea dentata	*Castanea sp.*	8.7 - 24.2	-3.9 - 16.7	21.6 - 29.4	473 - 1857	70 - 424	3 - 88	3 - 239
	Quercus alba	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Ulmus rubra	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
	Liquidambar styraciflua	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	**Cyrilla racemiflora*	*Cyrilla sp.*	13.6 - 23.9	4.3 - 19.4	23.6 - 27.9	961 - 1520	109 - 196	42 - 56	99 - 196
	Ilex verticillata	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Tilia americana	*Tilia sp.*	2.5 - 20.8	-17.7 - 13.3	15 - 28.1	373 - 1958	68 - 454	9 - 83	45 - 258
	Gordonia lasianthus	*Gordonia sp.*	14.4 - 25.5	0.9 - 21.4	20.2 - 29.4	810 - 2100	106 - 304	3 - 74	62 - 304
	Nyssa sylvatica	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Clethra alnifolia	*Clethra sp.*	7.4 - 27.7	-3.6 - 27	18.8 - 28.8	803 - 3151	113 - 389	1 - 165	94 - 229
	**Oxydendrum arboreum*	*Oxydendrum sp.*	11.2 - 21.1	-1.6 - 12.6	24 - 28.9	996 - 1347	117 - 146	52 - 75	89 - 142
	Fraxinus americana	*Fraxinus sp.*	0 - 24	-25.8 - 26.7	24.9 - 33.9	148 - 1844	28 - 358	2 - 95	0 - 239

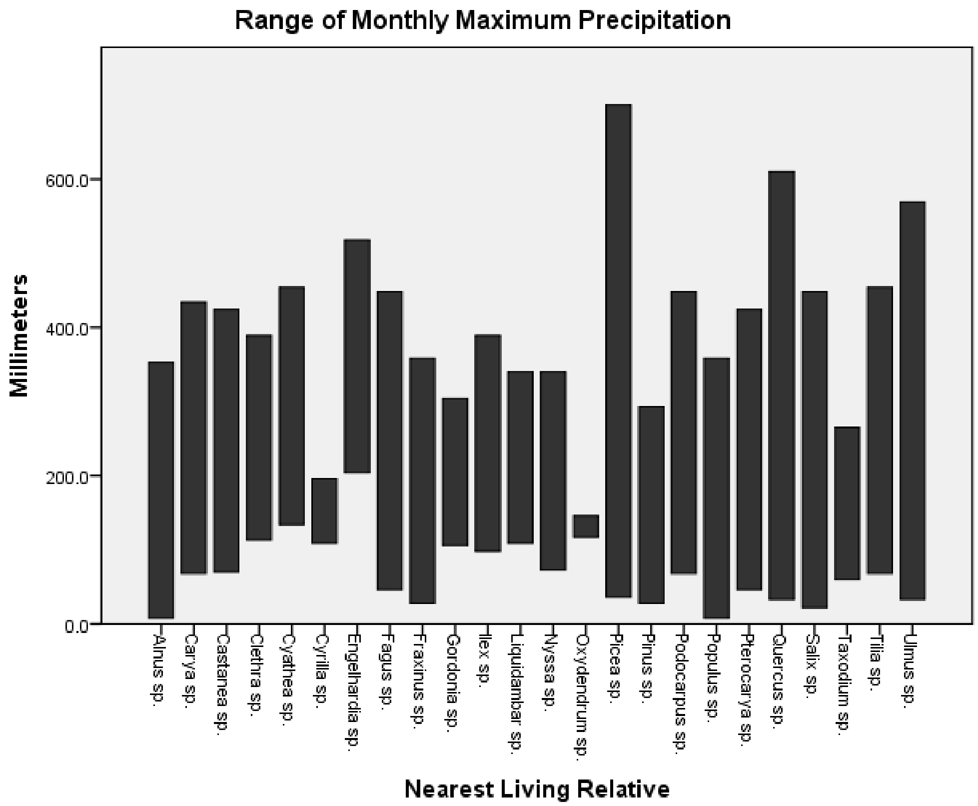
* Taxon is outlier in at least one climate interval

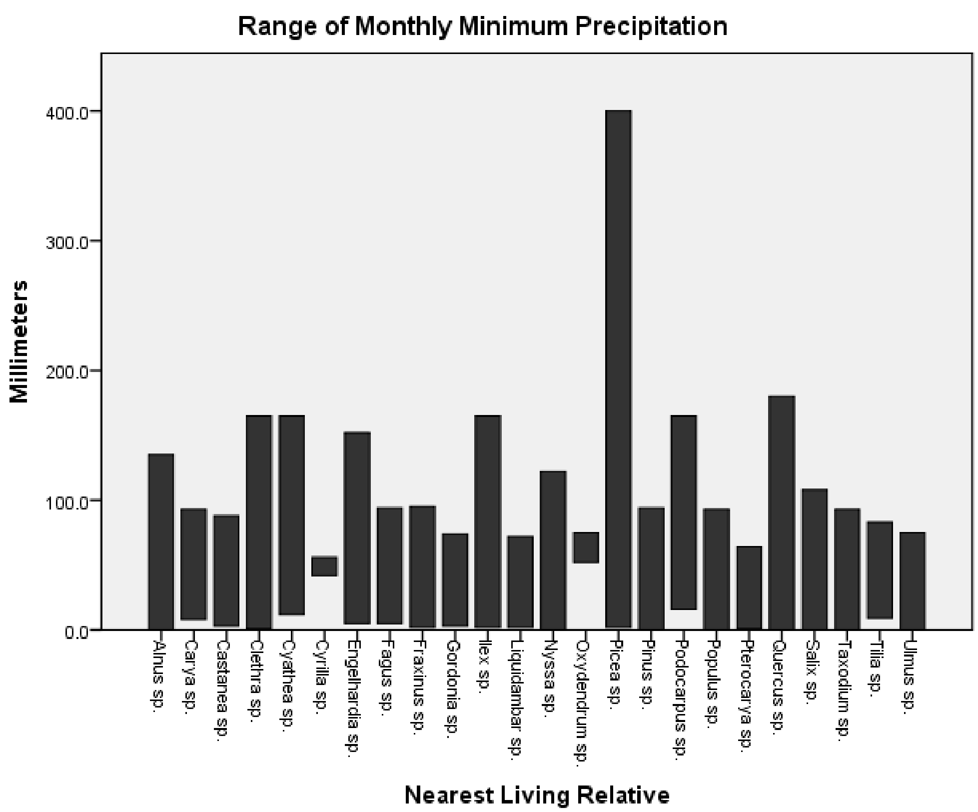

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Alnus sp.
Carya sp.
Castanea sp.
Clethra sp.
Cyathea sp.
Cyrilla sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Nyssa sp.
Oxydendrum sp.
Picea sp.
Pinus sp.
Podocarpus sp.
Populus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Taxodium sp.
Tilia sp.
Ulmus sp.
Nearest Living Relative

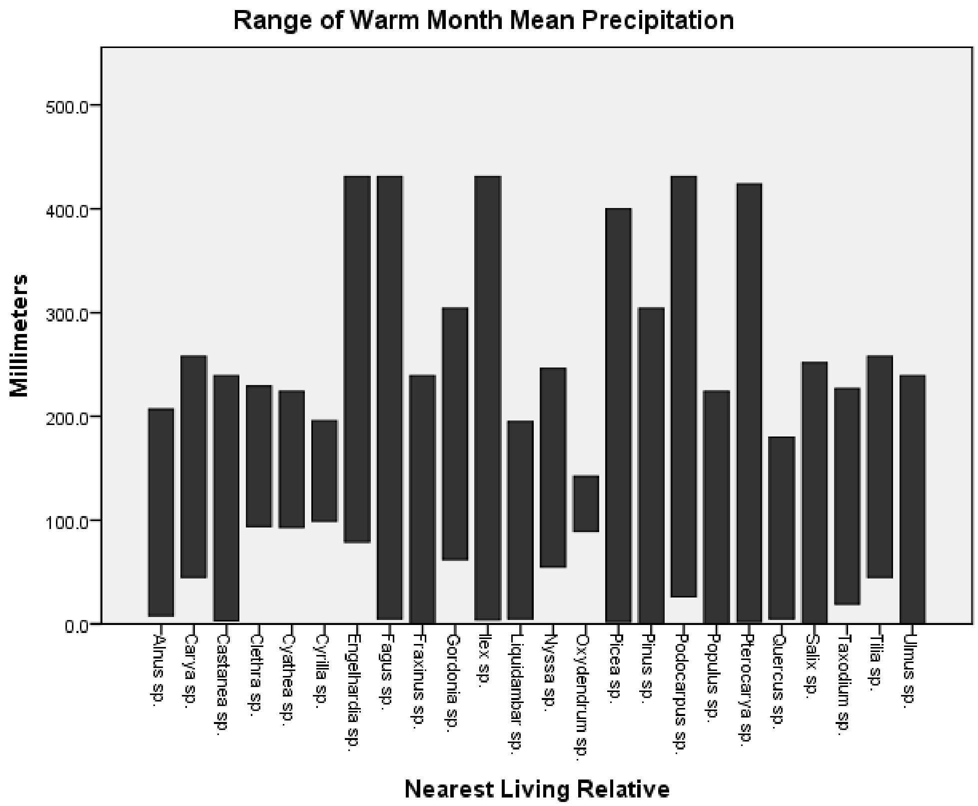

Range of Cold Month MeanTemperature
Degrees Celsius
40.0
20.0
0.0
-20.0
-40.0
-60.0
Alnus sp.
Carya sp.
Castanea sp.
Clethra sp.
Cyathea sp.
Cyrilla sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Nyssa sp.
Oxydendrum sp.
Picea sp.
Pinus sp.
Podocarpus sp.
Populus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Taxodium sp.
Tilia sp.
Ulmus sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Alnus sp.
Carya sp.
Castanea sp.
Clethra sp.
Cyathea sp.
Cyrilla sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Nyssa sp.
Oxydendrum sp.
Picea sp.
Pinus sp.
Podocarpus sp.
Populus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Taxodium sp.
Tilia sp.
Ulmus sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
6,000.0
5,000.0
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Alnus sp.
Carya sp.
Castanea sp.
Clethra sp.
Cyathea sp.
Cyrilla sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Nyssa sp.
Oxydendrum sp.
Picea sp.
Pinus sp.
Podocarpus sp.
Populus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Taxodium sp.
Tilia sp.
Ulmus sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Alnus sp.
Carya sp.
Castanea sp.
Clethra sp.
Cyathea sp.
Cyrilla sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Nyssa sp.
Oxydendrum sp.
Picea sp.
Pinus sp.
Podocarpus sp.
Populus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Taxodium sp.
Tilia sp.
Ulmus sp.
Nearest Living Relative


Range of Monthly Minimum Precipitation
Millimeters
400.0
300.0
200.0
100.0
0.0
Alnus sp.
Carya sp.
Castanea sp.
Clethra sp.
Cyathea sp.
Cyrilla sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Nyssa sp.
Oxydendrum sp.
Picea sp.
Pinus sp.
Podocarpus sp.
Populus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Taxodium sp.
Tilia sp.
Ulmus sp.
Nearest Living Relative



Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Alnus sp.
Carya sp.
Castanea sp.
Clethra sp.
Cyathea sp.
Cyrilla sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Nyssa sp.
Oxydendrum sp.
Picea sp.
Pinus sp.
Podocarpus sp.
Populus sp.
Pterocarya sp.
Quercus sp.
Salix sp.
Taxodium sp.
Tilia sp.
Ulmus sp.
Nearest Living Relative

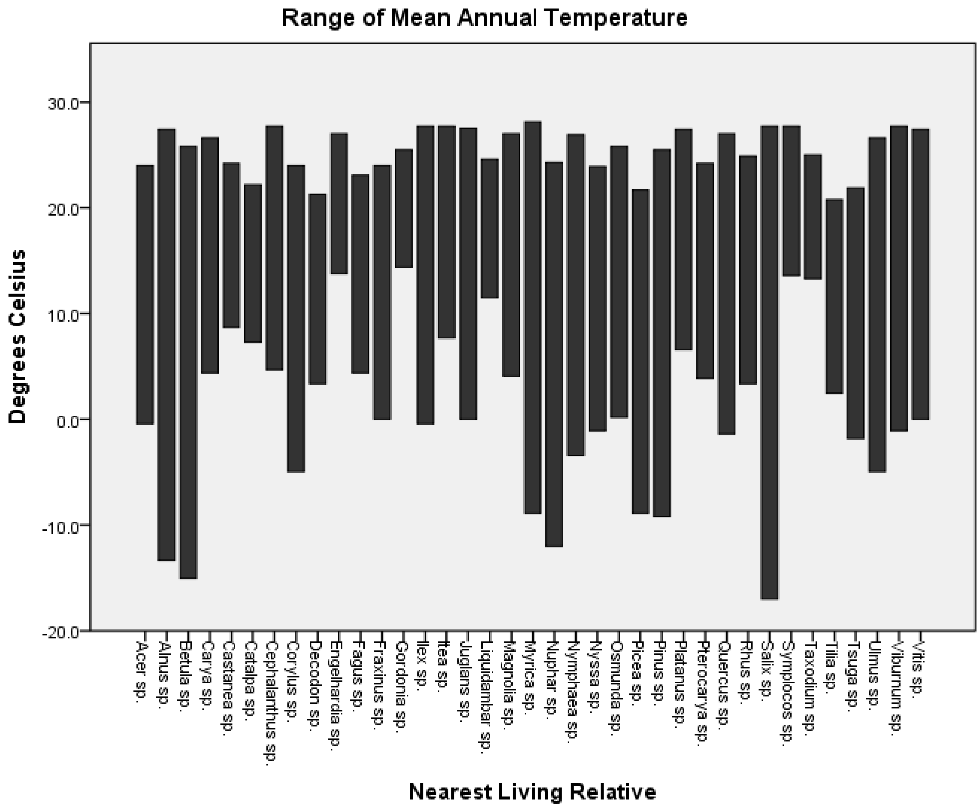
Appendix I

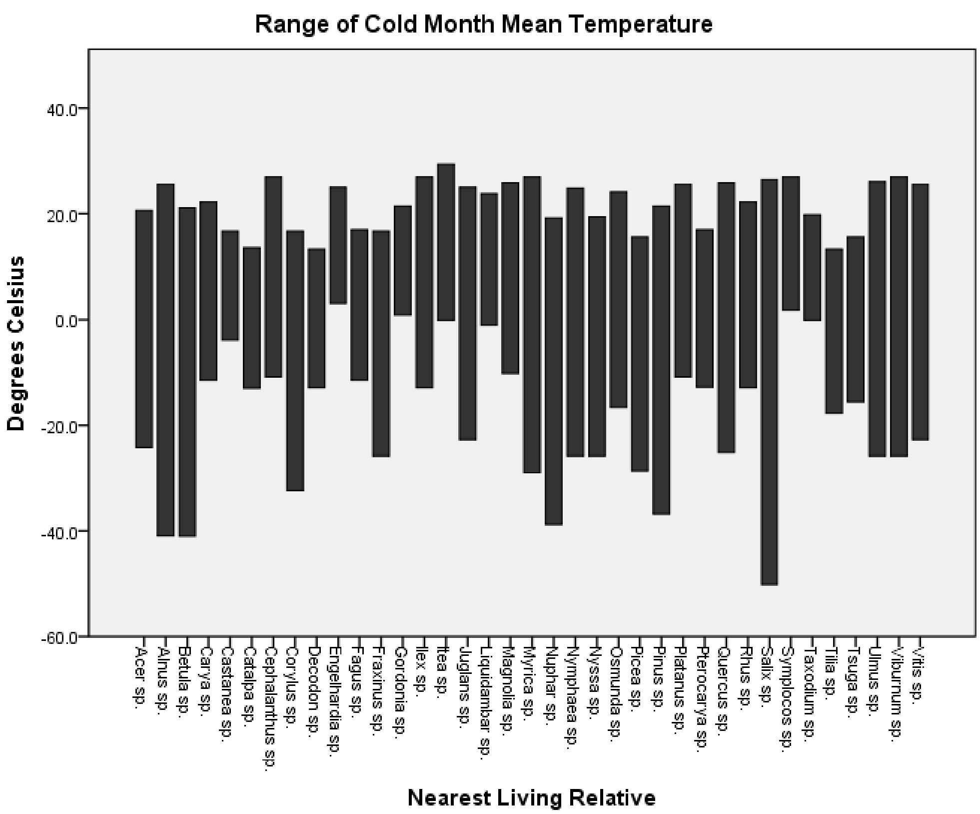
Ohoopee River Dune Field Raw Results and Climate Intervals

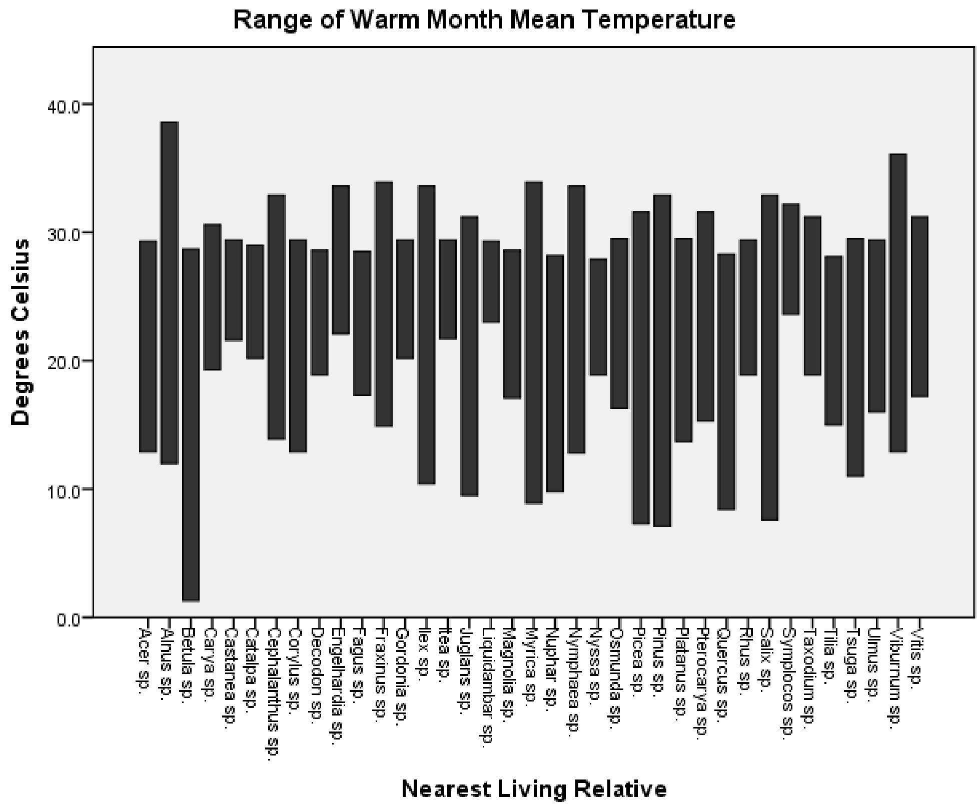
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Pollen	*Acer*	*Acer sp.*	-0.4 - 24	-24.2 - 20.6	12.9 - 29.3	115 - 2559	19 - 370	1 - 135	1- 366
	Alnus	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41 - 2559	8 - 353	0 - 135	8 - 207
	Betula	*Betula sp.*	-15 - 25.8	-41 - 21.1	1.3 - 28.7	110 - 2559	23 - 353	0 - 135	2 - 312
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Castanea	*Castanea sp.*	8.7 - 24.2	-3.9 - 16.7	21.6 - 29.4	473 - 1857	70 - 424	3 - 88	3 - 239
	Catalpa	*Catalpa sp.*	7.3 - 22.2	-13 - 13.6	20.2 - 29	396 - 1967	103 - 370	3 - 72	81 - 304
	Cephalanthus	*Cephalanthus sp.*	4.7 - 27.7	-10.9 - 27	13.9 - 32.9	184 - 3151	20 - 389	2 - 165	20 - 221
	Corylus	*Corylus sp.*	-4.9 - 24	-32.4 - 16.7	12.9 - 29.4	389 - 1682	45 - 343	3 - 73	3 - 239
	**Decodon*	*Decodon sp.*	3.4 - 21.3	-12.9 - 13.3	18.9 - 28.6	592 - 1613	103 - 195	22 - 93	58 - 195
	Fagus	*Fagus sp.*	4.4 - 23.1	-11.5 - 17	17.3 - 28.5	376 - 2648	46 - 448	5 - 94	5 - 431
	Fraxinus	*Fraxinus sp.*	0 - 24	-25.8 - 16.7	14.9 - 33.9	148 -1844	28 - 358	2 - 95	0 - 239
	Gordonia	*Gordonia sp.*	14.4 - 25.5	0.9 - 21.4	20.2 - 29.4	810 - 2100	106 - 304	3 - 74	62 - 304
	Ilex	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Itea	*Itea sp.*	7.7 - 27.7	-0.1 - 29.4	21.7 - 29.4	102 - 3151	49 - 389	25 - 165	13.52 - 221
	Juglans	*Juglans sp.*	0 - 27.5	-22.7 - 25	9.5 - 31.2	210 - 2617	28 - 582	1 - 114	2 - 189
	Liquidambar	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	Magnolia	*Magnolia sp.*	4.1 - 27	-10.2 - 25.9	17.1 - 28.6	578 - 3500	102 - 610	1 - 180	70 - 462
	***Momipites*	*Engelhardia sp.*	13.8 - 27	3.1 - 25	22.1 - 33.6	823 - 3172	204 - 518	5 - 152	79 - 431
	Myrica	*Myrica sp.*	-8.9 - 28.1	-29 - 27	8.9 - 33.9	233 - 3151	34 - 508	0 - 165	0 - 221
	Nuphar	*Nuphar sp.*	-12 - 24.3	-38.8 - 19.2	9.8 - 28.2	115 - 1958	19 - 281	4 - 83	11 - 177
	Nymphaea	*Nymphaea sp.*	-3.4 - 26.9	-25.8 - 24.8	12.8 - 33.6	287 - 2399	56 - 467	0 - 108	47 - 269
	Nyssa	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Osmunda	*Osmunda sp.*	0.2 - 25.8	-16.6 - 24.1	16.3 - 29.5	206 - 4150	34 - 914	2 - 59	2 - 228
	Picea	*Picea sp.*	-8.9 - 21.7	-28.6 - 15.6	7.3 - 31.6	142 - 6000	36 - 700	2 - 400	2 - 400
	Pinus	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Platanus	*Platanus sp.*	6.6 - 27.4	-10.9 - 25.6	13.7 - 29.5	399 - 2540	71 - 566	0 - 83	0 - 196
	Pterocarya	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1- 64	2 - 424
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Rhus	*Rhus sp.*	3.4 - 24.9	-12.9 - 22.2	18.9 - 29.4	735 - 1613	73 - 195	18 - 93	49 - 195
	Salix	*Salix sp.*	-17 - 27.7	-50.1 - 26.5	7.6 - 32.9	122 - 2399	22 - 448	0 - 108	0 - 252
	Symplocos	*Symplocos sp.*	13.6 - 27.7	1.8 - 27	23.6 - 32.2	505 - 3151	109 - 436	3 - 208	43 - 208
	Taxodium	*Taxodium sp.*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290 - 2615	60 - 265	0 - 93	19 - 227
	Tilia	*Tilia sp.*	2.5 - 20.8	-17.7 - 13.3	15 - 28.1	373 - 1958	68 - 454	9 - 83	45 - 258

Tsuga	*Tsuga sp.*	-1.8 - 21.9	-15.6 - 15.6	11 - 29.5	285 - 2648	48 - 350	0 - 108	0 - 344
Ulmus	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
Viburnum	*Viburnum sp.*	-1.1 - 27.7	-25.8 - 27	12.9 - 36.1	193 - 3151	46 - 389	0 - 165	0 - 226
Vitis	*Vitis*	0 - 27.4	-22.7 - 25.6	17.2 - 31.2	210 - 1562	44 - 264	0 - 94	2 - 176

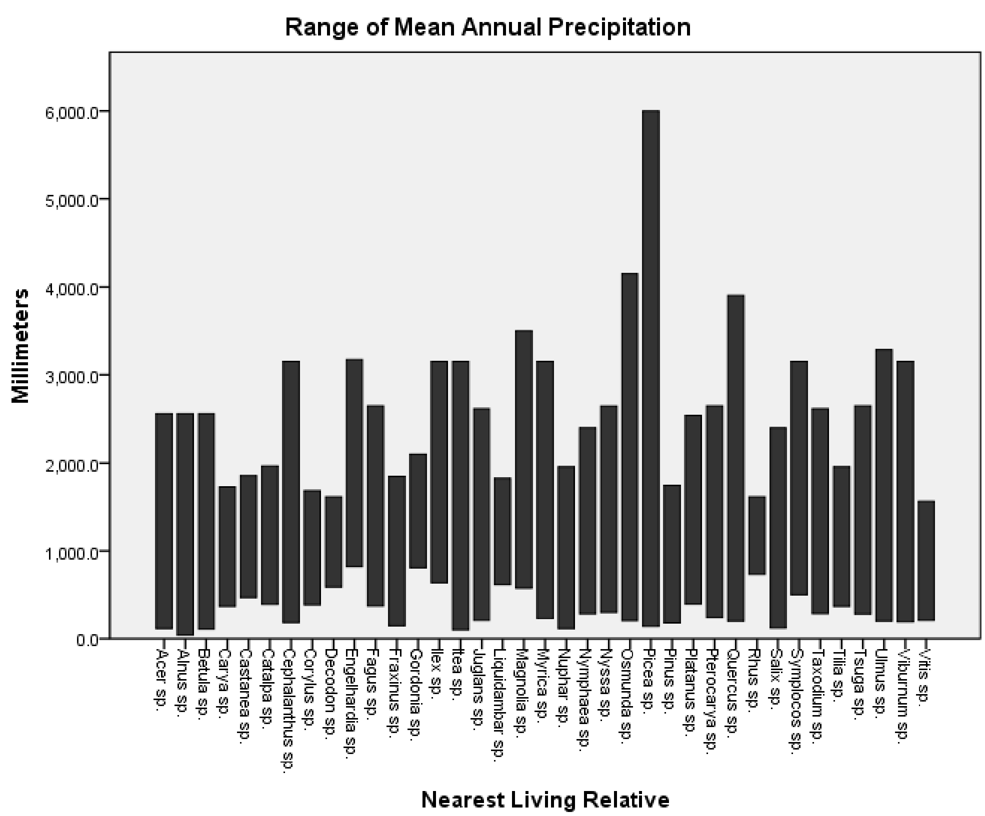
* Taxon is outlier in at least one climate interval
** Nearest Living Relative different genus than Fossil Taxon


Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Catalpa sp.
Cephalanthus sp.
Corylus sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Myrica sp.
Nuphar sp.
Nymphaea sp.
Nyssa sp.
Osmunda sp.
Picea sp.
Pinus sp.
Platanus sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

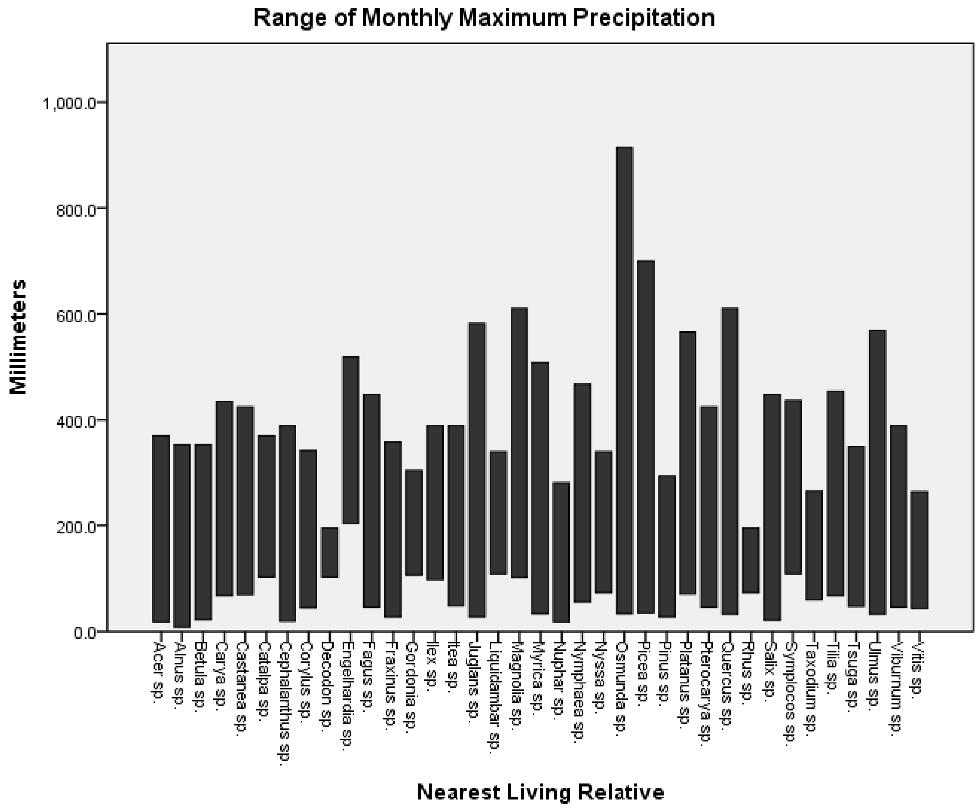

Range of Cold Month Mean Temperature
Degrees Celsius
40.0
20.0
0.0
-20.0
-40.0
-60.0
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Catalpa sp.
Cephalanthus sp.
Corylus sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Myrica sp.
Nuphar sp.
Nymphaea sp.
Nyssa sp.
Osmunda sp.
Picea sp.
Pinus sp.
Platanus sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

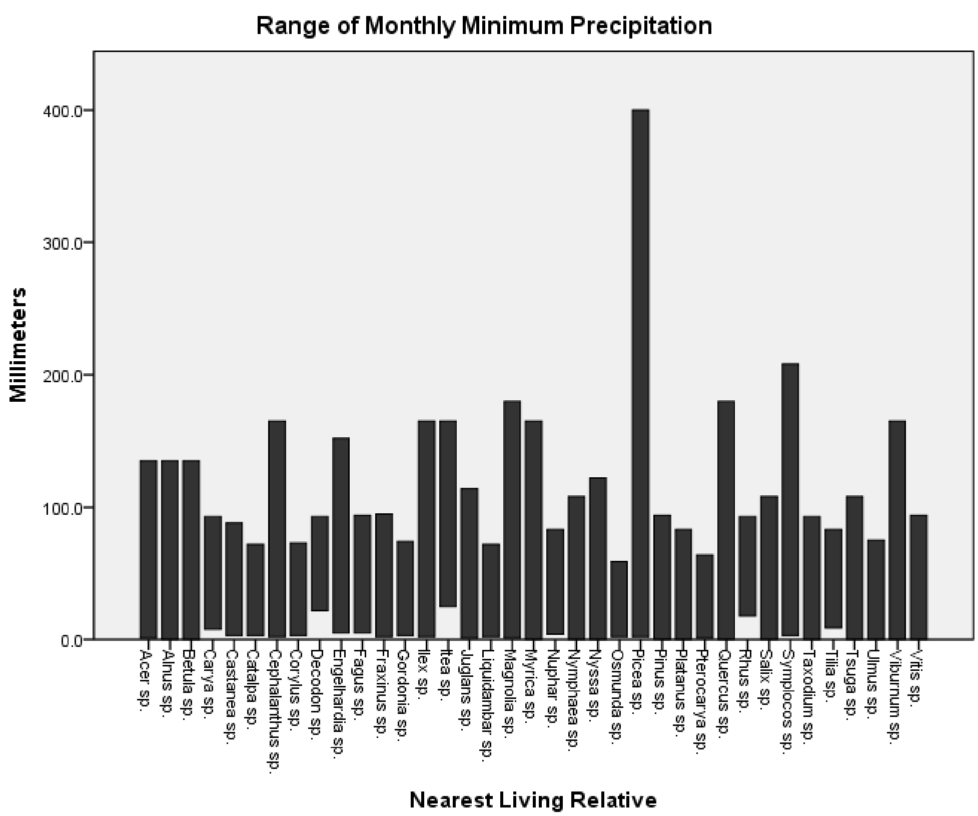


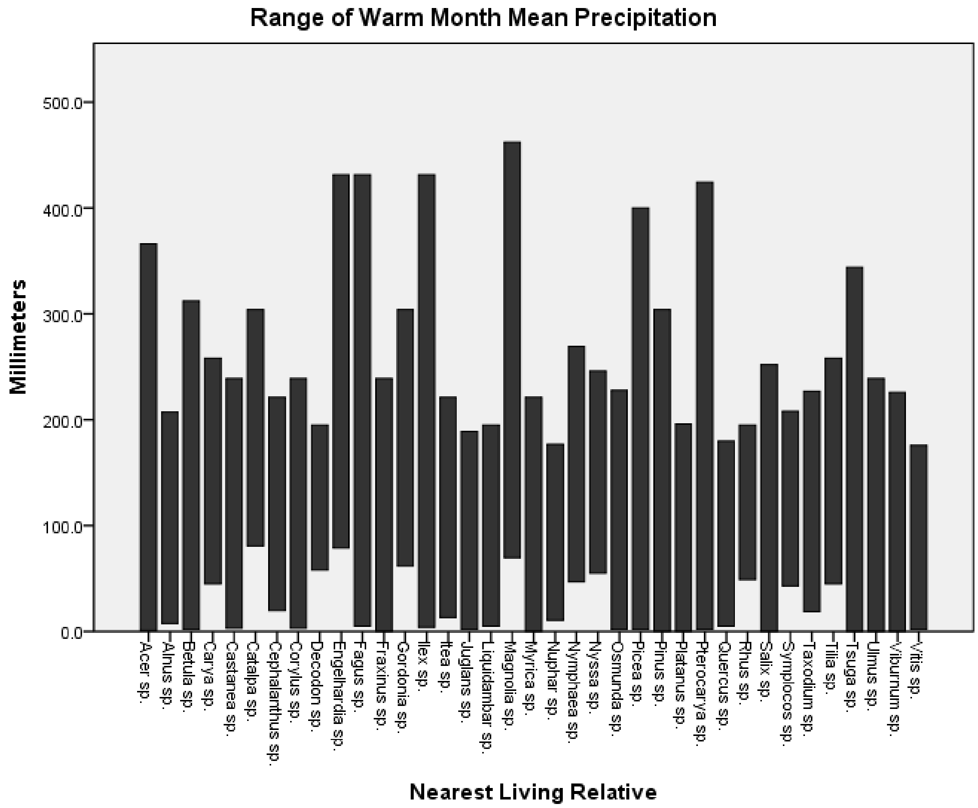
Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Catalpa sp.
Cephalanthus sp.
Corylus sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Myrica sp.
Nuphar sp.
Nymphaea sp.
Nyssa sp.
Osmunda sp.
Picea sp.
Pinus sp.
Platanus sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative



Range of Mean Annual Precipitation
Millimeters
6,000.0
5,000.0
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Catalpa sp.
Cephalanthus sp.
Corylus sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Myrica sp.
Nuphar sp.
Nymphaea sp.
Nyssa sp.
Osmunda sp.
Picea sp.
Pinus sp.
Platanus sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
1,000.0
800.0
600.0
400.0
200.0
0.0
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Catalpa sp.
Cephalanthus sp.
Corylus sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Myrica sp.
Nuphar sp.
Nymphaea sp.
Nyssa sp.
Osmunda sp.
Picea sp.
Pinus sp.
Platanus sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

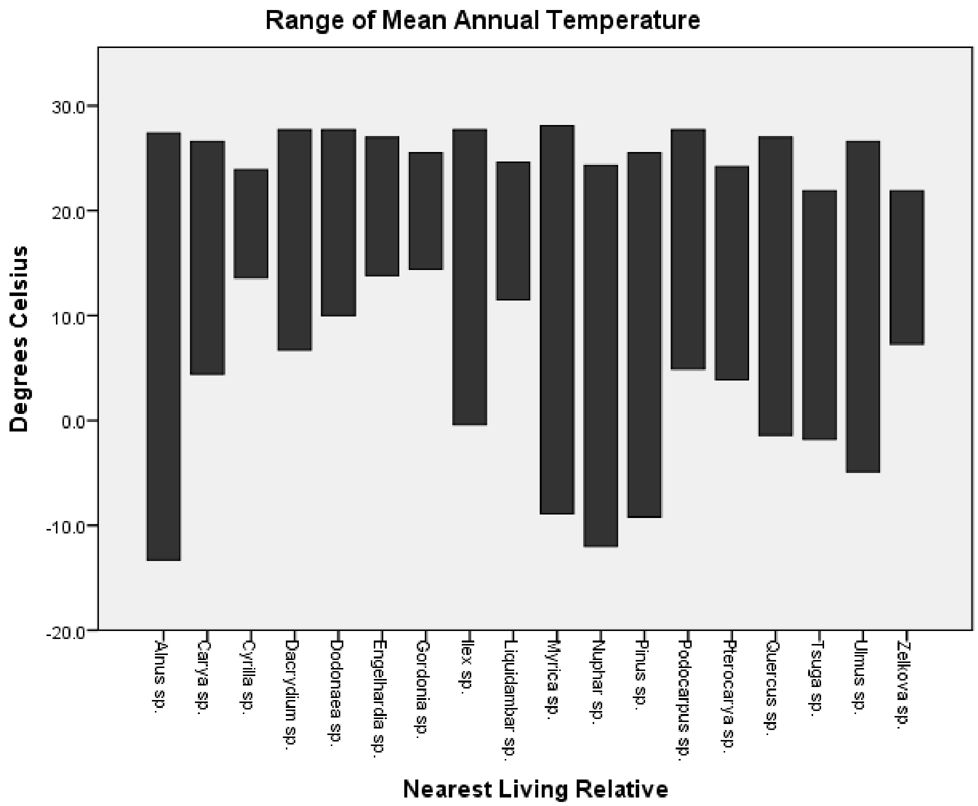

Range of Monthly Minimum Precipitation
Millimeters
400.0
300.0
200.0
100.0
0.0
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Catalpa sp.
Cephalanthus sp.
Corylus sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Myrica sp.
Nuphar sp.
Nymphaea sp.
Nyssa sp.
Osmunda sp.
Picea sp.
Pinus sp.
Platanus sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

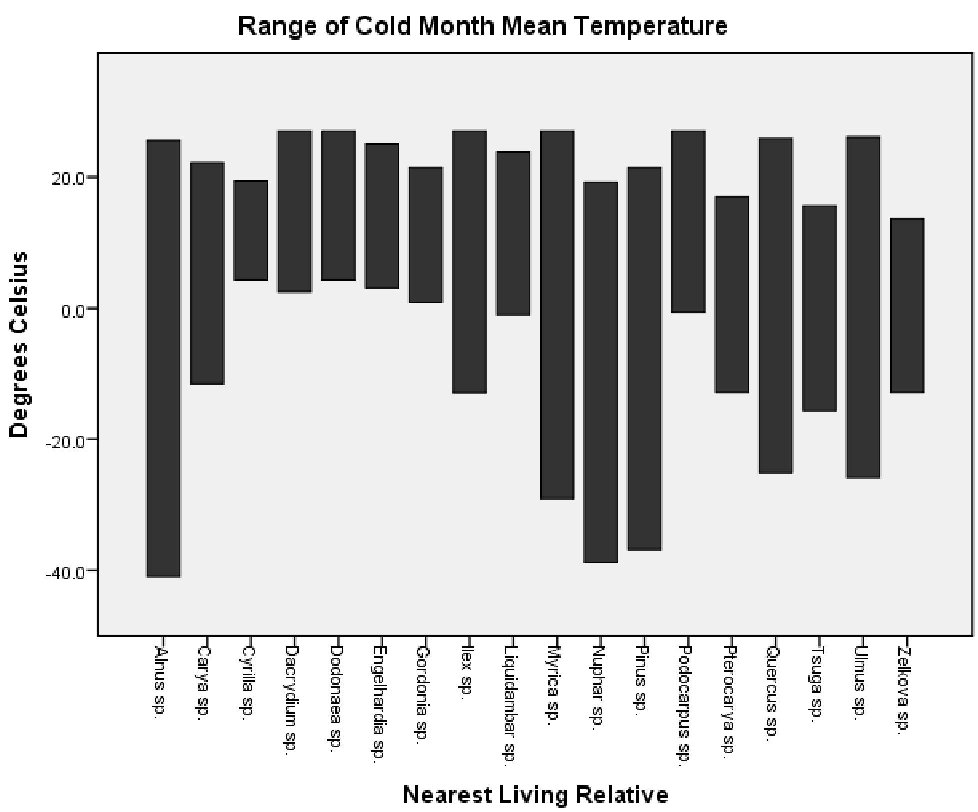

Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Acer sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Catalpa sp.
Cephalanthus sp.
Corylus sp.
Decodon sp.
Engelhardia sp.
Fagus sp.
Fraxinus sp.
Gordonia sp.
Ilex sp.
Itea sp.
Juglans sp.
Liquidambar sp.
Magnolia sp.
Myrica sp.
Nuphar sp.
Nymphaea sp.
Nyssa sp.
Osmunda sp.
Picea sp.
Pinus sp.
Platanus sp.
Pterocarya sp.
Quercus sp.
Rhus sp.
Salix sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Viburnum sp.
Vitis sp.
Nearest Living Relative

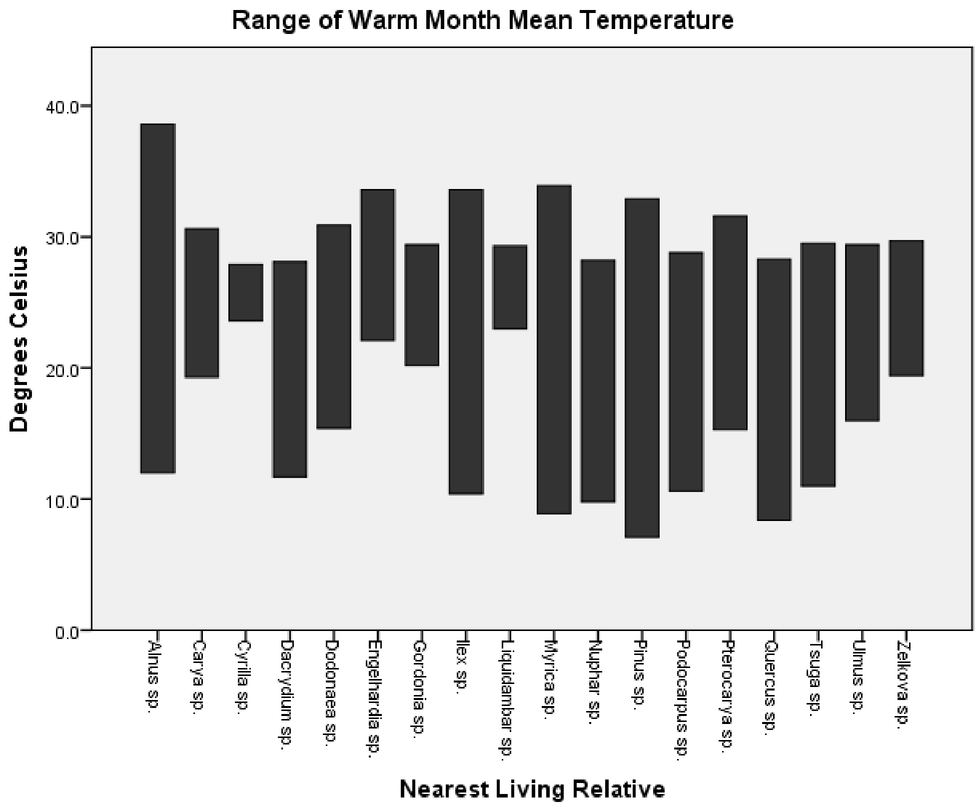
Appendix J

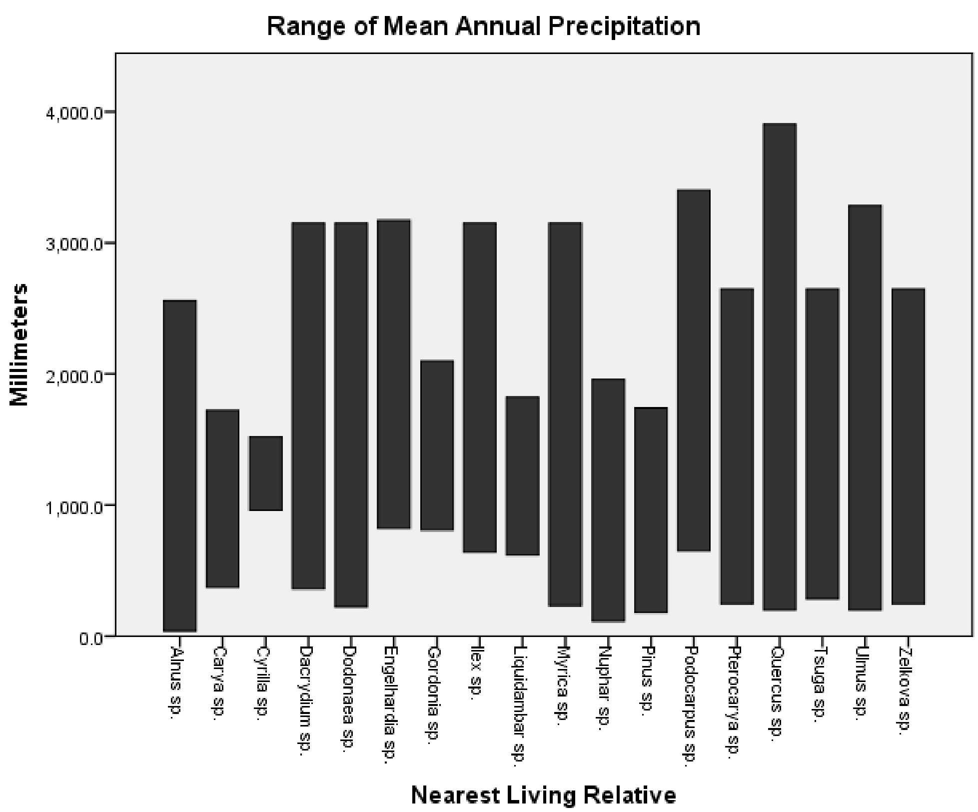
Peace Creek Raw Results and Climate Intervals

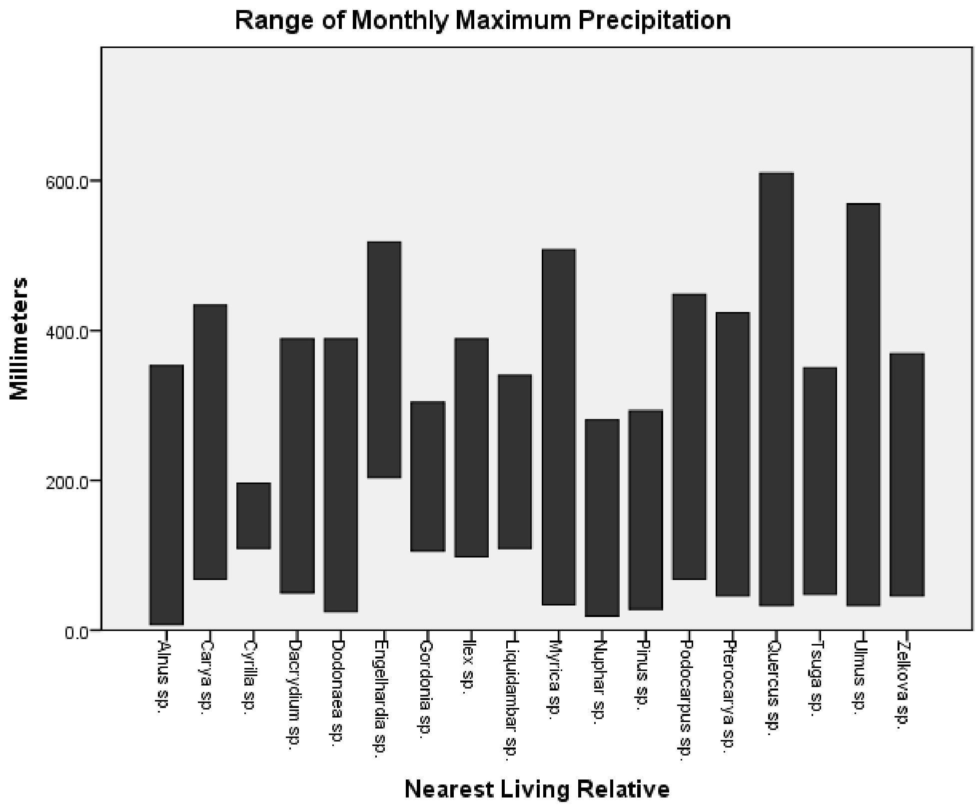
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Pollen	*Pinus*	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	Dodonaea	*Dodonaea sp.*	10 - 27.7	4.3 - 27	15.4 - 30.9	224 - 3151	25 - 389	6 - 165	18 - 304
	Liquidambar	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	Ulmus	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
	Pterocarya	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	Cyrilla racemiflora	*Cyrilla sp.*	13.6 - 23.9	4.3 - 19.4	23.6 - 27.9	961 - 1520	109 - 196	42 - 56	99 - 196
	Ilex	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Gordonia	*Gordonia sp.*	14.4 - 25.5	0.9 - 21.4	20.2 - 29.4	810 - 2100	106 - 304	3 - 74	62 - 304
	Myrica	*Myrica sp.*	-8.9 - 28.1	-29 - 27	8.9 - 33.9	233 - 3151	34 - 508	0 - 165	0 - 221
	Alnus	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41 - 2559	8 - 353	0 - 135	8 - 207
	Nuphar	*Nuphar sp.*	-12 - 24.3	-38.8 - 19.2	9.8 - 28.2	115 - 1958	19 - 281	4 - 83	11 - 177
	Tsuga canadensis-type/ cf. *Tsuga mertensiana*	*Tsuga sp.*	-1.8 - 21.9	-15.6 - 15.6	11 - 29.5	285 - 2648	48 - 350	0 - 108	0 - 344
	cf. *Dacrydium*	*Dacrydium sp.*	6.7 - 27.7	2.5 - 27	11.7 - 28.1	361 - 3151	50 - 389	2 - 165	2 - 221
	Podocarpus	*Podocarpus sp.*	4.9 - 27.7	-0.6- 27	10.6 - 28.8	652 - 3401	68 - 448	16 - 165	26 - 431
	cf. *Engelhardia*	*Engelhardia sp.*	13.8 - 27	3.1 - 25	22.1 - 33.6	823 - 3172	204 - 518	5 - 152	79 - 431
	cf. *Zelkova*	*Zelkova sp.*	7.3- 21.9	-12.8 - 13.6	19.4 - 29.7	24.6 - 2648	46 - 369	3 - 59	3 - 344

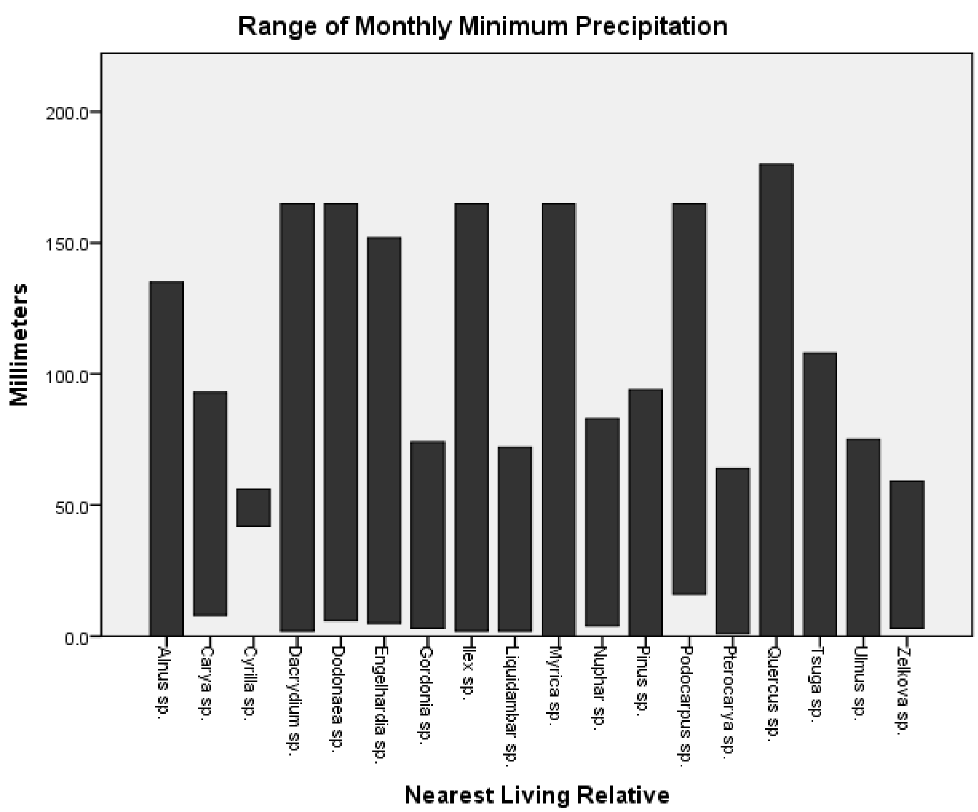

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Alnus sp.
Carya sp.
Cyrilla sp.
Dacrydium sp.
Dodonaea sp.
Engelhardia sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Myrica sp.
Nuphar sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative

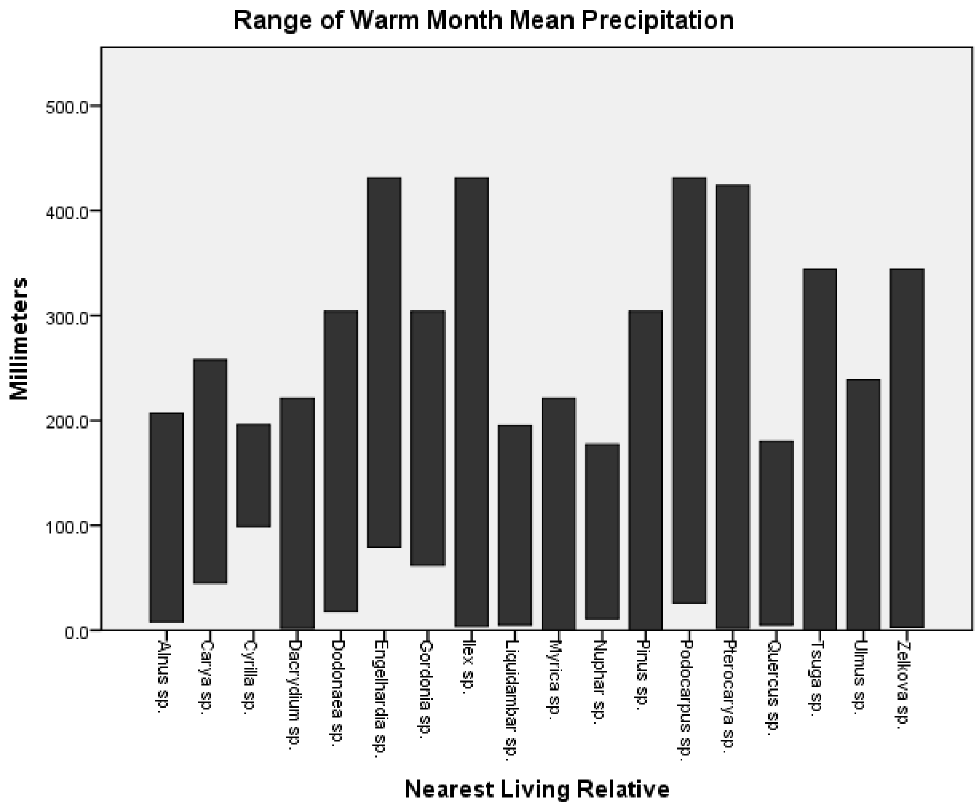

Range of Cold Month Mean Temperature
Degrees Celsius
20.0
0.0
-20.0
-40.0
Alnus sp.
Carya sp.
Cyrilla sp.
Dacrydium sp.
Dodonaea sp.
Engelhardia sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Myrica sp.
Nuphar sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Alnus sp.
Carya sp.
Cyrilla sp.
Dacrydium sp.
Dodonaea sp.
Engelhardia sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Myrica sp.
Nuphar sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Alnus sp.
Carya sp.
Cyrilla sp.
Dacrydium sp.
Dodonaea sp.
Engelhardia sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Myrica sp.
Nuphar sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Alnus sp.
Carya sp.
Cyrilla sp.
Dacrydium sp.
Dodonaea sp.
Engelhardia sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Myrica sp.
Nuphar sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative


Range of Monthly Minimum Precipitation
Millimeters
200.0
150.0
100.0
50.0
0.0
Alnus sp.
Carya sp.
Cyrilla sp.
Dacrydium sp.
Dodonaea sp.
Engelhardia sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Myrica sp.
Nuphar sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative



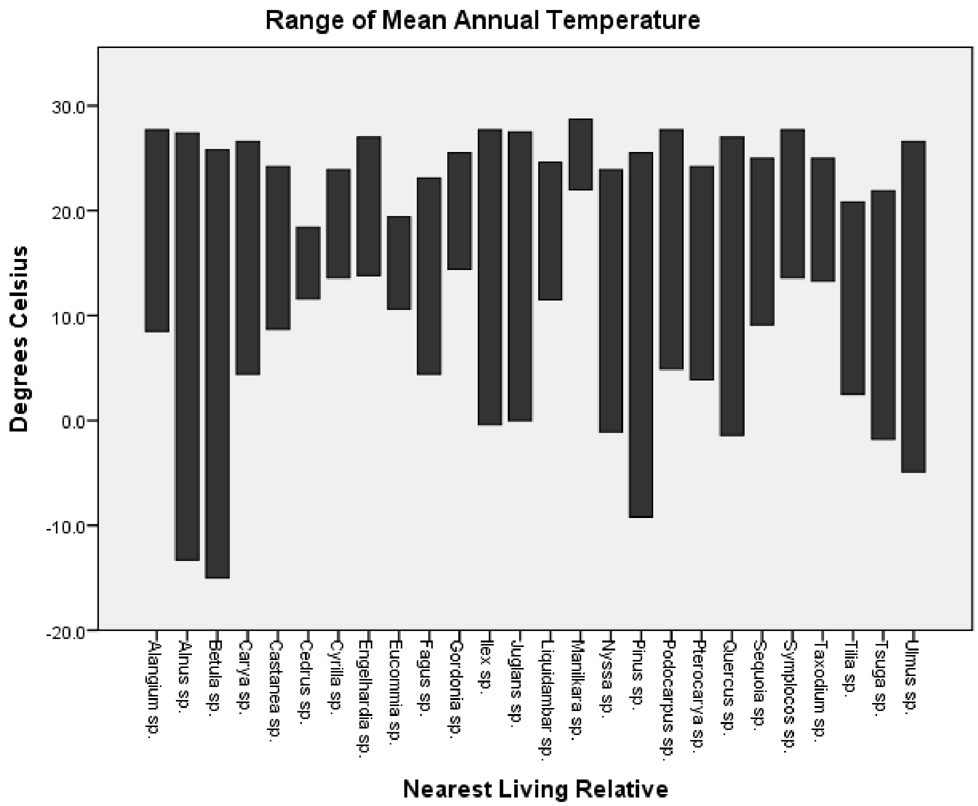
Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Alnus sp.
Carya sp.
Cyrilla sp.
Dacrydium sp.
Dodonaea sp.
Engelhardia sp.
Gordonia sp.
Ilex sp.
Liquidambar sp.
Myrica sp.
Nuphar sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Tsuga sp.
Ulmus sp.
Zelkova sp.
Nearest Living Relative

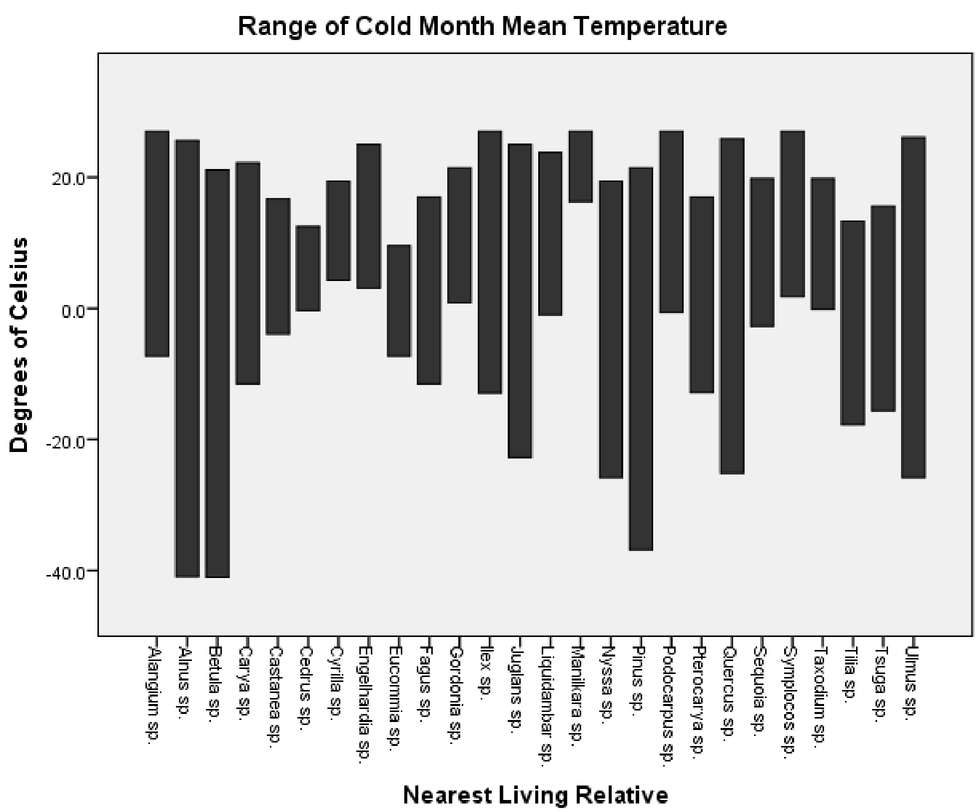
Appendix K

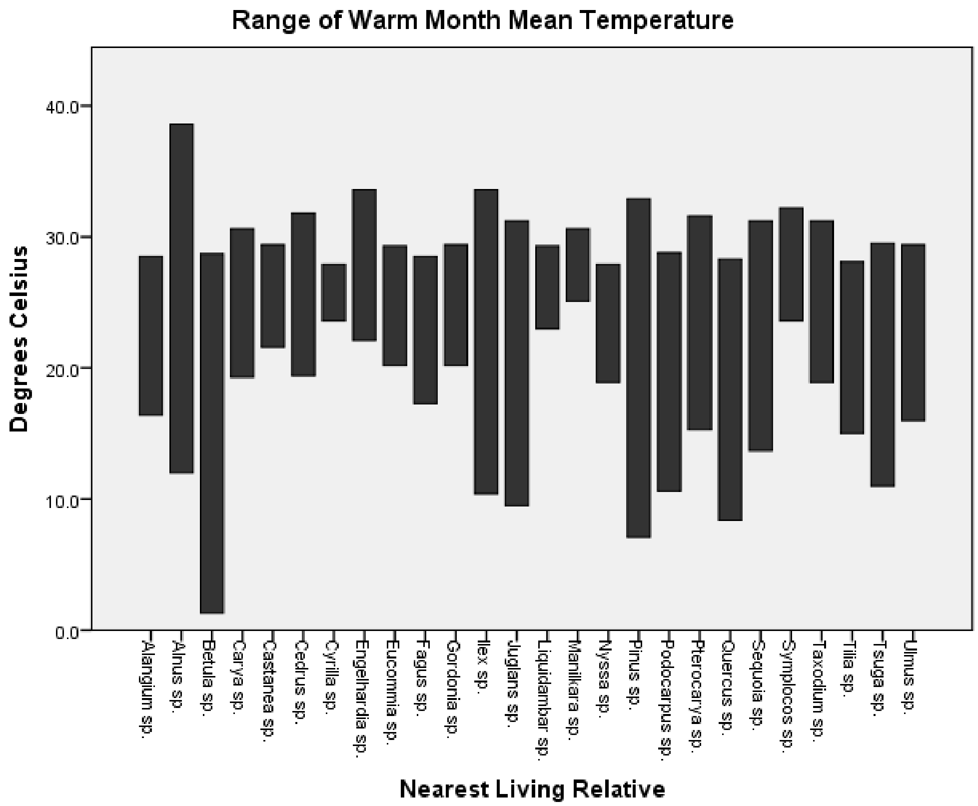
Pollack Farm Raw Results and Climate Intervals

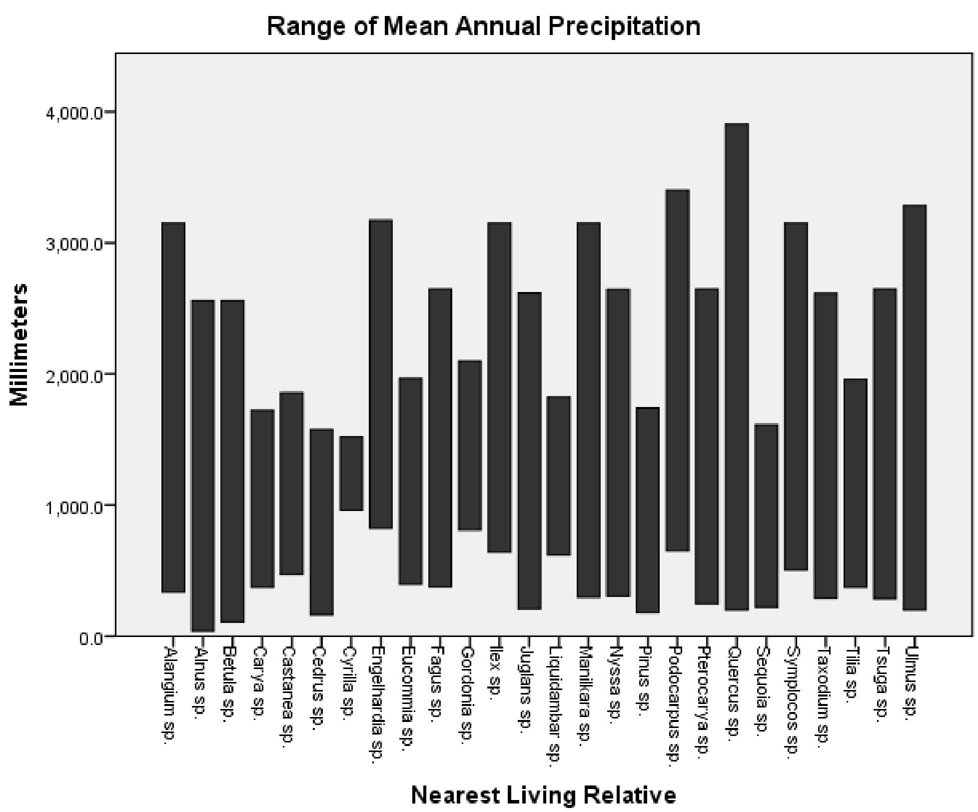
Organ	Fossil Taxon	NLR	MAT	CMMT	WMMT	MAP	MMaP	MMiP	WMMP
Pollen	*Alnus*	*Alnus sp.*	-13.3 - 27.4	-40.9 - 25.6	12 - 38.6	41 - 2559	8 - 353	0 - 135	8 - 207
	Betula	*Betula sp.*	-15 - 25.8	-41 - 21.1	1.3 - 28.7	110 - 2559	23 - 353	0 - 135	2 - 312
	Carya	*Carya sp.*	4.4 - 26.6	-11.5 - 22.2	19.3 - 30.6	373 - 1724	68 - 434	8 - 93	45 - 258
	**Momipites*	***Engelhardia sp.*	13.8 - 27	3.1 - 25	22.1 - 33.6	823 - 3172	204 - 518	5 - 152	79 - 431
	Juglans	*Juglans sp.*	0 - 27.5	-22.7 - 25	9.5 - 31.2	210 - 2617	28 - 582	1 - 114	2 - 189
	Pterocarya	*Pterocarya sp.*	3.9 - 24.2	-12.8 - 17	15.3 - 31.6	246 - 2648	46 - 424	1 - 64	2 - 424
	Castanea	*Castanea sp.*	8.7 - 24.2	-3.9 - 16.7	21.6 - 29.4	473 - 1857	70 - 424	3 - 88	3 - 239
	Fagus	*Fagus sp.*	4.4 - 23.1	-11.5 - 17	17.3 - 28.5	376 - 2648	46 - 448	5 - 94	5 - 431
	Quercus	*Quercus sp.*	-1.4 - 27	-25.1 - 25.9	8.4 - 28.3	201 - 3905	33 - 610	0 - 180	5 - 180
	Ilex	*Ilex sp.*	-0.4 - 27.7	-12.9 - 27	10.4 - 33.6	641 - 3151	98 - 389	2 - 165	4 - 431
	Liquidambar	*Liquidambar sp.*	11.5 - 24.6	-1 - 23.8	23 - 29.3	619 - 1823	109 - 340	2 - 72	5 - 195
	Nyssa	*Nyssa sp.*	-1.1 - 23.9	-25.8 - 19.4	18.9 - 27.9	305 - 2645	73 - 340	0 - 122	55 - 246
	Tilia	*Tilia sp.*	2.5 - 20.8	-17.7 - 13.3	15 - 28.1	373 - 1958	68 - 454	9 - 83	45 - 258
	Ulmus	*Ulmus sp.*	-4.9 - 26.6	-25.8 - 26.1	16 - 29.4	201 - 3285	33 - 569	0 - 75	0 - 239
	Cyrilla	*Cyrilla sp.*	13.6 - 23.9	4.3 - 19.4	23.6 - 27.9	961 - 1520	109 - 196	42 - 56	99 - 196
	Symplocos	*Symplocos sp.*	13.6 - 27.7	1.8 - 27	23.6 - 32.2	505 - 3151	109 - 436	3 - 208	43 - 208
	**Manilkara*	*Manilkara sp.*	22 - 28.7	16.3 - 27	25.1 - 30.6	298 - 3151	77 - 582	1 - 165	27 - 403
	Alangium(?)	*Alangium sp.*	8.5 - 27.7	-7.3 - 27	16.4 - 28.5	338 - 3151	92 - 389	1 - 165	66 - 221
	Gordonia	*Gordonia sp.*	14.4 - 25.5	0.9 - 21.4	20.2 - 29.4	810 - 2100	106 - 304	3 - 74	62 - 304
	Eucommia	*Eucommia sp.*	10.6 - 19.4	-7.3 - 9.6	20.2 - 29.3	396 - 1967	108 - 370	3 - 64	108 - 304
	Pinus	*Pinus sp.*	-9.2 - 25.5	-36.8 - 21.4	7.1 - 32.9	180 - 1741	28 - 293	0 - 94	0 - 304
	Tsuga	*Tsuga sp.*	-1.8 - 21.9	-15.6 - 15.6	11 - 29.5	285 - 2648	48 - 350	0 - 108	0 - 344
	Podocarpus	*Podocarpus sp.*	4.9 - 27.7	-0.6 - 27	10.6 - 28.8	652 - 3401	68 - 448	16 - 165	26 - 431
	**Cedrus*	*Cedrus sp.*	11.6 - 18.4	-0.3 - 12.5	19.4 - 31.8	164 - 1577	43 - 434	0 - 41	0 - 175
	Sequoia type	*Sequoia sp.*	9.1 - 25	-2.7 - 19.8	13.7 - 31.2	222 - 1613	60 - 245	0 - 93	3 - 227
	Taxodium	*Taxodium sp.*	13.3 - 25	-0.1 - 19.8	18.9 - 31.2	290 - 2615	60 - 265	0 - 93	19 - 227

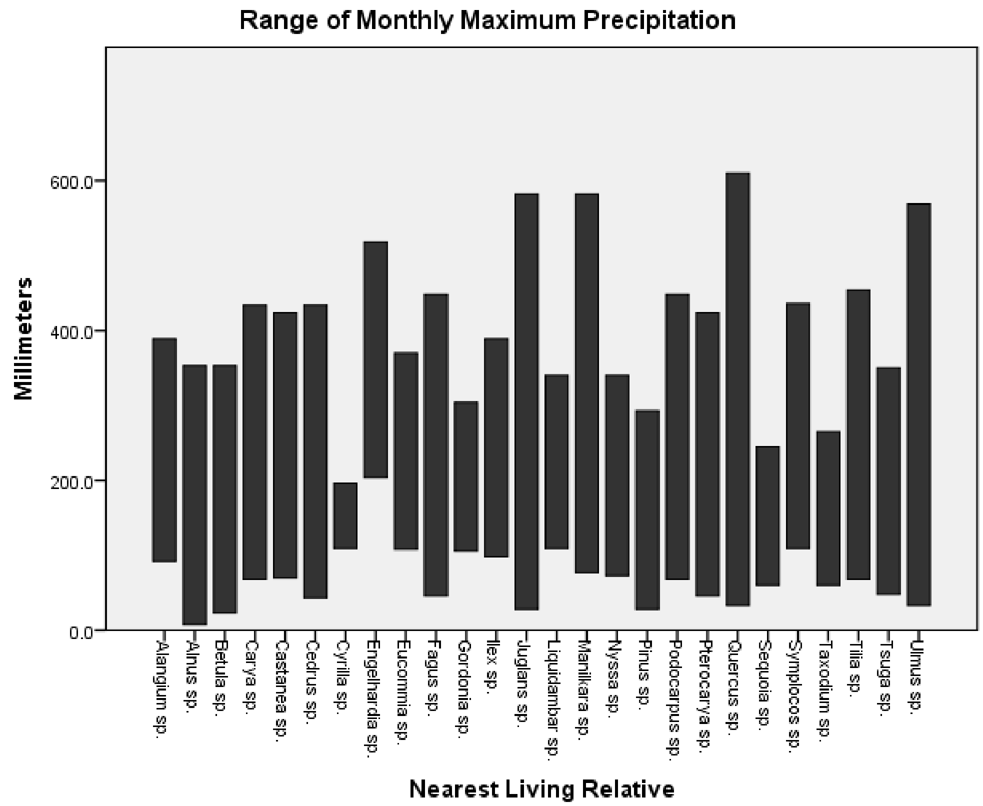
* Taxon is outlier in at least one climate interval
** Nearest Living Relative different genus than Fossil Taxon

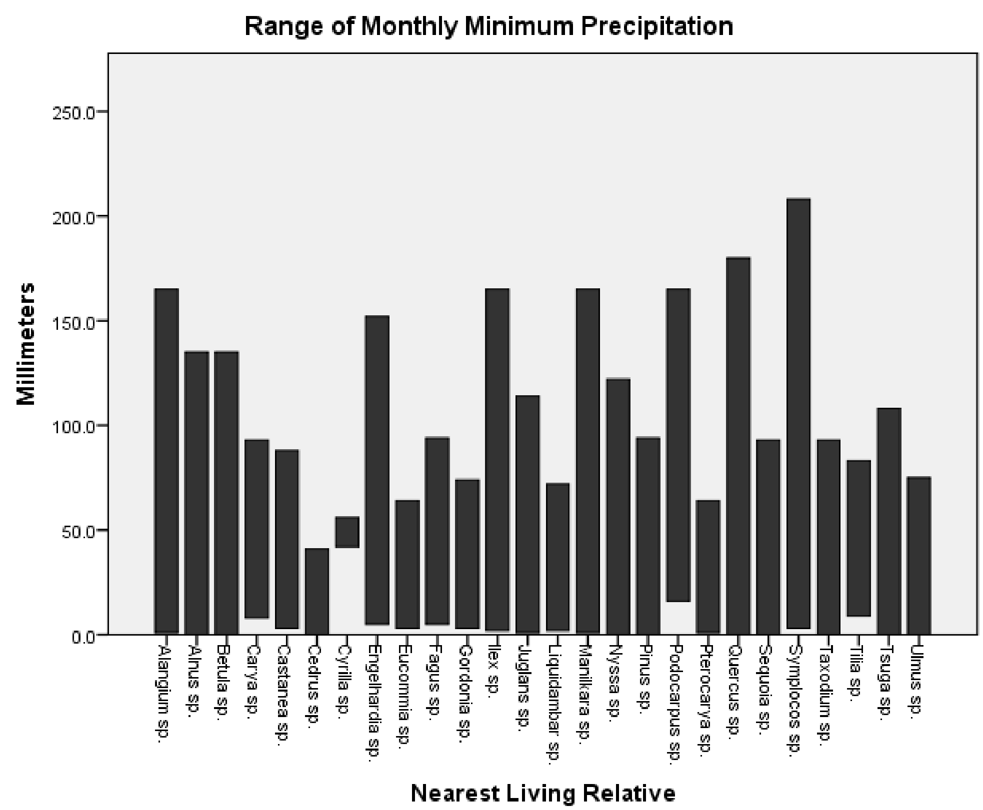

Range of Mean Annual Temperature
Degrees Celsius
30.0
20.0
10.0
0.0
-10.0
-20.0
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Cedrus sp.
Cyrilla sp.
Engelhardia sp.
Eucommia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Manilkara sp.
Nyssa sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Sequoia sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Nearest Living Relative

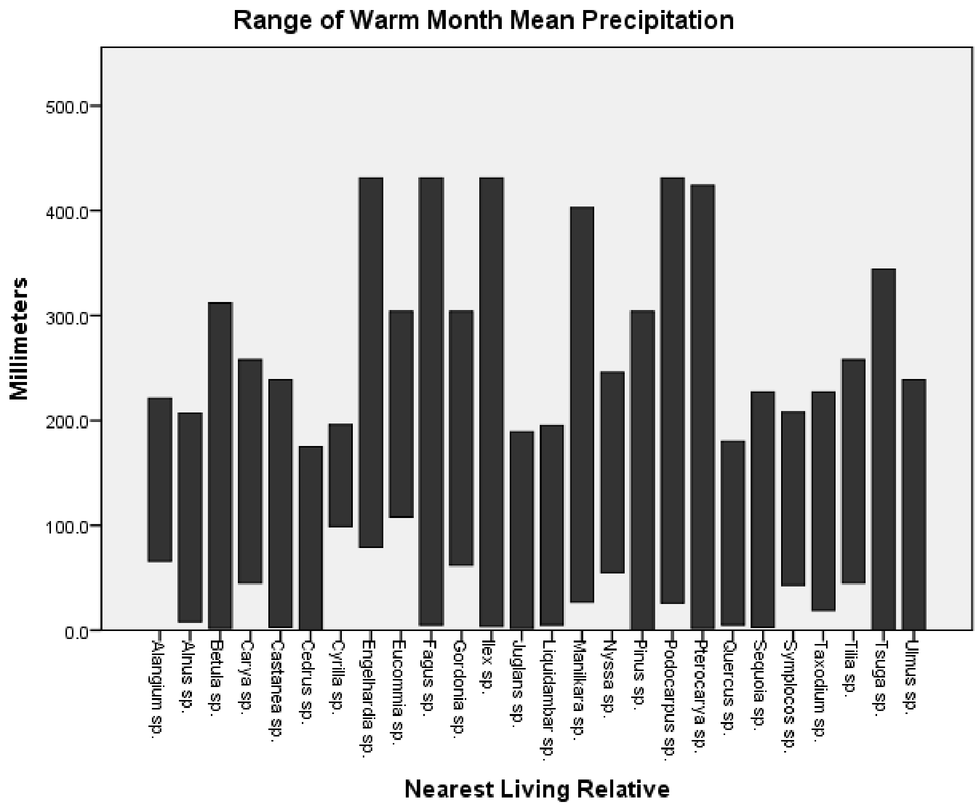

Range of Cold Month Mean Temperature
Degrees of Celsius
20.0
0.0
-20.0
-40.0
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Cedrus sp.
Cyrilla sp.
Engelhardia sp.
Eucommia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Manilkara sp.
Nyssa sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Sequoia sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Nearest Living Relative


Range of Warm Month Mean Temperature
Degrees Celsius
40.0
30.0
20.0
10.0
0.0
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Cedrus sp.
Cyrilla sp.
Engelhardia sp.
Eucommia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Manilkara sp.
Nyssa sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Sequoia sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Nearest Living Relative


Range of Mean Annual Precipitation
Millimeters
4,000.0
3,000.0
2,000.0
1,000.0
0.0
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Cedrus sp.
Cyrilla sp.
Engelhardia sp.
Eucommia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Manilkara sp.
Nyssa sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Sequoia sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Nearest Living Relative


Range of Monthly Maximum Precipitation
Millimeters
600.0
400.0
200.0
0.0
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Cedrus sp.
Cyrilla sp.
Engelhardia sp.
Eucommia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Manilkara sp.
Nyssa sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Sequoia sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Nearest Living Relative


Range of Monthly Minimum Precipitation
Millimeters
250.0
200.0
150.0
100.0
50.0
0.0
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Cedrus sp.
Cyrilla sp.
Engelhardia sp.
Eucommia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Manilkara sp.
Nyssa sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Sequoia sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Nearest Living Relative



Range of Warm Month Mean Precipitation
Millimeters
500.0
400.0
300.0
200.0
100.0
0.0
Alangium sp.
Alnus sp.
Betula sp.
Carya sp.
Castanea sp.
Cedrus sp.
Cyrilla sp.
Engelhardia sp.
Eucommia sp.
Fagus sp.
Gordonia sp.
Ilex sp.
Juglans sp.
Liquidambar sp.
Manilkara sp.
Nyssa sp.
Pinus sp.
Podocarpus sp.
Pterocarya sp.
Quercus sp.
Sequoia sp.
Symplocos sp.
Taxodium sp.
Tilia sp.
Tsuga sp.
Ulmus sp.
Nearest Living Relative

VITA

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Education:	Hanover-Horton Schools, Hanover and Horton, Michigan
	B.S. Program in the Environment, University of Michigan, Ann Arbor, Michigan 2012
	M.S. Biology, East Tennessee State University, Johnson City Tennessee 2014
Professional Experience:	Outreach Facilitator, University of Michigan Museum of Natural History, Ann Arbor, Michigan 2010-2011
	Docent, University of Michigan Museum of Natural History, Ann Arbor, Michigan 2010-12
	Volunteer Fossil Preparator, University of Michigan Museum of Paleontology, Ann Arbor, Michigan 2010-2012
	Paleontological Intern, The Mammoth Site of Hot Springs, South Dakota, 2011 and 2012
	Graduate Research Assistant, East Tennessee State University, Department of Biological Sciences, 2012-2014
	Lab Volunteer, Gray Fossil Site, Johnson City, Tennessee 2013-2014
Presentations:	Geological Society of America Annual Meeting, October, 2013 Baumgartner, Kyrie A. 2013. Paleoclimate Reconstructions of Three Mid-Atlantic Miocene Sites. Geological Society of America Abstracts with Programs 45:7.
	Lunchtime Lectures at the Gray Fossil Site, April 5, 2014 “Back to the Future: Paleoclimate, Paleoenvironment and the Gray Fossil Site”
Honors and Awards:	University Honors, University of Michigan, 2010 and 2012
	2013 GSA Southeast Section Student Travel Grant, Awarded by GSA

Golden Key International Honor Society Invitation, 2013

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ETSU Graduate & Professional Student Association-GPSA

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