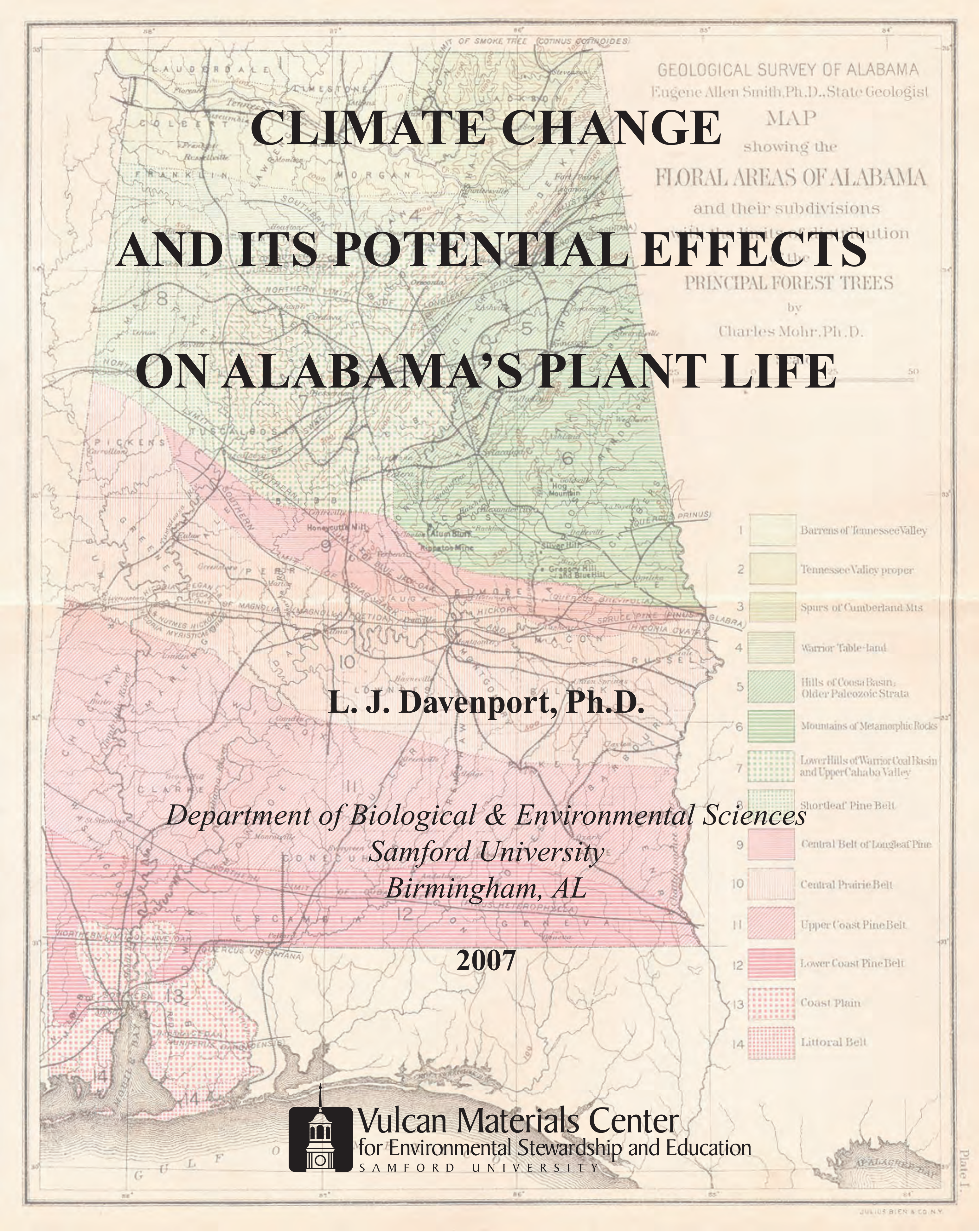
CLIMATE CHANGE

AND ITS POTENTIAL EFFECTS

ON ALABAMA'S PLANT LIFE



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2007

Vulcan Materials Center
for Environmental Stewardship and Education
SAMFORD UNIVERSITY

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PREFACE AND ACKNOWLEDGMENTS

Since the early 1980s, both scientists and the popular press have focused on climate change, or the potential for the Earth's surface temperatures to increase significantly. Almost immediately upon its "discovery," the issue of climate change became extremely political, with conservatives and liberals taking (polar) opposite sides: How much of this change is natural, and how much is human-induced? Most recently, the movie *An Inconvenient Truth*--written by, produced by, and starring former Vice President Al Gore--has heightened environmentalists' awareness of the potential warming while infuriating conservative columnists.

The purpose of this paper, however, is *not* to delve into the politics or examine the controversies concerning climate change. Instead, I will deal with potentials--the potential for warming and, very specifically, the potential for that warming to affect Alabama's plant life. The purpose of this paper, then, is to help the people of Alabama anticipate and prepare for this change--to know, in advance, what changes are likely to occur, and to modify current plans accordingly. Because the future will be, most likely, far different from the past.

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This project was undertaken during the summer of 2006, while I served as a Summer Scholar for the Vulcan Materials Center for Environmental Stewardship and Education. It was then presented to the Fall Conference ("Climate Change and Alabama: Prospects and Options") of the Alabama Environmental Education Consortium on 4 November 2006.

I am grateful to the Vulcan Materials Center for the sponsorship of this project, and especially to its directors and staff: Dr. Paul D. Blanchard, Dr. Ronald L. Jenkins, and Ms. Virginia N. Brown.

CLIMATE CHANGE AND ITS POTENTIAL EFFECTS ON ALABAMA’S PLANT LIFE

Chapter 1 - Climate Change and Global Warming

Chapter 2 - Climate Change and Alabama’s Native Plant Life

Chapter 3 - Climate Change and Alabama’s Agricultural Crops

Chapter 4 - Climate Change and Alabama’s Forests and Forest Products

CHAPTER 1 - Climate Change and Global Warming

Climate change, or global warming, is based on the study of past and present climates, plus the atmospheric factors that contribute to climate. Any significant trends are noted in these studies, and conjectures are made on the potential for the Earth's climate to change in the future.

Studies of climate change can be "pigeon-holed" into two basic categories: 1) those that measure current levels of atmospheric or "greenhouse" gases, and 2) those that examine trends in past climates. The combining of these lines of study leads to conjectures about future temperatures.

1a - Greenhouse Gases and Other Evidence for Climate Change

Greenhouse gases--carbon dioxide, nitrous oxide, methane, ozone, and others--are essential to life on Earth. These gases form a transparent blanket that allows sunlight through to warm the Earth's surface (and drive photosynthesis), trap reflected heat to sustain that warmth, and shield that surface from harmful radiation. In the words of Gates (1993, p 7): "Without the warm blanket, our planet would be too cold for life to prosper; without the ultraviolet shield, life would be destroyed; and without the clear window, life would not be formed."

But the accumulation of increased levels of these gases--whether from natural or human causes--can lead to the trapping of that heat and a concomitant rise in the Earth's surface temperatures. In recent years, scientists have examined trends in such heating both directly and indirectly, using data as diverse as historical records, atmospheric carbon dioxide levels, ice cores, and growth responses (especially tree rings and coral reefs). Mann et al. (1999) combined these data to produce a reconstruction of Northern Hemisphere surface temperature variations for the past millennium. This diagram (Figure 1) shows significant dips in temperature around 1500 CE (the "Little Ice Age") and rather cool temperatures during the 1800s, followed by a significant spike upward that continues today. Called the "hockey stick" due to its shape, this diagram and its attendant data have been scrutinized, debated and, at times, berated. A recent review by the National Research Council (2006), however, has validated the "hockey stick" and its re-creation of the past climate history of the Northern Hemisphere.

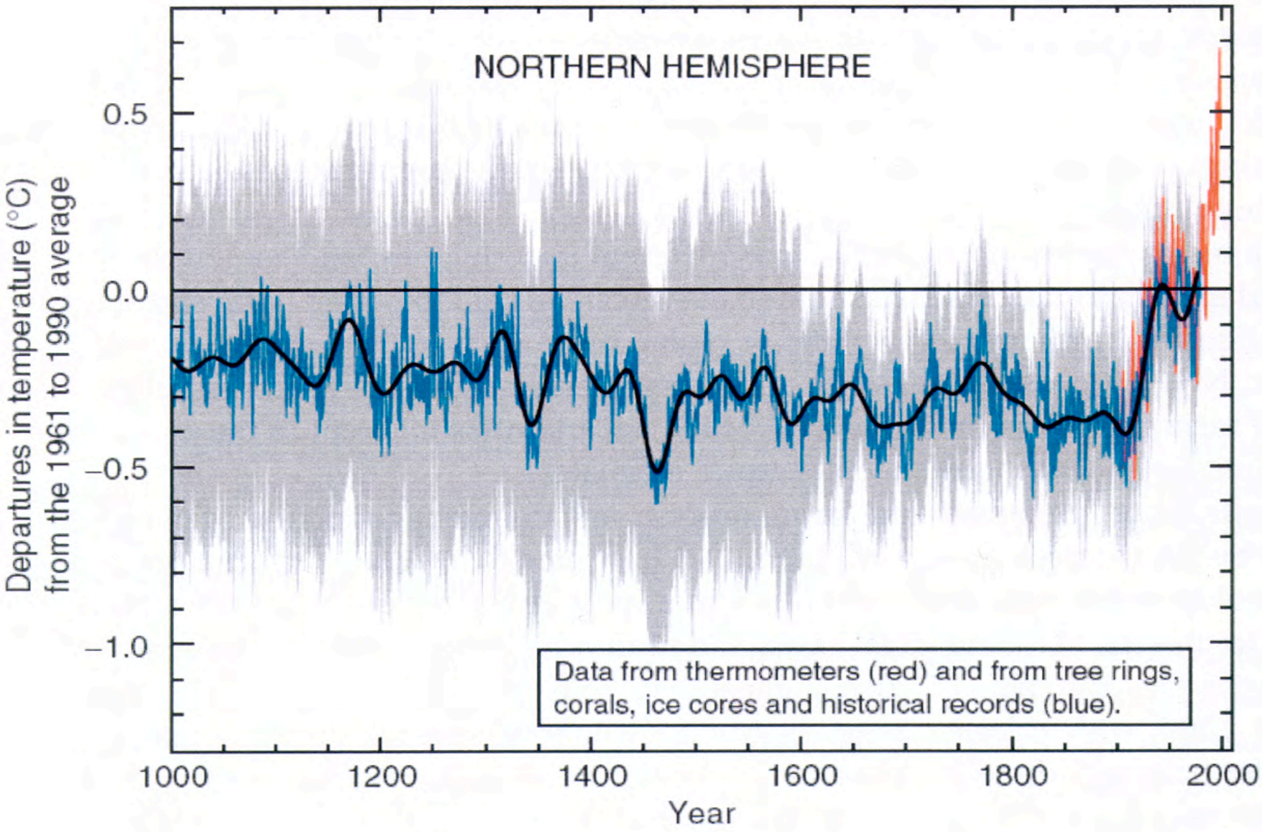


Figure 1. Reconstruction of Northern Hemisphere surface temperature variations over the past millennium (blue), along with 50-year average (black), a measure of the statistical uncertainty associated with reconstruction (gray), and instrumental surface temperature data for the last 150 years (red). Based on Mann et al. (1999); from National Research Council (2006).

1b - Predictions for Global Climate Change

Other scientists have developed models to predict future global climate change beyond the end of the "hockey stick." These models differ in the assumptions made for future greenhouse emissions, possible legal controls on such emissions, the potential ameliorating effects of cloud cover and ocean circulation, and numerous other factors. In a well-reasoned review for the Pew Center on Global Climate Change, Wigley (1999) chose four basic models and described their differing predictions. With these models, future global mean warming (from 1990-2100) ranged from 1.9 to 2.9C. Projected sea level rise, based on that temperature range combined with parameters for ice melt, ranged from 46 to 58 cm.

1c - Predictions for Regional Climate Change

Compared to the above global effects, predictions for regional climate change are more problematic. To make these conjectures, a number of general climate models (GCMs) have been devised, with each based on a different set of assumptions.

In continuing his review, Wigley (1999) evaluated fifteen different GCMs in two ways. First, he compared model simulations of present-day climate (in this case, precipitation) with actual observations, finding the highest correlation (0.77) with the United Kingdom's Hadley Centre's HadCM2 model. He then compared the results of the different models for projected climate change due to the doubling of carbon dioxide levels. The data used were seasonal-mean changes in both temperature and precipitation for winter, spring, summer, and fall.

As expected, the comparisons of the models differed greatly. The best results, with the greatest consistency between models, were obtained for winter temperature-change patterns, with many models showing enhanced winter warming in the northern United States. The worst results, with the greatest differences between models, were obtained for summer and fall precipitation-change patterns.

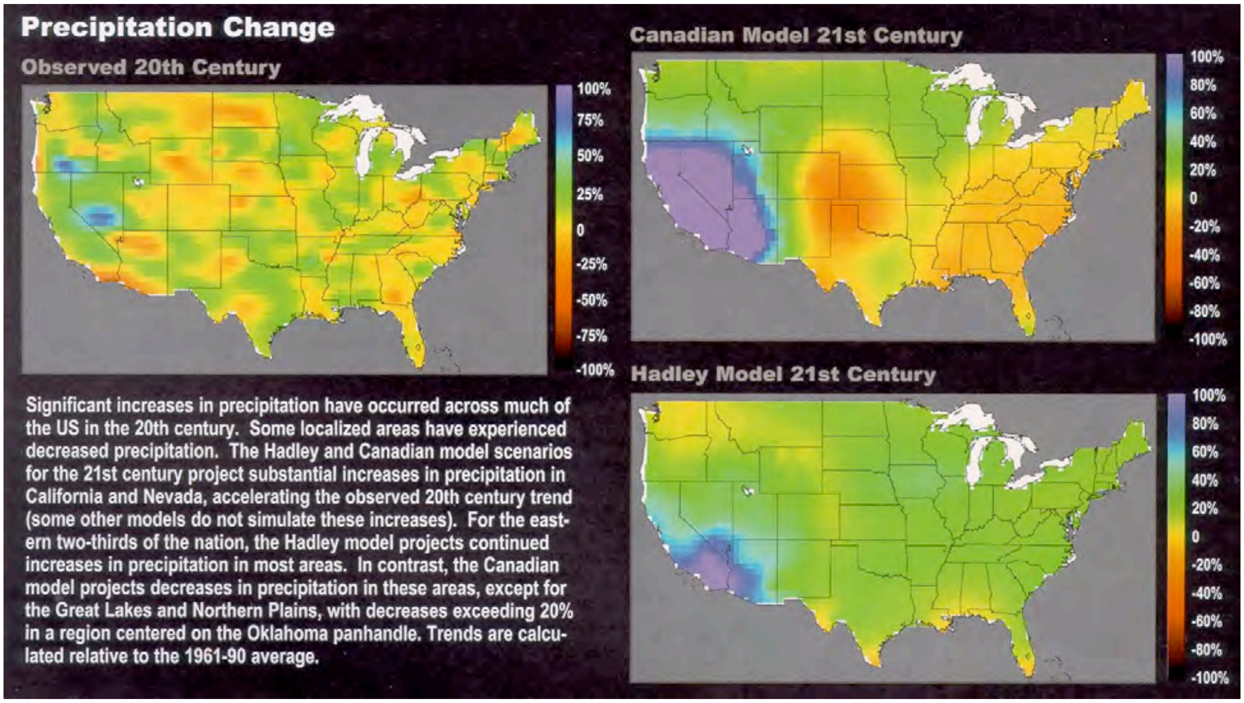
Wigley (1999) then combined the means for temperature change for the fifteen models, finding that, in most of the continental United States and in all four seasons, the projected warming exceeded the global mean rate. States from North Dakota eastward to Maine showed warming up to two times the global mean. In contrast, the Southeast and Southwest showed warming slightly below that mean. (While all of Alabama will likely experience some warming, the most significant amount will occur in its northern half.)

Wigley (1999) also combined the model-average results for precipitation change. (The percent precipitation change ranged from -4 to +8.) While most of the continent will undergo significant increases in precipitation, a large part of the Central States and Midwest is projected to suffer drought during the summer and fall. Alabama is projected to experience a slightly drier winter and summer, slightly wetter spring, and significantly wetter fall.

From his studies, Wigley (1999, p 30) also predicted that, with a general global warming trend, "the frequency of warm temperature extremes (on all time scales--days, seasons, and years) will increase and the frequency of cold extremes (like frost days) will decrease." Changes in the interannual variability of temperature and precipitation, however, have proved impossible to predict through these models.

Some studies (e.g., Fowler & Hennessy, 1995) suggest that, with increased temperatures, certain regions will experience more frequent and intense precipitation events; other regions will suffer more frequent and longer dry spells. But, again citing the large inter-model differences in projections of mean precipitation change, Wigley (1999, p 32) stated, “while both types of change (more frequent wet extremes and dry extremes) are possible in the United States, there is no unequivocal evidence for either.”

Obviously, due to the different assumptions made, little consensus can be found between these GCMs. To illustrate, the contrasting predictions of two such models (“Hadley Centre” and “Canadian”) for precipitation change and summer moisture change are shown in Figures 2 and 3.

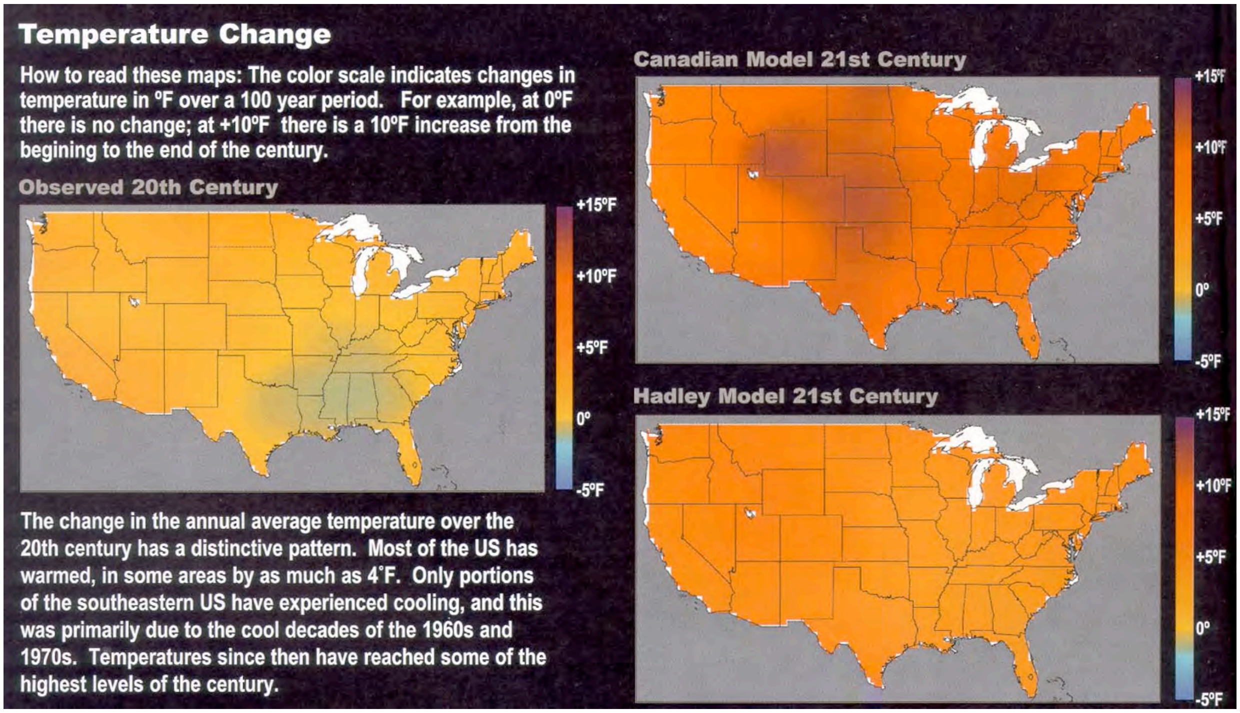


Significant increases in precipitation have occurred across much of the US in the 20th century. Some localized areas have experienced decreased precipitation. The Hadley and Canadian model scenarios for the 21st century project substantial increases in precipitation in California and Nevada, accelerating the observed 20th century trend (some other models do not simulate these increases). For the eastern two-thirds of the nation, the Hadley model projects continued increases in precipitation in most areas. In contrast, the Canadian model projects decreases in precipitation in these areas, except for the Great Lakes and Northern Plains, with decreases exceeding 20% in a region centered on the Oklahoma panhandle. Trends are calculated relative to the 1961-90 average.

Figure 2. Predictions of the Hadley and Canadian models for future regional precipitation change. From National Assessment Synthesis Team (2000).

1d - Predictions for Alabama’s Climate Change

Few predictions of climate change are devoted solely to Alabama. One website, maintained by the Union of Concerned Scientists (2006), has a number of such predictions or projections. However, the original sources for these projections were not cited:



Temperature Change

How to read these maps: The color scale indicates changes in temperature in °F over a 100 year period. For example, at 0°F there is no change; at +10°F there is a 10°F increase from the begining to the end of the century.

Observed 20th Century

The change in the annual average temperature over the 20th century has a distinctive pattern. Most of the US has warmed, in some areas by as much as 4°F. Only portions of the southeastern US have experienced cooling, and this was primarily due to the cool decades of the 1960s and 1970s. Temperatures since then have reached some of the highest levels of the century.

Canadian Model 21st Century

Hadley Model 21st Century

Figure 3. Predictions of the Hadley and Canadian models for future regional temperature change. From National Assessment Synthesis Team (2000).

1) A 3-10°F [1.6-5.5°C] rise in winter low temperatures and a 3-7°F [1.6-3.8°C] rise in summer highs.

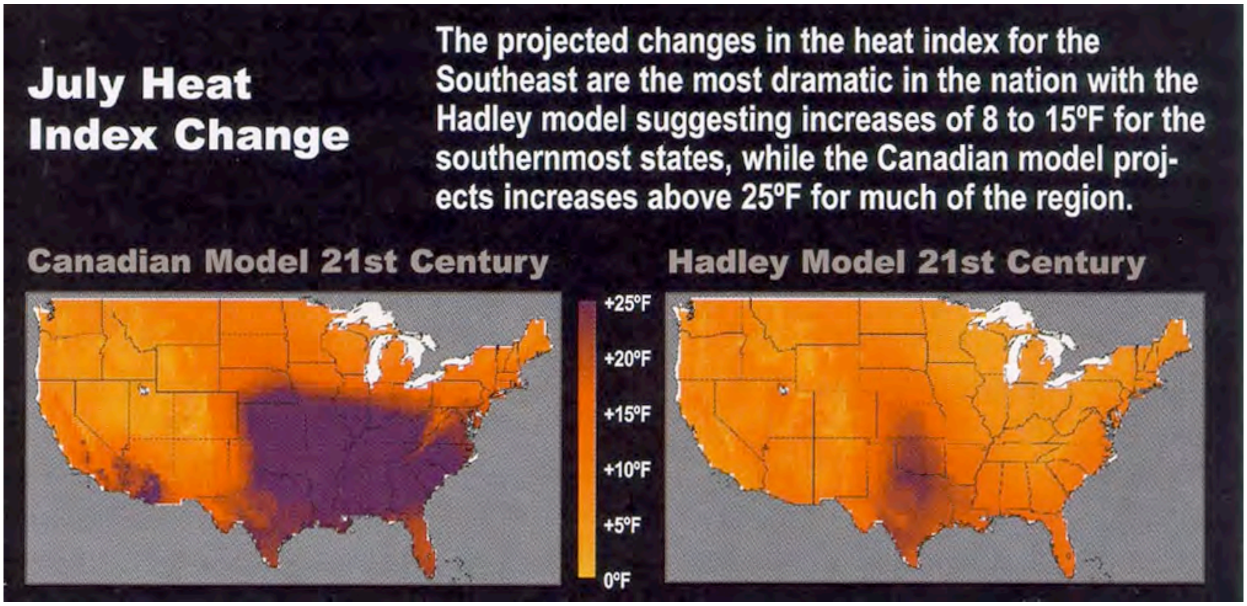
2) The July heat index could rise by 10-25°F in Alabama--a major jump in the temperature actually felt. (See Figure 4.)

3) The freeze line will move north.

4) Rainfall will decrease in the immediate coastal region.

5) Summer soil moisture will either increase or decrease in the northern parts of the state, depending on the model utilized. The same is true for upland areas.

6) "More frequent intense rainfall events are expected, with longer dry periods in between. Hurricane intensity...could increase slightly..., although changes in future hurricane frequency are



The projected changes in the heat index for the Southeast are the most dramatic in the nation with the Hadley model suggesting increases of 8 to 15°F for the southernmost states, while the Canadian model projects increases above 25°F for much of the region.

Figure 4. Predictions of the Hadley and Canadian models for future July heat index change. From National Assessment Synthesis Team (2000).

uncertain. Even if storm frequencies and intensities remain constant, the damages from coastal flooding and erosion will increase as sea level rises."

7) "Sea level will increase at a faster rate over the coming century. By 2100, ocean levels around Alabama could be 15 inches [38 cm] higher than today, based on a continued average subsidence rate of 2 inches per century and a mid-range sea-level rise scenario."

In general, these projections fit those made by Wigley (1999), although the projected temperature increases are more similar to those for northern states. The projected sea level rise for Alabama is below Wigley's global average. It should also be noted that Wigley (1999) raised doubts about the frequency and intensity of future extreme weather events.

CHAPTER 2 - Climate Change and Alabama's Native Plant Life

The biological diversity of Alabama is well-known and universally acknowledged. Of the United States, Alabama ranks fourth in total number of species of plants and animals, and second (to Florida) in the number of species per square mile (Hilton, 2000).

2a - History of Studies - Alabama's Ecoregions

Mohr (1880, 1901) was the first to systematically document Alabama's plant diversity. (His monumental *Plant Life of Alabama* remains the only complete treatment of the state's flora; see Davenport [1979, 1988] for details of the book's scope and history of its publication.) Mohr (1901) related the rich biodiversity of Alabama's plant life to a number of factors, including its equable climate, varied topography, and geologic and vegetational history:

> *Owing to its geographical position, extending from its northern confines to the Gulf shore, over five degrees of latitude, and further to the difference in elevation between its northern and southern sections, the State of Alabama is favored by a varied, but in its extreme not excessive climate. The climatic conditions give rise in the upper part of the State to a vegetation closely related in character to that prevailing in the cooler temperate zone, and in the lower division stamp upon it the features of subtropical regions.* (p 24-25)
>
> *Equally open to the influences of the warm and vapor-laden breezes from the Mexican Gulf and the intertropical Atlantic Ocean and the cool and drier aerial currents from the north unimpeded by mountain ranges or table-lands of very great elevation, the climate is mild and equable.* (p 25)

> *The meteorological region including Alabama receives the supply of moisture for its precipitation principally from the Gulf of Mexico. In the distribution over time and space the rainfall is of great uniformity. ...Such a plentiful and evenly distributed, but not excessive, supply of atmospheric moisture, in connection with a mild and equable temperature, is productive of a highly luxuriant vegetation, which is most strikingly exhibited in its arboreal growth.* (p 26)
>
> *[The northern portion of Alabama] offers great complexity in its geological formation, almost every stratum of the various geological epochs being here represented. This gives rise to greater diversity of topography and soil than exists in any other of the Gulf States, thus producing that variety of resources which gives Alabama such a prominent position among her sister States.* (p 18)
>
> *...[T]he occurrence of the hemlock...on the extreme southern extension of the Allegheny Mountains, in Winston County, Ala., in a completely isolated spot hundreds of miles distant from the range of its distribution, can be accounted for when they are regarded as the sole remnants of the northern arboreal flora which during the glacial period was pushed to lower latitudes and which on its recession to cooler zones left these trees behind....* (p 34)

Mohr (1901) listed about 2500 species of vascular plants growing without cultivation in Alabama, noting that only three of these were endemic or restricted to the state’s boundaries. He related this paucity of endemic species to

> *the absence of any serious obstacles to plant migration from and to all parts of the eastern section of this continent. The gradual descent of the Allegheny Mountains to the*

> *Coastal plain rendered the influx of plants from the north and east easy. The oldest types flourishing on the most ancient strata succumbed gradually to the vicissitudes of eons of time and gave way to later invaders. Completely open on the east and the west, the denizens of the plant world from these directions found no hindrance in peopling the new soils of the secondary (Mesozoic and Cenozoic) formations, after their rise above the water*. (p 39)

Mohr (1901) concluded that, due to this lack of obstacles to migration, the plant life of Alabama

> *coincides closely with the flora of the adjoining regions. In its southern portion it is very intimately related to the flora of western Florida, Mississippi, and eastern Louisiana, equally so to that of the maritime plain of North and South Carolina and Georgia, and in a less degree to that of western Louisiana and eastern Texas. In its central parts the same close connection exists with the flora of the middle region (Piedmont region) of these States and with that of southern Arkansas. The flora of the northern part of the State, with its mountains and the Tennessee Valley, presents a similar relationship with the flora of the Allegheny ranges south of the Potomac River, below an elevation of 2,000 to 2,500 feet above sea level, and with that of the southern extension of the Cumberland Mountains and the rim of the Highlands of Tennessee.* (p 39)

Based on the above observations on climate and plant distributions, Mohr (1901) created a multi-colored "Map showing the FLORAL AREAS OF ALABAMA and their subdivisions with the limits of distribution of the PRINCIPAL FOREST TREES" to include with his tome. (It is reproduced here as Figure 5.) He divided the state according to Merriam's Life Zones, which are based on general climate and average temperature, with the upper half designated as the

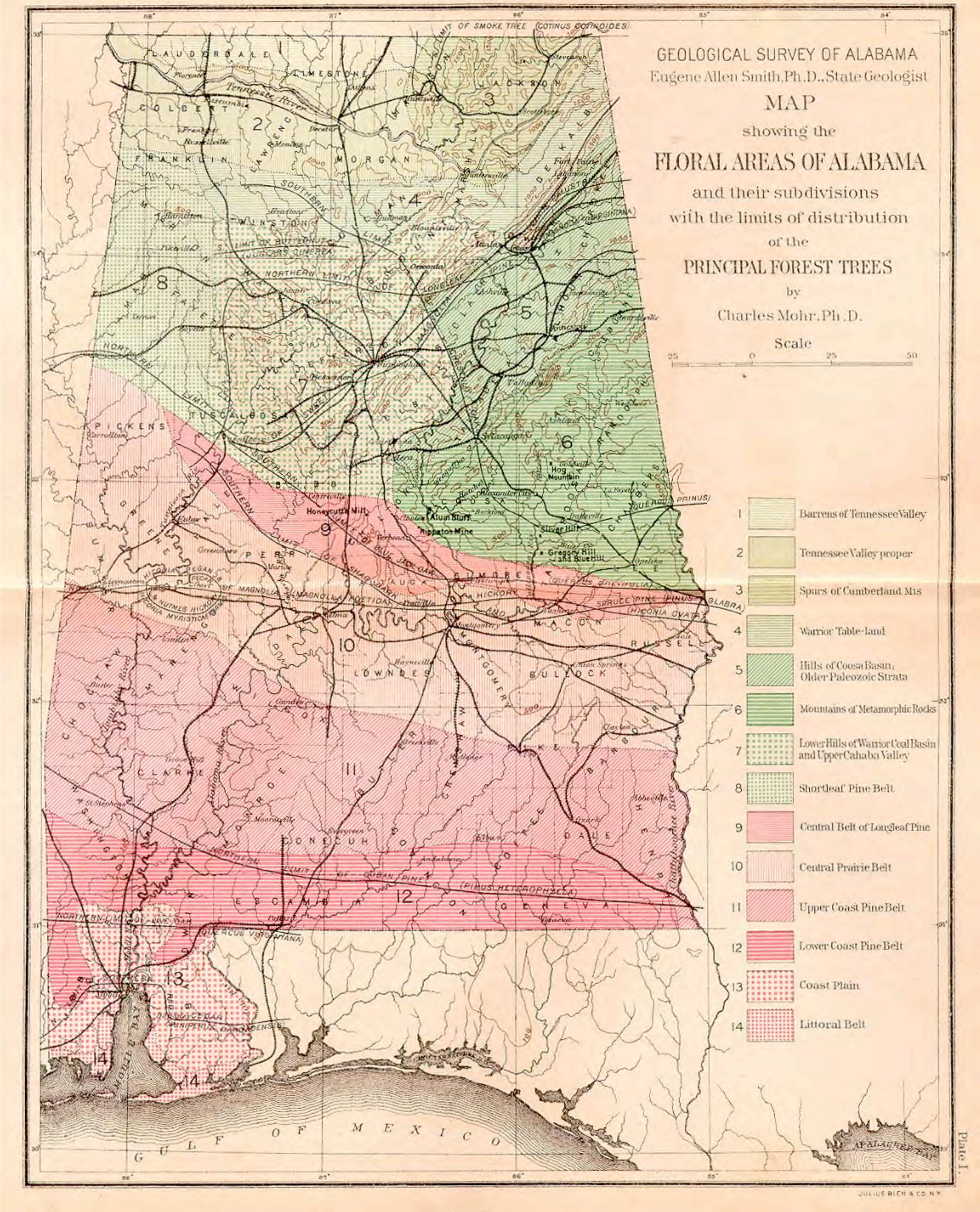


Figure 5. The first map of the floristic regions of Alabama. From Mohr (1901).

Carolinian Area and the lower half as the Austroriparian or Louisianan Area. He then subdivided these two climatic areas by soil, substrate, and other characteristics to create his floral areas or ecoregions, describing the plant associations within each.

Over forty years later, Harper (1943) revised and refined Mohr's depictions of the ecological regions of Alabama. He noted (p 63) that "in a state the size of ours, with no lofty mountains, the climate varies gradually from place to place, and the extremes are not far apart, so that it [climate] cannot be used for defining regions." Instead, "the geological formations influence the soil and topography so directly that a map of forest regions does not differ much in its broader features from a geological map." (Harper's map is reproduced here as Figure 6.) Harper's ecoregions, based primarily on geology and soils, remain nearly unchanged in the recent treatment by Griffith et al. (2001; see Figure 7).

2b - Alabama's Current Ecoregions

Griffith et al. (2001), in providing the most recent delineation, treat Alabama's ecoregions as continuous with those of adjoining states and standardize the treatment and terminology for the eastern United States. However, in painting with this broader brush, many details were omitted. Therefore, while the numbering, taxonomy, and basic discussion below follow Griffith et al. (2001), many of the details on the vegetation were added from Harper's (1943) work.

45 Piedmont

A triangular, northeast-southwest trending ecoregion**,** the Piedmont serves as a transitional area between the Appalachian Mountains and the flatter coastal plain formations. The fine-textured soils develop over a mosaic of Precambrian and Paleozoic metamorphic and igneous

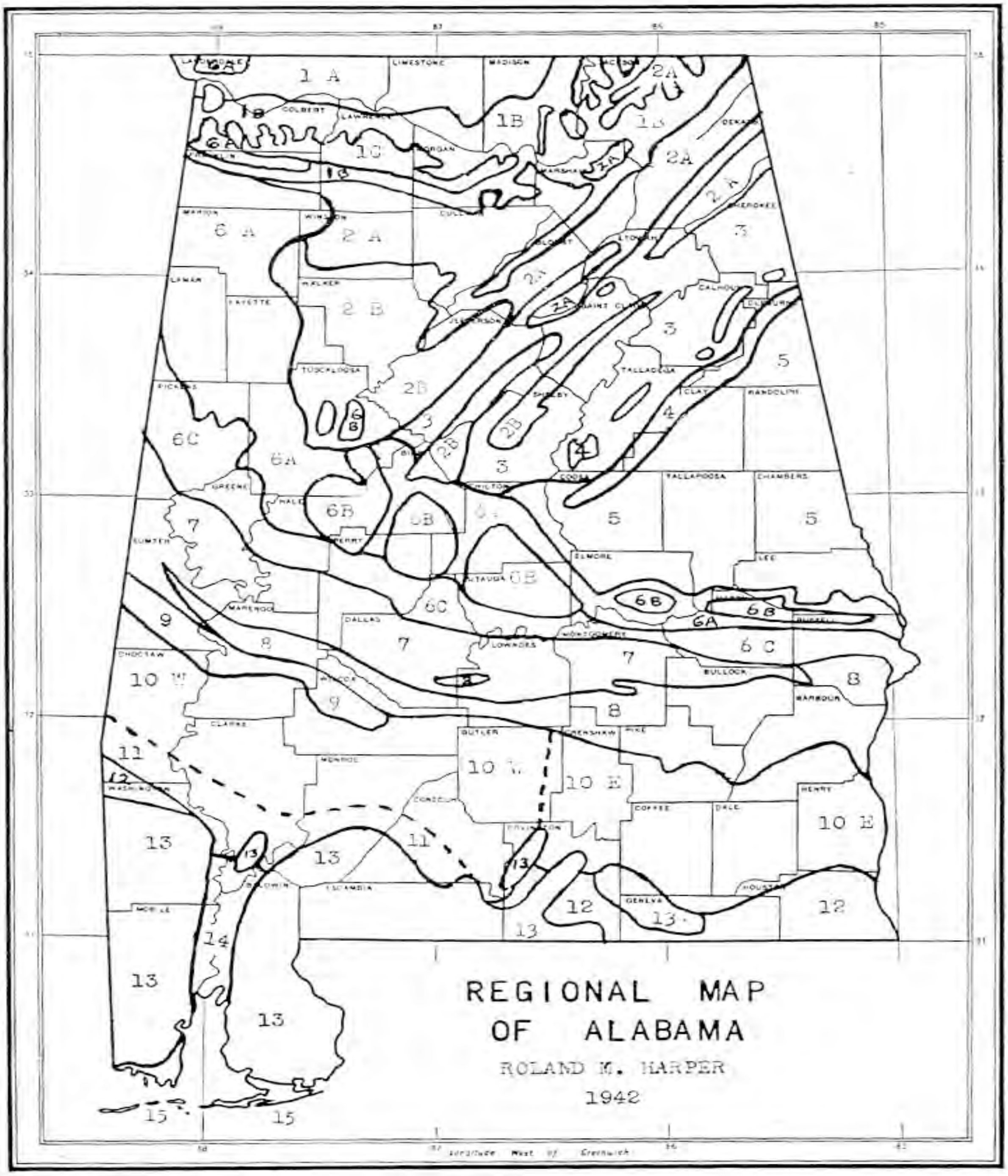


Figure 6. Harper's regional map of Alabama. From Harper (1943). 1A, the chert belt; 1B, the Tennessee Valley; 1C, Little Mountain; 2A, the plateau region; 2B, the coal basin; 3, Coosa Valley; 4, Blue Ridge; 5, Piedmont; 6A, the central short-leaf pine belt; 6B, the central long-leaf pine belt; 6C, the Eutaw belt; 7, the black belt; 8, the blue marl region; 9, post-oak flatwoods; 10, the southern red hills; 11, the lime hills; 12, the lime-sink region; 13, the southwestern pine hills; 14, Mobile delta; 15, the coast strip.

rocks. Once largely cultivated, the Piedmont has reverted to pine and hardwood forests. (Harper [1943] did not subdivide the Piedmont into "Outer" and "Inner," as below.)

45a Southern Inner Piedmont

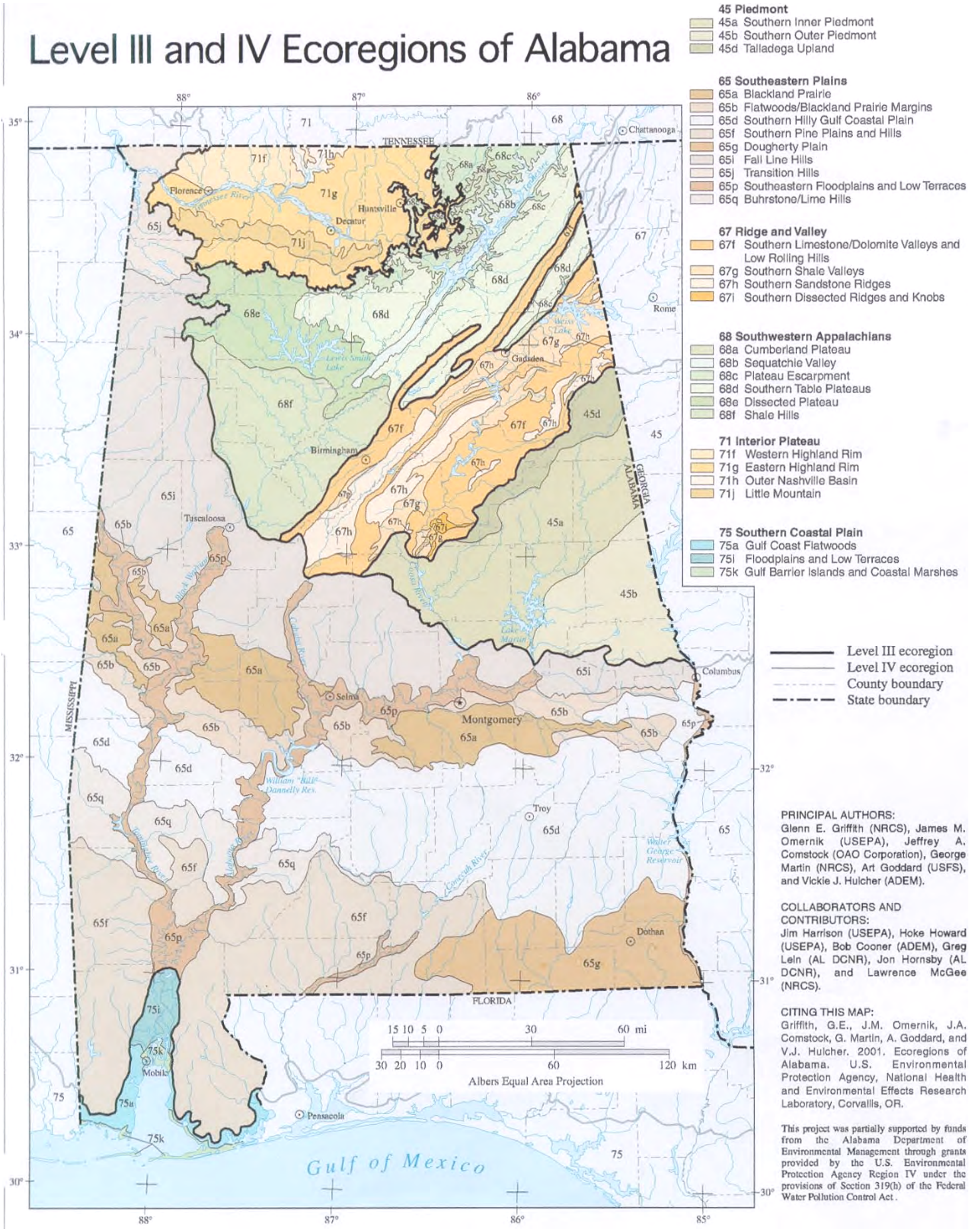
This region, covering most of the Ashland Plateau, is higher in elevation than 45b, and drained by tributaries of the Tallapoosa and Coosa rivers. Bedrock is mainly schist, gneiss and granite, with the soils showing glittering flakes. The region is mostly forested, with pines (loblolly, shortleaf, and longleaf) and oaks on the ridges; oaks, hickories, and other hardwoods occupy the slopes and ravines. (Harper [1943, p 122) stated that longleaf pine "is or was a prominent constituent of the upland forests of every county" of this region.) Today, open land is largely in pasture, with some smaller areas of cropland.

45b Southern Outer Piedmont

This triangular region, sometimes referred to as the Opelika Plateau, is found at the middle of the Alabama-Georgia border. Its southern boundary is the Fall Line, with drainage through the Tallapoosa and Chattahoochee systems. This region is lower in elevation, relief, and precipitation than 45a. The dominant rocks are schist and gneiss, producing red, clayey subsoils. The forests are similar to those in 45a, except for there being slightly more loblolly and shortleaf pines.

45d Talladega Upland

Harper (1943) treated this ecoregion as a continuation of the Blue Ridge Mountains, although he noted (p 114) that "geologists who have written about it in Alabama have not separated it from the Piedmont." It contains the highest elevations in the state, including Mount Cheaha (2407 ft), and much of the region is in public land (Cheaha State Park, Talladega National Forest). The climate is slightly wetter and cooler than in the other subdivisions (45a, 45b) of the



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Griffith, G.E., J.M. Omernik, J.A. Comstock, G. Martin, A. Goddard, and V.J. Hulcher. 2001. Ecoregions of Alabama. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, OR.

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Figure 7. Ecoregions of Alabama. From Griffith et al. (2001).

Piedmont. The geology is mostly Silurian to Devonian phyllites and quartzites, with sandstones on the ridges. The forests are a mix of oaks, hickories, and pines. Longleaf pine once dominated the higher levels and southern slopes, but was logged out in the 1890s (Harper 1943; Mohr 1897). Some montane longleaf pine communities remain at the former Fort McClellan site.

65 Southeastern Plains

The Cretaceous and Tertiary sands, silts, and clays of this region developed from former coastlines, and they differ markedly from the older metamorphic and igneous rocks of the Piedmont. The elevations and relief are also less than in the Piedmont, while the streams are of lower gradient, with sandy (rather than rocky) bottoms. Griffith et al. (2001) characterized this region as being "a mosaic of cropland, pasture, woodland, and forest."

65a Blackland Prairie

This flat to undulating, crescent-shaped region is the Black Belt of Harper (1943) and other authors. Its distinctive Cretaceous chalks develop into fertile clay soils that shrink when dry and swell when wet. Few pines were part of the virgin forests; instead, the natural vegetation was sweetgum, post oak, and red cedar, with patches of true bluestem prairie. (The prehistoric extent of these patches has long been debated; see Barone [2005], Jones & Patton [1966], and Rostlund [1957].) Today the area is largely pasture, cropland, and aquaculture ponds.

Harper (1943) pointed to this region as being the driest of the state, with a small portion of its rainfall occurring in the summer months. Furthermore, "these climatic peculiarities are more pronounced in the most typical portions of the black belt, where there is little or no sandy soil for many miles, as around Uniontown, than in the more sandy portions eastward" (p 159). Thus, the Blackland Prairie differs from its neighboring regions in geology, soils, vegetation, and climate.

65b Flatwoods/Blackland Prairie Margins

The two vegetation types within this ecoregion are found at the margins of the Blackland Prairie. While Griffith et al. (2001) described and mapped the components together, Harper (1943) separated them into Post Oak Flatwoods and Blue Marl regions.

Post Oak Flatwoods occur in low-lying areas near the Mississippi border, and are largely vegetated by post oak and loblolly pine. The poorly drained soils develop from marine clay deposits; due to mineral deficiencies, they are little utilized for farming.

Blue Marl regions occur along the central and eastern borders of Alabama's Blackland Prairie. These areas show higher relief and sandier, more fertile soils than the Post Oak Flatwoods, and so have been used much more for agriculture. The forests, according to Harper (1943, p 165), are a typical central Alabama mix of pines and hardwoods, and "so uninteresting botanically that nothing seems to have been written about them except incidentally in works covering the whole state."

65d Southern Hilly Gulf Coastal Plain

This broad band of dissected plains and low hills developed over east-west trending bands of Eocene formations; the subsoil is markedly red in color. This ecoregion has higher elevations, more rolling topography, greater relief, and streams with higher gradients than 65a, 65b, 65f, or 65g. The natural vegetation is oak-hickory-pine forest; the land is largely forested, with some cropland and pasture.

Harper (1943, p 170) treated this region as the Southern Red Hills, splitting it between Western and Eastern divisions, "differing perceptibly in soil, topography, population and climate. The boundary between them is indefinite, however, and represented by an arbitrary straight line on the map." He noted that the western portion is cut by two large rivers, the Tombigbee and Alabama, and attracted early settlers due to its more fertile soils. In contrast, no such rivers traverse the eastern portion, and agriculture developed later (with the advent of commercial fertilizers). He also noted unique geological and vegetational components of the eastern portion, including Blue Springs in Barbour County and the Pike County Pocosin.

65f Southern Pine Plains and Hills

This ecoregion forms an upside-down U around Mobile Bay, extending east along the Florida Panhandle. Here the native oak-hickory-pine forests of 65d grade into Southern mixed forests and longleaf pine savannas. The latter, with widely spaced trees and little underbrush, provide critical habitat for endangered species such as red-cockaded woodpeckers, gopher tortoises, and pitcher plants. However, loblolly and slash pine plantations have supplanted much of the original forests.

Harper (1943) referred to this region as the Southwestern Pine Hills. He noted that the climate is generally the warmest in the state, and that the proportion of summer rainfall increases toward the Gulf: "This copious warm rain through the ages has doubtless had an important influence in leaching the fertility out of the soil, and favoring the growth of pines and other evergreens" (p 192). He estimated that this region was originally 84% evergreen, forming the classic, fire-dominated coastal longleaf pine savannas.

65g Dougherty Plain

This flat to gently rolling area, occupying the southeast corner of the state, is greatly influenced by its near-surface layers of limestone. (For this reason, Harper [1943] referred to it as the Lime Sink region; others call it the Wiregrass, due to the presence of wire grass, *Aristida* *stricta*.) The karst topography contains many sinkholes, caves and springs; their adjoining marshes and forested riparian zones act as biological oases for wildlife.

Harper (1943, p 184) provided the following details on the native vegetation of the Wiregrass region:

> *In this region..., the prevailing original forest was a park-like growth of long-leaf pine, in which one could probably see about a quarter of a mile in almost any direction. Frequent fires eliminated most shrubs and vines.... The numerous shallow ponds were generally pretty well filled with pond cypress, slash pine, or black gum, and various smaller trees. ...Shallow depressions in which the water did not vary much in level through the year were filled with a dense growth of small trees, shrubs and vines, mostly evergreen, and known as bays.*

According to Harper (1943), the sandy soils of this region, although below average in natural fertility, respond well to artificial fertilizers and are easily tilled. For these reasons, "By 1940 the cleared land had increased to about 57 per cent, or considerably more than in any other region in the state" (p 186). The main crops are currently peanuts, cotton, soybeans, and melons.

65i Fall Line Hills

This L-shaped region extends south from the northwest corner of Alabama along the Mississippi border, then cuts across the middle of the state. This innermost (and oldest) portion of the coastal plain developed over clayey and sandy Cretaceous strata. Its low hills support oak-hickory-pine forests and pine plantations; longleaf pine is currently being re-introduced.

Harper (1943) referred to this region as the Central Pine Belt and divided it into three subregions--the Shortleaf Pine Belt, the Longleaf Pine Hills, and the Eutaw Belt.

65j Transition Hills

This area, constituting the extreme northwest corner of the state, was not treated as a distinct ecoregion by Harper (1943). According to Griffith et al. (2001), it shows characteristics of both the Southeastern Plains and Interior Plateau ecoregions, with Cretaceous-age coastal plain deposits overlying older limestones and shales. The area shows some of the highest elevations in the Southeastern Plains of Alabama. These ridges are heavily forested (oak-hickory-pine), while small areas of cropland and pasture dot the narrow valley bottoms.

65p Southeastern Floodplains and Low Terraces

This riverine ecoregion borders the larger rivers of Alabama including the Coosa, Cahaba, Tallapoosa, Black Warrior, Tombigbee, Alabama, Chattahoochee, and Conecuh. It consists of ponds, swamps, and oxbow lakes with accompanying forests of bald cypress and tupelo gum, plus oak-dominated bottomlands. Cropland is found on the higher, better-drained terraces.

Harper (1943) did not treat these narrow, finger-like areas as a separate ecoregion. Instead, he included them as parts of larger vegetational zones.

65q Buhrstone/Lime Hills

Although he treated it as a separate ecoregion, Harper (1943) found the Lime Hills region to be “not very distinct” from the western portion of the Southern Hilly Gulf Coastal Plain; he used only a dotted line to divide the two on his map. In contrast, Griffith et al. (2001) provided the following details on its unique topography, geology, habitats, and animal life:

> *The rough, hilly topography is attributed to the hardened beds of claystone and sandstone in the Tallahatta Formation and resistant limestones of other Eocene and Oligocene deposits. While 65q is more hilly than surrounding regions, its stream*

> *characteristics also differ from those in 65d and 65f. Many of the streams have relatively high gradients and hard-rock bottoms. Some fish species that are generally found above the Fall Line...are also found in this region because of its streams with upland characteristics. The Red Hills salamander, a federally-listed threatened species, is also found mostly within this region on cool, shady, moist ravines and bluff sites....*

67 Ridge and Valley

This series of parallel ridges and valleys stretches from Pennsylvania to Alabama, situated between the Blue Ridge or Piedmont to the east and the Appalachians to the west. Due to folding and faulting events, a broad range of geologic materials underlie these areas. Griffith et al. (2001) estimated that 50% of the ecoregion is currently forested.

67f Southern Limestone/Dolomite Valleys and Low Rolling Hills

This region of ridges, hills, and valleys is underlain mostly by limestone and cherty dolomite, resulting in many caves and springs. Land cover is mixed, including oak-hickory forests, oak-pine forests, pasture, cropland, urban, and industrial (Griffith et al., 2001).

Since most drainage here involves the Coosa River, Harper (1943) referred to this region as the Coosa Valley. He provided these observations:

> *The forest types are diversified, like the soil and topography. Many of the sandstone ridges and chert hills originally had a great deal of long-leaf pine. In Cherokee and Etowah Counties there are, or were, considerable areas of long-leaf pine flatwoods, with sandy and gravelly soil, resembling some near the coast even to the extent of containing pitcher-plants.* (p 108)

67g Southern Shale Valleys

Unlike Harper (1943), Griffith et al. (2001) treated the shale-dominated valleys of the Ridge and Valley province as being distinctive. The soils are deep, acidic, and moderately well-drained. While the valley bottoms support small fields of hay, corn, and soybeans, the slopes are used for pasture or have reverted to brush and mixed forest.

67h Southern Sandstone Ridges

Griffith et al. (2001) described the Southern Sandstone Ridges as being steep, forested ridges with narrow crests; the soils are stony, sandy, and of low fertility. Two separate areas of these ridges were mapped: several isolated mountains west of the Talladega Upland, and two broad fingers in north-central Alabama. Those fingers include “the Coosa and Cahaba ridges that are broader [than similar ridges in Georgia and Tennessee] and of younger Pennsylvanian-age sandstone and shale, with similarities to 68f,” the Shale Hills ecoregion (Griffith et al., 2001).

Harper’s (1943) treatment differs dramatically from the above. He chose not to treat the Southern Sandstone Ridges as a distinct ecoregion. Instead, he included these isolated mountains in his Blue Ridge region (equivalent to 45d, the Talladega Upland): “From the standpoint of vegetation it seems desirable to include with the main ridge some other mountains near by, which are disconnected, and differ in geological age, but are very similar lithologically” (p 114).

More importantly, Harper (1943) treated the Coosa and Cahaba ridges as part his Coal Basin, the Shale Hills ecoregion hinted at above by Griffith et al. (2001). To Harper, then, those ridges are not part of the Ridge and Valley province at all.

67i Southern Dissected Ridges and Knobs

This ecoregion consists of a single area near the southern end of the Ridge and Valley province. Griffith et al. (2001) described it as containing "more crenulated, broken, or hummocky ridges, compared to the smoother, more sharply crested sandstone ridges of 67h." A variety of geologic materials are represented, supporting oak and pine forests at the higher elevations and oak, hickory, and more mesic species on the lower slopes.

This ecoregion was not treated separately by Harper (1943).

68 Southwestern Appalachians

These low mountains stretch from Kentucky to Alabama, supporting a mosaic of forest, cropland, and pasture. Tablelands are dominated by oaks and shortleaf pines; a mixed mesophytic forest occupies ravine bottoms and adjoining slopes.

The treatment below of the "plateau" region by Griffith et al. (2001) is far more complex than that by Harper (1943).

68a Cumberland Plateau

These tablelands rise 1500-1700 feet, or about 1000 feet higher than the Eastern Highland Rim (71g) to the west. As such, they receive slightly more precipitation, with cooler annual temperatures, than surrounding areas of lower elevation. The Pennsylvanian-aged sandstones, siltstones, shales, and conglomerates are covered with acidic, low fertility soils. Most of the land is in forest or pasture.

68b Sequatchie Valley

This 100-mile-long valley extends diagonally into Alabama from the Alabama-Georgia-Tennessee junction. The Tennessee River flows through this anticlinal valley until it turns west at Guntersville. The valley's Mississippian to Ordovician limestones, dolomites, and shales create an agriculturally rich area, with pasture, hay, soybeans, and corn.

Harper (1943) treated this region as “the Tennessee Valley proper” and included the western portions as well. So it is difficult to combine his broader treatment with the more restricted Sequatchie Valley ecoregion of Griffith et al. (2001). However, in a previous work, Harper (1942) separated this “eastern valley” based on the prevalence of limestone slopes. Major trees include eastern redcedar, shagbark hickory, black walnut, and sycamore.

68c Plateau Escarpment

Griffith et al. (2001) characterized this ecoregion as having steep, forested slopes and high gradient streams. Local relief can be 1000 feet or more. Geologic strata include Mississippian and Pennsylvanian limestones, siltstones, sandstones, and shales. The streams, cutting into the limestones, have left behind huge, angular blocks of sandstone. Upper portions of ravines and gorges support dry mixed oak forests. Lower portions support a more mesic forest of beech, tulip poplar, sugar maple, basswood, and buckeye.

Harper (1943) did not consider this ecoregion, which borders both sides of the Sequatchie Valley, as a distinct one. Instead, he included it as part of his Plateau Region treated below.

68d Southern Table Plateaus

This extensive ecoregion includes major mountains such as Lookout, Sand, and Brindley. Although similar to the Cumberland Plateau with its Pennsylvanian-age sandstone, shales, and coal-bearing strata, it differs by being lower in elevation and having a warmer climate, with more land devoted to agriculture (Griffith et al., 2001).

Harper (1943, p 90) noted that, due to the low natural fertility of the yellowish gray sandy loams of the region, “the plateau presented little attraction to farmers. And much of the region was too cool for the successful growing of cotton...until the clearing away of some of the forest made the summer a little warmer." But the easily tilled soils respond well to fertilizers--similar to those of the agriculturally rich Dougherty Plain (65g) of southeastern Alabama.

Harper (1943) also noted some natural features of the region. Little River, whose gorge is now a national preserve, flows long the synclinal plateau of Lookout Mountain before dropping off precipitously to the southeast. To the southwest, Black Creek traverses the backbone of the same mountain before tumbling off at Noccalula Falls.

68e Dissected Plateau

In this region, the original plateau has been deeply dissected, forming steep-sided gorges and sandstone cliffs. As noted by Mohr (1901), some of these cool canyons contain plant species, like eastern hemlock, that are usually found farther north. The Bankhead National Forest takes up a large portion of 68e, with a large section set aside as the Sipsey Wilderness Area. Here the headwaters of the Sipsey Fork of the Black Warrior River have been designated as a National Wild and Scenic River; downstream, the river has been impounded to form Lewis Smith Lake.

Harper (1943) did not separate the Dissected Plateau from his larger Plateau Region.

68f Shale Hills

Sometimes called the Warrior Coal Field, due to its drainage by various forks of the Black Warrior River, or the Coal Measures, this region shows the lowest elevations of Ecoregion 68, despite its many hills and strongly sloping topography. Due to the preponderance of shale over sandstone, the soils are more silty than sandy, as in many of the other subdivisions of the larger ecoregion. Currently the area is mostly forested, although extensive open pit coal mines have certainly altered the vegetation, soils, land forms, and streams (Griffith et al, 2001).

Harper (1943), referring to this area as the Coal Basin, described the vegetation as consisting of "dry oak and pine forests, now including considerable second growth, on the ridges or uplands, dense thickets of [scrub pine] on the brows of bluffs, beech and various other hard-woods on steep rich slopes, and still others along streams" (p 98). He listed the commonest trees in the following order: loblolly pine, shortleaf pine, scrub pine, beech, and longleaf pine.

Harper's inclusion of longleaf pine as a major component of the Basin's forests is surprising, although it is based on historical rather than current fact. Before lumbering decimated this species, longleaf pine stands occupied large stretches of land near Jasper, extending north into Winston County. Harper supplied a photograph, taken 1 April 1906, of one such stand "near the extinct town of South Lowell."

71 Interior Plateau

This diverse ecoregion extends from southern Indiana and Ohio to northern Alabama. Rock types are largely Mississippian to Ordovician limestones, cherts, sandstones, siltstones, and shales; land forms are tablelands, hills, and plains. The Interior Plateau is an important agricultural region in Alabama, and its springs, sinks, and caves contribute to its distinct aquatic fauna (Griffith et al., 2001). The native forest is primarily deciduous, dominated by oaks and hickories; cedar glades provide unique habitats for rare plant species.

71f Western Highland Rim

This region of rolling terrain is found in the northwest corner of Alabama north of the Tennessee River. The limestone, chert, siltstone, and shale rocks produce soils that are gravelly and of low to moderate fertility. While the side slopes may still be forested, most of the uplands have been cleared for pasture and cropland--hay, cotton, soybeans, corn, and wheat (Griffith et al., 2001).

Harper (1943) referred to this area as the Chert Belt, based on the dominant rock type, which he noted as forming the resistant rocks of Muscle Shoals. He also noted the original presence of "pine islands" of loblolly and shortleaf pine in northern Limestone County, although the pines had since been cut: "Elsewhere the forests are nearly all hardwood, with red and white oaks predominating" (p 72).

71g Eastern Highland Rim

This ecoregion, which includes much of the west-flowing reaches of the Tennessee River, is generally flatter than 71f. Deep, well-drained, red soils have developed from Mississippian-age limestones, cherts, shales, and dolomites; these soils are intensively farmed, especially for cotton. The limestones have dissolved to form sinks, caves and springs, with their unique fauna; similarly, limestone outcrops form cedar glades with their unique flora.

Griffith et al. (2001) described the natural vegetation as being "transitional between the oak-hickory type to the west and the mixed mesophytic forests of the Appalachian ecoregions to the east." They also noted, "Much of the original bottomland hardwood forest has been inundated by impoundments."

As mentioned above, Harper (1943) treated this region as the western portion of his Tennessee Valley. In a previous work, Harper (1942, p 62) listed, in order of abundance, the following "Trees of the valley proper west of the mountains (red lands)": eastern redcedar, sweetgum, Southern red oak, loblolly pine, and sycamore.

71h Outer Nashville Basin

This small area on the Tennessee border, incorporating the Elk River drainage, was not treated by Harper (1943). Griffith et al. (2001) described it as a dissected escarpment of hilly topography. The bedrock is Ordovician non-cherty limestone and calcareous shale, and these rocks and their soils can be high in phosphorus. Oak-hickory and mixed mesophytic forests cover the steeper slopes, with cropland and pasture on the alluvial plains.

71j Little Mountain

This is one of the most easily defined and distinctive ecoregions of the state, consisting of a narrow, plateau-like ridge, 5-10 miles wide, paralleling and to the south of the Tennessee River. It differs from the surrounding Eastern Highland Rim (71g) by having sandstone (rather than limestone) bedrock, a hillier topography, and greater forest cover. The flat, broad uplands of Little Mountain show well-drained loamy soils useful for pasture and cropland (Griffith et al., 2001).

Harper (1943) listed the commonest trees of Little Mountain as being shortleaf pine, loblolly pine, sweetgum, mockernut hickory, and various oaks.

75 Southern Coastal Plain

This major ecoregion extends from South Carolina through Georgia, Florida, Alabama, Mississippi, and Louisiana. It is younger in age and lower in elevation, with lower relief and wetter soils, than Ecoregion 65, the Southeastern Plains. As described by Griffith et al. (2001): “Once covered by a variety of forest communities that included trees of longleaf pine, slash pine, pond pine, beech, sweetgum, southern magnolia, white oak, and laurel oak, land cover in the region is now mostly slash and loblolly pine [plantations] with oak-gum-cypress forest in some low-lying areas....”

75a Gulf Coast Flatwoods

This narrow strip consists of terraces and delta deposits of Quaternary sands and clays.

Low, swampy areas are generally forested, while pastures and crops are found on better-drained portions. Mobile and its suburbs occupy much of this region (Griffith et al., 2001).

Harper (1943, p 202) included this region as part of his Coast Strip, which was "not easy to define accurately, but it is here regarded as including the low flat areas bordering Mobile Bay, the beaches and dunes on the coast of Baldwin County, including the Fort Morgan peninsula, and the sea islands of Mobile County." His descriptions, discussions and photographs, however, deal almost exclusively with Dauphin Island and the Fort Morgan Peninsula, which Griffith et al. (2001) separated as Ecoregion 75k, the Gulf Barrier Islands and Coastal Marshes.

75i Floodplains and Low Terraces

Griffith et al. (2001) considered this ecoregion to be a continuation of the Southeastern Floodplains and Low Terraces (65p). In Alabama, it consists of the broad floodplains and terraces of the Mobile-Tensaw River System--sluggish rivers and backwaters with swamps, ponds, and oxbow lakes. The substrate, derived from river alluvium, is largely sand, silt, clay, and gravel. The vegetation is mainly swamp forest of bald cypress and water tupelo, plus oak-dominated bottomland hardwood forests.

Harper (1943) referred to this area as the Mobile Delta and designated, in his list of trees, whether a species was abundant in its upper or lower sections. His "upper" trees, in order of abundance, include sweetgum, American elm, sugarberry, and overcup oak; his "lower" trees include black gum, sweetbay, bald cypress, and red maple.

Besides providing wildlife habitats, these floodplains serve important purposes in the hydrological and ecological cycles of Mobile Bay and the fisheries of the Gulf of Mexico (Griffith et al., 2001). Large portions have been preserved through Alabama's Forever Wild Program.

75k Gulf Barrier Islands and Coastal Marshes

This southernmost ecoregion includes the salt marshes, brackish marshes, dunes, beaches, and barrier islands of the Gulf Coast (Griffith et al., 2001). Salt tolerant grasses, rushes, and sedges dominate the marshes, while the dunes and barrier islands support a xeric vegetation of slash pine, live oak, sea oats, and various succulent plants.

As previously mentioned, Harper (1943) included this region as part of his Coast Strip. He noted that 90% of the trees are evergreen, including the pines, oaks and redcedars: "a natural consequence of the poor soil and copious summer rain" (p 208). He also provided important photographs of the region before its development for summer homes and condominiums.

It should be mentioned, also, that the outermost parts of this region, the Fort Morgan Peninsula and Dauphin Island, serve as vital "re-fueling" areas for birds on their fall and spring trans-Gulf migrations. (See Davenport [2005] for a popular account.)

2c - Predictions - Migrations and Constrictions of Ecoregions

What will happen to Alabama's ecoregions with climate change? As shown in Chapter 1, predictions of future regional climates vary considerably, based on the model used and its inherent assumptions. But the following, rather conservative predictions can be made.

Some Alabama ecoregions will shift northward.

This prediction derives from studies of past climate changes and associated plant migrations, especially those migrations following Pleistocene glaciation and retreat. (These studies, e.g., Delcourt & Delcourt [1981], are based on sediment pollen records.) Under this scenario, ecoregions will shift their southern borders, moving as intact units, following the northward migration of isotherms, then be replaced in turn by their more southern neighbors (Solomon et al., 1981). This shift may especially be possible for Alabama's coastal plain ecoregions, which generally show east-west orientations. And those with the most generalist types of vegetation, like oak-pine-hickory forests, will have the greatest success in migrating. Such ecoregions would include the Southern Hilly Gulf Coast Plain (65d), the Southern Pine Prairie and Hills (65f), and the Fall Line Hills (65i).

Modern-day migrations, however, will face modern-day barriers such as cities, highways, and extensive agricultural fields (Gates, 1993). Some authors (e.g., Malcolm & Pitelka, 2000) have suggested that such migrations should be artificially assisted by the planting of propagules in advance of the main migration body.

Geology-based ecoregions will constrict.

As first noted by Harper (1943), Alabama's ecoregions are based more on geology than climate. Certain ecoregions are restricted to specific soil types and, with climate change, would remain in place, locked to that substrate but in a constricted state. Such would be the case of the Blackland Prairie (65a) and its required chalk formations, illustrated in Figure 8; with drying, in fact, this region might suffer desertification. The Dougherty Plain (65g), also based on limestone formations, would most likely constrict severely, as would the Buhrstone/Lime Hills (65q). Little Mountain (71j), an east-west trending sandstone ridge surrounded by the flatter, limestone-based Eastern Highland Rim (71g), would also constrict.

Specialized habitats within ecoregions will constrict or disappear.

With climate change, some geology- or moisture-based habitats within ecoregions could also constrict greatly or disappear entirely. Within the Eastern Highland Rim mentioned above,

Figure 8. Blackland Prairie, or Black Belt, near Epes, Sumter County, Alabama. With climate change, these chalk-based prairies may suffer desertification. Photograph by the author, 21 October 2006.

cedar glade habitats, when exposed to higher temperatures and drought conditions, could disappear, along with the threatened and endangered species depending on them. The Ketona glade habitats within the Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f), along with their assemblage of rare species, may be similarly affected.

The hemlock-based cove forests of the Dissected Plateau (68e), considered by Mohr (1901) to be remnants of glacial times, would probably constrict severely as well. (See Figure 9.) Again, a number of threatened and endangered species would be affected by this loss of habitat.

Figure 9. Hemlock-based cove forest along Thompson Creek, Bankhead National Forest, Winston County, Alabama. With climate change, these remnants of glacial times may constrict or disappear. Photograph by the author, 14 October 2006.

Montane ecoregions will shift northeastward or disappear.

Many of Alabama's plateau and montane ecoregions represent the southernmost extensions of larger systems to the north and east. With climate change, these extensions might retreat *within* that ecoregion toward Georgia and Tennessee. Ecoregions affected this way would be the Talladega Upland (45d), the Southern Sandstone Ridges (67h), and the Outer Nashville Basin (71h). In the case of the Talladega Upland, the last significant montane longleaf pine communities of the state could be lost.

Other montane ecosystems, currently restricted to a few isolated ridges, might disappear entirely. Included here are the Cumberland Plateau (68a) and the Plateau Escarpment (68c).

Valley-based ecoregions will shift northeastward.

In a similar way to their adjoining ridges, valley-based ecoregions--especially those based on geological features--would shift toward the northeast. This would especially be true if drying conditions--either annual or sporadic--become widespread. Such ecoregions would include the Southern Limestone/Dolomite Valleys & Low Rolling Hills (67f), Southern Shale Valleys (67g), and Sequatchie Valley (68b).

Some outer coastal plain ecoregions will disappear entirely.

The projected sea level rise associated with global warming would flood Alabama's current Gulf Barrier Islands and Coastal Marshes (75k). It would also lead to the northward retraction of the Floodplains and Low Terraces (75i) of the Mobile-Tensaw region.

2d - Predictions - Migrations and Constrictions of Plant Families

The above migration and constriction scenarios are based on a Clementsian view of ecological succession--the idea that ecosystems are organism-like in their structure and function and would migrate as whole "beings." (See Worster [1994] for a history of this and the following contrasting idea.) However, an ecosystem can also be viewed as an assemblage of component species, with each one adapted, individually, to a particular set of habitat requirements. This Gleasonian view demands that each species, genus, or family of plants be viewed in terms of its specific habitat needs. Conjectures can then be made as to how individual species or groups of species might migrate, and how new plant assemblages might result.

In one such study, Iverson & Prasad (1998) modeled the future abundances of eighty forest trees of the eastern United States under global warming conditions. Among their findings: 1) thirty species would expand their ranges by at least 10%; 2) thirty species would decrease their ranges by at least 10%; 3) four to nine species would leave the United States to the north; 4) thirty-six would shift at least 100 km northward; and 5) of the latter, seven would shift more than 250 km northward.

But what about Alabama, and what about non-tree species? To make such predictions, I analyzed the global distributions and origins of the 204 plant families currently represented in the state (Spaulding, 2005). The results are shown in Tables 1-4.

Table 1 shows that 44% (89) of Alabama's plant families are tropical in distribution. Under global warming, these families should expand their ranges within the state, especially if increased moisture were available to them. These tropical families contain mainly herbs, vines, and shrubs, rather than forest trees. (Two exceptions are Ebenaceae (*Diospyros*, persimmon) and Tiliaceae (*Tilia*, basswood). Several families include invasive (Lygodiaceae; *Lygodium*, Japanese climbing fern) or nuisance (Anacardiaceae; *Toxicodendron*, poison ivy) species.

Table 1. Families of Alabama plants with primarily tropical affinities. Family list is from Spaulding (2005); family affinities are from Judd et al. (2002), Lawrence (1951), and Mabberley (1997).

Psilotophyta (*whisk ferns*)
- Psilotaceae

Lycopodiophyta (*club mosses*)
- Selaginellaceae

Polypodiophyta (*ferns*)
- Azollaceae
- Blechnaceae
- Gleicheniaceae
- Lygodiaceae
- Marsileaceae
- Parkeriaceae
- Salviniaceae
- Vittariaceae

Magnoliophyta/Magnoliopsida (*dicots*)
- Acanthaceae
- Aizoaceae
- Amaranthaceae
- Anacardiaceae
- Annonaceae
- Apocynaceae
- Araliaceae
- Aristolochiaceae
- Asclepiadaceae
- Balsaminaceae
- Basellaceae
- Bataceae
- Begoniaceae
- Bignoniaceae
- Buddlejaceae
- Cabombaceae
- Calyceraceae
- Capparaceae
- Celastraceae
- Clethraceae
- Clusiaceae
- Cucurbitaceae
- Cyrillaceae
- Ebenaceae
- Lauraceae
- Loganiaceae
- Loranthaceae
- Lythraceae
- Magnoliaceae
- Malvaceae
- Melastomataceae
- Meliaceae
- Menispermaceae
- Molluginaceae
- Moraceae
- Myrsinaceae
- Nyctaginaceae
- Oxalidaceae
- Passifloraceae
- Pedaliaceae
- Phytolaccaceae
- Piperaceae
- Podostemaceae
- Rhamnaceae
- Rubiaceae
- Rutaceae
- Santalaceae
- Sapindaceae
- Sapotaceae
- Simaroubaceae
- Solanaceae
- Sphenocleaceae
- Sterculiaceae
- Styracaceae
- Symplocaceae
- Theaceae
- Tiliaceae
- Turneraceae
- Urticaceae
- Verbenaceae
- Vitaceae
- Zygophyllaceae

Magnoliophyta/Liliopsida (*monocots*)
- Amaryllidaceae
- Araceae
- Arecaceae
- Bromeliaceae
- Burmanniaceae
- Cannaceae
- Commelinaceae
- Cymodeaceae
- Dioscoreaceae
- Eriocaulaceae
- Haemodoraceae
- Marantaceae
- Mayacaceae
- Pontederiaceae
- Smilacaceae
- Stemonaceae
- Xyridaceae

Table 2 shows that 28% (58) of Alabama's plant families are temperate in distribution. Under global warming conditions, these families would likely migrate north- and northeastward,

Table 2. Families of Alabama plants with primarily temperate affinities. Family list is from Spaulding (2005); family affinities are from Judd et al. (2002), Lawrence (1951), and Mabberley (1997).

Polypodiophyta (*ferns*)

- Dryopteridaceae
- Hymenophyllaceae

Pinophyta (*conifers*)

- Cupressaceae
- Pinaceae
- Taxodiaceae

Magnoliophyta/Magnoliopsida (*dicots*)

- Aceraceae
- Apiaceae
- Berberidaceae
- Betulaceae
- Brassicaceae
- Calycanthaceae
- Cannabaceae
- Caprifoliaceae
- Cornaceae
- Diapensiaceae
- Dipsacaceae
- Elaeagnaceae
- Empetraceae
- Ericaceae
- Fagaceae
- Fumariaceae
- Gentianaceae
- Geraniaceae
- Hamamelidaceae
- Hippocastanaceae
- Hydrangeaceae
- Illicaceae
- Juglandaceae
- Lardizabalaceae
- Monotropaceae
- Nelumbonaceae
- Nyssaceae
- Onagraceae
- Orobanchaceae
- Papaveraceae
- Phrymaceae
- Platanaceae
- Polemoniaceae
- Polygonaceae
- Primulaceae
- Pyrolaceae
- Ranunculaceae
- Rosaceae
- Sarraceniaceae
- Saururaceae
- Saxifragaceae
- Schisandraceae
- Scrophulariaceae
- Staphyleaceae
- Ulmaceae
- Valerianaceae

Magnoliophyta/Liliopsida (*monocots*)

- Acoraceae
- Alismataceae
- Cyperaceae
- Juncaceae
- Juncaginaceae
- Ruppiaceae
- Sparganiaceae

Table 3. Families of Alabama plants with arid or Mediterranean affinities. Family list is from Spaulding (2005); family affinities are from Judd et al. (2002), Lawrence (1951), and Mabberley (1997).

Magnoliophyta/Magnoliopsida (*dicots*)

- Cactaceae
- Chenopodiaceae
- Cistaceae
- Resedaceae
- Tamaricaceae

Magnoliophyta/Liliopsida (*monocots*)

- Agavaceae

Table 4. Families of Alabama plants with cosmopolitan distributions. Family list is from Spaulding (2005); family affinities are from Judd et al. (2002), Lawrence (1951), and Mabberley (1997).

Equisetophyta (*horsetails*)
- Equisetaceae

Lycopodiophyta (*club mosses*)
- Isoetaceae
- Lycopodiaceae

Polypodiophyta (*ferns*)
- Aspleniaceae
- Dennstaedtiaceae
- Ophioglossaceae
- Osmundaceae
- Polypodiaceae
- Pteridaceae
- Thelypteridaceae

Magnoliophyta/Magnoliopsida (*dicots*)
- Aquifoliaceae
- Asteraceae
- Boraginaceae
- Buxaceae
- Callitrichaceae
- Campanulaceae
- Caryophyllaceae
- Ceratophyllaceae
- Convolvulaceae
- Cuscutaceae
- Droseraceae
- Elatinaceae
- Euphorbiaceae
- Fabaceae
- Grossulariaceae
- Haloragaceae
- Hydrophyllaceae
- Lamiaceae
- Lentibulariaceae
- Linaceae
- Menyanthaceae
- Myricaceae
- Nymphaeaceae
- Oleaceae
- Plantaginaceae
- Plumbaginaceae
- Polygalaceae
- Portulacaceae
- Salicaceae
- Thymelaeaceae

Magnoliophyta/Liliopsida (*monocots*)
- Hydrocharitaceae
- Iridaceae
- Lemnaceae
- Liliaceae
- Najadaceae
- Orchidaceae
- Poaceae
- Potamogetonaceae
- Typhaceae
- Zannichelliaceae

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perhaps vacating the state. Included in this table are families containing the majority of Alabama's forest trees. These include Pinaceae (*Pinus*, pine), Taxodiaceae (*Taxodium*, cypress), Aceraceae (*Acer*, maple), Betulaceae (*Betula*, beech; *Populus*, cottonwood), Cornaceae (*Cornus*, dogwood), Fagaceae (*Fagus*, beech; *Quercus*, oak), Hamamelidaceae (*Liquidambar*, sweetgum), Hippocastanaceae (*Aesculus*, buckeye), Juglandaceae (*Carya*, hickory; *Juglans*, walnut), Nyssaceae (*Nyssa*, gum), Platanaceae (*Platanus*, sycamore), Rosaceae (*Prunus*, cherry), and Ulmaceae

(*Ulmus*, elm). Obviously, the migration and/or constricting of ranges of these families would severely affect and alter Alabama's forest ecosystems.

Tables 3 and 4 show that only 3% (6) of Alabama's plant families have arid or Mediterranean requirements, while 25% (50) are cosmopolitan. Cosmopolitan families are the least likely to be affected by climate change, while arid families would expand northward only with increasingly dry conditions. Included in the latter group are such families as Agavaceae (*Manfreda*, false aloe) and Cactaceae (*Opuntia*, prickly pear).

What about future Alabama ecosystems and plant associations? The above predictions, based on individual plant family origins and affinities, can be fused together. If these predictions hold true, then the ecoregions of the northern half of Alabama would be most severely affected by climate change. These hardwood forests are composed primarily of temperate families, including Pinaceae (pines), Aceraceae (maples), Fagaceae (oaks and beeches), and Juglandaceae (hickories and walnuts), which are all projected to migrate north--perhaps out of the state entirely. Only minor or subcanopy elements of these forests show tropical affinities and might be enhanced: Anacardiaceae (poison ivy), Annonaceae (pawpaw), Ebenaceae (persimmon), Magnoliaceae (various magnolias, cucumber tree), Moraceae (mulberry), Tiliaceae (basswood), and Vitaceae (various grapes).

2e - Alabama's Threatened and Endangered Plant Species

Currently, seventeen Alabama plant species or varieties are federally listed as threatened or endangered. Of these, two are ferns, twelve are dicots, and three are monocots (Table 5). A brief treatment of each species follows.

***Asplenium scolopendrium* var. *americanum*, American Hart's Tongue Fern.** This variety demands the high humidity and deeply shaded conditions found at cave entrances and near limestone sinks. It shows a spotty distribution in the eastern United States. In Alabama, it is known only from Morgan and Jackson counties (Johnson & Wehrle, 2006; Wagner et al., 1993).

***Thelypteris pilosa* var. *alabamensis*, Alabama Streak-Sorus Fern.** Similar to the American Hart's Tongue Fern, this species needs the cool, shady conditions provided by coves, where it grows on overhangs and cliff faces. In the United States, it is only known from Winston County, Alabama, fully 2000 km distant from its nearest, Mexican populations (Johnson & Wehrle, 2006; Smith, 1993).

***Ptilimnium nodosum*, Harperella**. This species grows on rocky banks and shoals. In Alabama, it is known only from two northeastern counties, Cherokee and Dekalb (Johnson & Wehrle, 2006).

***Marshallia mohrii*, Mohr's Barbara's Buttons.** This species grows in wet, open areas of woodlands and along streams. It is known from Bibb County in the central part of Alabama and from Calhoun, Cherokee, and Etowah counties to the northeast (Johnson & Wehrle, 2006).

***Lesquerella lyrata*, Lyrate Bladderpod.** This annual plant grows on the exposed, shallow soils of cedar glades. In Alabama, it is only found in Colbert, Franklin, and Lawrence counties in the northwestern corner of the state (Johnson & Wehrle, 2006).

***Apios priceana*, Price's Potato-Bean.** This climbing vine grows from a potato-like tuber. It prefers forest openings in mixed hardwood stands, especially where valley slopes grade into creek bottoms. In Alabama, it is only known from Autauga County in the central region and from Madison and Marshall counties in the northeast (Johnson & Wehrle, 2006).

Table 5. Alabama's federally listed threatened (T) and endangered (E) plant species.

Polypodiophyta (*ferns*)	
Aspleniaceae	
Asplenium scolopendrium var. *americanum* (T)	American Hart's Tongue Fern
Thelypteridaceae	
Thelypteris pilosa var. *alabamensis* (T)	Alabama Streak-Sorus Fern
Magnoliophyta/Magnoliopsida (*dicots*)	
Apiaceae	
Ptilimnium nodosum (E)	Harperella
Asteraceae	
Marshallia mohrii (T)	Mohr's Barbara's Buttons
Brassicaceae	
Lesquerella lyrata (T)	Lyrate Bladderpod
Fabaceae	
Apios priceana (T)	Price's Potato-Bean
Dalea foliosa (E)	Leafy Prairie Clover
Gentianaceae	
Spigelia gentianoides var. *alabamensis* (E)	Alabama Gentian Pinkroot
Ranunculaceae	
Clematis morefieldii (E)	Morefield's Leather Flower
Clematis socialis (E)	Alabama Leather Flower
Sarraceniaceae	
Sarracenia oreophila (E)	Green Pitcher Plant
Sarracenia rubra ssp. *alabamensis* (E)	Alabama Canebrake Pitcher Plant
Scrophulariaceae	
Amphianthus pusillus (T)	Little Amphianthus
Schwalbea americana (E)	American Chaffseed
Magnoliophyta/Liliopsida (*monocots*)	
Alismataceae	
Sagittaria secundifolia (T)	Kral's Water Plantain
Liliaceae	
Trillium reliquum (E)	Relict Trillium
Xyridaceae	
Xyris tennesseensis (E)	Tennessee Yellow-Eyed Grass

***Dalea foliosa*, Leafy Prairie Clover.** Like the Lyrate Bladderpod, this species demands open, cedar glade habitats. In Alabama, it is known only from the north-central and northwestern counties: Franklin, Jefferson, Lawrence, and Morgan (Johnson & Wehrle, 2006).

***Spigelia gentianoides* var. *alabamensis*, Alabama Gentian Pinkroot.** Until recently, the endangered Gentian Pinkroot was only known from a few localities in the Florida Panhandle (USFWS, 1990). However, a pink (rather than blue) form was discovered during the initial 1992 botanical survey of the Ketona glade communities of Bibb County, Alabama (Allison & Stevens, 2001). A few years later, this pink form was described as a distinct variety (Gould, 1996). Thus far, this variety is known only from these rare dolomitic limestone outcrops.

***Clematis morefieldii*, Morefield's Leather Flower.** This vine grows near seeps on limestone slopes under mixed hardwoods. Until recently, this species was only known from Marshall County, Alabama, near the Tennessee state line (Johnson & Wehrle, 2006; Pringle, 1997), but it has since been discovered in the Cumberland Plateau region of Franklin County, Tennessee (Estes & Fleming, 2006).

***Clematis socialis*, Alabama Leather Flower.** This herb grows in full sunlight in wet, silty-clay areas near creeks and in bottomland woods. This species is only known from three counties in northeastern Alabama: Cherokee, Etowah, and St. Clair (Johnson & Wehrle, 2006; Pringle, 1997).

***Sarracenia oreophila*, Green Pitcher Plant.** This species grows in open boggy areas, at streambanks or near seeps. As with other pitcher plants, fire is needed to clear out competitors and ensure its survival. This species is only known from wet sites in the northeastern counties of the state: Cherokee, Dekalb, Etowah, Jackson, and Marshall (Johnson & Wehrle, 2006).

***Sarracenia rubra* ssp. *alabamensis*, Alabama Canebrake Pitcher Plant.** Like the Green Pitcher Plant, this species demands open boggy areas and frequent fires. It is only known from central Alabama: Autauga, Chilton, and Elmore counties (Johnson & Wehrle, 2006).

***Amphianthus pusillus*, Little Amphianthus.** This small, aquatic, annual plant grows only in pools on granite outcrops (Murdy & Carter, 2000). In Alabama, it is only known from Chambers and Randolph counties near the Georgia border (Johnson & Wehrle, 2006).

***Schwalbea americana*, American Chaffseed.** This hemiparasite is partially dependent on other plants, although not host-specific. Like the pitcher plants described above, it demands open, moist savannas with frequent fires. In Alabama, it is only known from Baldwin County (Johnson & Wehrle, 2006).

***Sagittaria secundifolia,* Kral's Water Plantain.** This aquatic plant grows in rocky creek beds. Until recently, it was known in Alabama only from three drainages of the Southwestern Appalachian region in the northern half of the state: Little River (Cherokee and Dekalb counties), Town Creek (Dekalb County), and the Sipsey Fork of the Black Warrior River (Winston County) in Bankhead National Forest (Johnson & Wehrle, 2006). It is also known from Hatchet Creek, Coosa County, near the center of Alabama, in the Piedmont region (Threlkeld & Soehren, 2003).

***Trillium reliquum*, Relict Trillium.** Like other trilliums, this species grows best in moist, shady hardwood forests and is adversely affected by fire. In Alabama, it is known only from three southeastern counties: Bullock, Henry, and Lee (Johnson & Wehrle, 2006).

***Xyris tennesseensis*, Tennessee Yellow-Eyed Grass.** This species is found in open, wet seepage areas and on stream banks. In Alabama, it is known only from Bibb, Calhoun, and Franklin counties (Johnson & Wehrle, 2006).

2f - Predictions - Responses of Alabama's T & E Plant Species to Climate Change

As is typical of such species worldwide, Alabama's threatened and endangered plant species reside in scarce, rare, or disappearing habitats. While all of these habitats will be affected by climate change, some will be affected more than others, or completely disappear. As is the case, discussed previously, with entire ecosystems, those individual species demanding specific geologic or soil formations may be the most severely compromised.

One tropically based species will survive under warmer, wetter conditions.

Of the seventeen Alabama threatened or endangered species, Tennessee Yellow-Eyed Grass (Figure 10) is the only one whose family (Xyridaceae) has tropical affinities. As long as water is available to the open seepage areas that it needs, this species should survive.

Four temperate zone based aquatic, bog, or wetland species may also survive.

Kral's Water Plantain, which grows in rocky creek beds, should not be affected by climate change, as long as the water regime is not altered. The same is true for the Green Pitcher Plant, Alabama Canebrake Pitcher Plant, and American Chaffseed. The latter three species also demand frequent fires; such fires would naturally occur under hotter, drier conditions.

Species demanding shady ravines and stream banks will constrict in distribution.

The American Hart's Tongue Fern and Alabama Streak-Sorus Fern demand shady cove habitats, which will most likely shift north or constrict with climate change. The same is true of the hardwood forests needed by Price's Potato-Bean and Relict Trilllium. Four species needing wet forest openings or seeps--Harperella, Mohr's Barbara's Buttons, Morefield's Leather Flower, and Alabama Leather Flower--will need to shift with shifting climates and water sources. All four will be adversely affected if drier conditions prevail in future forests.

Figure 10. Tennessee Yellow-Eyed Grass growing in a roadside seepage area, Calhoun County, Alabama. Photograph by the author, 16 August 2006.

Geology-based species will most likely constrict in distribution or disappear.

The remaining threatened or endangered species are only known from rock outcrop or cedar glade habitats. Under some climate change scenarios, these habitats will dry out and/or constrict severely. The two annual plants, Little Amphianthus and Lyrate Bladderpod, would survive as long as their life cycles coincide with available spring rainfall; despite climate shifts, they would be restricted to granite outcrop and cedar glade habitats, respectively. The two perennials, Leafy Prairie Clover and Alabama Gentian Pinkroot, would suffer greatly under drier conditions and perhaps disappear entirely.

2g - Plant Conservation and Nature Preserves

As indicated above, future climate change will greatly affect current efforts to maintain endangered, threatened, or rare plant species and their required habitats. According to Peters (1991, p 109), "Small, remnant populations of most species, surrounded by cities, roads, reservoirs, and farm land, would have little chance of reaching new habitat if climate change makes the old [habitat] unsuitable." He then outlined the ways that such anticipated losses and changes might be mitigated. These include:

1) *Design current reserves for anticipated changes*. "[S]ound conservation now, in which we try to conserve more than just the minimum number of individuals of a species necessary for present survival, would be an excellent way to start planning for climate change" (p 109).

2) *Modify conditions in reserves, by either irrigation or drainage, based on new moisture patterns.* The modification of the water table would greatly affect the survival of the bog- and seep-dependent species described in the previous section.

3) *Control competitors and invading species*. The elimination of competitors is essential for the fire-dependent species described in the previous section.

4) *Transfer individuals to new reserves that better retain the "old" characteristics.*

5) *Design and locate new reserves to minimize the effects of changing temperature and moisture*. "The existence of multiple reserves for a given species or community type increases the probability that, if one reserve becomes unsuitable for climatic reasons, the organisms may still be represented in another reserve" (p 112).

6) *Design new reserves to encompass a diversity of habitats.* "Reserves should be heterogeneous with respect to topography and soil types, so that even given climatic change, remnant populations may be able to survive in suitable microclimatic areas. Species may survive better in reserves with wide variations in altitude, since, from a climatic point of view, a small altitudinal shift corresponds to a large latitudinal one" (p 112).

7) *Establish corridors between reserves*. Corridors should be established to "allow some natural migration of species to track climate shifting. Corridors along altitudinal gradients are likely to be most practical, because they can be relatively short compared with the longer distances necessary to accommodate latitudinal shifting" (p 112).

8) *In the Northern Hemisphere, site new reserves near the northern limit of a species' or community's range, where conditions should remain suitable longer.*

9) *Maximize reserve size.* "Maximizing the size of reserves will increase long-term persistence of species by increasing the probability that suitable microclimates exist, by increasing the probability of altitudinal variation, and by increasing the latitudinal distance available to shifting populations" (p 112).

It should be noted that many of Peters' suggestions--especially numbers 6, 7 and 9--are supported by the Island Biogeography Theory first promoted by MacArthur and Wilson (1967).

(This theory uses mathematics to explain the number of species predicted to be found on islands or in island-like situations, such as nature preserves.)

2h - Predictions and Needs - Alabama's Nature Preserves

Alabama currently enjoys a number of nature preserves in the forms of state parks, wildlife management areas, and holdings by the Nature Conservancy and Forever Wild. It is important, of course, that these holdings be increased for both the future needs of humans and wildlife. In addition to size, however, the following considerations should be made:

Add in-holdings to current preserves.

In-holdings, which can be developed or highly modified by their owners, block the migration of species through natural ecosystems. All attempts should be made to purchase such tracts and fuse them into the larger preserve. (See Figure 11.)

Link current reserves by corridors, especially in a north-south direction.

It is possible that some of Alabama's ecoregions will successfully shift northward with climate change. The addition of north-south corridors between existing preserves would enhance the potential for species migration. (See Figure 11.)

Expand the northern boundaries of current preserves.

Such expansion is critical to allow for species migration northward. This is especially true along Alabama's Gulf Coast, where the current southern boundaries of preserves, such as Forever Wild's Grand Bay Savannah, will likely be inundated by rising sea levels.

Create new preserves along north-south riverine corridors.

These corridors, designated Southeastern Floodplains and Low Terraces (65p) by Griffith

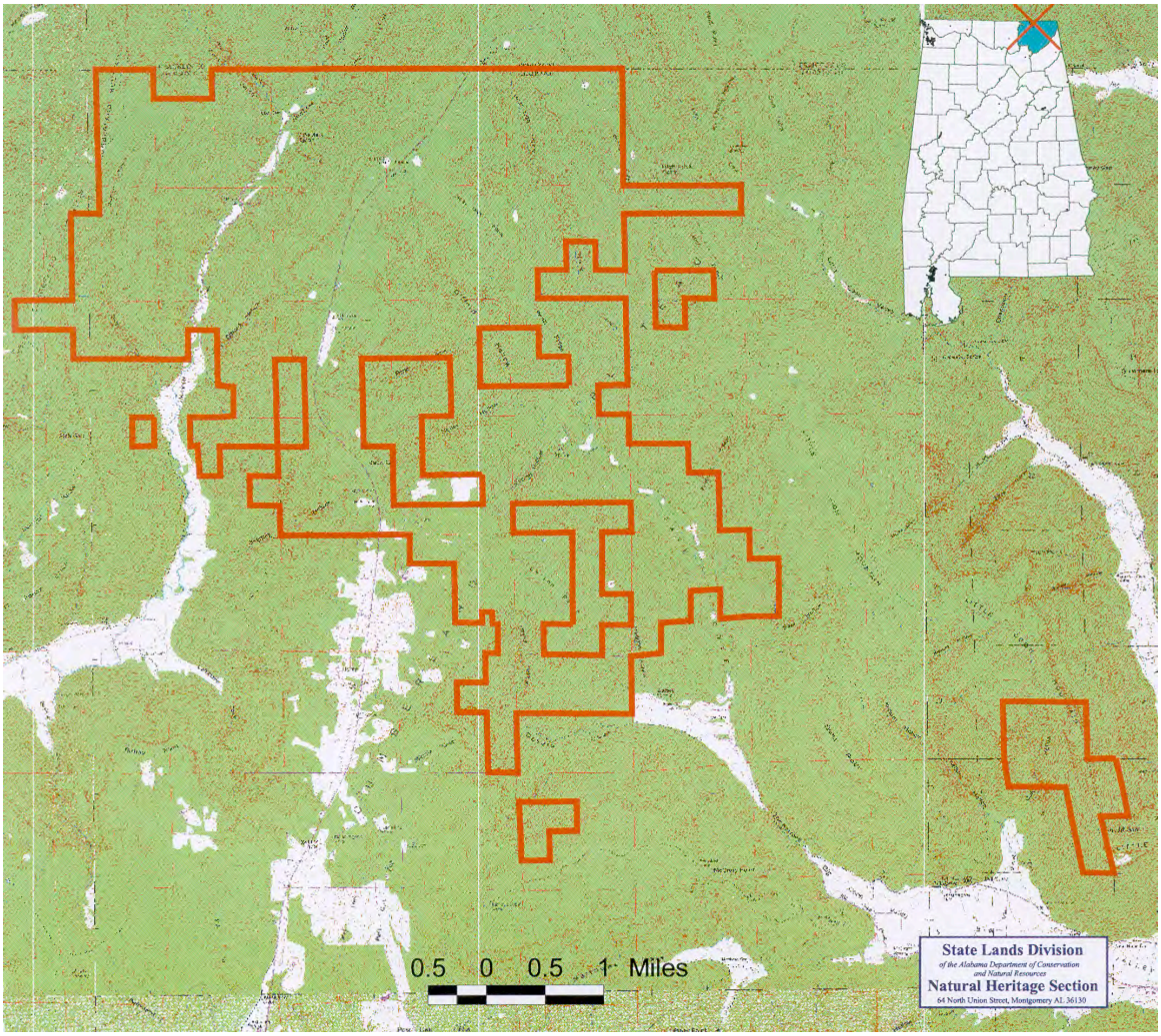


Figure 11. Forever Wild's Walls of Jericho tract, Jackson County, Alabama. The 12,510 Alabama acres adjoin 8943 in Tennessee, creating a massive preserve with several north-south riverine corridors. The purchase of in-holdings and corridors linking external parcels would further increase its value to wildlife during climate change.

et al. (2001), generally run north-south, connecting different ecoregions. They provide moist, uniform, linear oases for organisms, especially under drier future conditions.

CHAPTER 3 - Climate Change and Alabama's Agricultural Crops

Dudek (1991, p 180) noted that agriculture is "the economic sector most directly affected by climate and weather." The potential effects of climate change on agriculture, of course, are critical to the continued feeding of the Earth's human population.

3a - Potential Effects of Climate Change on United States Agriculture

In their summary article, Adams et al. (1999, p ii) predicted that, while agriculture in developing nations may suffer due to climate change, "the United States is likely to continue to be able to feed itself." The net effect of climate change on United States agriculture could, in fact, be small. This is due mainly to predicted northward shifts in agricultural production, with crop yields increasing in the northern states and decreasing "in the already warm, low-latitude regions of the southern United States," including Alabama (Adams et al., 1999; p 1). Thus, while the national effects of climate change may be small, the regional effects may be great.

Adding more complexity to the agriculture picture is the fact that crop plants (as well as native plants) will increase their yields with higher carbon dioxide levels and moderate temperature increases (2-3°C). However, this *fertilization effect*--often touted as the "good" side of climate change--will fall if global temperatures rise above 4°C (Adams et al., 1999).

And different crops have different responses to carbon dioxide levels. Temperate zone crops, such as wheat, barley, oats, potatoes, and most vegetables, respond most favorably--their predicted yields (with a doubling of carbon dioxide levels) range from +15 to +20 percent. Tropical crops, such as corn, sorghum, and sugar cane, are less responsive, with their yields increasing only by five percent (Adams et al., 1991).

More uncertainty derives from the contrasting predictions about the frequency of destructive storms, winds, and droughts with climate change. “Agricultural systems are most sensitive to extreme climatic events such as floods, wind storms, and droughts, and to seasonal variability such as periods of frost, cold temperatures, and changing rainfall patterns. Climate change could alter the frequency and magnitude of extreme events and could change seasonal patterns” (Adams et al., 1999; p 1), increasing the demand for irrigation.

Additional stresses on agricultural systems will come from “changes in the incidence and distribution of pests and pathogens, [and] increased rates of soil erosion and degradation.... [The] expansion of irrigated acreage may stress environmental and natural resources, including water quantity and quality, wetlands, soil, fish, and wildlife” (Adams et al., p 2).

Keeping these future changes and uncertainties in mind, United States farmers can be proactive in a number of ways. They can change planting and harvesting dates, modify tillage and irrigation practices, and select their crops and crop varieties with future climates in mind (Adams et al., 1999). In these ways, farmers can ameliorate the potential negative effects of climate change.

3b - An Overview of Alabama’s Current Agriculture

Although Alabama farmers utilize portions of most of the state’s ecoregions to grow a variety of crops, the major producers of the main products utilize the best soils and microclimates. Although cotton and corn production (Figure 12) are spread throughout the state, the greatest production is in the northern (bordering the Tennessee River) and southern (coastal plain) counties. Soybean production (Figure 13) is concentrated in the same northern and southern

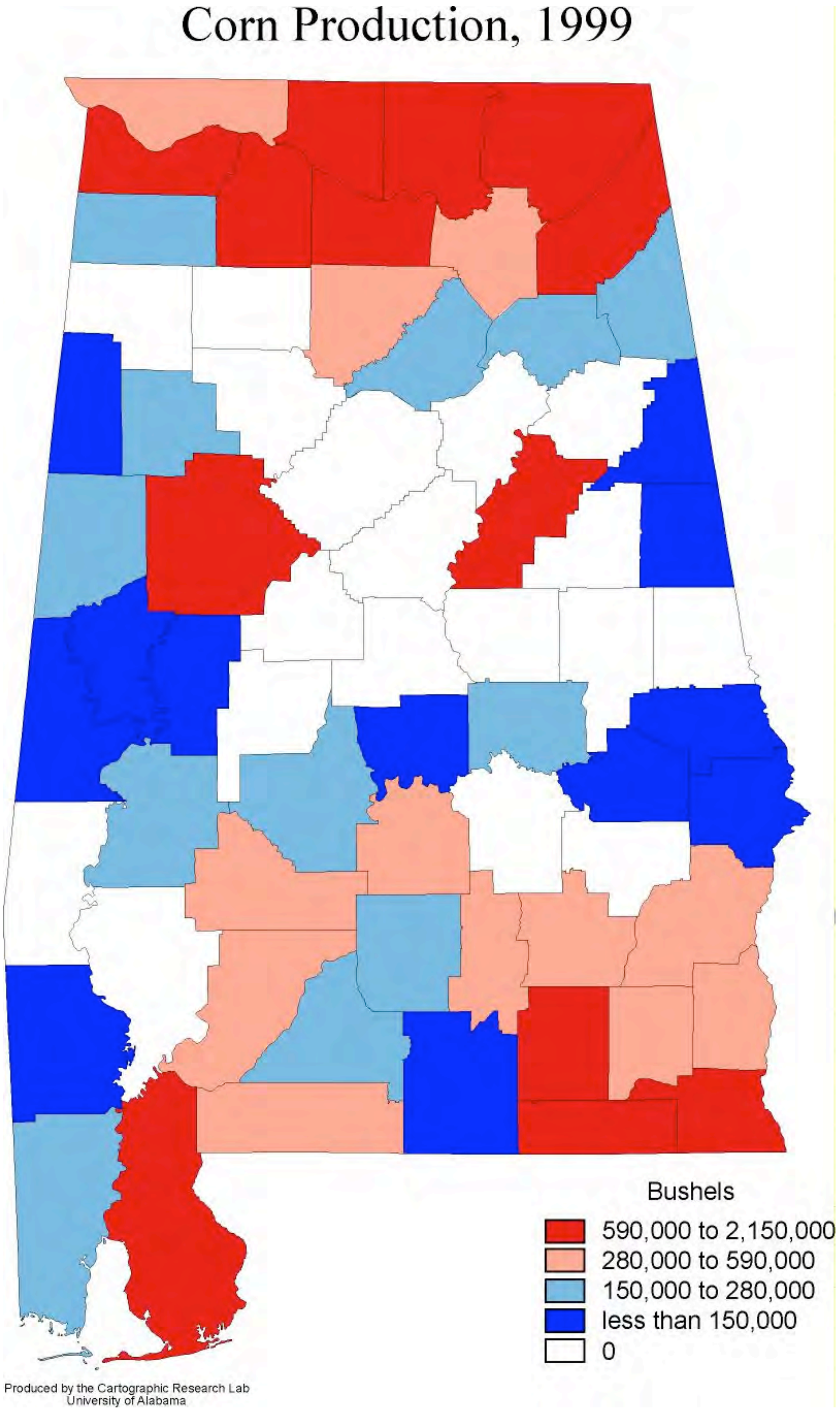
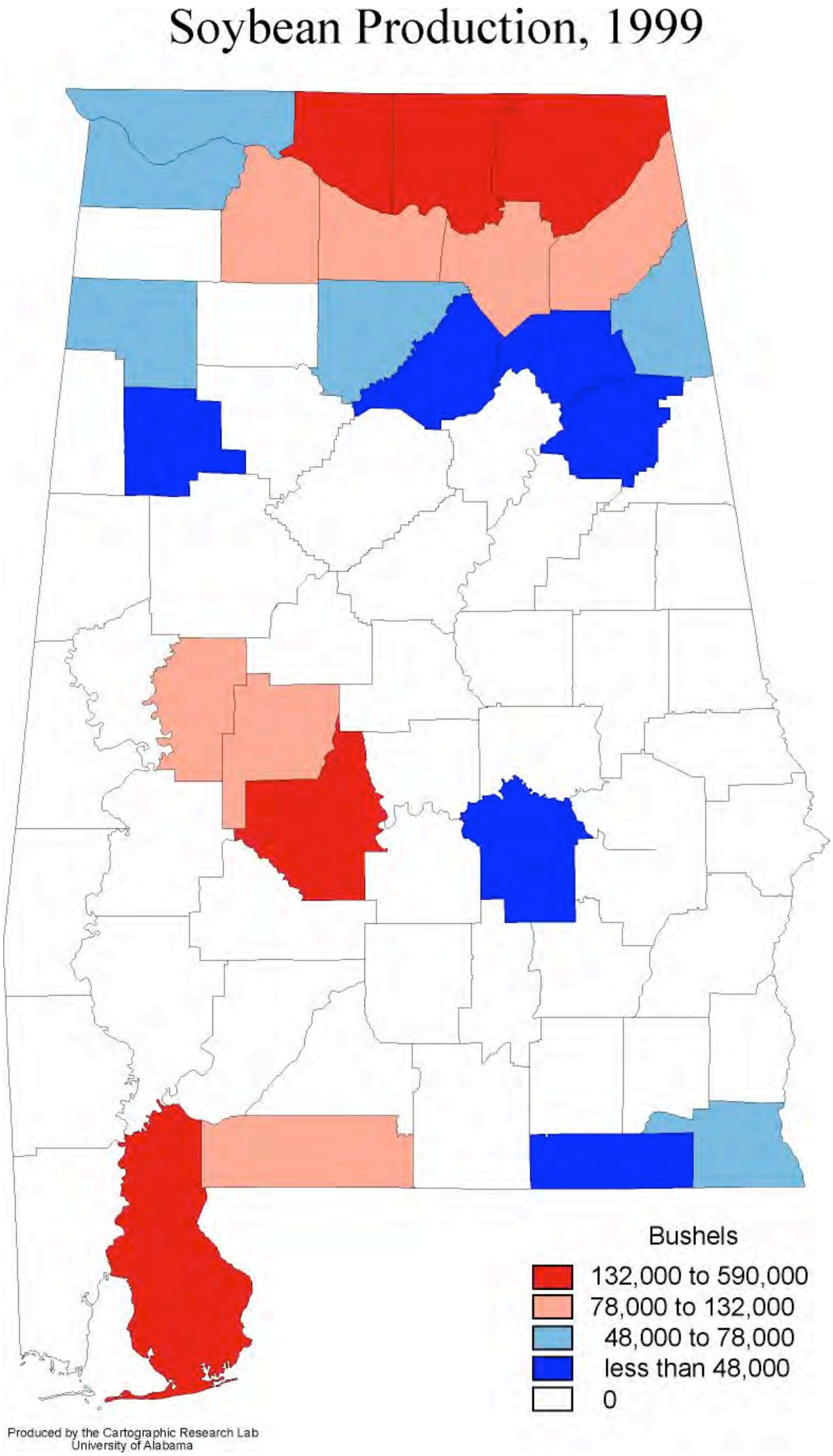


Figure 12. Corn production in Alabama, 1999. From Alabamamaps (2007).



Soybean Production, 1999

Produced by the Cartographic Research Lab
University of Alabama

Figure 13. Soybean production in Alabama, 1999. From Alabamamaps (2007).

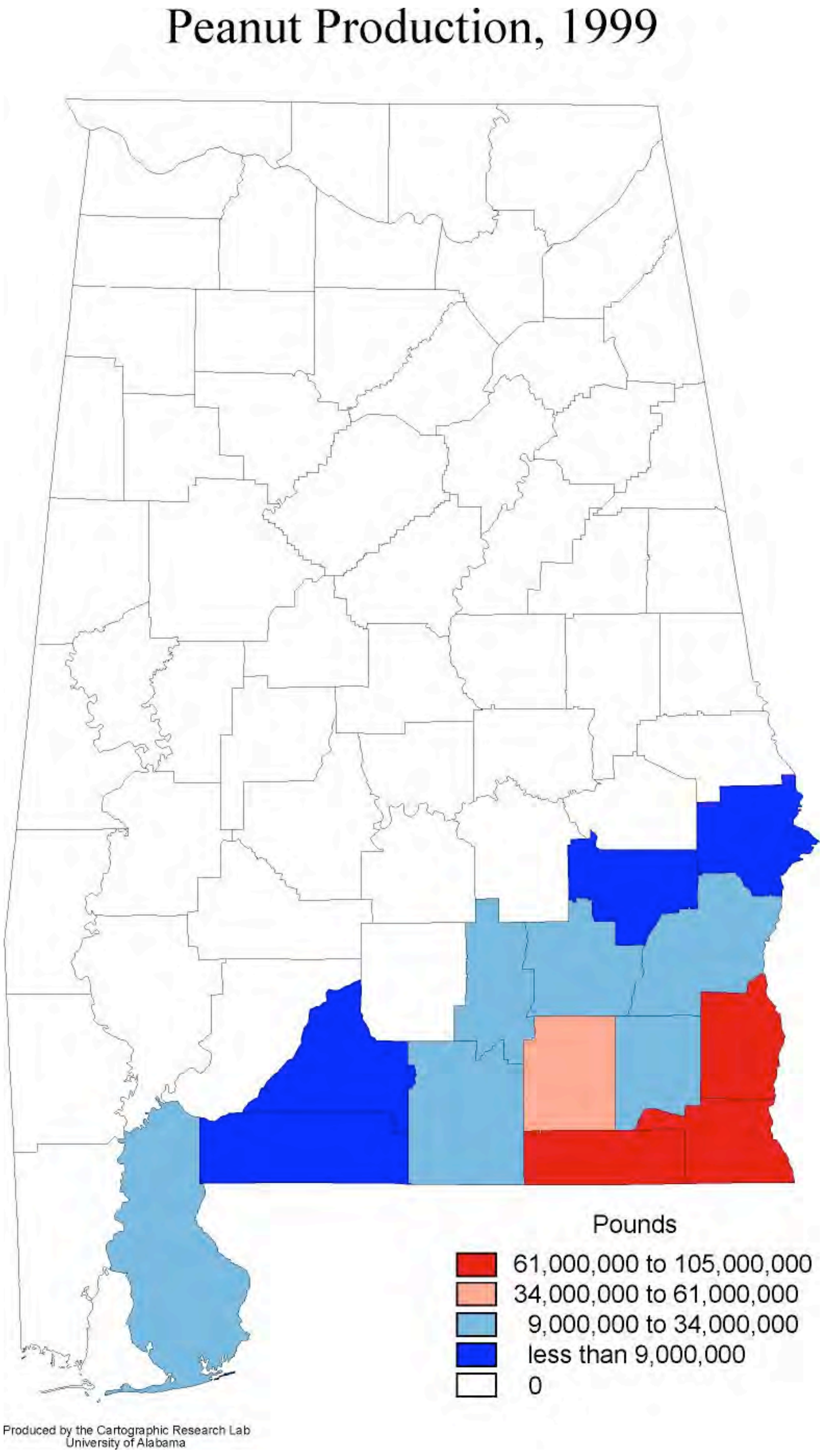


Figure 14. Peanut production in Alabama, 1999. From Alabamamaps (2007).

counties and largely absent from the state's center, while peanuts (Figure 14) are grown exclusively in the Dougherty Plain (Wiregrass) and adjoining ecoregions of Alabama's southeastern corner.

3c - Predictions - Potential Effects of Climate Change on Alabama's Agriculture

As noted previously by Adams et al. (1999), the potential effects of climate change on agriculture in Southern states, like Alabama, may be great. The following predictions are made:

Yields from temperate-based crops and fruit trees will decrease or cease.

It is likely that several of Alabama's temperate-based crops will follow the predicted national trends and shift northward. These include soybeans (a temperate herb of the Fabaceae or legume family) and wheat (a temperate grass). With increased temperatures, production of these two crops may cease in Alabama unless new, warm weather varieties are developed.

Production of temperate-based fruits, such as peaches and apples, is dependent on the number of chill hours (hours of 45°F or less) during winter dormancy. (Both of these fruits are members of the temperate-based Rosaceae or rose family.) Peaches, for example, demand at least 1000 such hours for proper bloom and fruit set (Sikora, 1999). With climate change, the ideal conditions for peach production--cold winters for bud dormancy but warm springs without late freezes--will shift northward away from the narrow central belt of peach-producing counties. Apple production, now mainly in Alabama's northern counties, may shift out of the state.

All current crops will suffer without irrigation.

Currently, Alabama ranks last in the United States in the number of irrigated acres of cropland, with only 130,000 to 170,00 such acres (Faulk, 2006a). The state is thus poorly prepared for the warmer and drier conditions that may prevail in the future. Some of these conditions may have already arrived (Faulk, 2006b).

Researchers at five Alabama universities are currently studying different means to collect the state's abundant winter rainfall and retain it for use during summer droughts (Faulk, 2006a). The building of such ponds, irrigation channels, and cisterns is essential for the continuance of Alabama agriculture under climate change.

All current crops will demand increased use of pesticides and herbicides.

Dudek (1991) noted a strong interaction between climate, pest populations, and crop damage. Pest populations of insects, currently limited by cold temperatures, are predicted to both expand northward and increase their number of annual reproductive cycles, leading to the greater use of pesticides. Fungal disease infestations will also increase, especially under warmer-wetter conditions.

Tropically-based weeds and invasive species, likewise currently limited by cold temperatures, are also predicted to expand their ranges northward with climate change. (See Chapter 5.)

Some tropically-based crops may increase in productivity and importance.

With climate change, some of Alabama's tropically-based crops may increase in productivity, thus becoming more important to the state's agriculture and economy. These include two tropical grasses, corn and sorghum; cotton (of the Malvaceae or hibiscus family); tomatoes and peppers (both of the Solanaceae or potato family); squashes, pumpkins and melons (of the Cucurbitaceae or squash family); and peanuts (a legume of tropical origin). Due to geological factors, however, peanuts may remain restricted to the Wiregrass region.

It must be emphasized, however, that the providing of irrigation water during summer droughts is essential to the maintenance and expansion of these tropical crops.

New tropical crops may be added to Alabama's current agricultural products.

As noted by Adams et al. (1999, p 11), "[A] reduced incidence of killing frosts could benefit southern regions growing heat tolerant crops such as citrus." Citrus fruits, such as grapefruits and oranges, could replace the more cold-demanding peaches and apples in Alabama's orchards. In addition, the relatively new biofuels industry could benefit from high-yield crops based on tropical and dryland grasses. Much research is currently being conducted on this potential new direction for Alabama agriculture (Bransby, 2006).

CHAPTER 4 - Climate Change and Alabama's Forests and Forest Products

4a - Potential Effects of Climate Change on the United States Forest Industry

Because forest products are, in essence, long-term agricultural crops, climate change will affect forests in a similar way to agriculture. According to Shugart et al. (2003, p ii),

> *the net impacts of climate change on the forestry sector will be small...; however, gains and losses will not be distributed evenly through the United States. The Southeast, which is currently a dominant region for forestry, is likely to experience net losses, as tree species migrate northward and tree productivity declines. Meanwhile, the North is likely to benefit from tree migration and longer growing seasons.*

Like agriculture, the effects of climate change on forestry depend upon actions taken and adaptations to that change. To minimize those effects, foresters must substitute better-adapted species for failing ones, relocate the forestry industry to productive regions, and salvage trees during diebacks (Shugart et al., 2003).

4b - An Overview of Alabama's Current Forest Industry

Alabama's general forest types are shown in Figure 15. Longleaf-slash pine forests are restricted to the outer coastal plain and central mountaintops; loblolly-shortleaf pine forests cover the upper coastal plain ecoregions, becoming patchier in the state's northern half; oak-pine forests dominate that northern half, with oak-hickory in the northernmost counties. Both private and public timber growers have modified these natural systems by the addition of pine plantations (especially of loblolly pine) where pine trees do not naturally dominate.

The cash receipts gained from forest products in each of Alabama's 67 counties are shown

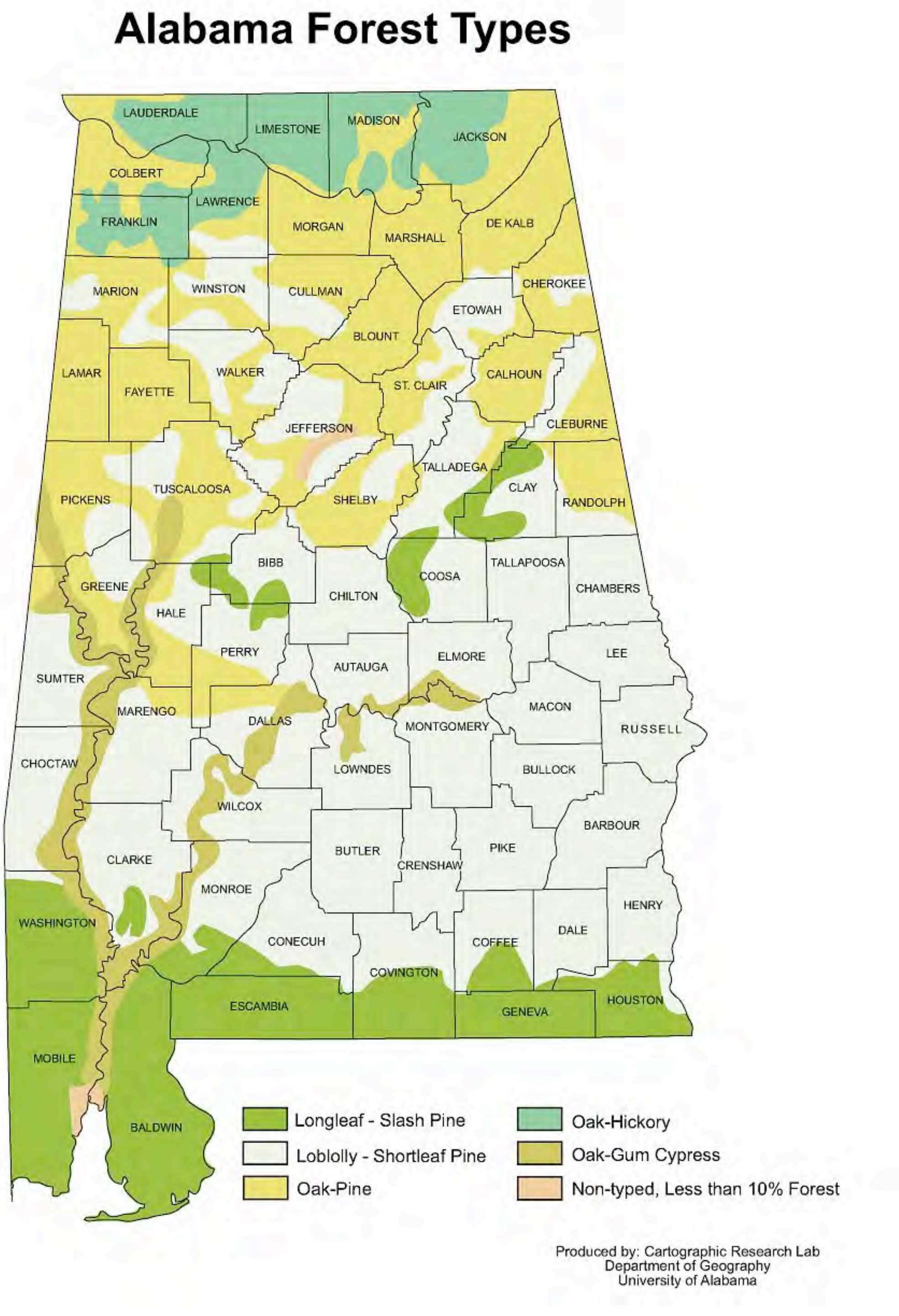


Figure 15. Alabama's current forest types. From Alabamamaps (2007).

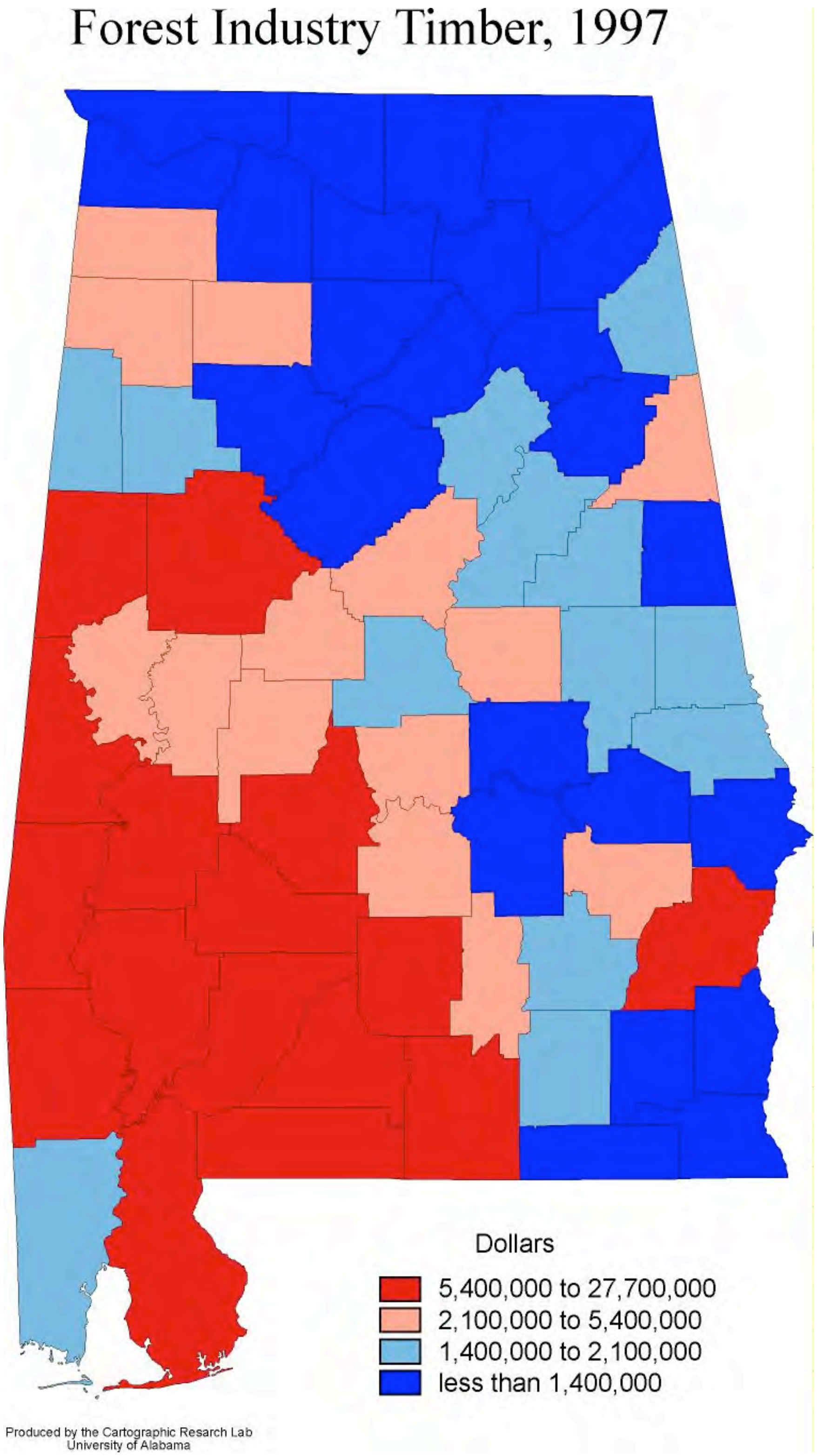


Figure 16. Alabama timber sales, 1997. From Alabamamaps (2007).

in Figure 16. These receipts show little correlation with the state's ecoregions, with the largest receipts (in 1997) from counties in the southwestern quarter of the state, and the smallest receipts from the north and east.

4c – Predictions - Potential Effects of Climate Change on Alabama's Forests

Figure 17 shows the projected dominant forest types in the eastern United States for the years 2070-2100. (Currently, no models specifically examine Alabama's forests.) The Hadley Centre Model, based on a predicted warmer and wetter climate, predicts that oak-pine forests will stretch further across Alabama, with oak-hickory forests withdrawing northward. Loblolly-shortleaf pine forests will become patchy across the state's mid-section, while longleaf-slash pine forests will constrict along the Gulf Coast. The Canadian Model, based on a warmer and drier future climate, predicts surprisingly similar changes. According to this model, though, longleaf-slash pine forests will cease to exist along the Gulf Coast; instead, they will occupy large portions of the Coal Measures vacated by oak-pine forests.

With the above broad-based models on future forests in mind, the following Alabama-specific predictions (and suggestions) are made:

More drought- and fire-resistant tree species should be planted.

The Canadian Model, especially, demands that foresters plant more drought- and fire-resistant species for future Alabama forests. This may involve the substitution of longleaf pines for loblolly pines, plus greater management of forests through prescribed burns. Both of these practices would also return the longleaf pine ecosystem to its once prominent place among Alabama's critical habitats (as in the Dougherty Plain or Wiregrass Region).

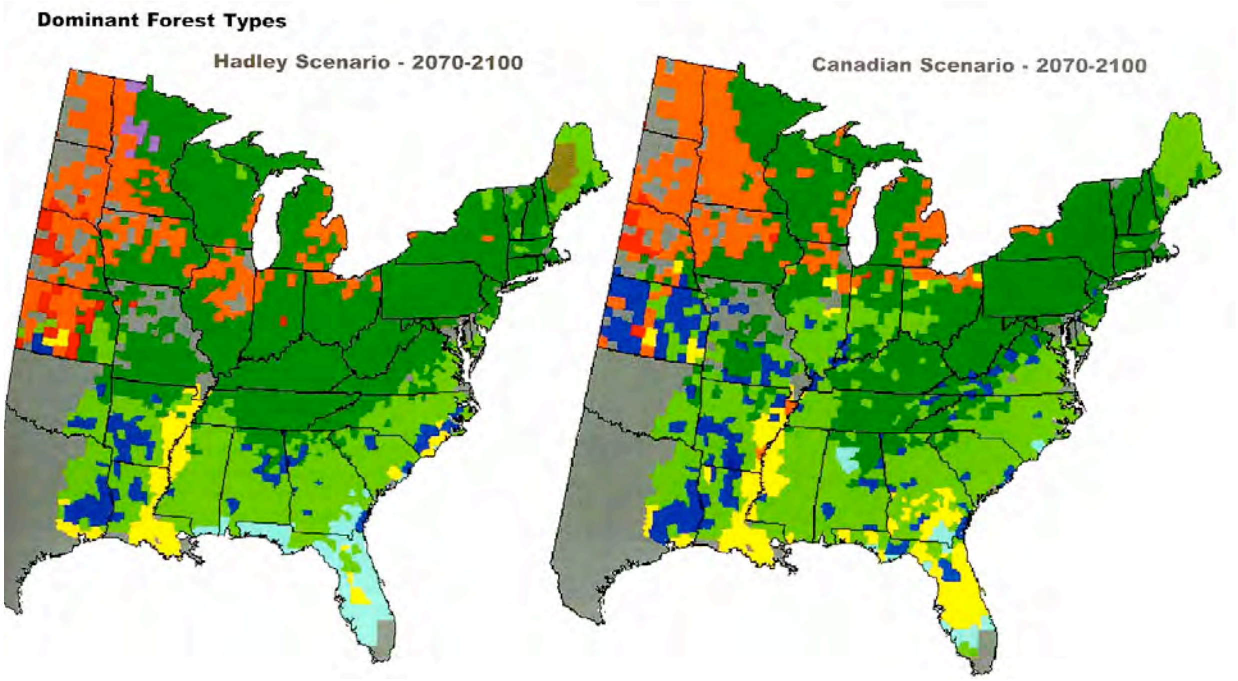


Figure 17. Future forest types of eastern North America, 2070-2100; the Hadley Centre and Canadian models; longleaf-slash pine (light blue), loblolly-shortleaf pine (dark blue), oak-pine (light green), and oak-hickory (dark green).

Expect more frequent forest fires.

The Canadian model predicts a 30% increase in fire hazard for the southeastern United States (National Assessment Synthesis Team, 2000). But like irrigation in agriculture, Alabama currently lacks the infrastructure and personnel needed for the more frequent forest fires predicted for the future. Such a system may be modeled after current fire-fighting systems utilized in Western states.

Forest structure may change, with vines becoming more dominant.

Studies suggest that forest structure may be modified by climate change, with vines growing more vigorously (and becoming more dominant) as a response to higher carbon dioxide levels (Williamson, 2006). Many of these vines are invasive plants, including kudzu, Japanese honeysuckle, English ivy, and various nonnative wisterias. (These vines will be discussed in the next chapter.)

The hazards of forestry may increase due to greater virulence of poisonous plants.

In addition to vines growing more vigorously in general, the native forest vine, poison ivy, is also becoming more virulent with higher carbon dioxide levels (Mohan et al., 2006). These higher concentrations of its critical exudate, urushiol, will pose even greater hazards to forestry workers in the future.

Pest infestations will increase, causing greater timber loss.

As in agriculture, pest infestations of forest trees are likely to increase with climate change. Warmer summer temperatures (and the lack of winter freezes) will allow pest species to undergo additional reproductive cycles.

Gan (2004) concluded that the doubling of atmospheric carbon dioxide levels will intensify the risk of Southern pine beetle infestations by 2.5-5 times. (Salvage harvest operations will help to lessen that risk.) Monetary loss from such infestations would be 4-7.5 times higher than the current value of trees killed annually.

CHAPTER 5 - Climate Change and Alabama's Pest Plants and Invasives

5a - Alabama's Pest Plants and Invasives

The southeastern United States is already well known for its broad array of invasive plants. Some of these plants were intentionally "released" in the South to provide ground cover and erosion control or to sustain wildlife. Others are escaped ornamental plants, mostly from Southeast Asia. (The floras of the southeastern United States and Southeast Asia share many entities, due to similar climates and shared climatic histories. Plants from one area are thus pre-adapted to the growing conditions of the other. For details see Morin [1983], Tiffney [1985].)

Miller (2003) compiled the basic information on invasive plants of Southeastern forests--their biology, habitat demands, origins, and means of control. He listed forty-three such species or groups of species as being troublesome invasives in Alabama. His complete list, rearranged to reveal taxonomic groupings, is shown in Table 6.

5b - Predictions of the Climate Change Model

Table 7 shows the elements of the Alabama invasive flora that have primarily tropical affinities. These 14 elements will most likely expand geographically, especially northward, with climate change. Among these are several vines (Japanese climbing fern, English ivy, winter creeper, and the climbing yams) that may be "fortified" by the higher carbon dioxide levels of the future (Williamson, 2006). Purple loosestrife, a major invader of wetlands (Stuckey, 1980), would expand only as long as water is available to those habitats.

Table 8 contains the Alabama invasives with primarily temperate affinities. These eight species, all dicots, are predicted to decline in extent with climate change.

Table 6. Alabama's invasive plants. This list is extracted and modified from Miller (2003).

Polypodiophyta (*ferns*)		
Lygodiaceae	*Lygodium japonicum*	Japanese climbing fern
Magnoliophyta/Magnoliopsida (*dicots*)		
Apocynaceae	*Vinca* spp.	various periwinkles
Araliaceae	*Hedera helix*	English ivy
Asteraceae	*Centaurea biebersteinii*	spotted knapweed
Berberidaceae	*Nandina domestica*	sacred bamboo
Caprifoliaceae	*Lonicera japonica*	Japanese honeysuckle
Caprifoliaceae	*Lonicera* spp.	various bush honeysuckles
Celastraceae	*Celastrus orbiculatus*	Oriental bittersweet
Celastraceae	*Euonymus fortunei*	winter creeper
Elaeagnaceae	*Elaeagnus pungens*	silver thorn
Elaeagnaceae	*Elaeagnus umbellata*	autumn olive
Euphorbiaceae	*Aleurites fordii*	tung oil tree
Euphorbiaceae	*Sapium sebiferum*	popcorn tree
Fabaceae	*Albizia julibrissin*	mimosa
Fabaceae	*Coronilla varia*	purple crownvetch
Fabaceae	*Lespedeza bicolor*	shrubby lespedeza
Fabaceae	*Lespedeza cuneata*	sericea
Fabaceae	*Pueraria lobata*	kudzu
Fabaceae	*Wisteria* spp.	various nonnative wisterias
Lauraceae	*Cinnamomum camphora*	camphor tree
Lythraceae	*Lythrum salicaria*	purple loosestrife
Meliaceae	*Melia azedarach*	chinaberry
Moraceae	*Broussonetia papyrifera*	paper mulberry
Moraceae	*Morus alba*	white mulberry
Myrsinaceae	*Ardisia crenata*	coral ardisia
Oleaceae	*Ligustrum japonicum*	Japanese privet
Oleaceae	*Ligustrum sinense*	Chinese privet
Rosaceae	*Rosa* spp.	various nonnative roses
Salicaceae	*Populus alba*	white poplar
Scrophulariaceae	*Paulownia tomentosa*	princess tree
Simaroubaceae	*Ailanthus altissima*	tree of heaven
Solanaceae	*Solanum viarum*	tropical soda apple
Ulmaceae	*Ulmus pumila*	Siberian elm
Magnoliophyta/Liliopsida (*monocots*)		
Dioscoreaceae	*Dioscorea* spp.	various climbing yams
Poaceae	*Arundo donax*	giant reed
Poaceae	*Imperata cylindrica*	cogon grass
Poaceae	*Lolium arundinaceum*	tall fescue
Poaceae	*Microstegium vimineum*	Nepalese browntop
Poaceae	*Miscanthus sinensis*	Chinese silvergrass
Poaceae	*Panicum repens*	torpedo grass
Poaceae	*Paspalum urvillei*	Vasey grass
Poaceae	*Sorghum halepense*	Johnson grass
Poaceae	*Phyllostachys* spp.	various nonnative bamboos

Table 7. Alabama invasive plants with primarily tropical affinities.

Polypodiophyta (*ferns*)		
Lygodiaceae	*Lygodium japonicum*	Japanese climbing fern
Magnoliophyta/Magnoliopsida (*dicots*)		
Apocynaceae	*Vinca* spp.	various periwinkles
Araliaceae	*Hedera helix*	English ivy
Celastraceae	*Celastrus orbiculatus*	Oriental bittersweet
Celastraceae	*Euonymus fortunei*	winter creeper
Lauraceae	*Cinnamomum camphora*	camphor tree
Lythraceae	*Lythrum salicaria*	purple loosestrife
Meliaceae	*Melia azedarach*	chinaberry
Moraceae	*Broussonetia papyrifera*	paper mulberry
Moraceae	*Morus alba*	white mulberry
Myrsinaceae	*Ardisia crenata*	coral ardisia
Simaroubaceae	*Ailanthus altissima*	tree of heaven
Solanaceae	*Solanum viarum*	tropical soda apple
Magnoliophyta/Liliopsida (*monocots*)		
Dioscoreaceae	*Dioscorea* spp.	various climbing yams

Table 8. Alabama invasive plants with primarily temperate affinities.

Polypodiophyta (*ferns*)		
Lygodiaceae	*Lygodium japonicum*	Japanese climbing fern
Magnoliophyta/Magnoliopsida (*dicots*)		
Berberidaceae	*Nandina domestica*	sacred bamboo
Caprifoliaceae	*Lonicera japonica*	Japanese honeysuckle
Caprifoliaceae	*Lonicera* spp.	various bush honeysuckles
Elaeagnaceae	*Elaeagnus pungens*	silver thorn
Elaeagnaceae	*Elaeagnus umbellata*	autumn olive
Rosaceae	*Rosa* spp.	various nonnative roses
Scrophulariaceae	*Paulownia tomentosa*	princess tree
Ulmaceae	*Ulmus pumila*	Siberian elm

Finally, Table 9 shows the 21 Alabama invasives whose families are cosmopolitan in distribution. Some of these will expand with warmer temperatures, while others will contract,

Table 9. Alabama invasive plants with cosmopolitan affinities.

Magnoliophyta/Magnoliopsida (*dicots*)		
Asteraceae	*Centaurea biebersteinii*	spotted knapweed
Euphorbiaceae	*Aleurites fordii*	tung oil tree
Euphorbiaceae	*Sapium sebiferum*	popcorn tree
Fabaceae	*Albizia julibrissin*	mimosa
Fabaceae	*Coronilla varia*	purple crownvetch
Fabaceae	*Lespedeza bicolor*	shrubby lespedeza
Fabaceae	*Lespedeza cuneata*	sericea
Fabaceae	*Pueraria lobata*	kudzu
Fabaceae	*Wisteria* spp.	various nonnative wisterias
Oleaceae	*Ligustrum japonicum*	Japanese privet
Oleaceae	*Ligustrum sinense*	Chinese privet
Salicaceae	*Populus alba*	white poplar
Magnoliophyta/Liliopsida (*monocots*)		
Poaceae	*Arundo donax*	giant reed
Poaceae	*Imperata cylindrica*	cogon grass
Poaceae	*Lolium arundinaceum*	tall fescue
Poaceae	*Microstegium vimineum*	Nepalese browntop
Poaceae	*Miscanthus sinensis*	Chinese silvergrass
Poaceae	*Panicum repens*	torpedo grass
Poaceae	*Paspalum urvillei*	Vasey grass
Poaceae	*Sorghum halepense*	Johnson grass
Poaceae	*Phyllostachys* spp.	various nonnative bamboos

based on water availability and other factors. Species like the popcorn tree and Chinese privet, which prefer the moist soils of streambanks and flood plains, may contract in distribution under drier conditions. In contrast, open roadside plants, such as mimosa, cogon grass, and the exotic bamboos (Figure 18), are likely to expand their distributions under such conditions.

The two vines of cosmopolitan affinities, kudzu and the nonnative wisterias, might follow the "fortified vine" model described above, becoming still more prevalent.

Figure 18. Roadside stands of golden bamboo and other invasive grasses are likely to expand with climate change. Photograph by the author, 21 September 2006, Talladega County, Alabama.

CHAPTER 6 - Conclusions

The uncertainty of future climate conditions makes it difficult to predict what the future holds for Alabama's plant life. How much warmer will it be? Will the general climate be wetter or drier? Will fires dominate our ecosystems? Will storms increase in their frequency and severity? Despite these uncertainties, the following summary predictions are made:

Some of Alabama's current ecoregions will shift northward or northeastward. Others, based on specific geological features, will constrict severely or disappear entirely.

With climate change, ecosystems will present new associations of plant species. In many cases, those associations will show a preponderance of tropical-based species.

Many of Alabama's threatened and endangered plant species will decline further with climate change and associated habitat loss. The boundaries of our current preserves should be expanded with future climate change in mind.

Temperate-based crops, such as wheat and peaches, will most likely suffer great losses with climate change. In anticipation of those losses, Alabama's agricultural community should consider shifting to more tropical-based crops, such as tomatoes and melons.

Under warmer-drier conditions, both crop plants and forests will suffer more frequent droughts. In anticipation, Alabama's agricultural community should build the infrastructure needed for greater use of irrigation water, while the forestry community should invest in fire-fighting equipment and personnel.

In addition to species migrations and losses, Alabama's forests will suffer increased pest problems and increased populations of vines. The salvaging of diseased and dying trees will become an important part of future forestry practices.

Alabama's future pest and invasive plant species will be more tropical-based. Alabama's forests, agricultural fields, and suburban yards will be invaded by aggressive tropical species, including numerous grasses.

An understanding of climate change, and its potential impacts on plant life, can help Alabama citizens anticipate that change and, in certain cases, act to mitigate or ameliorate its effects. This is especially true in the realms of agriculture and forestry.

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