AN EXAMINATION OF THE RIPARIAN BOTTOMLAND FOREST IN NORTH CENTRAL TEXAS THROUGH ECOLOGY, HISTORY, FIELD STUDY, AND COMPUTER SIMULATION

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This paper explores the characterization of a riparian bottomland forest in north central Texas in two ways: field study, and computer simulation with the model ZELIG. First, context is provided in Chapter One with a brief description of a southern bottomland forest, the ecological services it provides, and a history of bottomland forests in Texas from the nineteenth century to the present. A report on a characterization study of the Lake Ray Roberts Greenbelt forest comprises Chapter Two. The final chapter reviews a phytosocial study of a remnant bottomland forest within the Greenbelt. Details of the ZELIG calibration process follow, with a discussion of ways to improve ZELIG's simulation of bottomland forests.

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INTRODUCTION

Bottomland hardwood forests are valuable ecosystems that are disappearing rapidly in Texas. Impoundments, development, and timber harvesting are among the factors contributing to this decline. In addition to providing habitat for a variety of wildlife, they perform necessary ecological functions such as flood control, erosion control, and sequestration of sediments and chemical pollutants (Kellison and Young, 1997). Approximately twenty percent of these forests have been lost in the southern states since 1950 (Kellison and Young, 1997); by 1986, over one-half million acres had been inundated by reservoirs in Texas (McMahan, 1986). Thus it has become increasingly important to protect and to manage carefully the remaining bottomland forests, so that they may continue to perform the biological functions necessary for a healthy watershed.

This paper explores the process of characterizing a riparian bottomland forest in north central Texas in two different ways: by field study, and by computer simulation with the forest gap model ZELIG. First, however, context is provided in Chapter One with a brief description of a typical southern bottomland hardwood forest, and what ecological services this type of ecosystem provides. Chapter One also includes an overview of historic losses of bottomlands and forest conservation efforts in Texas from the late nineteenth century to the present. A report on a characterization study of the Lake Ray Roberts Greenbelt forest makes up the second chapter. The final chapter begins with a review of a detailed phytosocial forest study of a remnant bottomland forest within the Greenbelt. Details of the ZELIG model calibration process follow, and the chapter concludes with a discussion of possible ways to improve the model's performance in bottomland hardwood forests. If the Greenbelt forest can be modeled with a reasonable degree of accuracy, it may be possible in the future to use the model to simulate different management and restoration techniques, in order to judge their potential to achieve a mature forest resembling the remnant forest modeled for this study.

The objectives of this paper are

1. to provide justification of the preservation and restoration of bottomland hardwood forests in north central Texas by reviewing their ecology, ecological benefits, and history of use and abuse in Texas;
2. to characterize the Lake Ray Roberts Greenbelt corridor with regard to its potential value for a particular ecological benefit (wildlife habitat)
3. to calibrate the ZELIG forest simulation model for bottomland hardwood forests in north central Texas using field data from the Lake Ray Roberts Greenbelt.

CHAPTER 1

BOTTOMLAND HARDWOOD FORESTS IN ECOLOGICAL AND HISTORICAL CONTEXT

The Ecology of Bottomland Hardwood Forests

In 1989, the U.S. Army Corps of Engineers (COE), the Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (USFWS), and the Soil Conservation Service (SCS) expanded their wetland definition criteria to include bottomland hardwood forests (Kellison and Young, 1997). However, this expansion resulted in a storm of controversy and revision of wetland designation criteria, demonstrating that the political ramifications of scientific definitions of wetlands, including bottomland hardwood forests, can be extensive and unpleasant. This section of this paper is a brief description of bottomland forests based upon documented distinguishing features.

Although no exact rules exist for defining any ecosystem, bottomland hardwood forests possess several distinguishing characteristics that enable them to be differentiated from other types of systems. One such characteristic is their location; according to Hodges (1997), "bottomland hardwoods occur primarily on alluvial floodplain sites, although other non-alluvial wet sites also support many of the same hardwood species." Periodic inundation or soil saturation is typical of these forest sites. A hydrological regime such as this supports mixed hardwood and, in the southern United States, hardwood-cypress forests (Gower et al., 1997). Topography and hydrology in turn affect the soil origin and composition, which gives the forests another of their major distinguishing features (Hodges, 1997).

The topography of major southern stream valleys includes a current floodplain and a series of terraces formed from older floodplains (Wharton et al., 1982). Forests in the floodplain and youngest terrace are most subject to flooding and the accompanying sediment deposition, and so they tend to be the most productive (Hodges, 1997). The geomorphological profile of these areas is characterized by a series of small ridges, flats, and sloughs, which influence water retention, sediment deposition, and soil texture (Hodges, 1997). Species composition also varies with the topography as one proceeds along a trajectory moving away from the river. A typical major stream bottom in the southern United States may have willows and cottonwoods on the riverbanks; less water tolerant species (e.g. elm, pecan, and sugarberry) growing on the ridges; water-loving species (e.g. water hickory and overcup oak) in the sloughs; and mixtures of both types, as well as median species (e.g. green ash) on the flats (Hodges, 1997). Table 1 lists topographical features of a major southern bottomland forest, along with some of the species associations found on them.

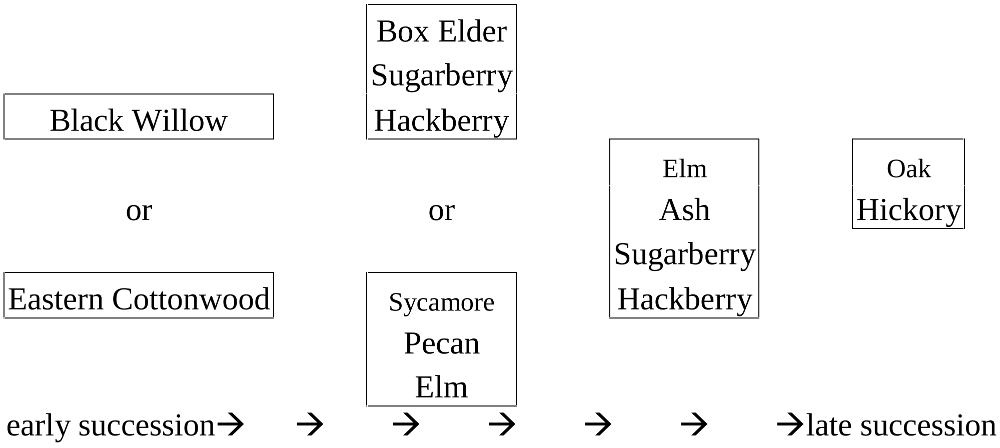
Succession of species in major southern stream bottoms follows one of two general patterns, depending upon whether the site is well or poorly drained; rate of sediment deposition also affects the pattern of species succession (Hodges, 1997). Figure 1 shows the general order of succession on major southern bottomlands, with regard to the species found in the Ray Roberts Greenbelt bottomland. The most pristine remnant bottomland hardwood stand in the Greenbelt is dominated by the elm-hackberry-ash

Table 1. Topographical Features and Examples of Corresponding Species Associations Found in Major Southern River Bottoms

Topographical feature	Species Composition
Bar	Willow, Cottonwood
Front	Elm, Sycamore, Pecan, Sugarberry
Flat	Nutall Oak, Green Ash, Sugarberry, Elm, Red Maple
Slough	Willow, Overcup Oak, Water Hickory
Ridge	Sweetgum, Water Oak, Willow Oak, Green Ash
Flat	Overcup Oak, Water Hickory
Swamp	Baldcypress, Water Tupelo
Ridge	Sweetgum, Hickory, Red Oak, Swamp Chestnut Oak, Winged Elm, Blackgum
Flat	Sweetgum, Water Oak, Willow Oak, Green Ash, Nuttall Oak
Slough	Overcup Oak, Water Hickory

(adapted from Hodges, 1997)

association, with some cottonwood, oak, and other species. See Table 2 for a list of species in this remnant. Other areas along the Elm Fork contain black willow, pecan, and sycamore, but the hackberry/elm/ash association remains the dominant one (Barry et al., 1999). As one progresses up the terraces to higher ground, the forest composition shades into upland species.



(adapted from Hodges, 1997)

Figure 1. Ray Roberts Greenbelt tree species associations, in order of general successional pattern.

Table 2. Tree Species from the Remnant Bottomland Forest on the Ray Roberts Greenbelt

Common Name	**Scientific Name**
Box Elder	*Acer negundo*
Chittamwood	*Bumelia lanuginosa*
Pecan	*Carya illinoensis*
Sugar Hackberry	*Celtis laevigata*
American Hackberry	*Celtis occidentalis*
Rough-leaf Dogwood	*Cornus drummondii*
Hawthorn	*Crataegus* spp.
Common Persimmon	*Diospytos virginiana*
Green Ash	*Fraxinus pennsylvanica*
Honey Locust	*Gleditsia triacanthos*
Black Walnut	*Juglans nigra*
Eastern Red Cedar	*Juniperus virginiana*
Bois d'arc	*Maclura pomifera*
Red Mulberry	*Morus rubra*
American Sycamore	*Platanus occidentalis*
Eastern Cottonwood	*Populus deltoides*
Bur Oak	*Quercus macrocarpa*
Shumard Oak	*Quercus shumardii*
Black Willow	*Salix nigra*
Eve's Necklace	*Sophora affinis*
Winged Elm	*Ulmus alata*
American Elm	*Ulmus americana*
Cedar Elm	*Ulmus crassifolia*
Slippery Elm	*Ulmus rubra*

(from Barry and Kroll, 1999)

Ecological Services Performed by Bottomland Hardwood Forests

The ecological role of the bottomland hardwood forest has only recently begun to be acknowledged. Historically, this productive ecosystem was perceived to be more valuable as farmland, but that perception is changing (Kellison and Young, 1997). Now, the bottomland forest is known to provide many crucial ecological services. Perhaps the most obvious and best documented is that of wildlife habitat. In addition to the resident bird population, bottomland forests, particularly in riparian areas, host a wide variety of migratory waterfowl (Kellison and Young, 1997). Many animal species, both game and non-game, also use these areas as homes and as corridors between habitats (Mathew, 1992, cited in Kellison and Young, 1997). In fact, the diversity of plant and animal species found in these forests is a subtropical echo of the richness of the tropical rainforests, and is nearly unrivalled in the lower 48 United States (Kellison and Young, 1997).

Wildlife habitat is only one of many benefits of intact bottomland forest ecosystems. Another is flood and erosion control (Maxwell and Martin, 1970; Clark and Benforado, 1981). The natural topography of riparian bottomlands includes sloughs and basins that fill and hold water during a flood event, reducing the magnitude of flooding downstream (Kellison and Young, 1997). Water retention also facilitates the recharge of aquifers (Maxwell and Martin, 1970; USFWS, 1985). Moreover, the thick vegetation found in these ecosystems anchors soil, thus reducing the scouring effects of rapid water movement that lead to erosion (Wharton, 1980). A benefit of the water-retention service of bottomland hardwoods is improved downstream water quality (Kellison and Young, 1997). By holding floodwaters in their sloughs and basins, riparian forests sequester sediments that would otherwise flow into the stream channel and increase the stream's turbidity. Moreover, riparian hardwood systems contain soils with predominately clay-sized particles, which are able to attract and bind a number of chemical pollutants, including pesticides (Dickson, 1986). They also hold "radioactive cesium, oil, nitrogen, sewage, and fly ash" (Dickson, 1986). Thus, bottomland forests shield precious water resources from damage by anthropogenic contaminants (Odum, 1978; in Dickson, 1986).

Another ecological function related to the water-retention capabilities of bottomland systems is nutrient cycling (Kellison and Young, 1997). As sediments are deposited in the backwater areas, nutrients are sequestered and released gradually into the stream over time (Chabreck, 1986). This process stabilizes the amount of nitrogen and other nutrients that reach the stream channel, preventing eutrophication of downstream systems. Eutrophication and increased turbidity, both of which are associated with alterations of riparian hydrology, are potentially devastating to estuarine systems, because they lead to lower dissolved oxygen levels (Chabreck, 1986). Bottomland systems also regulate and maintain an appropriate salinity gradient in estuaries. Removal of the forests results in a wide fluctuation of salinity levels from very low during flooding events to very high during periods of low water flow (Chabreck, 1986). Because fish and wildlife are not adapted to such wide variations in salinity, estuarine productivity declines when bottomland forests are destroyed. The Gulf Coast region supports the most productive fisheries, maintains the highest harvest of fur-bearing animals, and supports the largest populations of migratory birds in the United States (Chabreck, 1986). All of these are dependent on the estuaries of the Gulf Coast, which must maintain normal salinity gradients to remain productive. Thus, the disappearance of bottomland hardwood forests can be devastating to downstream estuaries as well as the watersheds in which they are located.

Discussions of the ecological benefits provided by any ecosystem raise the question of how to value these benefits in economic terms. Ecosystem benefits can be divided into two categories: goods, which includes timber and other commodities actually harvested from the forest and sold, and services, which include "environmental functions that produce benefit flows over time," such as those mentioned in the foregoing section (Aylward and Barbier, 1992). Traditionally, only the goods that could be extracted from an ecosystem have been considered in any economic appraisal. In recent decades, however, attempts have been made to evaluate ecosystems in terms of what the services they provide would cost if society had to undertake the performance of the same services (Costanza et al., 1997). Although a full discussion of this topic is beyond the scope of this paper, a brief introduction is included here, in order to provide further justification for the effort expended upon study, restoration, and preservation of these ecosystems.

Barde and Pearce (1991) and Aylward and Barbier (1992) list four different values that can be attached to ecosystems:

1. use value, which represents the actual uses (e.g. recreational) made of the area, as well as the goods extracted from it;
2. indirect value, which is the services provided by the intact ecosystem;
3. option value, which refers to the potential future value of the area; and
4. existence value, which is the value of the ecosystem for people who wish it to remain intact but do not intend to use it directly.

Moreover, ecological diversity may greatly impact the value of the goods and services an ecosystem provides, and should be considered in any economic valuation of that ecosystem, (Aylward and Barbier, 1992). Since bottomland hardwood forests are highly diverse systems, this last point is particularly applicable to them. Another consideration to be made is how a change, either qualitative or quantitative, in an ecosystem’s services can change the value of the goods harvested from that ecosystem (Costanza et al., 1997). Thus, the different levels of use are linked, which further complicates the issue of how to value ecosystems in economic terms. Given that bottomland forests provide so many essential services, preserving them is in the interests of people as well as the wildlife that call these forests home.

A History of Bottomland Hardwood Forests in Texas

It is clear that significant amounts of bottomland hardwood forests have been lost nationally and in Texas since the time of European settlement, although the extent of the loss is impossible to quantify precisely. Dahl and Johnson (1991, cited in Kellison and Young, 1997) estimate that total wetland loss in the lower forty-eight states from pre-colonial times to 1985 is 48.1 million of the original 89.5 million hectares (118.9 million and 221.2 million ac, respectively). More specifically, bottomland hardwood forests in the Mississippi Delta region had been reduced from a pre-colonial level of 25 million acres (10.1 million ha) to 4.5 million ac (1.8 million ha) by the mid-1980's, according to Dickson (1986). Kellison and Young (1997) estimate the losses differently. Measuring productive bottomland forests, i.e. forests capable of producing at least 1.4 m^3/ha/yr of saleable timber, they estimate the pre-colonial extent in the South to be more than 16 million ha (39.54 ac). After reaching a historic low in the late nineteenth century, the forests had recovered somewhat by the 1950's, only to drop again to 12,223 million ha (30,203 ac) in 1985 (Kellison and Young, 1997). In 1985, non-industrial, private landowners were found to own approximately 69% of bottomland forests in the South, but they were responsible for 92% of the loss of these systems between 1952 and 1985

(Kellison and Young, 1997). Table 3 contains ownership and loss estimates in the South for this thirty-three year period.

Table 3. Percentage of Distribution and Loss of Bottomland Forests in the South

Forest Management Type	National forest	Other public ownership	Forest industry	Non-industrial private ownership
% Relative distribution in 1985	1.5	6	23.7	68.8
% Loss of forest area 1952-1985	4		4	92

(adapted from Kellison and Young, 1997)

In Texas, 1.8 million ac (730,000 ha) of bottomland forests were present in 1976 (USFWS, 1985; Lay, 1986). Of this amount, over 700,00 ac (283,290 ha) was rated "poorly stocked" and needing regeneration; 46,100 ac (18,656.67 ha) was rated "medium stocked" (USFWS, 1985; Lay, 1986). The 1.8 million ac was calculated to be an eighteen percent loss from 1935 acreage, with 660,000 ac having been lost to impoundments alone in the twentieth century (USFWS, 1985; Lay, 1986). North central Texas has lost 5767 ac (2333.9 ha) in the past twenty years to the impoundment of Lake Ray Roberts (IAS, 1988; 1999). Approximately 500 ha (1235.5 ac) of bottomland forest located in the Ray Roberts Greenbelt (Barry et al., 1999) are threatened with damage due to altered hydrological regimes. While these figures are merely estimates, and often do not precisely agree, they show dramatic losses to bottomland hardwood forests since European colonization.

The history of the use of bottomland hardwood forests in Texas can be divided into three different, although not altogether distinct, time periods. These could be thought of as the period prior to European settlement, a period of exploitation, and a period of misuse tempered somewhat by conservation efforts. Lay (1986) demarcates these periods as pre-1820, 1820-1920, and 1920-1970, respectively. Prior to 1820, "a full complement of plants and animals was present to fill all ecological niches. Diversity was at its peak because all stages of plant succession were present.... It was not a perfect stand of large trees. All kinds and ages were present, including dead and dying" (Lay, 1986). In addition to species found in bottomland forests today, one could see animals such as Carolina parakeets, passenger pigeons, black bears, and red wolves, which are now completely or locally extinct. Native Americans used the ecotone between the bottomland and upland forests as camping sites, in order to have easy access to the rich hunting (Lay, 1986). While one should avoid the temptation to view this period as overly idyllic, it is certainly clear that human impact had not yet disrupted the ecological functions of the ecosystem.

This began to change with the arrival of European settlers. During the period from 1820 to 1920, the forests were overgrazed, overhunted, overharvested, and cleared for agriculture (Lay, 1986). No effort was made to conserve the resources, or even to use them efficiently. Timber harvesting all over the state increased exponentially after the Civil War, as mill owners established ever larger empires; by 1880 many individual owners controlled over 100,000 acres of forestland each (Maxwell and Martin, 1970). Logging practices were wasteful and inefficient, as both machinery and skidders carrying cut trees knocked down smaller trees that had escaped cutting (Maxwell and Martin, 1970). As a result, resources were exhausted, and by 1920 timber production had dropped almost to the post-Civil War level. Indeed, for the majority of Texas forests, "from virgin forest to cutover wasteland had taken only twenty-five years" (Maxwell and Martin, 1970). Despite the specter of dwindling forest resources and the young but growing conservation movement in both the United States and Texas, exploitation continued into the twentieth century.

Some of the continued exploitation of bottomland forests arose out of the necessity of the Great Depression. As people made temporary homes along rivers, riparian forests were hunted so heavily that even common animals such as deer became scarce (Lay, 1986). Timber companies scoured the forests for the last virgin stands and merchantable second growth. Harvesting practices remained inefficient, and ecologically unsound techniques such as highgrading (cutting all trees above a certain diameter) were ubiquitous (Lay, 1986). Additionally, in east Texas, hardwood and mixed hardwood-pine forests were being converted to pure pine stands as result of “an all-out propaganda and subsidy war on hardwoods" (Lay, 1986). The building of reservoirs has inundated more than one-half million acres of bottomland forests statewide since 1920, and much of the remaining stands have been adversely affected by the changes in hydrology resulting from those projects (McMahan, 1986). Other human activities of this period that have destroyed or damaged hardwood forests include recreation, urbanization, and pollution (Dickson, 1986). Thus, the history of bottomland hardwood forests in Texas since 1820 has been one of misuse and exploitation. However, since approximately the turn of the century efforts have begun to reverse this bleak trend. What follows is a history of policies enacted with the intent of preserving these valuable ecosystems.

The History of Forest Preservation Policy in Texas

Although the foregoing section presents a bleak picture of the fate of bottomland hardwoods in Texas, in the period between 1820 and 1970, the situation was not entirely hopeless. During the twentieth century, despite wasteful harvesting practices and losses due to other anthropogenic factors, some recovery of the forests did occur. Reductions in grazing, easing of suppression of hardwood species, and reintroduction of animals such as otters and beavers contributed to the partial recovery (Lay, 1986). Perhaps the most important factor was the change from a completely *laissez-faire*, utilitarian attitude to a more conservation-oriented philosophy of forest management. Much of this change is due to the work of William Goodrich Jones (1860-1950), the "Father of Forestry in Texas" (Maxwell and Martin, 1970). His accomplishments include leading the effort to establishing Texas Arbor Day (Feb. 22), promoting scientific forest management, surveying the forests of east Texas in 1899, and founding the Texas Forestry Association. His efforts eventually led to the appointment of a state forester and the establishment of Texas A&M’s Department of Forestry (Maxwell and Martin, 1970). Jones’ passion and commitment are evident in the following excerpt of his writing:

> The ghosts of our hacked, scorched, and wasted forests are already beginning to walk the land, and orators, expansionists, and future legislators are invited to listen to facts. Some who have tolled the death knoll of the forests have been called "Cassandra prophets," cranks, and calamity howlers. Recently a change has taken place and the men who have known so many things that were not so are no longer exploiting their learning. The crime of 1900 will go down to history and will be laid at the doors of Texas [sic] who cannot longer plead ignorance or lend an inattentive ear. The butchery of our timber and the shocking waste has sped on from year to year at an ever increasing rate and today we stand no longer as prophets but pointing to the end which comes in sight. When the forests are gone, great will be the lament from coast to western ranch, and to governors,

> legislators and mill-men will come to [sic] choice anathamas [sic] and invectives of an outraged people. (Jones, ca. 1900, reprinted in Maxwell and Martin, 1970)

In 1917, Article 16 of the Texas Constitution was amended. Section 59 established that the conservation and development of natural resources are "all hereby declared public rights and duties and the Legislature shall pass all such laws as may be appropriate thereto" (Vernon's Ann. Tex. Const. Art. 16, Sec. 59). Thus began the history of forest conservation in Texas.

Other early forest conservationists include John H. Foster and Eric O. Siecke, the first and second state foresters, respectively. Under Foster, the state forestry program was established and saved from the state legislature's efforts to scuttle it (Maxwell and Martin, 1970). During Siecke's twenty-five year tenure (1918-1943), the Department of Forestry at Texas A&M became the Texas Forest Service, and state forests were established in 1924, 1925, and 1927 (see Table 4). A Civilian Conservation Corps (CCC) performed many forest management duties during the Great Depression. Finally, Siecke was responsible for establishing the boundaries of several national forests, a duty delegated to him by the state legislature (see Table 4) (Maxwell and Martin, 1970). Additional supporters of Texas forest conservation in the first half of the twentieth century include several governors, legislators, and presidents of the Texas Forestry Association. Although the main thrust of conservation efforts was concentrated in the upland forests of east Texas, bottomlands also benefited somewhat, as small parcels of hardwood forest were located within the protected state and national forests (USFWS, 1985).

Table 4. State and National Forests Established in Texas, 1920-1940

State Forests	Acres	Year	National Forests	Acres	Year
E.O. Siecke	1,720	1924	Angelina	148,943	1935-36
I.D. Fairchild	2,630	1925	Davy Crockett	155,545	1935-36
W. Goodrich Jones	1,725	1927	Sabine	179,182	1935-36
John Henry Kirby	600	1927	Sam Houston	145,397	1935-36

(from Maxwell and Martin, 1970)

While early Texas conservationists struggled to enact sound forest management policy on the state level, the era of Theodore Roosevelt and Gifford Pinchot was under way nationally. A number of federal laws was subsequently passed between 1911 and 1933, which supported Texas' forest conservation efforts (Maxwell and Martin, 1970). The Weeks Law (1911) "established a pattern of state-federal cooperation in protecting watershed lands from fire and erosion and enabled the federal government to buy land for new national forests" (Maxwell and Martin, 1970). It was strengthened several times, most notably with the passage of the Clarke-McNary Act (1924), which provided the money to purchase land for the Texas National Forests. The Smith-Lever Act and Capper-Ketchum Act (1914 and 1928, respectively) established and expanded forestry the Extension Service's forestry programs. A forest research program was funded by the McSweeney-McNary Act (1928), which provided for a resource survey in Texas. Trees were planted in Texas' national forests as a result of the Knutsen-Vandenburg Act's authorization of a national tree-planting program (1930). Finally, the CCC was established and deployed in a variety of forest conservation and management tasks with the passage of the Emergency Conservation Act (1933) (Maxwell and Martin, 1970). These laws provided Texas conservationists with additional means to expand the state's forest preservation capacity.

More recent Texas statutes affecting forest conservation and preservation began to be passed in the 1970's. Title 1, Section 1.003 of the Water Code (1971) specifically declares forest conservation to be within the purview of the state's power (V.T.C.A., Water Code Section 1.003). Amendments to the Water Code, such as Section 11.149, address wildlife habitat issues and thus have the potential to affect bottomland forest conservation directly (McKinney and Rieff, 1986). Other amendments of the same year address issues of in-stream water uses, fish and wildlife protection, granting of development permits, and water quality; all of these affect the quality of bottomlands indirectly (McKinney and Rieff, 1986). In 1995, the Water Code was amended again to organize and establish the powers and responsibilities of the Texas Natural Resources Conservation Commission, which assumed the duties of enforcement of the Water Code, previously the bailiwick of the Texas Water Commission (V.T.C.A., Water Code Title 2). A very recent amendment to Title 5 of Texas Parks and Wildlife Code "delineates powers of government to regulate wildlife and endangered species through habitat preserves and habitat conservation plans" (V.T.C.A., Parks and Wildlife Code Sections 83.011-83.020).

A few of the more recent federal laws potentially affecting bottomland forest preservation include the Wilderness Act (1964) and National Wildlife Refuge System Administration Act (1966), which directly address protection of wilderness and habitat areas (USFWS, 1985). The Wild and Scenic Rivers Act (1968) slates certain rivers and riparian areas for protection, and the National Environmental Policy Act (1969) establishes general environmental regulations, such as requiring Environmental Impact Statements for any development project (USFWS, 1985). Judicious use of these and many other statutes could lead to progressive bottomland forest protection plans, when combined with careful research efforts.

Given the ecological benefits provided by bottomland hardwood forests, it seems clear that they are worth the effort to preserve and restore them. Moreover, the history of abuse and exploitation to which these ecosystems have been subjected in Texas seems to warrant more effective preservation efforts than have been made in the last century. Unfortunately, it is not clear exactly how much bottomland forest needs to be preserved, or what kinds of human intervention are needed to preserve it. Much depends upon a number of factors, e.g. the condition of the area to be preserved or restored, the surrounding land use, and the ultimate goals of the preservation or restoration effort. Also, since conservation biology and restoration ecology are young sciences, research methods are continually being developed. Despite the difficulties, efforts to study and preserve bottomland hardwood forests are being made. Chapters 2 and 3 show how two different approaches, field work and computer modeling, can improve ecologists' knowledge of the bottomland forest, and also help to determine the extent of preservation that may be necessary in a particular area.

CHAPTER 2

FOREST CHARACTERIZATION STUDY OF LAKE RAY ROBERTS GREENBELT

Introduction

Since wildlife habitat is one of the primary benefits that bottomland forests provide, and these forests are still disappearing in north Texas as a result of the factors discussed in Chapter One, research concerning how much forest is necessary to sustain resident species is very much needed. As wildlife habitat becomes more fragmented, corridors of similar habitat connecting these fragments become increasingly important. However, the extent of historical forestland is a debatable issue; even if a particular period in history is chosen as the ideal goal, experts disagree on the extent of unbroken forest alive at that time (Hodges, 1997; Hamel and Buckner, 1998). Colonization of tree species since the last Ice Age is also an ever-changing process (Hamel and Buckner, 1998). Moreover, river systems themselves are in a continual state of flux, as erosion, deposition, current flow, and many other factors change the shape of the a river over time (Forman, 1995). Thus, determining the optimum extent of unbroken, or at least connected, forest habitat based upon utilitarian goals may be a better choice than basing the decision upon historical conditions.

As stated in Chapter One, wildlife habitat is one of the primary benefits provided by bottomland hardwood forests. Studies have been done regarding the issue of forest corridor width, and its relationship to wildlife habitat. Everson and Boucher (1998) found that tree species richness increased with forest corridor width. Tischendorf and

Wissell (1997) and Haddad (1999) demonstrated that increasing forest corridor width resulted in asymptotic increases in the movements of small animals and butterflies, respectively. Skagen et al. (1998) showed that riparian habitat of any size was important to migratory birds in Arizona, and Perault and Lomolino (2000) found that the presence of corridors connecting fragments of old growth forest positively affected the populations of mammal species in the larger forest patches. For general purposes, Andreassen et al. (1995) recommend maximizing corridor width and structural variety while minimizing gaps in order to benefit the maximum number of species. Regarding riparian corridors, Forman (1995) recommends extending the corridor into the upland interior to facilitate movement of animal species, including upland interior species. However, in areas where discharge of pollutants threatens water quality, a wider corridor is needed to absorb these pollutants before they reach the stream channel (Forman, 1995).

While useful information regarding forest corridors can be gleaned from sources such as these, specific study of a riparian corridor in north central Texas was needed to make recommendations for that area. In 1997, an ecological survey of the bottomland forest within the Army Corps of Engineers land between the Ray Roberts and Lewisville reservoirs in north central Texas was begun. The Ray Roberts Greenbelt Corridor Study was undertaken to “explore how biodiversity assessment, habitat analysis, and landscape evaluations at various scales can provide conceptual guidelines for the design, evaluation, restoration, and management of riparian wildlife corridors (IAS, 1999).” Four major components make up the characterization study: a phytosociology study, an avian study, a habitat suitability study for avian species, and a mammalian study (Barry et al., 1999).

See Appendix A for a list of species found on the Greenbelt during the course of the characterization study. Barry (2000) and Hoffman (2001) analyzed data from this study and developed recommendations regarding riparian forest management for the north central Texas region. Their findings are presented in the discussion section of this chapter.

One component of the Greenbelt Corridor study was a phytosocial survey analyzing the Greenbelt forest with regard to its value as habitat for different species of birds and mammals, in both the narrow corridor areas and the larger patches. The purpose of the phytosocial survey was to gather relevant data about the forest, such as tree species counts, diameters of trees, successional stage, and canopy attributes. Various analytical techniques were used to determine how the importance of various species changes from one successional stage to another, and whether there is significant difference in physical forest characteristics between the larger patches of habitat and the narrow corridors of habitat that connect them.

Study Area

Lake Ray Roberts is a reservoir on the Elm Fork of the Trinity River. It is situated approximately 16 kilometers north of Denton, Texas (University of North Texas, 1995). After the construction of the dam, the Army Corps of Engineers established a greenbelt area that stretches from just below the dam at FM 455 to U.S. Highway 380, a linear distance of approximately 16 km (Barry et al., 1999). The set-aside area is intended for wildlife habitat and human recreational activity. Bottomland hardwood forest comprises one quarter of the nearly 2000 ha total area of the Ray Roberts Greenbelt (Barry et al., 1999). Figure 2 shows an aerial photograph of the Greenbelt.

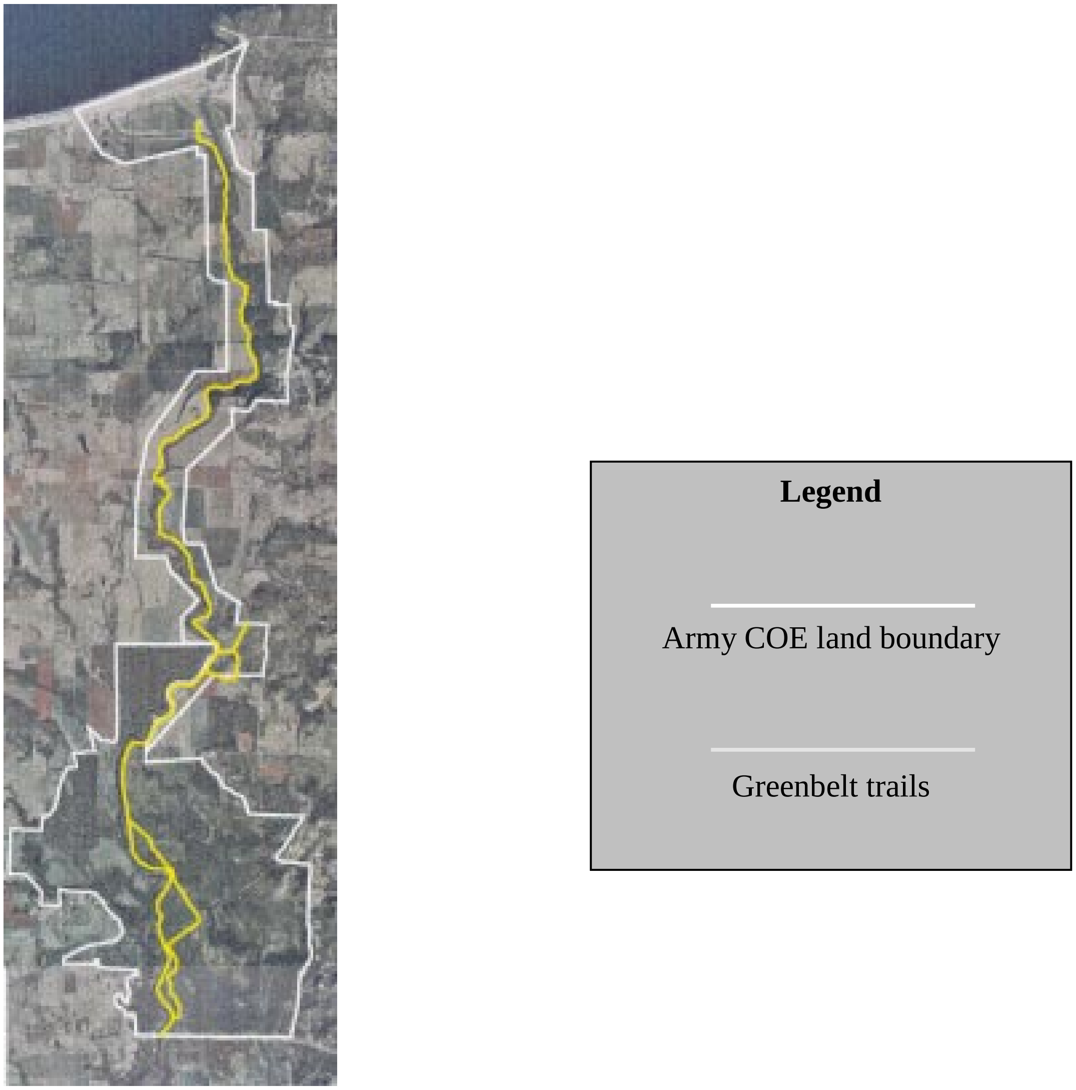


Figure 2. Lake Ray Roberts Greenbelt.

Materials and Methods

Study plots for the forest habitat characterization survey coincide with the avian survey plots in the Greenbelt corridor study. The first of these plots is located immediately south of Lake Ray Roberts dam, and plots occur every 250 meters in a southerly direction along the Elm Fork. The east-west position was determined using GIS, and located at the center of the forest patch or corridor at every 250-meter mark. Whether a plot lies east or west of the river depends upon whether the center of the forest habitat is located east or west of the river at that point.

Upon arrival at an avian plot, surveyors selected the area judged to be the most representative of the immediately surrounding forest as the forest characterization survey plot. The circular plots each had an area of approximately 100 m^2. Plot boundaries were determined using a 5.64 m rope pre-cut to the correct length. All stems of at least 10 cm in dbh within the plot were measured. The standardized height at which measurements were taken was 1.43 m above the base of the trunk (Oliver and Larson 1990). Measurements were made passing the tape under any twining vines if possible; otherwise the vines were included in the measurement and 1-3 cm deducted from the value obtained, according to vine thickness. All trunks split below 1.43 m from the base were measured as separate stems (Oliver and Larson 1990).

Forest seral stage was another category of data recorded at each plot. For this classification, the average dbh of overstory trees, stem density, and species composition within visual range were estimated. These allowed samplers to classify the area around each plot as one of the following seral stages: stand initiation (seedlings or saplings), stem exclusion (pole timber), understory reinitiation (saw timber), and old growth.

Canopy assessment, including number and mean height of layers was a substantial component of the forest survey. Number of canopy layers was determined by first noting presence or absence of each of the following: ground/herb, shrub, understory, midstory, canopy, and emergents. Presence of a layer was judged by whether enough of that layer occurred in the immediate area to afford perching or foraging opportunities for birds. Mean height of each layer was obtained by selecting a representative member to measure, either directly with a meter tape (ground and shrub) or using a clinometer (understory, midstory, canopy, and emergents).

For the fall characterization survey, plots were selected along the corridor in a stratified-random manner. The corridor was divided into lengths encompassing five or six avian plots. Then five or six numbers representing distances within those lengths were selected randomly for placement of a survey plot. The locations were determined from the aerial photos used to find the avian plots. Each plot was surveyed in the manner described above for the avian plots. Raw data from the phytosocial survey of the Greenbelt characterization study can be found in Appendix B.

Analysis of the data began with calculating importance values for each tree species, plus snags, over the entire forest for the avian plots and again for the random plots. The tree data were then separated according to successional stage, and importance values were again calculated for each stage. This was done for both avian and random plots. Complexity and foliage height diversity indices were calculated for each plot to provide additional attributes for comparison. The equation for the complexity index is

$$\text{CI}=\text{Density}*\text{Sum of Basal Area}*\text{Canopy layers}*\text{Species Richness}*10^{-5}$$

(adapted from Holdridge et al. 1971 and Shear et al. 1996). The foliage height diversity equation is $\text{FHD} = -\Sigma p_i \log p_i$, where p_i = the proportion of the total canopy height of canopy layer i (FHD is the H’ diversity index; Brower et al. 1998, MacArthur and MacArthur 1961).

The DOQQ data set assigned a category of corridor or patch to each individual avian survey plot according to the size (width, area) of the forest at that plot and the distance to the nearest edge. Importance values for the different tree types were recalculated for corridor and patch plots. The equation for importance value is

$$\text{IV} = (\text{Relative Density} + \text{Relative Dominance} + \text{Relative Frequency})/3$$

(Brower et al. 1998). Percentage of similarity was the metric adapted to compare importance values between corridor and patch areas. The equation used for percent similarity is

$$\text{PS} = \Sigma \text{ minimum } (p1i, p2i)$$

where $p1i$ is the importance value of species i in class 1 (corridor plots) and $p2i$ is the importance value of species i in class 2 (patch plots) (Brower et al. 1998; Dyer 1978). Percent similarity was also used to compare the importance values of the random plots to the corridor avian plots and to the patch avian plots. Finally, the total-forest values were compared between the avian plots and the random plots using this index.

Complexity, foliage height diversity, and canopy coverage were compared between corridor and patch areas using the Mann-Whitney U test. They were also compared between avian and random plots. Total density, total dominance, snag density, and large snag (>25 cm DBH) density were the last items compared, and these were also done between the corridor and patch plots and between the avian and random plots. See Table 5 for a summary of the metrics used in the analysis of Greenbelt data.

Table 5. Summary of Metrics and Tests in Greenbelt Characterization Study

Metric/Test	Plots
Complexity Index (CI) Foliage Height Diversity Index (FHD)	All
Importance Value (IV)	All Avian All Random Each Successional Stage- Avian Each Successional Stage- Random Avian Corridor Avian Patch
Percent Similarity of IV Mann-Whitney Total Density, Total Dominance, Snag Density, Large Snag Density, CI, FHD, Percent Canopy Cover	Avian Corridor v. Avian Patch Avian Corridor v. All Random Avian Patch v. All Random All Avian v. All Random

Results

For the avian plots, calculation of importance values for the entire forest revealed Hackberry, Green Ash, Snag, Cedar Elm, and American Elm to be the most important trees from a habitat perspective, i.e. these were the trees with importance values greater than 5. The actual values were 34.94, 19.75, 11.23, 8.82, and 5.25, respectively. Importance values were then calculated within each successional stage, and the values of Hackberry, Green Ash, Snag, Cedar Elm, and American Elm were plotted on a graph to determine the likely trend for each as the forest proceeds through its successional stages (see Figure 3). The values for all of these tree types were <10 in the Stand Initiation stage. Hackberry increased dramatically to a high of 36.24 in Understory Reinitiation, then declined slightly to 32.03 in the Old Growth stage. Green Ash showed a similar, though less dramatic trend, increasing to 22.41 in Understory Reinitiation and declining to 14.71 in Old Growth. Cedar Elm began at zero in Stand Initiation, climbed to 11.75 in Stem Exclusion, dropping slightly in Understory Reinitiation, and going back to zero in Old Growth. American Elm displayed a slow, steady increase from zero in Stand Initiation to 5.68 in Old Growth. Snags showed the most erratic pattern, beginning at 8.99 and increasing to 16.49 in Stem Exclusion, then dropping slightly below the Stand Initiation value to 7.54 in Understory Reinitiation before soaring to 28.33 in Old Growth. All values are listed in Table 6.

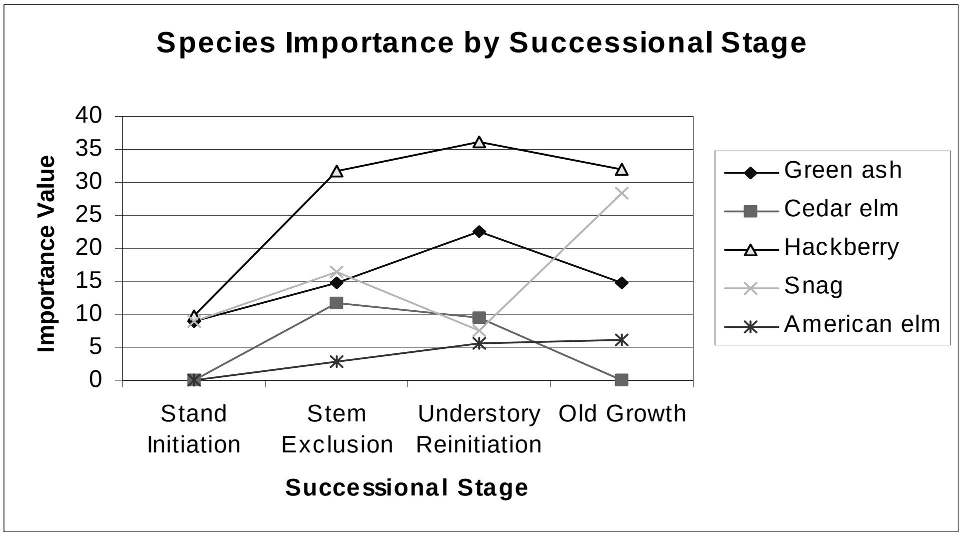


Figure 3. Avian plot species importance by successional stage for the most important forest species and snags.

Table 6. Avian Plot Species Importance Values for All Forest Species and Snags

Species	Stand Initiation	Stem Exclusion	Understory Reinitiation	Old Growth
Green ash	8.84	14.81	22.41	14.71
Cedar elm	0	11.75	9.34	0
Bois d'arc	0	3.82	1.03	0
Hackberry	9.59	31.65	36.24	32.03
Snag	8.99	16.49	7.54	28.33
Chittamwood	0	0.36	0	0
Red Mulberry	0	0	3.04	3.68
Black walnut	0	1.09	0	0
Bur oak	0	0	2.02	11.33
Honey locust	13.93	1.88	0.39	0
Hawthorn	0	0	0.39	0
Slippery elm	0	0	2.82	0
Shumard oak	0	0	0.4	0
Box Elder	0	4.46	2.9	0
Pecan	0	3.82	2.77	3.71
American elm	0	2.91	5.68	6.21
Cottonwood	33.5	2.61	2.51	0
Post oak	0	1.42	0	0
Blackjack oak	0	1.09	0	0
Black willow	25.16	1.84	0	0
Sycamore	0	0	0.54	0

For the random plots, the species with total-forest importance values greater than 5 were Hackberry, Slippery Elm, American Elm, Green Ash, Snag, and Cedar Elm. The actual values were 22.00, 17.52, 12.19, 11.49, 11.16, and 11.07 respectively. These species were graphed according to their importance values over the different successional stages (see Figure 4). This time, all species had values <10 in the Stand Initiation stage except for Green Ash, which was 24.79. Green Ash then dropped below 15 and remained near 15 through the Old Growth stage. Cedar Elm soared to 28.20 in the Stem Exclusion stage, but plummeted to below 5 by Old Growth. Hackberry climbed to 30.03 in the Understory Reinitiation stage, then fell nearly 10 points in Old Growth. Snags had values just above 8 in the first and last stages, with values near 14 in the middle stages. Slippery Elms had the lowest values, 2.96 initially, then dropping below 1 for two stages, and peaking at 6.59 in the last stage. American Elm values held steadily near 8 for two stages, then leapt to around 18 for the last two stages. Table 7 lists the values for all these species in all stages.

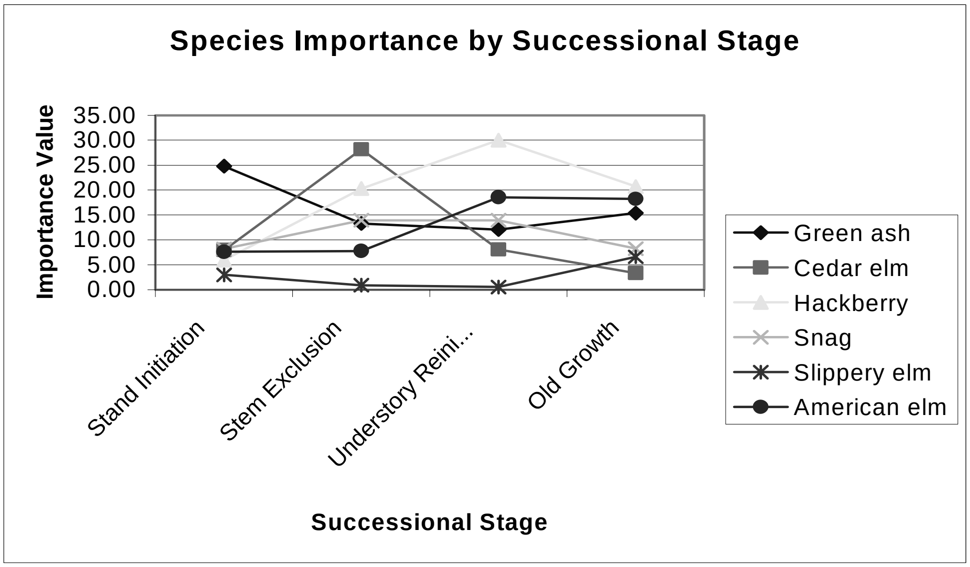


Figure 4. Random plot species importance values by successional stage for the most importance forest species and snags.

Percent similarity analysis of importance values between different data sets revealed a range of 69.31% (avian patch vs. total random plots) to 76.52% (avian corridor vs. avian patch plots). The mid-range similarity values were 71.79% (avian corridor vs. total random plots) and 71.91% (total avian vs. total random plots). Table 8 contains all percent similarity values.

Table 7. Random Plot Species Importance Values for All Forest Species and Snags

Species	Stand Initiation	Stem Exclusion	Understory Reinitiation	Old Growth
Green ash	24.79	13.28	12.06	15.34
Cedar elm	7.96	28.20	8.04	3.35
Bois d’arc	3.01	1.07	1.36	0.00
Hackberry	5.96	20.27	30.03	20.68
Snag	8.18	13.95	13.93	8.26
Chittamwood	0.00	0.85	0.00	0.00
Red Mulberry	0.00	0.84	3.37	4.93
Black walnut	0.00	0.00	0.00	0.00
Bur oak	0.00	3.22	3.90	10.82
Honey locust	0.00	0.00	0.51	0.00
Hawthorn	0.00	0.00	0.00	0.00
Slippery elm	2.96	0.91	0.51	6.59
Shumard oak	2.89	3.60	0.00	0.00
Box Elder	7.84	2.42	5.18	7.01
Pecan	16.09	0.00	1.06	0.00
American elm	7.61	7.78	18.59	18.19
Cottonwood	3.85	0.84	0.56	0.00
Post oak	0.00	0.00	0.00	0.00
Blackjack oak	0.00	0.00	0.00	0.00
Black willow	8.84	1.09	0.00	0.00
Sycamore	0.00	0.00	0.91	0.00
Mesquite	0.00	0.84	0.00	0.00
Chinaberry	0.00	0.85	0.00	0.00
vine	0.00	0.00	0.00	4.82

Comparisons of complexity indices, foliage height density values, canopy coverage, total density and dominance, and snag and large snag density were made among the different data sets using a Mann-Whitney U test. These were done in the following configurations: avian plots vs. random plots, avian patch vs. avian corridor plots, avian patch vs. random plots, and avian corridor vs. random plots. Most of the comparisons showed no significant difference at the 0.05 alpha level. The comparisons that did show a significant difference, or at least came close, were the total avian-total random complexity index (*p* value = 0.05), the avian patch-total random complexity index (*p* value = 0.06), and the avian patch-total random dominance comparison (*p* value = 0.07).

Table 8. Percent Similarity in Importance Values for All Species, by Data Set Comparison

Comparison	Percent Similarity
Avian Corridor vs. Avian Patch	76.52
Avian Corridor vs. Total Random	71.79
Avian Patch vs. Total Random	69.31
Total Avian vs. Total Random	71.91

Discussion

The results of the importance value analysis with respect to successional stage show, overall, an expected pattern in the avian plots. Green Ash, Cedar Elm, Hackberry, and American Elm, all species associated with earlier successional stages peaked in importance in Understory Reinitiation or earlier and declined in Old Growth. Snag importance value, however, increased dramatically in the Old Growth stage. This would seem to indicate an increase in suitable habitat for species that rely on standing deadwood as the forest succeeds to Old Growth. Currently, however, Old Growth patches are rare in the Lake Ray Roberts Greenbelt, and if past development patterns are continued, these patches may be lost along with the opportunity to increase this desirable habitat in the future.

In the random plots, the pattern is less clear. The rise in the Green Ash and Slippery Elm importance values and the decline in snag importance values, seem to run counter to the trend established by the avian plots. This could be due to the small number of the old growth and stand initiation plots sampled in the Greenbelt. It could also be due to error in identification of successional stage during the fall survey. There was some difficulty distinguishing between Slippery Elm and American Elm species during the fall survey as well.

The percent similarity analysis shows greater than two-thirds similarity for all data set comparisons, and greater than three-quarters similarity for the avian corridor and avian patch plot comparison. This would seem to indicate that, concerning physical habitat characteristics, little difference exists between the areas designated as corridor and those designated as patch. If so, this result supports the practice of providing corridors connecting larger patches of habitat, demonstrating that there is a continuation of habitat value from the patch to the corridor. The fact that there was no significant difference between corridor and patch areas with regard to complexity indices and foliage height diversity is further evidence of the similarity between the two sizes of habitat area. Indeed, the lack of significant difference in most of the data set comparisons, regardless of the metric compared, seems to indicate that the Greenbelt forest has somewhat similar habitat characteristics throughout. Only three of the comparisons come close to having significant difference at the $\alpha=0.05$ level, and two of them are complexity index comparisons. The reason for this is not clear; it could simply be an artifact of the metric itself.

Habitat fragmentation is an ecological issue that is becoming increasingly urgent as more land is developed for human use. As fragmentation increases, the need for corridors connecting habitat patches rises. This study indicates that it may be possible to maintain much of the habitat value present in larger patches along the corridors connecting them. Of course, further research on actual patterns of animal usage and movement through the corridors to determine whether the apparent habitat value is truly functional. Given the importance of the bottomland forest ecosystem as wildlife habitat, corridors connecting fragments of this valuable and productive habitat are essential.

Using avian demographic data from the Greenbelt corridor study, Hoffman (2001) found a positive correlation between corridor width and forest interior species richness. Similarly, a positive correlation occurred between distance to nearest edge and forest interior species. Analysis of the curves of best fit to the data revealed similar results; to maximize forest interior species richness, a forest patch should be approximately 450 m wide, with approximately 200m to the nearest edge (Hoffman, 2001). Thus, managing the Greenbelt forest to maximize forest interior bird species richness would involve widening corridor stretches to at least 200 m on each side of the river.

Applying landscape analysis to the same data, Barry (2000) found that amount of forest was the most common landscape factor affecting both species richness and abundance in the forest corridors. Furthermore, the entire avian community, not only the forest interior species, were affected by the amount of forest cover, width of the corridor, and distance to the nearest forest patch containing interior forest. Corridor width thresholds ranged from 200-470 m, with upper quartiles from 200-210 m in the Barry study. The distance to the nearest interior patch proved to be an important consideration; for conservation of forest interior bird species, “efforts should be made to make these corridors as short as possible, while extending the area of the extant patches as much as possible" (Barry, 2000). Barry's recommended average maximum distance is 125 m. Finally, habitat suitability analysis for selected bird species corroborated the results of the phytosocial study; the corridor and patch areas of the Greenbelt forest showed no significant differences with regard to habitat value (Barry, 2000).

If the management goal is to provide optimum habitat for birds, particularly forest interior species, then Barry and Hoffman have delineated specific recommendations with regard to forest corridors on the Ray Roberts Greenbelt. In summary, they are to provide a minimum of 200 m width on either side of the river, to provide a minimum of 35% forest cover within 1 km of the Greenbelt, and to maximize larger forests patch areas, connecting them with corridors of 125 m or less (Barry, 2000; Hoffman, 2001). Broadening the management goal to include a greater variety of animals, Greenbelt managers could expand corridor width to include upland interior, as Forman (1995) suggests. Since much of the Greenbelt corridor is narrower than the minimum recommended width of 200 m, restoration from other land uses would be necessary.

Successful restoration efforts require detailed information about the ecosystem being restored. Fortunately, one relatively large and pristine area of bottomland forest remains on the Greenbelt; it was the subject of a recent intensive study conducted by Barry and Kroll (1999). The results of that study were used to calibrate the ZELIG forest simulation model. Computer simulation may be able to provide information that could assist the restoration process. For example, it could give an approximation of the amount of time necessary to achieve the desired climax forest community. Additionally, if restoration efforts were to extend from the river bottom into the upland terrace, a series of simulations could demonstrate changes in the forest across a variety of spatial gradients. The third chapter provides a summary of Barry and Kroll's study, and describes the process of calibrating the model.

CHAPTER 3

USING THE FOREST GAP MODEL ZELIG TO SIMULATE A REMNANT BOTTOMLAND FOREST IN THE RAY ROBERTS GREENBELT

Introduction

Computer modeling is one way to evaluate the potential impacts of different forest management techniques and environmental stressors (Acevedo et al., 1997). With regard to corridor widths, it could help to determine the feasibility of achieving specific optimum width recommendations, such as Barry's and Hoffman's, based on a site's physical characteristics (e.g. soil moisture). It could also demonstrate the changes in forest species composition along transects from floodplain to upland in areas where the riparian corridor extends into the upland terrace, following Forman's corridor width recommendation.

The ZELIG model, developed by Dean L. Urban, is a type of forest simulator known as a gap model. Gap models, unlike other types of forest simulators, emphasize the effects of environmental factors on forest growth and composition as the simulation runs (Acevedo et al., 1995). They can also be grouped into the category of science-based models, which form something of a partially data-driven middle ground between statistical (empirical) and mathematical (theoretical) models (Rogers and Johnson, 1998). Science-based models "possess realism and generality but sacrifice accuracy" (Rogers and Johnson, 1998). Even so, gap models contain enough predictive power to be useful for a variety of purposes (Urban and Shugart, 1992). As such, ZELIG is a general ecological model that can be modified to suit specific sites and data sets (Urban, 1993). Further details about gap models in general, and ZELIG in particular, can be obtained from Urban and Shugart (1992).

For this project, the ZELIG model was calibrated with data from a patch of bottomland hardwood forest in north central Texas. Comparing the model's output with known ecological data of this type is a common method of testing gap models (Urban and Shugart, 1992). The purpose of the project was to determine the potential of the ZELIG model to simulate the bottomland forest of the Lake Ray Roberts greenbelt. After the simulations were run, the results were analyzed, and difficulties modeling various aspects of the forest noted. Suggestions for future model study and experimentation were advanced.

Data Sources

A phytosocial study of the remnant bottomland forest by Barry and Kroll (1999), reviewed below, provided calibration data for the model. The goal was to approximate the species composition of the Greenbelt forest as indicated by the importance values obtained by that study at some point within the model simulation. A window of 300-500 years was considered to be a reasonable estimated range, since the forest would be mature by that time. Allowance was made for possible succession beyond the community seen in the Ray Roberts Greenbelt remnant forest, since it did not represent the oak-dominated climax community presented in the ecological literature.

Some tree parameter values for the model, such as maximum height, maximum age, and crown type, were estimated from general literature (Vines, 1984; TFS, 1990; Grimm, 1962; Sargent, 1949; Preston, 1961; USDA, 1990; Little, 1998).

Weather data were obtained the National Oceanic and Atmospheric Administration (NOAA, 1992), and the National Solar Radiation Database (NSRD, 1992). Specific measurements, such as height and diameter data for individual trees were obtained from the field for this project. Values for the soil parameters were assigned according to soil textures within the patch, as listed in the Natural Resources Conservation Service's Soil Survey Geographic (SSURGO) database (1995).

Phytosocial Study of Ray Roberts Greenbelt Remnant Forest

The greatest area of protected riparian forest in Denton County is the Lake Ray Roberts Greenbelt. One large (93 ha) relict bottomland hardwood forest within the Greenbelt containing some old growth patches is located approximately two-thirds of the way down the Elm Fork, nearer to U.S. Highway 380. A variety of tree species can be found here, including green ash (*Fraxinus pennsylvanica*), cedar elm (*Ulmus crassifolia*), hackberry (*Celtis occidentalis* and *C. laevigata*), bur oak (*Quercus macrocarpa*), pecan (*Carya illinoensis*), black walnut (*Juglans nigra*), and bois d'arc (*Maclura pomifera*). A phytosocial study of this remnant was conducted in 1997 to determine some of the major tree community features (Barry and Kroll, 1997). The results of this study provide a model bottomland forest to guide managers in their preservation and restoration efforts. Figure 5 contains an aerial photo of the Greenbelt with detail of the relict bottomland forest.

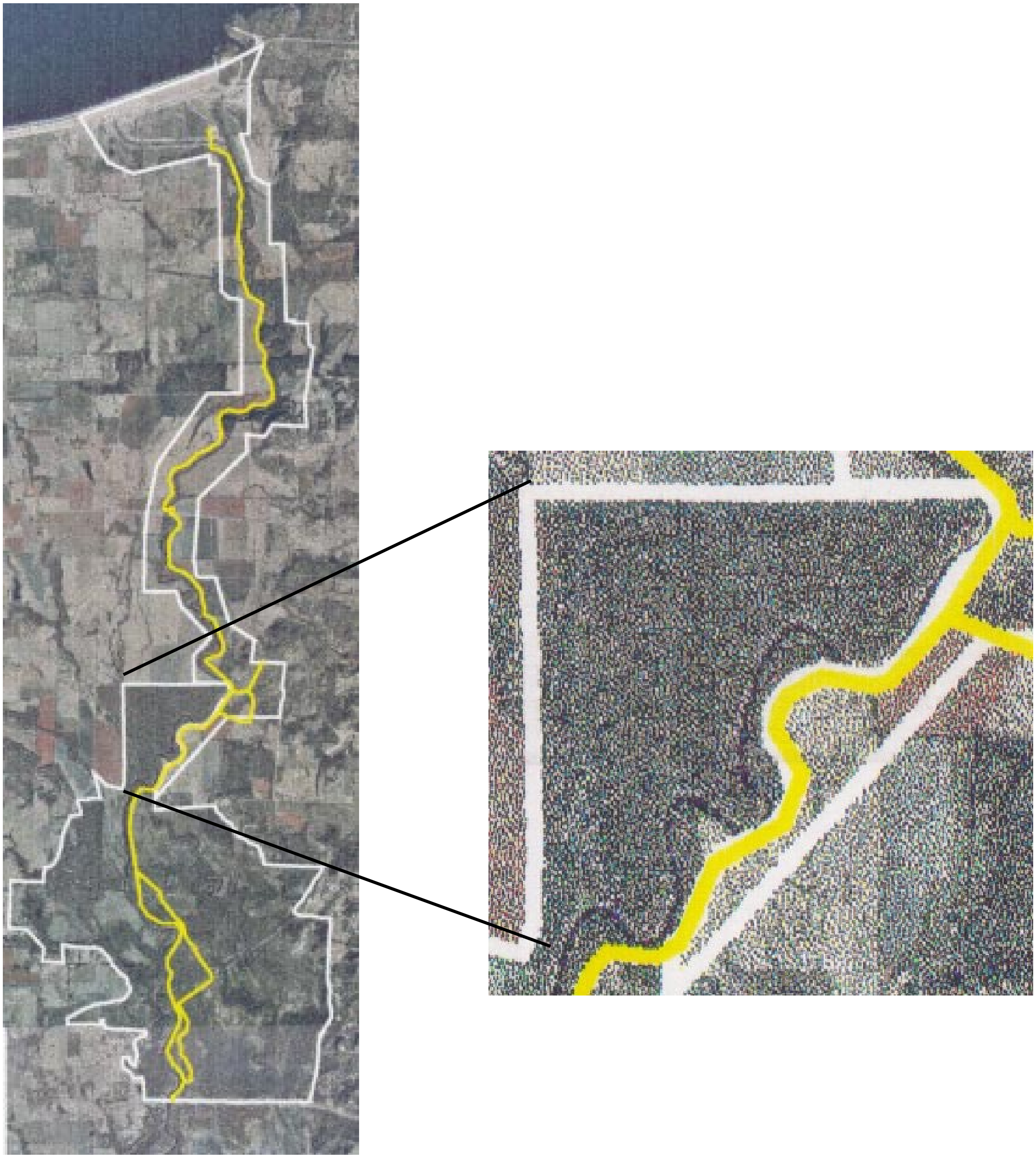


Figure 5. Aerial photograph of the Ray Roberts Greenbelt study area, with enlarged detail of the relict bottomland forest.

Methods

For this study, 128 circular, 100 m^2 plots were laid out in a grid. Standard forestry metrics such as diameter at breast height (dbh), density, and frequency were measured in each plot. Out of a total of 972 trees, twenty-four Hackberry specimens, thirteen Green Ash, and four Bur Oak were randomly selected from all size classes for age determination. Using a sixteen-inch increment borer with a 0.2-inch diameter, surveyors took cores from each tree at breast height. Rings were double-counted and the cores replaced and sealed with mud (Barry and Kroll, 1999).

Relative dominance (basal area per unit area sampled), relative density (number of stems per hectare), and frequency of occurrence were calculated for each species. Importance values were obtained by averaging the metrics. Linear regressions were run on the age data for Hackberry, Green Ash, and Bur Oak, with dbh as the independent variable and age class as the dependent variable. The regression curves were tested at $\alpha = 0.05$, and 95% confidence limits obtained from descriptive statistics. Relative similarity of individual plots was determined with cluster analysis. Specified cluster designation was obtained with K-means clustering, using the complete linkage joining algorithm to maximize differences between plot distances, the percent disagreement distance algorithm for categorical data (presence/absence), and the city-block distance algorithm for continuous data to maximize effects from extreme values (Barry and Kroll, 1999).

Results

Thirteen tree species, plus snags, were sampled in this study; nine more species were encountered, but did not fall within a sampling plot. Of the species sampled, the ones with the highest importance values were Hackberry (40.19%), Cedar Elm (28.13%), and Green Ash (9.51%). Snags, an important component of bottomland forests, were found to have an importance value of 7.17%. All other species' importance values were less than 5%. Table 9 lists importance values for all species sampled; refer to Table 2 for a list of all twenty-four species encountered in the study. According to these results, the classification for this bottomland forest is hackberry/elm/ash (Barry and Kroll, 1999).

Table 9. Importance Values for Species of the Relict Bottomland

Species	**Relative Dominance**	**Relative Density**	**Relative Frequency**	**Importance Value**
Hackberry	53.61	39.81	27.14	40.19
Cedar Elm	38.33	23.56	22.49	28.13
Green Ash	4.17	12.14	12.22	9.51
Snags	1.29	7.51	12.71	7.17
Black Walnut	0.15	4.22	5.62	3.33
Bur Oak	1.98	2.37	5.13	3.16
Chittamwood	0.15	1.95	4.40	2.17
Bois d'arc	0.23	2.26	3.67	2.05
Hawthorn	0.05	2.47	2.20	1.57
Box Elder	0.02	1.44	0.73	0.73
Red Mulberry	0.00	0.72	1.47	0.73
Slippery Elm	0.00	0.51	0.74	0.42
Eve's Necklace	0.00	0.51	0.49	0.33
Shumard Oak	0.02	0.31	0.49	0.27
Honey Locust	0.00	0.11	0.25	0.12
Paper Mulberry (shrub)	0.00	0.11	0.25	0.12
Sum	100.00	100.00	100.00	100.00

(Barry and Kroll, 1999).

The regression analysis of the dbh and age data for Hackberry and Green Ash showed a positive correlation of age to dbh; $R^2 = 0.68$ ($p < 0.0001$) and $R^2 = 0.7088$ ($p < 0.0003$), respectively. The Bur Oak data were not analyzed with a linear regression because of small sample size. Instead, an average ratio of 2.3 years per cm of diameter was calculated. Table 10 contains the formulae for the age estimations. Cluster analysis of plot metrics and presence/absence of species revealed the patchy nature of the forest. Patchiness is observed in both species composition and association. Fourteen classification clusters were found at the 50% relative dissimilarity level. The 5 category K-Means clustering showed that many spatially adjacent plots are not clustered in terms of species composition (Barry and Kroll, 1999). Extreme patchiness of this kind is consistent with the characteristics of riparian bottomland forests, whose species tend to vary greatly with differences in micro-topography and distance from the river (Hodges, 1997).

Table 10. Allometric Formulae for Age Estimation

Species	**Age Estimation Formula**	**95% Confidence Limits**
Hackberry	age = (1.7015*dbh) + 7.4975	+/- 0.03*dbh
Green Ash	age = (1.0175*dbh) + 14.597	+/- 0.23*dbh
Bur Oak	age = 2.3*dbh	+/- 0.38*dbh

(from Barry and Kroll, 1999)

Discussion

The dominance of the hackberry, cedar elm, and green ash species, and their wide distribution throughout the size classes, indicate that the hackberry/elm/ash association is replacing itself and maintaining itself as a climax community. Bur and Shumard Oaks, while not common, are present in large enough numbers, both as mature trees and as seedlings, to indicate that succession to the oak-hickory community described by Hodges (1997) could occur. Indeed, the change in hydrology brought about by the Ray Roberts dam may be assisting the change in species composition. Drier soils and absence of flooding have encouraged the propagation of Black Walnut and Bur Oak seedlings. Additionally, these conditions do not favor the hackberry/elm/ash association, which is adapted to wetter environments. It is conceivable, then, that the forest could eventually succeed to an association of oaks and walnuts, and become a classic old growth or late-successional bottomland forest. Currently, the forest as a whole can be classified as transitional old growth, based on the classification system of Oliver and Larson (1990), although small patches of true old growth can occasionally be found within it (Barry and Kroll, 1999).

Studies like this are important because very little detailed information exists about the condition of bottomland forests in north Texas. The phytosocial analysis reveals a remnant that can be taken as a model for restoration of degraded bottomlands, and as a baseline for comparison with other existing bottomland forests. This is particularly true since Barry and Kroll's study is a characterization of the forest itself, whereas many of the recent studies of bottomlands have been conducted as wildlife habitat studies. The methodology can be used as a template for monitoring the health of forests across the area. It may also be helpful in developing and evaluating restoration efforts. For this project, it provided empirical data for the calibration of the ZELIG model for simulation of bottomland hardwood forests in north central Texas.

ZELIG Model Calibration Process

Methods

As stated above, the model parameter values were calculated using field data and literature. Site parameters include all the values relating to soil, such as depth, profile, wilting point, and fertility. The first three of these were estimated as a function of topography and soil type. Fertility was estimated near the high end of the scale (from <5 to 25), since bottomland hardwood forests are highly productive systems with histories of sediment deposition on their sites. Site parameters also included the climate variables of temperature, precipitation and solar radiation, which were needed to calculate potential evapotranspiration (PET). These were obtained from a meteorological source such as NOAA. Species parameters for ZELIG include maxima for age, height, and diameter at breast height (dbh) for each species represented in the model. These were obtained directly from field guides and natural history literature. The particular species to be modeled are known from the Ray Roberts Greenbelt characterization study. Other parameters, such as shade tolerance, nutrient response class, and seedling establishment rate, were researched in more detail from botanical literature. ZELIG's offline support program, WEATHER, estimated temperature tolerance limits for each species, while growth rates were estimated allometrically in Splus. Height allometry parameters were calculated from non-linear regression of tree height to DBH. Raw data for the regression were obtained from the field measurements of height and dbh of individual trees. Other allometric parameter values were assigned according to crown type. All these values were stored in the input file of the ZELIG model.

Prior to running the forest model, data for ZELIG's input files were obtained from a variety of sources. Values for parameters directly related to the different tree species were estimated from forestry literature. The Silvics Manual online (USDA, 1999) provided information, such as shade and drought tolerance, geographic range, competitive fitness, and vegetative reproductive ability, from which many of the input parameters were estimated. Other parameters, such as maximum age, height, and diameter, were obtained from field guides and natural history sources (Vines, 1984; TFS, 1990; Grimm, 1962; Sargent, 1949; Preston, 1961). Weather data from NOAA (1992) was used to obtain maximum and minimum growing degree-days for each species, based on the geographic ranges given in Silvics. The process of determining degree-days is discussed below. This study required temperature and precipitation records for the area, from 1895-1989 (NOAA, 1992), and solar radiation data for Fort Worth from 1961-1990 (NSRDB, 1992). Information on soil types in the Greenbelt forest was obtained from the Soil Survey of Denton County (NRCS, 1980), and the SSURGO database (NRCS, 1995).

The ZELIG model requires three input files to run a forest simulation. Examples of these files are shown in Appendix C. The first is the control driver file, which simply determines the size of the plot matrix, the number of years to run the simulation, the time interval at which to print the results, and the like. The site driver file contains information about the site of the forest simulation. Included in it are the latitude, longitude, and elevation of the area. These are followed by theta, phiB, phiD, and light extinction parameters, all of which have default values, which were used for this simulation. Tree size and maximum canopy height complete the top grouping of parameters. Tree size is given as 100 m^2, a general estimate of the total canopy coverage of one of the largest trees in the forest. Maximum canopy height is also estimated based on the maximum height of the largest tree species on the site (Acevedo et al., 1997).

The next section of the site file contains soil data. ZELIG can simulate up to nine types of soil. For each soil type, the number of layers must be given; ten is the maximum (default) value. Also, soil fertility must be estimated, on a scale of 1-25, 25 being maximum fertility. Since the Ray Roberts Greenbelt is on a major stream bottomland, the soil fertility was estimated at a value of twenty. Depth in centimeters must be given for each soil layer, and again the default is ten. Other values for soil are the field capacity and wilting point (per layer), both of which were obtained from values in the ZELIG manual for silty clay loam, the closest soil type to the Ovan Clay found in the Greenbelt. Soil type information was obtained from the Soil Survey of Denton County (NRCS, 1980).

Climate parameters follow the soil parameter values. The first two lines contain average temperatures (in degrees Celsius) and their standard deviations for each month. Average monthly precipitation levels (cm) and their standard deviations are contained in the next two lines. Average monthly solar radiation data follows the precipitation data. As mentioned above, temperature and precipitation data for the Greenbelt site were obtained from NOAA (1992), and solar radiation from the NSRDB (1992). The bottom of the site file contains a digital soils map. It is a matrix of soil types to be simulated, the number of rows and columns of which are stated in the control file. Since the SSURGO database (NRCS, 1995) shows that the Ovan Clay, resembling a silty clay loam, underlies almost all of the Greenbelt forest, silty clay loam was the only soil type simulated.

The third input file required by the ZELIG model is the species driver file. In order to simplify the modeling process, only the top five species from the relict bottomland were selected to model. These species were selected by analyzing the results from the Barry and Kroll study. Hackberry, Cedar Elm, Green Ash, Black Walnut, and Bur Oak had the highest importance values; all were greater than 3.0 (refer to Table 9). For that study, however, snags were measured, and found to have an importance value of 7.17. Since ZELIG does not include snags in its output, only the top five living species were selected. Moreover, ZELIG uses an alternative calculation for importance value; it excludes relative frequency from the equation. The equation for ZELIG's importance value calculation is IV = (Relative Density + Relative Dominance)/2. Consequently, the importance values for the top five species were recalculated as though they were the only species, and recalculated again using only relative density and relative dominance in the equation (see Table 11). Finally, Pecan was substituted for Black Walnut, because most of the small Black Walnuts were very likely misidentified Pecans. The importance value for Pecan was estimated to be slightly less than that of Bur Oak (Barry, 2000).

Table 11. Top Five Importance Values Recalculated

Species	**Importance Value (Top 5 spp only)**	**Importance Value (Rel. Dens. And Rel. Dom. only)**
Hackberry	46.81	51.52
Cedar Elm	32.91	33.88
Green Ash	11.95	9.50
Black Walnut	4.34	2.64
Bur Oak	3.99	2.45
sum	100	100

ZELIG's species file lists several species and environmental parameters for each tree species. Maximum age (Amax), maximum diameter (Dmax), and maximum height

(Hmax) are the first three species parameters. These were all estimated from the Silvics Manual and other tree literature. Two parameters, b2 and b3, are coefficients obtained from an allometric ratio of diameter to height. This allometry was performed using a specially written program in Splus. The equation for the calculation is $H = h_1[1\text{-}\exp(h_2D)]^{h3}$, where h_1 is the maximum height for a particular species, D is diameter, and h_2 and h_3 represent the height and steepness of the curve, as determined by regression. A growth rate value (g) is also listed for each species. It can be obtained by using ZELIG's offline program GROW, but in this case it was obtained from a special Splus program. Growth patterns are approximated by the life form parameter (lf). The ZELIG manual lists nine codes that correspond to different tree genera. Of these nine codes, only the codes for *Quercus* (8) and Other Deciduous (9) were needed. Finally, reproductive success is estimated with the parameters Seed, NSprt, and Sdmax. They represent seedling establishment rate, capability to resprout from stumps, and the maximum diameter at which stump sprouting will occur, respectively. The first two are values between 1 and 5, and represent each species' rank relative to the others. All three of these were estimated as nearly as possible from the Silvics manual.

The environmental parameters approximate several environmental conditions required by each species for growth. First among these are minimum (DDmin) and maximum (DDmax) temperature limits, estimated as degree-days. These were obtained by noting the northern and southern limits of the natural range of each tree species, as given in the Silvics Manual. Site input files were developed for each of the range limits for each species, and the offline program WEATHER was run on each new site file.

Output from WEATHER includes degree-days for each site, based on mean daily temperatures. To calculate degree-days, WEATHER subtracts a growth threshold temperature from each day's mean temperature, and sums the results over an entire year. Degree-day values were used in the species driver file, with the northern value as the minimum and the southern value as the maximum for each species. Following these are environmental tolerance parameters L, M, and N, which estimate tolerance to shade, drought, and nutrient deficiency, respectively. L and M are estimated on a scale from 1 to 5 (1=intolerant), and N is estimated on a scale from 1 to 3 (1=intolerant). None of these estimations is absolute; they are all ranks based upon each species' tolerance relative to the others'.

Once initial values were derived for each input file parameter, the model was run. ZELIG's main program produces five output files from which the results of the simulation can be determined. Output files include a print file, a log file, a tracer file, a punch file, and a profile of the leaf area index (LAI); see Appendix D for examples. The punch file summarizes ecological data for each 100-m^2 plot in the simulation. Represented variables in the punch file are year (kyr), row (kr), column (kc), soil type (ksol= msol[kr,kc]), density, biomass (mg/ha), basal area, (m^2/ ha^2), cumulative leaf area index (m^2/m^2), maximum canopy height (m), size class distribution (stems/ha, in 20 10-cm size classes), and basal area per species. This summary of per-plot data allows the investigator to compare variability among plots and to "illustrate stand attributes on a plot-by-plot basis" (Urban, 1993). The LAI profile breaks down the LAI by plot, and gives a separate value for each row, column, and canopy height on the model's grid. This profile may be processed and represented in graphical form to produce a detailed picture of the LAI by plot.

For the purposes of this paper, however, the print, log, and tracer files are more important than the other two. The print file contains information on stand structure and species composition for the forest as a whole, and prints it at user-specified time intervals. It begins with a review of the site and species input parameters. Then, at the end of each print interval (e.g. years 100, 200, etc. for a 100-year print interval), the file displays the stand structure by species, in stems per hectare in each of twenty 10-cm size classes. Totals for all species are also given. Species composition is summarized in a table listing density, relative density, basal area, relative basal area, importance value, and frequency. For ZELIG, the importance value is the arithmetic mean of relative density and relative basal area. Finally, for each print interval, several stand aggregates are listed: total density, total basal area, mean dbh, total woody biomass, mean LAI, and mean canopy height.

Print file data are important for determining how closely the simulation matches results from Barry and Kroll’s study of the actual forest. Also important to the analysis of the results of each run are the log and tracer files. The log file begins with a summary of site and climate conditions. It then gives reports the number of trees dying during the simulation, by size class. One interesting feature of this table is the division of dead trees into categories representing age-related mortality and stress-related mortality. Another table gives the growth status of each individual tree in one representative plot on the model’s grid. This table lists the species, dbh, and height of each tree, followed by a series of growth multipliers. Multipliers represent available light, soil moisture, soil fertility, and degree-days, and determine how much of each tree's growth potential it was able to achieve. This information proved to be very important to this study, because limiting environmental factors in the site could be identified and corrected for. Tables summarizing regeneration and light profile throughout the plot complete the log file. Since these factors did not influence the results of the model for this study, these tables were of limited importance to the analysis.

The tracer file consists of "a condensed stand-level output file which is designed to be ported directly to a graphics package, to illustrate the temporal dynamics of the simulated stand (Urban, 1992)." Included in this file are year, density, biomass, standard deviation o biomass, total basal area, mean LAI, mean canopy height, and basal area per species. These values are printed at user-determined time intervals within the simulation. Tracer file data were used to determine whether values such as basal area and total biomass exhibited oscillatory behavior over time, and whether values such as the leaf area index were typical for a southern bottomland forest.

The procedure of the ZELIG modeling experiment consisted of running the model using the best estimates for the parameters of each input file discussed above. Output files, particularly the print, log, and tracer files, were examined and evaluated. Then parameters in either the site or species driver files were altered experimentally, with the hope of achieving results closer to the actual field study. Details of these experiments, with their results, are presented in the next section.

Results

As stated above, the initial model run was made using parameter estimates based on forestry literature, allometric calculations in Splus, and some ZELIG default values. It was expected that the importance value results of this run would not match the Barry and Kroll study, and they did not. Table 12 shows the change in importance values over the simulation period of 500 years. What was not expected was that the trees would exhibit lack of growth even at 300-500 years. See Figures 6 and 7 for diameter class and average canopy height values, respectively. Manipulation of the species parameters brought the species composition results closer to the Barry study, but did not improve tree growth. Inspection of the log file showed the lack of growth to be the consequence of water stress. In most individual cases, the multiplier for soil moisture was at or near zero, resulting in little or no tree growth for the time interval shown in the file. To correct this problem, the depth of each soil layer was increased to retain more water within the root zone.

Table 12. Change in Importance Values for Each Species Over Simulation Period

	Yr 50	Yr 100	Yr 150	Yr 200	Yr 250	Yr 300	Yr 350	Yr 400	Yr 450	Yr 500
Species	**Importance Value**									
Green Ash	42.21	58.03	33.29	53.33	21.48	45.79	32.15	30.67	50.55	36.47
Cedar Elm	0.62	5.37	4.87	2.22	4.02	0	0.53	7.1	0	0.23
Hackberry	0.59	1.71	7.87	7.55	9.79	0	1.84	10.41	29.47	0.47
Bur Oak	56.58	34.89	53.74	36.89	64.15	54.21	65.48	51.82	19.98	62.83
Pecan	0	0	0.23	0	0.56	0	0	0	0	0

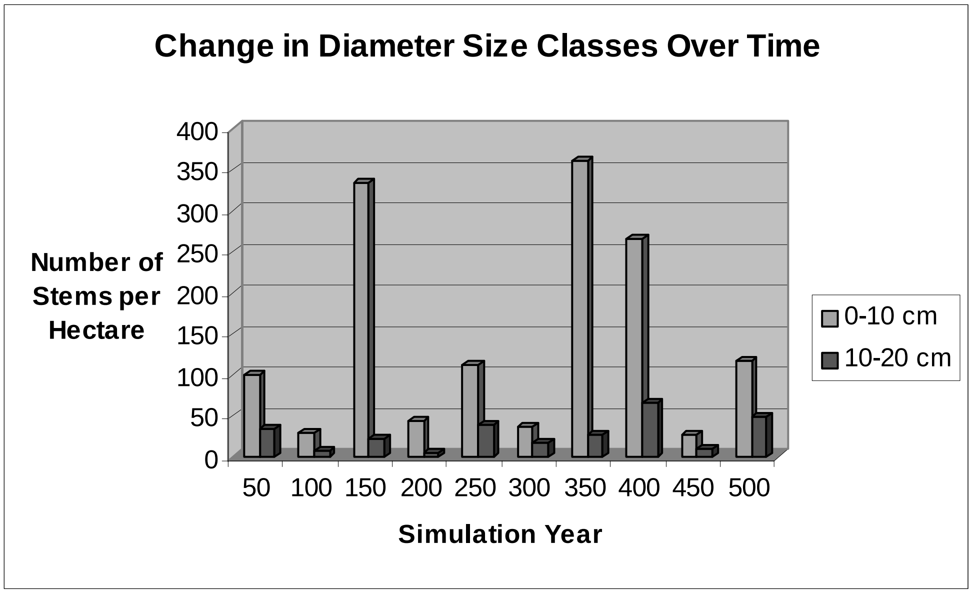


Figure 6. Diameter size classes over simulation period.

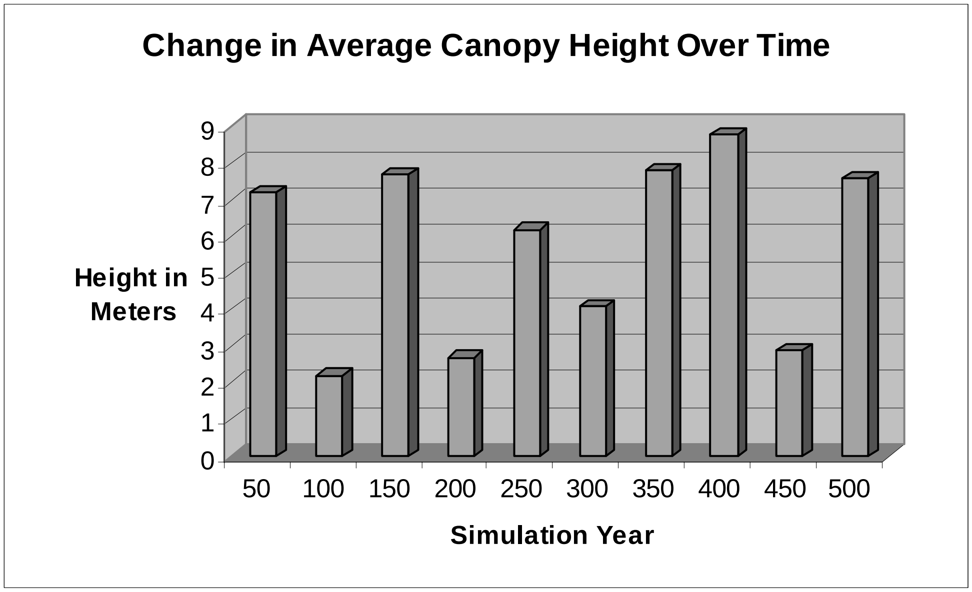


Figure 7. Average canopy heights over simulation period.

The soil depth parameters in the site driver file were then increased from 10 cm to 12 cm, and again to 15 cm. This increased the trees' diameters somewhat, but they remained far lower than actual tree diameters for the Greenbelt forest. Again, the log file showed that the problem was still one of water stress. Further manipulation of species parameters, including increasing drought tolerance to the maximum value for all species, did not improve the situation. In fact, this particular experiment altered the species' abilities to compete with one another, which resulted in unacceptable changes in the species composition of the forest. Giving Bur Oak a drought tolerance of 5 in every case gave it superior competitive advantage, and allowed it to dominate the forest.

Inspection of graphs of the tracer file data at this point also showed oscillatory behavior in biomass, standard deviation of biomass, total basal area, and basal area per species over time. To correct the tree size problem as well as this behavior,

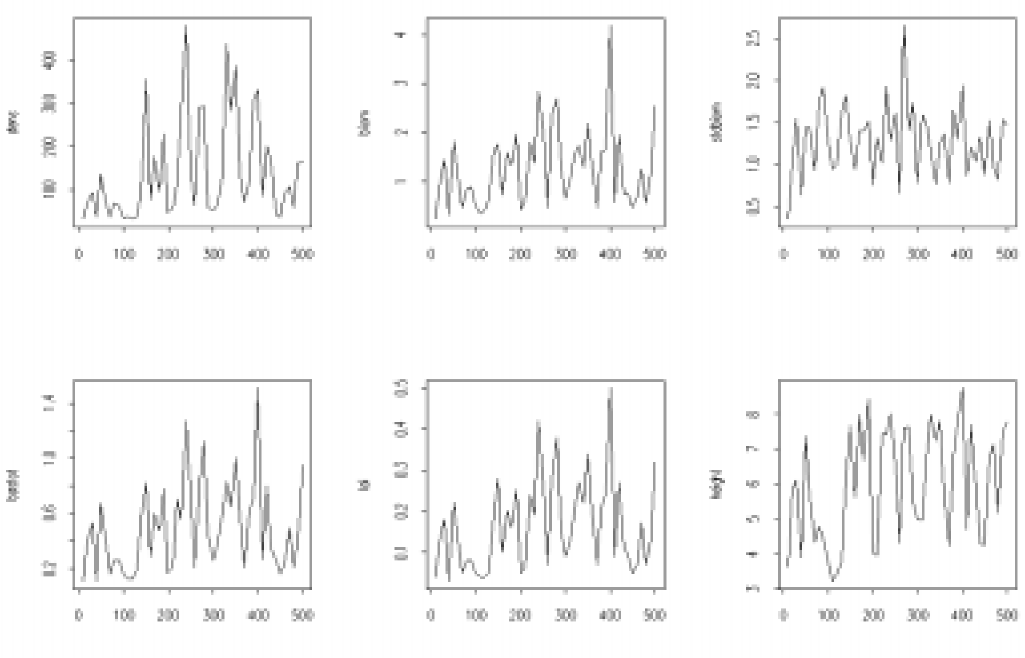


Figure 8 Tracer file graphs as displayed in Splus. The curves shown are, from left to right and top to bottom, density, total biomass, standard deviation of biomass, total basal area, leaf area index, and average canopy height.

precipitation values and their standard deviations were doubled experimentally. While this did result in a dramatic increase in tree size, some of the oscillatory behavior in the tracer file graphs remained. The standard deviations of the precipitation values were restored to their previous levels, but the actual values remained doubled. This produced the result of somewhat smoother tracer file curves while maintaining the gains in tree size. Model runs were then made with different precipitation levels, increasing at 10% increments, from the actual precipitation data to double the actual precipitation values. Standard deviations were left at the actual levels for each run. This was done in order to discover at what level the oscillatory behavior of the tracer file values would begin to smooth out. Results showed that oscillations decreased satisfactorily at approximately 180% of actual precipitation values; this result became the guideline for modification of the drought tolerance parameter in the species file.

Alteration of empirical climate data achieved the goal of raising soil moisture to levels at which tree growth could occur. However, this was an unacceptable means of accomplishing this goal. The next experiment was to change the drought tolerance function so that the species' drought tolerance parameters would effectively be increased tenfold. This maintained the positive gains in tree growth achieved by increasing precipitation values. Precipitation values were returned to the actual values for the Greenbelt site. Further experimentation with non-integer drought tolerance parameter values also increased the resolution of that parameter, which in turn led to the ability to fine-tune the species' competitive advantage, relative to one another. Examination of the ZELIG manual revealed that the species input file would accept a two-digit value for the drought tolerance parameter. Thus it became apparent that the tenfold increase in drought tolerance, as well as the finer resolution, could be achieved simply by choosing values between approximately 10 and 60 for that parameter. The drought tolerance function was returned to its original state, and the drought tolerance parameters for all species were experimentally increased by 10. Positive results were maintained.

Finally, to achieve the results obtained using the 180% precipitation levels, the drought tolerance parameters for all species were increased over their original levels (prior to the tenfold increase) proportionally to the decrease in the number of dry days from the original precipitation values to the increased ones. This was accomplished by averaging the number of dry days for all soil layers over the entire run of the model for each precipitation level. The average for the original precipitation run was divided by the average for the 180% precipitation run, resulting in a ninefold decrease in dry days for the 180% precipitation run. All species' drought tolerance parameters were then increased ninefold over their original levels, which achieved results in the tracer file similar to the 180% precipitation runs. Other species parameters were then fine-tuned to achieve the desired importance values and successional order. Final results of the drought tolerance alteration experiment can be seen in Table 13 and Figures 9 through 11.

Table 13. Change in Importance Values for Each Species Over Simulation Period

	Yr 50	Yr 100	Yr 150	Yr 200	Yr 250	Yr 300	Yr 350	Yr 400	Yr 450	Yr 500
Species	**Importance Value**									
Green Ash	36.34	25.94	13.44	11.02	14.41	11.71	11.45	12.81	10.63	13.71
Cedar Elm	17.49	21.74	33.12	32.38	22.95	26.19	33.43	26.77	32.58	28.21
Hackberry	15.19	24.22	30.75	39.19	49.49	53.91	49.86	56.28	53.21	54.51
Bur Oak	5.31	5.44	5.73	6.31	6.04	4.58	3.03	3.47	2.69	1.67
Pecan	25.67	22.66	16.97	11.09	7.1	3.62	2.22	0.67	0.88	1.91

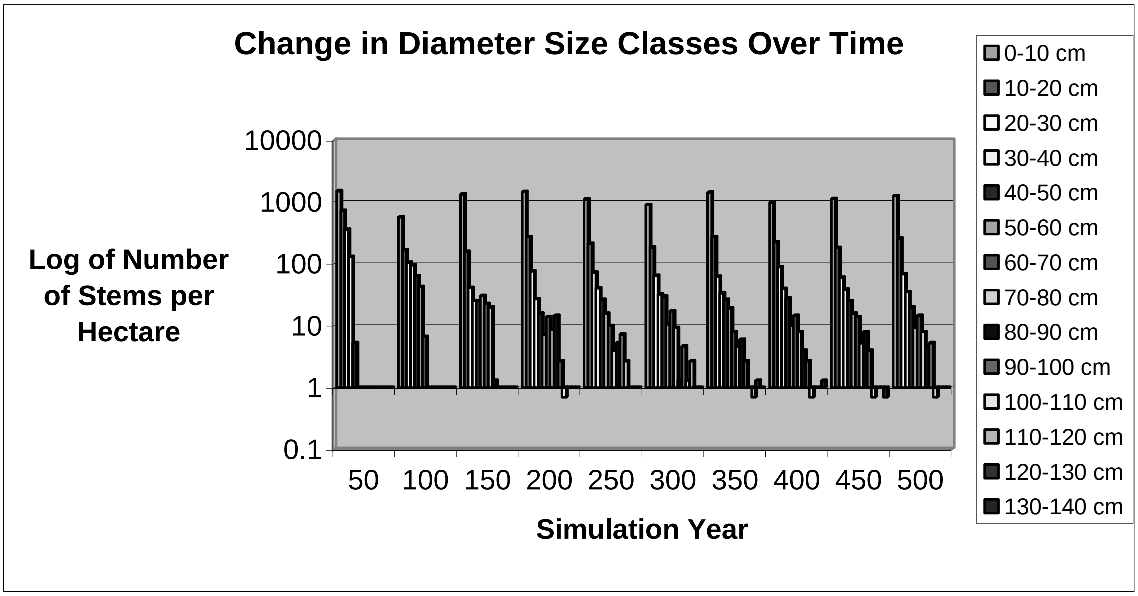


Figure 9. Change in diameter size classes over simulation run. Note the difference in the number of size classes, compared to original run (Figure 7).

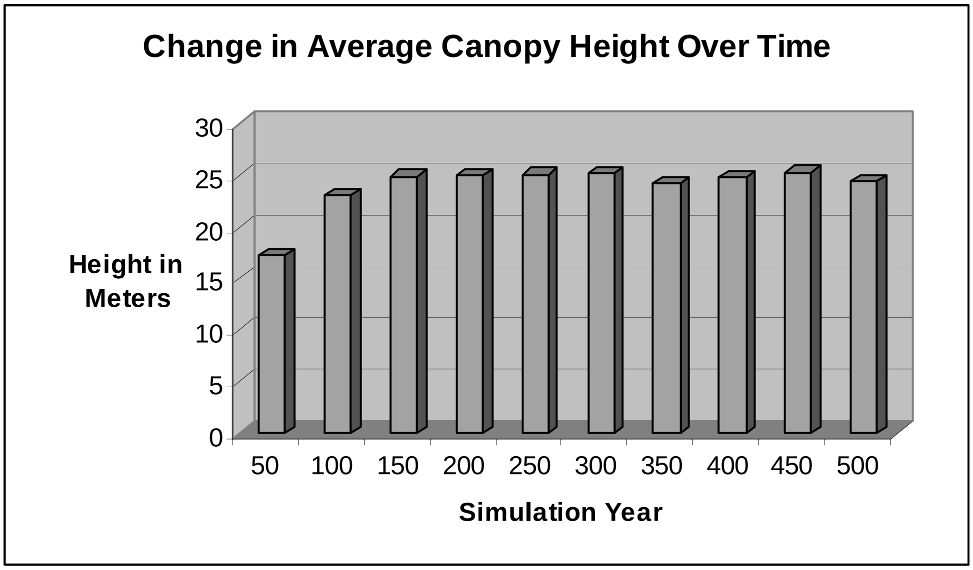


Figure 10. Change in average canopy height over simulation run. Note the difference from the original run (Figure 8).

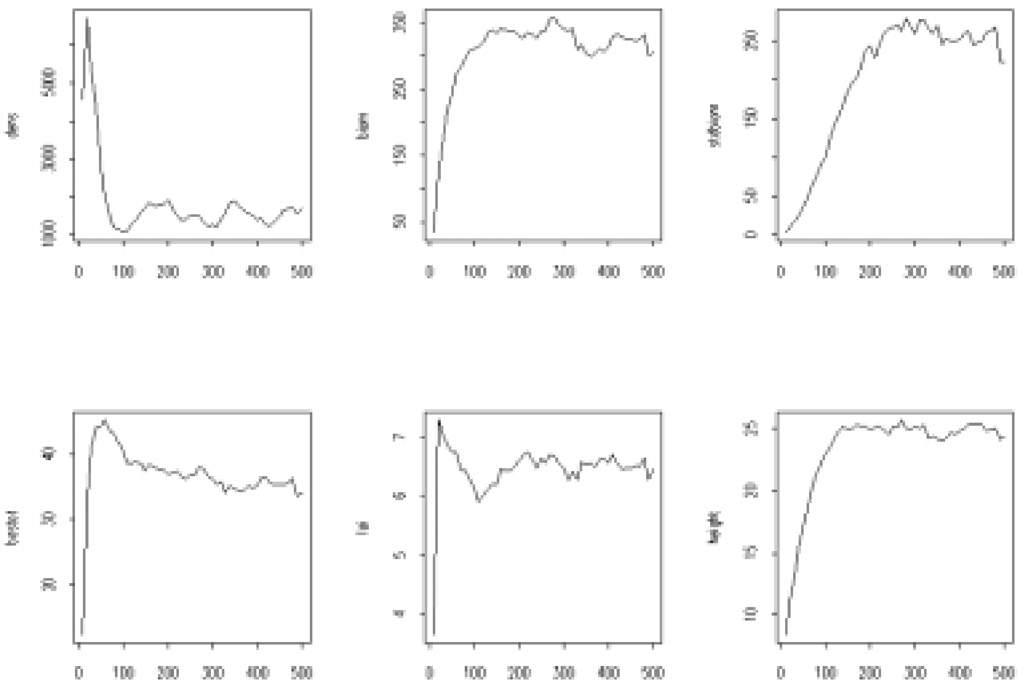


Figure 11. Tracer file graphs for final ZELIG run. Note that the oscillatory behavior is almost gone, although most curves retain a drop at around year 300.

The reason for this drop was never discovered. The curves displayed are density, total biomass, standard deviation of biomass, total basal area, leaf area index, and average canopy height.

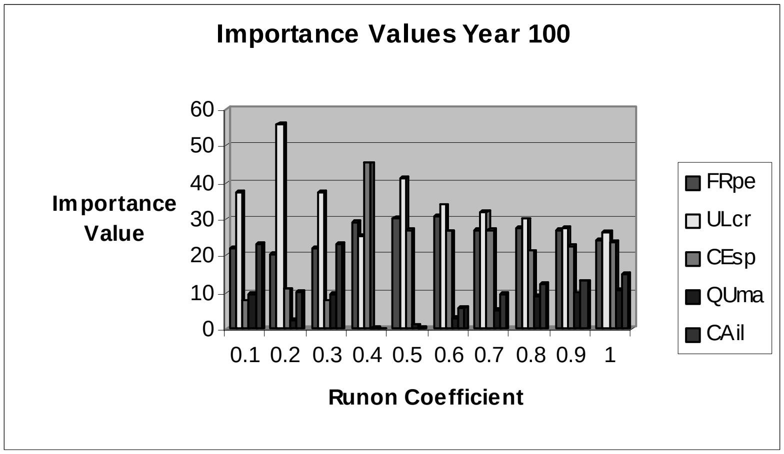
Although a better choice than changing empirical data such as precipitation values, altering the drought tolerance parameter to such a degree is still an undesirable method of adapting the ZELIG model to bottomland conditions because it changes a modeled biological characteristic of the tree species rather than an aspect of the model itself. Increasing the drought tolerance parameter to a level approximately ten times its intended value simulates a scenario in which trees thrive on much less water than they actually need. Therefore, another experiment was developed, in which the soil moisture was increased by adapting the model itself, rather than altering species parameters.

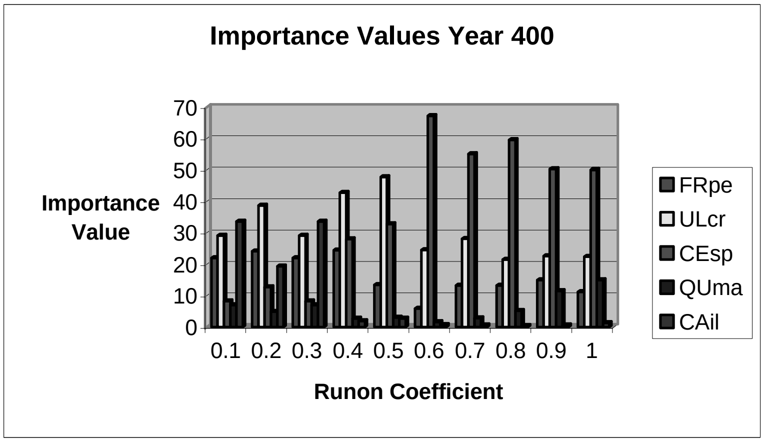
One disadvantage of the ZELIG model is that it does not simulate surface water runoff or pooling. The only function that allows for any water accumulation on the surface is the function that builds the snowpack. Since this function is temperature-dependent as well as precipitation-dependent, and since the Ray Roberts Greenbelt site is so warm, the simulations in this project never showed a snowpack. However, an experiment was developed whereby the snowpack function was adapted to simulate water running onto the plots in the simulated forest. A feature such as this was deemed to be reasonable, since river bottoms are low-lying areas, and water characteristically collects in them via flooding from the river or runoff from higher terraces and uplands nearby.

For this experiment, the part of the snowpack function related to temperature was bypassed, and the snowpack was simply set to a percentage of the precipitation, expressed as a runon coefficient written into the site driver file. The initial experimental value for the runon coefficient was 0.10, or ten percent of precipitation. No attempt was made to add a pooling function; all the water added to the surface as runon was treated as soaking directly into the top layer of soil. Upon entering the top layer of soil, it was subject to the normal surface evaporation and evapotranspiration functions of the model. ZELIG uses the Priestley-Taylor equations to calculate potential evapotranspiration.

Water moving through the soil layers is simulated as a “tipping bucket” process; as one layer becomes saturated, excess water enters the next layer down. Any excess water remaining in the bottom soil layer is lost to the water table, and is written to the log output file as cumulative runoff. Prior to the current experiment, the log file showed no runoff in any simulation interval, except for intervals of unusually high precipitation. Adding another 10 percent of water to the simulation was expected to increase deep runoff, but it did not. Tree growth, as shown in the print file, was improved over the original run, but not very much; trees still did not exceed 20 cm dbh or 9 m in average canopy height in any interval. Tree dbh did not exceed 20 cm until the runon coefficient was increased to 0.4. At this point, green ash and cedar elm reached a maximum of 50-60 cm at year 250, and hackberry reached a maximum of 80-90 cm at year 350. Thus it appeared that a runon coefficient threshold was reached between 0.3 and 0.4.

Further runs were made, increasing the runon coefficient in 0.1 increments, to a maximum of 1.0. The runon coefficient of 1.0 mimicked the doubling of the precipitation levels of the first experiment, except instead of manipulating the actual precipitation data, the change was engineered by introducing water from a hypothetical surface source, e.g. flooding from the river or surface runoff from higher elevations. The run that achieved importance values that most closely matched the Barry and Kroll study results was the run with a runon coefficient of 0.7, around year 400. Comparisons of importance values for each species with different runon coefficients at simulation years 100, 400, and 500 are shown in Figure 12. These particular years were chosen to show the forest at an immature stage, at the year containing optimum species composition results, and at the final (climax) stage. Appendix E contains graphs of the change in importance values over the entire run for several different runon coefficients. It also contains tracer file graphs for the same coefficients.





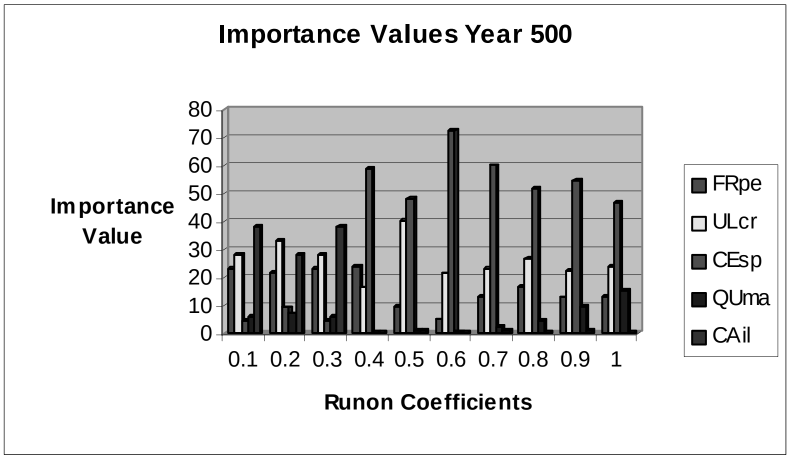
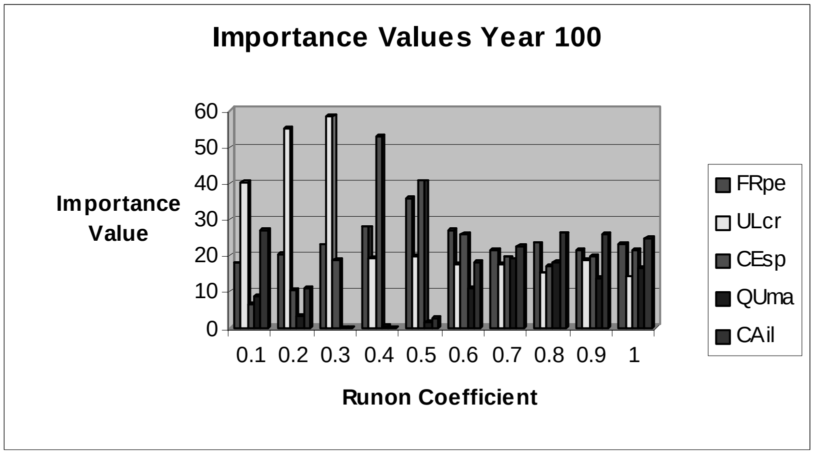
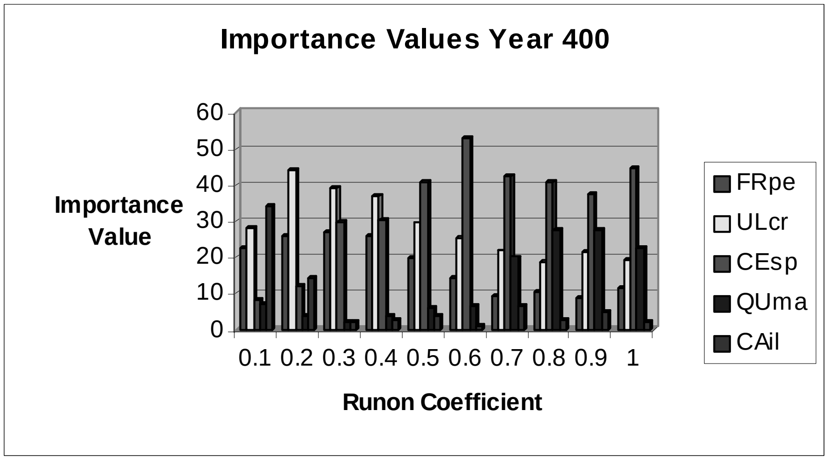


Figure 12. Comparison of importance values for significant simulation years, runon coefficient experiment. Note: FRpe = Green Ash (*Fraxinus pennsylvanica*), ULcr = Cedar Elm (*Ulmus crassifolia*), CEsp = Hackberry (*Celtis* spp.), QUma = Bur Oak (*Quercus macrocarpa*), and CAil = Pecan (*Carya illinoensis*).

Since the runon coefficient had to be raised to unrealistically high values to achieve the desired tree growth, one final experiment was attempted. In the ZELIG model, water trickles through the soil column at a fixed rate, with no possibility of pooling on the surface. Any excess is lost to the water table from the bottom soil layer. For this experiment, the snowpack function was further modified to allow water to infiltrate at a variable rate dependent upon the amount of water within the soil column. As the soil column developed a water deficit, water from the surface infiltrated the top layer in a proportional amount. If the deficit exceeded the available surface water, the entire pool infiltrated the top layer, and percolated through the column in the usual manner.

This alteration to the snowpack function stopped excess water from being lost to the water table, and made some difference in the development of the forest. Although some growth of trees beyond 20 cm dbh occurred at a runon coefficient of 0.3, particularly in the hackberries, consistent growth similar to the previous experiment did not occur until the runon coefficient was raised to 0.4. Optimum results were achieved at a lower runon coefficient, however. Species composition results closest to the Barry and Kroll study occurred with a runon coefficient of 0.6, year 400. Figure 13 shows a comparison of importance values at simulation years 100, 400, and 500 as above. Graphs of importance values for entire runs at several different runon coefficients are shown in Appendix F.





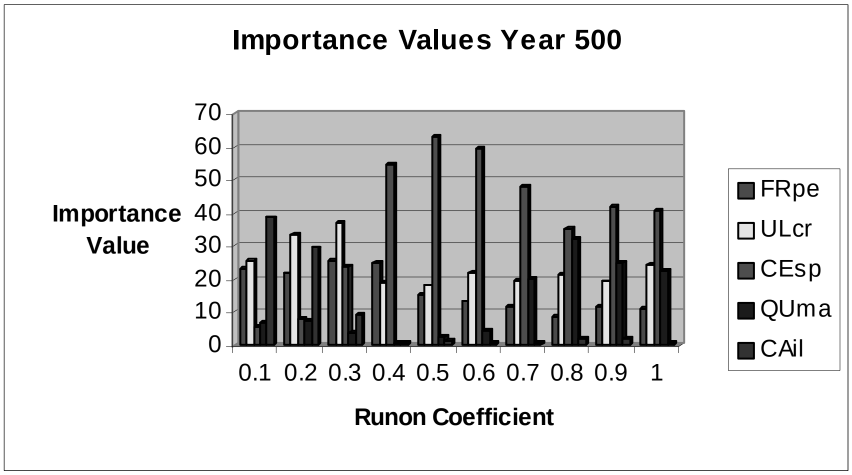


Figure 13. Comparison of importance values for significant simulation years, pond experiment. Note: FRpe = Green Ash (*Fraxinus pennsylvanica*), ULcr = Cedar Elm (*Ulmus crassifolia*), CEsp = Hackberry (*Celtis* spp.), QUma = Bur Oak (*Quercus macrocarpa*), and CAil = Pecan (*Carya illinoensis*).

The goal of this study was to adapt the ZELIG model to a southern bottomland hardwood forest. The first experiment, artificially increasing the amount of precipitation at the Greenbelt site, demonstrated that increasing the available soil moisture was necessary to achieve the actual tree growth. In the absence of a source of additional soil moisture, the second experiment of raising each species' drought tolerance parameter could simulate the same results. However, since both of these methods were artificial, ways of altering the model to account for all available water sources were sought.

The last two experiments were focused on simulating surface water running onto the low-lying bottomland forest plots. In the third experiment, a runon coefficient was added via the snowpack function in the model. A pooling adjustment was made to the same function in order to slow the rate of water infiltration through the soil layer and stop the loss of excess water to deep percolation in the final experiment. Both of these experiments were moderately successful, but the runon coefficient had to be set unrealistically high in order to achieve results close to observed tree growth. Suggestions for further experimentation with the ZELIG model to simulate bottomland hardwood forests are presented below.

Discussion

In the course of this study, the ZELIG model was noted to be incompatible with the simulation of a bottomland hardwood forest because of the inability to simulate a nearby water source. Most of the experimentation, as presented in the previous section, was concerned with accommodating this problem. In order to avoid the artificial manipulation of actual precipitation data and biological parameters, some simple modifications to the model's code were made to try to simulate an additional source of soil moisture associated with riparian bottomland systems. With further experimentation, other sources of soil moisture could be simulated, and the combination of these modifications could allow the researcher to adjust the model to accommodate a soil moisture gradient from the riverbank to the upland terrace.

Further attempts to refine the runon coefficient should be made. One way to do this could be to tie the changes in runon coefficient to the topographical profile of the forest being simulated. For more general simulations, the coefficient could be tied to a general riparian topological profile, such as those shown by Forman (1995).

In addition to simulating the addition of surface runon, it may be possible to develop a function or subroutine to simulate access to the water table as a function of proximity to the river. The soil in the Ray Roberts Greenbelt contains a large percentage of clay-sized particles (NRCS, 1980). In silty and clayey soils, water often percolates upward from the water table via capillary action (McCuen, 1998). It may be that the trees of the Greenbelt are able to tap water from this capillary fringe. Access to groundwater would certainly increase soil moisture over what is apparently available from precipitation alone. To test this idea, field data could be collected from the Greenbelt site. Walking a transect perpendicular to the Elm Fork, one could test the soil moisture and water table level at regular intervals from the riverbank to the upland terrace. These field data could then be incorporated into this new function or subroutine, so that water table access could reflect actual site conditions.

Coupled with both of the above suggestions could be an additional function to simulate wet days. A flood tolerance parameter would be added to the species file for use with this function. During wet periods, species that are more flood-tolerant, such as Green Ash, would be favored. If this parameter and one of the above suggestions for retaining soil moisture were to be applied as a function of distance to the river, or as a function of topography, the result could be a much patchier forest that more closely resembles a natural forest. As Barry and Kroll (1999) showed, the remnant bottomland forest of the Ray Roberts Greenbelt is highly patchy.

After the soil moisture problem, the next most difficult aspect of the model, with regard to this study, was the fact that shade tolerance is treated as the absolute determining factor in the order of succession. This created a conflict between the literature sources. In particular, Bur Oak is listed as not being especially shade tolerant (USDA, 1999). However, ecology literature suggests that the oak-dominated forest is the climax condition for southern bottomland hardwoods (Hodges, 1997). For this study, a compromise with regard to shade tolerance was reached, so that the successional order would reflect that in the ecological literature, and so that the forest would approximate the importance values found by Barry and Kroll (1999) at some point in the simulation between 300 and 500 years. It might be possible to improve this situation by adopting a similar approach to the shade tolerance parameter that was applied to the drought tolerance parameter in this study. That is, increase the magnitude and resolution of the possible values. Further study and experimentation would be needed to assess the validity of this approach.

Finally, the length of the growing season reported by in the log file was an item of interest in this study, although it was not known to have had any impact on the results of the simulations. In many of the runs, the growing season was reported to be 365 days, due to the warm climate at the Greenbelt site. While it is true that the temperature remains high enough to allow growth throughout the year, it is also true that the forest being simulated in this study is a deciduous one. It would be interesting to find out whether the model simulates a period of dormancy for deciduous trees, or whether the trees continue growing throughout the simulation’s growing period. Since that was a minor issue with regard to this study, it was not pursued.

CONCLUSION

To recapitulate, the objectives for this study were to present the need for preserving bottomland hardwood forests in north central Texas; to characterize the Lake Ray Roberts Greenbelt forest with regard to its physical habitat characteristics; and to calibrate the ZELIG model for that particular bottomland hardwood forest.

Chapter One achieved the first objective by presenting a basic description of southern bottomland hardwood forest ecology. Many of the ecological benefits that these ecosystems provide were listed as well, and the potential economic value of said benefits was mentioned briefly. An overview of the history of efforts to preserve bottomland forests in Texas, as well as some historic reasons for doing so, concluded the first chapter.

Chapter Two reported on the phytosocial study of the Ray Roberts Greenbelt Corridor Study. This area fell entirely within the riparian zone around the Elm Fork of the Trinity River, between the Ray Roberts and Lewisville reservoirs. Most of the Greenbelt land would historically have been bottomland hardwood forest, but has been used for other purposes, such as farming and grazing at various times since European settlement. A detailed phytosocial survey of the species composition and stand characteristics of the corridor and patch areas of the Greenbelt forest met the second study objective. Little difference was found between corridor and patch areas with regard to physical habitat characteristics such as percent similarity of species, complexity indices, and canopy height diversity. Thus, it was concluded that the corridors provide habitat similar to that of the patches, and can serve as vital connectors between larger areas of habitat. Recommendations regarding optimum width of forest corridors were presented, based upon a specific habitat goal (protecting forest interior bird species), and based upon more general goals (optimizing movement within the forest of a variety of species).

Chapter Three described the process by which the ZELIG gap model was calibrated to simulate the Ray Roberts Greenbelt forest. First, a phytosocial study of the largest and most pristine remnant bottomland forest within the Greenbelt was summarized. Importance value results from this study were used to calibrate the model with regard to species composition. Problems with the low soil moisture factor were encountered during this process. Three experiments undertaken to solve them were also presented: raising the species' drought tolerance parameters, modifying the snowpack function to simulate water runon, and simulating water pooling to stop loss of excess water to deep percolation. A discussion of possibilities for further study of the ZELIG model and bottomland hardwood forests ended the chapter.

The bottomland hardwood forest, an ecosystem that provides essential ecological benefits, is disappearing at an alarming rate due to logging, water impoundment, development, and other factors. Detailed field studies can help researchers to understand and evaluate the remaining areas of mature bottomland forest. In the absence of the time and resources necessary to conduct such studies, however, computer simulations may be able to provide needed information. This project was an attempt to understand the bottomland hardwood forest in north central Texas through its ecology and history as well as through field study and computer simulation. Perhaps as society begins to know these ecosystems in broad contexts, it may begin to value them more highly as intact systems than for their saleable goods.

APPENDIX A

SPECIES OF THE LAKE RAY ROBERTS GREENBELT

Trees

Common Name	Scientific Name
Box Elder	*Acer negundo*
Chittamwood	*Bumelia lanuginosa*
Pecan	*Carya illinoensis*
Sugar Hackberry	*Celtis laevigata*
American Hackberry	*Celtis occidentalis*
Hawthorn	*Crataegus* spp.
Green ash	*Fraxinus pennsylvanicus*
Honey locust	*Gleditsia triacanthos*
Black walnut	*Juglans nigra*
Bois d'arc	*Maclura pomifera*
Red Mulberry	*Morus rubra*
Sycamore	*Platanus occidentalis*
Cottonwood	*Populus deltoides*
Bur oak	*Quercus macrocarpa*
Blackjack oak	*Quercus marilandica*
Shumard oak	*Quercus shumardii*
Post oak	*Quercus stellata*
Black willow	*Salix nigra*
Wild Chinaberry	*Sapindus* spp.
Cedar elm	*Ulmus crassifolia*
Slippery elm	*Ulmus rubra*
American elm	*Umus americana*

Birds

Common Name	Scientific Name
Red-winged Blackbird	*Agelaius phoeniceus*
Ruby-throat Hummingbird	*Archilochus colubris*
Upland Sandpiper	*Bartramia longicauda*
Broad-winged Hawk	*Buteo platytperus*
American Goldfinch	*Carduelis tristis*
House Finch	*Carpodacus mexicanus*
Great Egret	*Casmerodius albus*
Belted Kingfisher	*Ceryle alcyon*
Inca Dove	*Columbina inca*
Eastern Wood Pewee	*Contopus pertinax*
Yellow-rumped Warbler	*Dendroica coronata*
Yellow Warbler	*Dendroica petechia*
Barn Swallow	*Hirundo rustica*
Dark-eyed Junco	*Junco hyemalis*
Lincoln's Sparrow	*Melospiza lincolnii*
Brown-headed Cowbirds	*Molothrus ater*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Hairy Woodpecker	*Picoides villosus*
European Starling	*Sturnus vulgaris*
Bewick's Wren	*Thryomanes bewickii*
Carolina Wren	*Thryothorus ludovicianus*
Eastern Kingbird	*Tyrannus tyrannus*
Canada Warbler	*Wilsonia canadensis*
Stellar's Flycatcher	

Mammals

Common Name	Scientific Name
Beaver	*Castor canadensis*
Nine-banded Armadillo	*Dasypus novemcinctus*
Opossum	*Didelphis marsupialis*
Bobcat	*Lynx rufus*
Striped Skunk	*Mephitis mephitis*
White-tailed Deer	*Odocoileus virginanus*
Raccoon	*Procyon lotor*
Coyote	*Canis latrans*
Eastern Conttontail	*Sylvilagus floridanus*

(adapted from Barry et al., 2000)

APPENDIX B

RAY ROBERTS GREENBELT PHYTOSOCIAL STUDY RAW DATA

Avian Plot Raw Tree Data

Plot	Species	Species Code	dbh (cm)	Basal area (cm^2)	Sum of Basal area	Total Trees	Canopy Layers	Species Richness	Complexity Index
1 E	Hackberry	4	95	7088.218425	8335.823407	3	5	2	2.500747
	Hackberry	4	13.5	143.1388153					
	Box Elder	14	37.5	1104.466167					
2 E	Pecan	17	14	153.93804	2816.045115	11	4	3	3.717180
	Pecan	17	17.5	240.5281875					
	Pecan	17	11.5	103.8689071					
	Pecan	17	13	132.7322896					
	Pecan	17	12	113.0973355					
	Pecan	17	15.5	188.6919088					
	Pecan	17	22.5	397.6078202					
	Pecan	17	13	132.7322896					
	Cedar Elm	2	22	380.1327111					
	Cedar Elm	2	32.5	829.5768101					
	Black Walnut	8	13.5	143.1388153					
3 W	Hackberry	4	37.5	1104.466167	11476.63066	7	5	4	16.067283
	Hackberry	4	47	1734.944543					
	Hackberry	4	32	804.2477193					
	Hackberry	4	39	1194.590607					
	Bois d’Arc	3	22	380.1327111					
	American Elm	18	76.5	4596.346402					
	snag	5	46	1661.902514					
4 W	Hackberry	4	28	615.7521601	3094.665113	6	4	2	1.485439
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	14	153.93804					
	Hackberry	4	13	132.7322896					
	Green Ash	1	39	1194.590607					
	Green Ash	1	20	314.1592654					
5 E	Slippery Elm	12	23.5	433.7361357	4802.51342	5	5	3	3.601885
	Slippery Elm	12	16.5	213.82465					
	Slippery Elm	12	47.5	1772.054606					
	Hackberry	4	53	2206.183441					
	Red Mulberry	7	15	176.7145868					
6 W	Hackberry	4	28	615.7521601	4840.80158	4	4	2	1.549057
	Hackberry	4	43.5	1486.169675					
	Hackberry	4	41	1320.254313					
	American Elm	18	42.5	1418.625433					
7 W	Red Mulberry	7	22.5	397.6078202	8666.083335	5	5	4	8.666083
	Hackberry	4	52.5	2164.753688					
	snag	5	19	283.528737					
	snag	5	30.5	730.6166415					
	Bur Oak	9	80.5	5089.576448					
8 E	Pecan	17	34.5	934.820164	2940.923423	4	4	4	1.882191
	American Elm	18	15.5	188.6919088					
	Hackberry	4	45	1590.431281					
	snag	5	17	226.9800692					
9 E	Hackberry	4	36.5	1046.346703	6925.051956	4	5	2	2.770021
	Hackberry	4	43	1452.201204					
	Hackberry	4	50	1963.495408					
	Green Ash	1	56	2463.00864					
10 W	Cottonwood	19	79	4901.669938	8043.85164	8	5	3	9.652622
	Hackberry	4	23	415.4756284					
	Hackberry	4	24.5	471.4352476					
	Hackberry	4	19.5	298.6476516					
	Hackberry	4	16	201.0619298					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	35	962.1127502					
	snag	5	30	706.8583471					
11 E	Box Elder	14	23.5	433.7361357	8422.806254	8	4	4	10.781192
	Slippery Elm	12	18	254.4690049					
	Slippery Elm	12	12.5	122.718463					
	Slippery Elm	12	43.5	1486.169675					
	snag	5	14	153.93804					
	Hackberry	4	18.5	268.8025214					
	Hackberry	4	61	2922.466566					

	Hackberry	4	59.5	2780.505848					
12 E	Hackberry	4	19.5	298.6476516	5306.93539	7	4	2	2.971884
	Hackberry	4	19.5	298.6476516					
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	44.5	1555.284713					
	Hackberry	4	13	132.7322896					
	Hackberry	4	24	452.3893421					
	Green Ash	1	49	1885.74099					
13 E	Cedar Elm	2	23	415.4756284	3881.045024	12	5	4	9.314508
	Cedar Elm	2	19	283.528737					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	14	153.93804					
	Hackberry	4	12.5	122.718463					
	Hackberry	4	41.5	1352.651987					
	Hackberry	4	12	113.0973355					
	Hackberry	4	13.5	143.1388153					
	Hackberry	4	12.5	122.718463					
	Green Ash	1	23.5	433.7361357					
	Green Ash	1	24	452.3893421					
	snag	5	16	201.0619298					
14 W	Green Ash	1	11.5	103.8689071	103.8689071	1	3	1	0.003116
15 E	Green Ash	1	12.5	122.718463	7301.650376	5	5	5	9.127063
	Hackberry	4	37	1075.210086					
	Shumard Oak	13	59.5	2780.505848					
	Bur Oak	9	41	1320.254313					
	Cedar Elm	2	50.5	2002.961666					
16 E	Hackberry	4	52	2123.716634		3	5	3	3.285743
	Green Ash	1	54.5	2332.828895					
	snag	5	63	3117.245311					
17 E	Bois d’Arc	3	36	1017.87602	3283.357022	5	5	2	1.641679
	Bois d’Arc	3	26.5	551.5458602					
	Bois d’Arc	3	34	907.9202769					
	Bois d’Arc	3	26.5	551.5458602					
	snag	5	18	254.4690049					
18 E	Post Oak	20	14.5	165.1299639	762.2289176	4	4	3	0.365870
	Post Oak	20	10.5	86.59014751					
	Blackjack Oak	21	11	95.03317777					
	Cedar Elm	2	23	415.4756284					
19 E	Cedar Elm	2	46	1661.902514	7053.857255	4	4	1	1.128617
	Cedar Elm	2	48.5	1847.45283					
	Cedar Elm	2	48	1809.557368					
	Cedar Elm	2	47	1734.944543					
20 E	Cedar Elm	2	37.5	1104.466167	3824.496357	5	4	2	1.529799
	Hackberry	4	48	1809.557368					
	Hackberry	4	25	490.8738521					
	Hackberry	4	18	254.4690049					
	Hackberry	4	14.5	165.1299639					
21 E	Green Ash	1	33.5	881.4130889	9437.73703	6	5	3	8.493963
	Green Ash	1	65	3318.30724					
	Green Ash	1	19	283.528737					
	Pecan	17	12.5	122.718463					
	Hackberry	4	26	530.9291585					
	Hackberry	4	74	4300.840343					
22 E	Bur Oak	9	93	6792.908715	11883.85961	7	5	4	16.637403
	Hackberry	4	18.5	268.8025214					
	Hackberry	4	26.5	551.5458602					
	Hackberry	4	54.5	2332.828895					
	Hackberry	4	26.5	551.5458602					
	Pecan	17	26	530.9291585					
	snag	5	33	855.2985999					
23 W	Slippery Elm	12	20.5	330.0635782	16960.28064	5	5	3	12.720210
	Pecan	17	114	10207.03453					
	Pecan	17	74.5	4359.156156					
	Hackberry	4	18	254.4690049					
	Hackberry	4	48	1809.557368					
24 W	Hackberry	4	19	283.528737	4604.985782	4	4	4	2.947191
	Green Ash	1	39	1194.590607					
	snag	5	21	346.3605901					
	Slippery Elm	12	59.5	2780.505848					

25 E	Hackberry	4	21	346.3605901	15270.69284	10	5	3	22.906039
	Hackberry	4	39	1194.590607					
	Hackberry	4	57.5	2596.722678					
	Hackberry	4	22	380.1327111					
	snag	5	27.5	593.9573611					
	snag	5	71	3959.192142					
	snag	5	14.5	165.1299639					
	snag	5	24.5	471.4352476					
	Green Ash	1	73.5	4242.917228					
	Green Ash	1	41	1320.254313					
26 E	Box Elder	14	24.5	471.4352476	7278.28478	7	5	4	10.189599
	Box Elder	14	37	1075.210086					
	American Elm	18	30	706.8583471					
	American Elm	18	41.5	1352.651987					
	American Elm	18	38.5	1164.156428					
	Green Ash	1	29	660.5198554					
	Hackberry	4	48.5	1847.45283					
27 W	Hackberry	4	35	962.1127502	6312.441389	6	4	5	7.574930
	Hackberry	4	21	346.3605901					
	Green Ash	1	58	2642.079422					
	Cedar Elm	2	48	1809.557368					
	Red Mulberry	7	18.5	268.8025214					
	Bur Oak	9	19	283.528737					
28 E	Green Ash	1	27	572.5552611	5193.445355	9	3	4	5.608921
	Green Ash	1	24	452.3893421					
	Green Ash	1	28	615.7521601					
	Green Ash	1	47	1734.944543					
	Bur Oak	9	16	201.0619298					
	Hackberry	4	19.5	298.6476516					
	Hackberry	4	23	415.4756284					
	Box Elder	14	20.5	330.0635782					
	Box Elder	14	27	572.5552611					
29 W	Red Mulberry	7	11	95.03317777	4165.16281	4	5	3	2.499098
	Hackberry	4	10.5	86.59014751					
	American Elm	18	44	1520.530844					
	American Elm	18	56	2463.00864					
30 W	Green Ash	1	45	1590.431281	1723.16357	2	4	2	0.275706
	Box Elder	14	13	132.7322896					
31 E	snag	5	14.5	165.1299639	4956.058761	6	3	3	2.676272
	Cedar Elm	2	29	660.5198554					
	Cedar Elm	2	35.5	989.7980354					
	Cedar Elm	2	37.5	1104.466167					
	Cedar Elm	2	36.5	1046.346703					
	Chittamwood	6	35.5	989.7980354					
32 E	Hackberry	4	10	78.53981634	3637.767943	9	4	2	2.619193
	Hackberry	4	13	132.7322896					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	11	95.03317777					
	Hackberry	4	13.5	143.1388153					
	Cedar Elm	2	33	855.2985999					
	Cedar Elm	2	30	706.8583471					
	Cedar Elm	2	20	314.1592654					
	Cedar Elm	2	39.5	1225.417484					
33 E	Honey Locust	10	10.5	86.59014751	687.6160921	4	4	3	0.330056
	Honey Locust	10	16.5	213.82465					
	snag	5	13	132.7322896					
	Hackberry	4	18	254.4690049					
34 W	Bur Oak	9	50	1963.495408	7598.138182	6	5	5	11.397207
	Hackberry	4	50	1963.495408					
	Hackberry	4	65	3318.30724					
	snag	5	14	153.93804					
	American Elm	18	11.5	103.8689071					
	Box Elder	14	11	95.03317777					
35 W	Hackberry	4	34	907.9202769	6233.312524	6	4	4	5.983980
	Hackberry	4	33	855.2985999					
	Hackberry	4	32.5	829.5768101					
	American Elm	18	48	1809.557368					
	Green Ash	1	46.5	1698.227179					

	snag	5	13	132.7322896					
36 E	Green Ash	1	70	3848.451001	22207.32942	10	4	2	17.765864
	Green Ash	1	40	1256.637061					
	Green Ash	1	38	1134.114948					
	Green Ash	1	61	2922.466566					
	Green Ash	1	45	1590.431281					
	Green Ash	1	48	1809.557368					
	Green Ash	1	45	1590.431281					
	Green Ash	1	68	3631.681108					
	Green Ash	1	74	4300.840343					
	snag	5	12.5	122.718463					
37 W	snag	5	36	1017.87602	9029.133636	5	5	3	6.771850
	American Elm	18	10	78.53981634					
	American Elm	18	10	78.53981634					
	American Elm	18	10	78.53981634					
	Green Ash	1	99.5	7775.638167					
38 W	Hackberry	4	27.5	593.9573611	3350.901264	4	4	2	1.072288
	Hackberry	4	17.5	240.5281875					
	Hackberry	4	30	706.8583471					
	Cedar Elm	2	48	1809.557368					
39 W	Hackberry	4	23	415.4756284	5187.947568	10	4	4	8.300716
	Hackberry	4	26	530.9291585					
	Hackberry	4	14.5	165.1299639					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	22	380.1327111					
	snag	5	17	226.9800692					
	snag	5	12.5	122.718463					
	Cedar Elm	2	31.5	779.3113276					
	Cedar Elm	2	51.5	2083.072279					
	Bois d’Arc	3	22.5	397.6078202					
40 W	Green Ash	1	25.5	510.7051557	8143.793556	4	4	2	2.606014
	Green Ash	1	11	95.03317777					
	Green Ash	1	59	2733.971007					
	Hackberry	4	10.5	86.59014751					
41 W	Hackberry	4	14	153.93804	4830.591404	7	4	4	5.410262
	Cedar Elm	2	28	615.7521601					
	Cedar Elm	2	23.5	433.7361357					
	snag	5	13	132.7322896					
	snag	5	35	962.1127502					
	snag	5	55.5	2419.222693					
	Hawthorn	11	12	113.0973355					
Notes:	(Large snag is Bur Oak.)			0					
42 W	Cedar Elm	2	47	1734.944543	3984.128533	7	3	3	2.510001
	Cedar Elm	2	34.5	934.820164					
	Cedar Elm	2	26	530.9291585					
	snag	5	20.5	330.0635782					
	snag	5	14	153.93804					
	Hackberry	4	12.5	122.718463					
	Hackberry	4	15	176.7145868					
43 W	Green Ash	1	18.5	268.8025214	4440.444866	7	4	5	6.216623
	Green Ash	1	18	254.4690049					
	Green Ash	1	17.5	240.5281875					
	Hackberry	4	44.5	1555.284713					
	Honey Locust	10	21	346.3605901					
	Cedar Elm	2	12	113.0973355					
	Bur Oak	9	46	1661.902514					
44 E	Green Ash	1	31	754.767635	3804.861403	5	5	2	1.902431
	Green Ash	1	24	452.3893421					
	Green Ash	1	41	1320.254313					
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	27.5	593.9573611					
45 E	Cedar Elm	2	39.5	1225.417484	4025.950986	5	4	1	0.805190
	Cedar Elm	2	26.5	551.5458602					
	Cedar Elm	2	21.5	363.050301					
	Cedar Elm	2	43	1452.201204					
	Cedar Elm	2	23.5	433.7361357					
46 E	American Elm	18	41.5	1352.651987	5724.570863	4	5	3	3.434743
	snag	5	13.5	143.1388153					
	Hackberry	4	48	1809.557368					

	Hackberry	4	55.5	2419.222693					
47 E	Hackberry	4	31	754.767635	7731.85222	9	5	3	10.438000
	Hackberry	4	29	660.5198554					
	Hackberry	4	48	1809.557368					
	snag	5	46.5	1698.227179					
	snag	5	10	78.53981634					
	Cedar Elm	2	27	572.5552611					
	Cedar Elm	2	31	754.767635					
	Cedar Elm	2	18.5	268.8025214					
	Cedar Elm	2	38	1134.114948					
48 E	Hackberry	4	12	113.0973355	2502.671248	7	5	4	3.503740
	Hackberry	4	15	176.7145868					
	American Elm	18	14.5	165.1299639					
	American Elm	18	14	153.93804					
	American Elm	18	13	132.7322896					
	snag	5	44	1520.530844					
	Green Ash	1	17.5	240.5281875					
49 E	Green Ash	1	12.5	122.718463	2108.008671	12	5	5	6.324026
	Green Ash	1	11.5	103.8689071					
	snag	5	10	78.53981634					
	snag	5	13	132.7322896					
	snag	5	12	113.0973355					
	snag	5	13.5	143.1388153					
	snag	5	11	95.03317777					
	snag	5	25	490.8738521					
	American Elm	18	13	132.7322896					
	Box Elder	14	19.5	298.6476516					
	Box Elder	14	19	283.528737					
	Hackberry	4	12	113.0973355					
50 E	Green Ash	1	44	1520.530844	10901.52286	4	5	3	6.540914
	Green Ash	1	59	2733.971007					
	American Elm	18	13.5	143.1388153					
	snag	5	91	6503.882191					
51 E	Green Ash	1	62	3019.07054	10200.9477	6	5	4	12.241137
	Green Ash	1	76.5	4596.346402					
	Green Ash	1	44	1520.530844					
	American Elm	18	26	530.9291585					
	snag	5	22	380.1327111					
	Hackberry	4	14	153.93804					
52 E	Hackberry	4	16	201.0619298	12468.98124	6	5	4	14.962777
	Hackberry	4	17	226.9800692					
	Green Ash	1	38.5	1164.156428					
	Green Ash	1	38.5	1164.156428					
	Bois d’Arc	3	12.5	122.718463					
	snag	5	110.5	9589.907925					
53 E	Hackberry	4	36.5	1046.346703	4580.245739	3	5	3	2.061111
	Green Ash	1	61	2922.466566					
	American Elm	18	17	226.9800692					
54 W	Hackberry	4	13	132.7322896	7323.445175	9	5	4	13.182201
	Hackberry	4	14.5	165.1299639					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	11	95.03317777					
	Hackberry	4	18.5	268.8025214					
	Hackberry	4	17	226.9800692					
	Red Mulberry	7	24.5	471.4352476					
	Cottonwood	19	69.5	3793.669479					
	Green Ash	1	51.5	2083.072279					
55 E	Black Willow	22	14.5	165.1299639	3546.661756	13	6	5	13.831981
	Black Willow	22	20	314.1592654					
	Black Willow	22	22.5	397.6078202					
	snag	5	13	132.7322896					
	snag	5	17.5	240.5281875					
	snag	5	16.5	213.82465					
	snag	5	15	176.7145868					
	snag	5	10	78.53981634					
	snag	5	12.5	122.718463					
	Hackberry	4	18	254.4690049					
	Box Elder	14	17.5	240.5281875					
	Box Elder	14	28	615.7521601					

	Cottonwood	19	27.5	593.9573611					
56 W	Pecan	17	40.5	1288.249338	9189.94391	9	5	4	16.541899
	Pecan	17	41.5	1352.651987					
	Pecan	17	41.5	1352.651987					
	Hackberry	4	14.5	165.1299639					
	Hackberry	4	13	132.7322896					
	Hackberry	4	12	113.0973355					
	Hackberry	4	18	254.4690049					
	Cottonwood	19	75	4417.864669					
	Slippery Elm	12	12	113.0973355					
57 E	Cottonwood	19	19.5	298.6476516	1716.094987	7	4	2	0.961013
	Cottonwood	19	17.5	240.5281875					
	Cottonwood	19	16.5	213.82465					
	Cottonwood	19	12.5	122.718463					
	Black Willow	22	13	132.7322896					
	Black Willow	22	15	176.7145868					
	Black Willow	22	26	530.9291585					
58 W	Sycamore	23	34.5	934.820164	4168.697102	6	5	5	6.253046
	Sycamore	23	53	2206.183441					
	American Elm	18	17.5	240.5281875					
	Bois d’Arc	3	13.5	143.1388153					
	Red Mulberry	7	12	113.0973355					
	Green Ash	1	26	530.9291585					
59 E	Green Ash	1	30	706.8583471	2682.134728	10	5	3	4.023202
	Green Ash	1	10	78.53981634					
	Green Ash	1	18.5	268.8025214					
	Green Ash	1	24	452.3893421					
	Green Ash	1	16.5	213.82465					
	Green Ash	1	12	113.0973355					
	Green Ash	1	15	176.7145868					
	Green Ash	1	13	132.7322896					
	Cedar Elm	2	17.5	240.5281875					
	Honey Locust	10	19.5	298.6476516					
60 E	Hackberry	4	10.5	86.59014751	5095.270585	7	5	4	7.133379
	Hackberry	4	13	132.7322896					
	Hackberry	4	18	254.4690049					
	Hackberry	4	12	113.0973355					
	Cottonwood	19	72	4071.504079					
	Pecan	17	20	314.1592654					
	Red Mulberry	7	12.5	122.718463					
61 W	Cottonwood	19	33.5	881.4130889	2445.533531	6	5	3	2.200980
	Cottonwood	19	20	314.1592654					
	Red Mulberry	7	16	201.0619298					
	Red Mulberry	7	12.5	122.718463					
	Red Mulberry	7	25.5	510.7051557					
	Hackberry	4	23	415.4756284					
62 W	Box Elder	14	45	1590.431281	14253.99492	6	5	4	17.104794
	Box Elder	14	44.5	1555.284713					
	American Elm	18	16.5	213.82465					
	Cottonwood	19	112	9852.034562					
	Green Ash	1	25	490.8738521					
	Green Ash	1	26.5	551.5458602					

Random Plot Raw Tree Data

Plot	Species	Species Code	dbh (cm)	Basal area (cm^2)	Sum of Basal area	Total Trees	Canopy Layers	Species Richness	Complexity Index
R 1	Pecan	17	58	2642.079422	6167.731777	2	3	1	0.370063907
	Pecan	17	67	3525.652355					
R 2	Green Ash	1	12	113.0973355	2488.92678	2	5	2	0.497785356
	Bur Oak	9	55	2375.829444					
R 3	Green Ash	1	20	314.1592654	1962.71001	8	4	1	0.628067203
	Green Ash	1	20	314.1592654					
	Green Ash	1	20	314.1592654					
	Green Ash	1	11	95.03317777					
	Green Ash	1	10	78.53981634					
	Green Ash	1	21	346.3605901					
	Green Ash	1	14	153.93804					
	Green Ash	1	21	346.3605901					
R 4	Red Mulberry	7	13	132.7322896	2585.923453	6	4	4	2.482486515
	American Elm	18	46.5	1698.227179					
	American Elm	18	15	176.7145868					
	American Elm	18	18	254.4690049					
	Bur Oak	9	16	201.0619298					
	Hackberry	4	12.5	122.718463					
R 5	Bur Oak	9	97.5	7466.191291	7812.551881	2	4	2	1.250008301
	American Elm	18	21	346.3605901					
R 6	Cedar Elm	2	13	132.7322896	3004.540674	10	4	4	4.807265079
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	18.5	268.8025214					
	Shumard Oak	13	37	1075.210086					
	Shumard Oak	13	10.5	86.59014751					
	Shumard Oak	13	23.5	433.7361357					
	Mesquite	24	13.5	143.1388153					
	Bur Oak	9	11	95.03317777					
	Bur Oak	9	24.5	471.4352476					
	Bur Oak	9	13	132.7322896					
R 7	American Elm	18	41	1320.254313	6148.882221	8	5	3	7.378658665
	American Elm	18	30	706.8583471					
	American Elm	18	49	1885.74099					
	snag	5	15	176.7145868					
	snag	5	23	415.4756284					
	snag	5	24	452.3893421					
	Red Mulberry	7	26	530.9291585					
	Red Mulberry	7	29	660.5198554					
R 8	Hackberry	4	20	314.1592654	4620.890094	7	4	3	3.881547679
	Hackberry	4	25	490.8738521					
	Hackberry	4	40.5	1288.249338					
	Hackberry	4	28.5	637.9396582					
	Hackberry	4	43	1452.201204					
	snag	5	14	153.93804					
	American Elm	18	19	283.528737					
R 9	snag	5	17.5	240.5281875	4575.7297	5	5	3	3.431797275
	snag	5	35	962.1127502					
	snag	5	46.5	1698.227179					
	Red Mulberry	7	15.5	188.6919088					
	American Elm	18	43.5	1486.169675					
R 10	American Elm	18	45.5	1625.970548	4637.187106	10	5	4	9.274374212
	American Elm	18	34	907.9202769					
	American Elm	18	19.5	298.6476516					
	American Elm	18	15	176.7145868					
	American Elm	18	16	201.0619298					
	American Elm	18	11	95.03317777					
	American Elm	18	12.5	122.718463					
	Hackberry	4	35.5	989.7980354					
	Pecan	17	10.5	86.59014751					
	snag	5	13	132.7322896					
R 11	American Elm	18	27	572.5552611	9407.499201	8	5	3	11.28899904
	American Elm	18	37.5	1104.466167					
	American Elm	18	18	254.4690049					

	American Elm	18	70	3848.451001					
	American Elm	18	38.5	1164.156428					
	snag	5	30.5	730.6166415					
	Hackberry	4	20	314.1592654					
	Hackberry	4	42.5	1418.625433					
R 12	Hackberry	4	26.5	551.5458602	7207.206246	9	5	3	9.729728433
	Hackberry	4	32	804.2477193					
	Hackberry	4	19	283.528737					
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	42.5	1418.625433					
	Cedar Elm	2	52.5	2164.753688					
	snag	5	29.5	683.4927517					
	snag	5	26	530.9291585					
R13	Hackberry	4	61	2922.466566	7888.342804	5	5	3	5.916257103
	Hackberry	4	50	1963.495408					
	Hackberry	4	51.5	2083.072279					
	American Elm	18	15.5	188.6919088					
	Green Ash	1	30.5	730.6166415					
R 14	Shumard Oak	13	10	78.53981634	78.53981634	1	4	1	0.003141593
R 15	Cedar Elm	2	30	706.8583471	2249.57669	4	5	2	0.899830676
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	23	415.4756284					
	snag	5	35	962.1127502					
R16	Bur Oak	9	81	5152.99735	9986.730347	8	5	4	15.97876855
	Bur Oak	9	20	314.1592654					
	Bur Oak	9	63.5	3166.921744					
	Cedar Elm	2	14	153.93804					
	Cedar Elm	2	13	132.7322896					
	Cedar Elm	2	28	615.7521601					
	Green Ash	1	21	346.3605901					
	Hackberry	4	11.5	103.8689071					
R 17	Hackberry	4	26.5	551.5458602	3654.654004	8	4	2	2.338978562
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	22.5	397.6078202					
	Hackberry	4	17.5	240.5281875					
	Hackberry	4	26	530.9291585					
	Hackberry	4	11.5	103.8689071					
	Hackberry	4	26	530.9291585					
	Green Ash	1	28	615.7521601					
R 18	Cedar Elm	2	12	113.0973355	1933.453929	15	5	2	2.900180893
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	12.5	122.718463					
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	13.5	143.1388153					
	Cedar Elm	2	12	113.0973355					
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	11.5	103.8689071					
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	15	176.7145868					
	Cedar Elm	2	12.5	122.718463					
	Cedar Elm	2	16	201.0619298					
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	10	78.53981634					
	snag	5	13.5	143.1388153					
R 19	Cedar Elm	2	19	283.528737	2114.291856	10	4	1	0.845716742
	Cedar Elm	2	12	113.0973355					
	Cedar Elm	2	16.5	213.82465					
	Cedar Elm	2	16.5	213.82465					
	Cedar Elm	2	19	283.528737					
	Cedar Elm	2	22	380.1327111					
	Cedar Elm	2	12.5	122.718463					
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	10	78.53981634					
	Cedar Elm	2	20.5	330.0635782					
R 20	Cottonwood	19	86	5808.804816	9828.472617	10	5	4	19.65694523
	snag	5	16.5	213.82465					
	Box Elder	14	29	660.5198554					
	Box Elder	14	16.5	213.82465					

	Box Elder	14	21.5	363.050301					
	Box Elder	14	23	415.4756284					
	American Elm	18	25	490.8738521					
	American Elm	18	24	452.3893421					
	American Elm	18	28	615.7521601					
	American Elm	18	27.5	593.9573611					
R 21	American Elm	18	33.5	881.4130889	3426.495837	3	4	2	0.822359001
	Hackberry	4	44.5	1555.284713					
	Hackberry	4	35.5	989.7980354					
R 22	snag	5	67	3525.652355	8493.492089	7	5	4	11.89088892
	Shumard Oak	13	18.5	268.8025214					
	Shumard Oak	13	61	2922.466566					
	Shumard Oak	13	19	283.528737					
	Shumard Oak	13	36	1017.87602					
	Hackberry	4	22	380.1327111					
	Cedar Elm	2	11	95.03317777					
R 23	Cedar Elm	2	10.5	86.59014751	5737.333584	10	5	4	11.47466717
	Cedar Elm	2	24	452.3893421					
	Red Mulberry	7	19.5	298.6476516					
	snag	5	12.5	122.718463					
	snag	5	32	804.2477193					
	American Elm	18	30	706.8583471					
	American Elm	18	16	201.0619298					
	American Elm	18	58	2642.079422					
	American Elm	18	14	153.93804					
	American Elm	18	18.5	268.8025214					
R 24	Hackberry	4	79	4901.669938	9646.063893	7	5	4	13.50448945
	Hackberry	4	25	490.8738521					
	Slippery Elm	12	62	3019.07054					
	Green Ash	1	29	660.5198554					
	American Elm	18	15.5	188.6919088					
	American Elm	18	10.5	86.59014751					
	American Elm	18	19.5	298.6476516					
R 25	Green Ash	1	10	78.53981634	8148.113246	15	4	3	14.66660384
	Green Ash	1	30	706.8583471					
	Green Ash	1	26	530.9291585					
	Green Ash	1	42	1385.44236					
	Green Ash	1	28.5	637.9396582					
	Green Ash	1	35	962.1127502					
	Green Ash	1	10.5	86.59014751					
	Green Ash	1	19	283.528737					
	Green Ash	1	30	706.8583471					
	Green Ash	1	18	254.4690049					
	Green Ash	1	19	283.528737					
	snag	5	11.5	103.8689071					
	snag	5	39.5	1225.417484					
	American Elm	18	12.5	122.718463					
	American Elm	18	31.5	779.3113276					
R 26	American Elm	18	24	452.3893421	5155.942593	11	4	3	6.805844223
	American Elm	18	41.5	1352.651987					
	American Elm	18	27	572.5552611					
	Hackberry	4	11	95.03317777					
	Hackberry	4	11.5	103.8689071					
	Hackberry	4	15	176.7145868					
	Hackberry	4	13	132.7322896					
	Hackberry	4	12	113.0973355					
	Hackberry	4	16.5	213.82465					
	Hackberry	4	25	490.8738521					
	snag	5	43	1452.201204					
R 27	Hackberry	4	20	314.1592654	7420.245498	10	4	3	8.904294598
	Hackberry	4	20.5	330.0635782					
	Hackberry	4	10	78.53981634					
	Hackberry	4	24	452.3893421					
	Hackberry	4	25	490.8738521					
	Hackberry	4	16	201.0619298					
	Hackberry	4	14	153.93804					
	snag	5	11.5	103.8689071					
	snag	5	10	78.53981634					
	American Elm	18	81.5	5216.810951					

R 28	American Elm	18	17.5	240.5281875	5936.432018	5	5	4	5.936432018
	snag	5	16.5	213.82465					
	snag	5	14	153.93804					
	Hackberry	4	40	1256.637061					
	Pecan	17	72	4071.504079					
R 29	Sycamore	23	33.5	881.4130889	6475.411508	8	5	4	10.36065841
	Sycamore	23	33	855.2985999					
	Sycamore	23	41	1320.254313					
	Box Elder	14	12.5	122.718463					
	Box Elder	14	17	226.9800692					
	Box Elder	14	30.5	730.6166415					
	Red Mulberry	7	36	1017.87602					
	Hackberry	4	41	1320.254313					
R 30	Bur Oak	9	78	4778.362426	7169.114435	8	5	4	11.4705831
	Box Elder	14	21	346.3605901					
	Box Elder	14	18	254.4690049					
	Bois d’arc	3	16	201.0619298					
	Hackberry	4	41	1320.254313					
	snag	5	11	95.03317777					
	snag	5	11	95.03317777					
	snag	5	10	78.53981634					
R 31	American Elm	18	13.5	143.1388153	8648.804575	7	5	5	15.13540801
	American Elm	18	81.5	5216.810951					
	Slippery Elm	12	21	346.3605901					
	Green Ash	1	31	754.767635					
	Green Ash	1	47.5	1772.054606					
	Red Mulberry	7	15.5	188.6919088					
	snag	5	17	226.9800692					
R 32	Cedar Elm	2	41.5	1352.651987	6107.059769	5	5	3	4.580294827
	Cedar Elm	2	34	907.9202769					
	Cedar Elm	2	54.5	2332.828895					
	Hackberry	4	35	962.1127502					
	snag	5	26.5	551.5458602					
R 33	Cedar Elm	2	26	530.9291585	2733.578308	7	5	2	1.913504815
	Cedar Elm	2	22.5	397.6078202					
	Cedar Elm	2	31	754.767635					
	Cedar Elm	2	15.5	188.6919088					
	Cedar Elm	2	24	452.3893421					
	Cedar Elm	2	20	314.1592654					
	snag	5	11	95.03317777					
R 34	Cedar Elm	2	10.5	86.59014751	362.4612524	3	5	2	0.108738376
	Cedar Elm	2	13.5	143.1388153					
	snag	5	13	132.7322896					
R 35	Hackberry	4	16	201.0619298	2836.661817	8	4	3	2.723195344
	Hackberry	4	21	346.3605901					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	35.5	989.7980354					
	Hackberry	4	17.5	240.5281875					
	Hackberry	4	18	254.4690049					
	snag	5	17	226.9800692					
	Honey Locust	10	25	490.8738521					
R 36	Box Elder	14	15.5	188.6919088	1153.357203	4	5	2	0.461342881
	Box Elder	14	14.5	165.1299639					
	Box Elder	14	17	226.9800692					
	Green Ash	1	27	572.5552611					
R 37	Green Ash	1	56	2463.00864	4619.711997	3	5	2	1.385913599
	Green Ash	1	35	962.1127502					
	snag	5	39	1194.590607					
R 38	Box Elder	14	25.5	510.7051557	11494.49847	5	5	3	8.620873853
	Box Elder	14	22	380.1327111					
	Green Ash	1	78	4778.362426					
	Green Ash	1	84	5541.769441					
	snag	5	19	283.528737					
R 39	vine	26	11	95.03317777	7248.046951	6	5	4	8.697656341
	Bur Oak	9	69.5	3793.669479					
	Slippery Elm	12	19	283.528737					
	Slippery Elm	12	13	132.7322896					
	American Elm	18	57.5	2596.722678					
	American Elm	18	21	346.3605901					

R 40	Red Mulberry	7	20.5	330.0635782	3319.288988	4	5	3	1.991573393
	Hackberry	4	46	1661.902514					
	Hackberry	4	39	1194.590607					
	American Elm	18	13	132.7322896					
R 41	Cedar Elm	2	22	380.1327111	4543.724725	9	5	2	4.089352252
	Cedar Elm	2	31	754.767635					
	Cedar Elm	2	28	615.7521601					
	Cedar Elm	2	17	226.9800692					
	Cedar Elm	2	15.5	188.6919088					
	Cedar Elm	2	33	855.2985999					
	Cedar Elm	2	29	660.5198554					
	Cedar Elm	2	29	660.5198554					
	snag	5	16	201.0619298					
R 42	Hackberry	4	29.5	683.4927517	3088.185578	9	3	4	3.335240425
	Hackberry	4	24	452.3893421					
	Hackberry	4	21.5	363.050301					
	Hackberry	4	23	415.4756284					
	Hackberry	4	22	380.1327111					
	Cedar Elm	2	14.5	165.1299639					
	snag	5	24.5	471.4352476					
	snag	5	10	78.53981634					
	Bois d'arc	3	10	78.53981634					
R 43	Green Ash	1	13.5	143.1388153	1792.867657	5	5	2	0.896433829
	Green Ash	1	25	490.8738521					
	Green Ash	1	15.5	188.6919088					
	Green Ash	1	22.5	397.6078202					
	Hackberry	4	27	572.5552611					
R 44	Hackberry	4	52	2123.716634	8708.102137	5	5	4	8.708102137
	Hackberry	4	37	1075.210086					
	Red Mulberry	7	18	254.4690049					
	Bur Oak	9	80.5	5089.576448					
	Green Ash	1	14.5	165.1299639					
R 45	Cedar Elm	2	19.5	298.6476516	3338.138544	9	5	2	3.00432469
	Cedar Elm	2	22	380.1327111					
	Cedar Elm	2	17.5	240.5281875					
	Cedar Elm	2	33	855.2985999					
	Cedar Elm	2	10	78.53981634					
	Cedar Elm	2	24.5	471.4352476					
	snag	5	25.5	510.7051557					
	snag	5	15.5	188.6919088					
	snag	5	20	314.1592654					
R 46	Box Elder	14	30.5	730.6166415	3423.157895	5	4	2	1.369263158
	Box Elder	14	39	1194.590607					
	Box Elder	14	33.5	881.4130889					
	Box Elder	14	16	201.0619298					
	snag	5	23	415.4756284					
R 47	Hackberry	4	38	1134.114948	8715.759769	5	5	2	4.357879884
	Hackberry	4	55	2375.829444					
	Hackberry	4	56	2463.00864					
	Hackberry	4	40	1256.637061					
	Cedar Elm	2	43.5	1486.169675					
R 48	American Elm	18	37	1075.210086	7723.21284	8	4	5	12.35714054
	Hackberry	4	68	3631.681108					
	Hackberry	4	29.5	683.4927517					
	snag	5	10	78.53981634					
	snag	5	12	113.0973355					
	Cedar Elm	2	20	314.1592654					
	Cedar Elm	2	16	201.0619298					
	Bur Oak	9	45.5	1625.970548					
R 49	Slippery Elm	12	13.5	143.1388153	1025.730001	6	5	3	0.923157001
	Green Ash	1	12.5	122.718463					
	Green Ash	1	19.5	298.6476516					
	Green Ash	1	11	95.03317777					
	Green Ash	1	16	201.0619298					
	American Elm	18	14.5	165.1299639					
R 50	Green Ash	1	27	572.5552611	1595.340019	5	2	4	0.638136008
	Bois d'arc	3	16	201.0619298					
	Black Willow	22	19.5	298.6476516					
	Black Willow	22	21	346.3605901					

	Cedar Elm	2	15	176.7145868					
R 51	Cottonwood	19	36.5	1046.346703	1132.936851	2	4	2	0.181269896
	Hackberry	4	10.5	86.59014751					
R 52	snag	5	38	1134.114948	7985.339477	3	5	3	3.593402765
	American Elm	18	46.5	1698.227179					
	Green Ash	1	81	5152.99735					
R 53	Hackberry	4	14.5	165.1299639	5642.104056	4	4	2	1.805473298
	Hackberry	4	11.5	103.8689071					
	Green Ash	1	63.5	3166.921744					
	Green Ash	1	53	2206.183441					
R 54	Green Ash	1	46	1661.902514	3493.254681	6	3	4	2.515143371
	Green Ash	1	37	1075.210086					
	Bois d’arc	3	12.5	122.718463					
	Bois d’arc	3	12	113.0973355					
	American Elm	18	23.5	433.7361357					
	snag	5	10.5	86.59014751					
R 55	Black Willow	22	22.5	397.6078202	2272.549586	3	4	2	0.545411901
	Black Willow	22	15	176.7145868					
	Green Ash	1	46.5	1698.227179					
R 56	Box Elder	14	18	254.4690049	2048.51476	9	3	3	1.659296955
	Box Elder	14	16.5	213.82465					
	Box Elder	14	11	95.03317777					
	Box Elder	14	11.5	103.8689071					
	Box Elder	14	17.5	240.5281875					
	Box Elder	14	19.5	298.6476516					
	Box Elder	14	16	201.0619298					
	Cottonwood	19	24	452.3893421					
	snag	5	15.5	188.6919088					
R 57	Green Ash	1	57.5	2596.722678	4307.712577	3	5	3	1.93847066
	Hackberry	4	32.5	829.5768101					
	Chittamwood	6	33.5	881.4130889					
R 58	Bois d’arc	3	13	132.7322896	3027.906269	10	4	5	6.055812539
	Bois d’arc	3	14.5	165.1299639					
	Green Ash	1	13	132.7322896					
	Green Ash	1	25	490.8738521					
	Hackberry	4	25.5	510.7051557					
	Hackberry	4	18	254.4690049					
	Hackberry	4	17	226.9800692					
	snag	5	23.5	433.7361357					
	snag	5	10.5	86.59014751					
	Chinaberry	25	27.5	593.9573611					
R 59	Green Ash	1	17	226.9800692	941.6923979	5	3	3	0.423761579
	Green Ash	1	20	314.1592654					
	Black Willow	22	11	95.03317777					
	Box Elder	14	17	226.9800692					
	Box Elder	14	10	78.53981634					
R 60	Cedar Elm	2	38	1134.114948	3442.40015	4	4	1	0.550784024
	Cedar Elm	2	37	1075.210086					
	Cedar Elm	2	29	660.5198554					
	Cedar Elm	2	27	572.5552611					
R 61	snag	5	17.5	240.5281875	1528.581176	5	4	4	1.22286494
	snag	5	12	113.0973355					
	American Elm	18	36	1017.87602					
	Box Elder	14	10	78.53981634					
	Hackberry	4	10	78.53981634					
R 62	Hackberry	4	25.5	510.7051557	1437.867688	6	4	4	1.38035298
	Hackberry	4	13.5	143.1388153					
	Hackberry	4	19	283.528737					
	American Elm	18	14	153.93804					
	Green Ash	1	13	132.7322896					
	snag	5	16.5	213.82465					
R 63	Hackberry	4	27	572.5552611	2388.788514	4	5	2	0.955515406
	Hackberry	4	30	706.8583471					
	Hackberry	4	28.5	637.9396582					
	snag	5	24.5	471.4352476					

Summary of Avian Plot Tree Data - Importance Values

Species	**Dbh (cm)**	**Basal area (cm^2)**	**Basal area (m^2)**	**Dominance (m^2/ha)**	**Rel. Dom.**	**Total Trees**	**Density (trees/ha)**	**Rel. Dens.**	**Freq.**	**Rel. Freq.**	**Imp. Val.**
Green ash	2433	4647245.111	464.725	363.066	28.024	65	50.781	16.667	29	14.573	19.754
Cedar elm	1294	1315098.959	131.510	102.742	7.930	39	30.469	10.000	17	8.543	8.824
Bois d’arc	193.5	29407.074	2.941	2.297	0.177	8	6.250	2.051	5	2.513	1.580
Hackberry	3263	8362266.978	836.227	653.302	50.426	120	93.750	30.769	47	23.618	34.938
Snag	1222	1172822.511	117.282	91.627	7.072	47	36.719	12.051	29	14.573	11.232
Chittamwood	35.5	989.798	0.099	0.077	0.006	1	0.781	0.256	1	0.503	0.255
Red Mulberry	170	22698.007	2.270	1.773	0.137	10	7.813	2.564	8	4.020	2.240
Black walnut	13.5	143.139	0.014	0.011	0.001	1	0.781	0.256	1	0.503	0.253
Bur oak	345.5	93753.175	9.375	7.324	0.565	7	5.469	1.795	7	3.518	1.959
Honey locust	67.5	3578.470	0.358	0.280	0.022	4	3.125	1.026	3	1.508	0.852
Hawthorn	12	113.097	0.011	0.009	0.001	1	0.781	0.256	1	0.503	0.253
Slippery elm	253.5	50471.453	5.047	3.943	0.304	9	7.031	2.308	5	2.513	1.708
Shumard oak	59.5	2780.506	0.278	0.217	0.017	1	0.781	0.256	1	0.503	0.259
Box Elder	367.5	106072.931	10.607	8.287	0.640	14	10.938	3.590	9	4.523	2.917
Pecan	524	215651.486	21.565	16.848	1.300	17	13.281	4.359	7	3.518	3.059
American elm	620.5	302394.197	30.239	23.625	1.823	23	17.969	5.897	16	8.040	5.254
Cottonwood	554.5	241486.570	24.149	18.866	1.456	12	9.375	3.077	8	4.020	2.851
Post oak	25	490.874	0.049	0.038	0.003	2	1.563	0.513	1	0.503	0.339
Blackjack oak	11	95.033	0.010	0.007	0.001	1	0.781	0.256	1	0.503	0.253
Black willow	111	9676.891	0.968	0.756	0.058	6	4.688	1.538	2	1.005	0.867
Sycamore	87.5	6013.205	0.601	0.470	0.036	2	1.563	0.513	1	0.503	0.351
Sum	**11663**	**16583249.5**	**1658.3249**	**1295.56636**	**100**	**390**	**304.6875**	**100**	**199**	**100**	**100**

Summary of Random Plot Tree Data - Importance Values

Species	**Dbh (cm)**	**Basal area (cm^2)**	**Basal area (m^2)**	**Dominance (m^2/ha)**	**Rel. Dom.**	**Total Trees**	**Density (trees/ha)**	**Rel. Dens.**	**Freq.**	**Rel. Freq.**	**Imp. Val.**
Green ash	1534	1846959.796	184.696	293.168	16.048	53	84.127	6.600	22	11.828	11.492
Cedar elm	1467	1689094.765	168.909	268.110	14.677	71	112.698	8.842	18	9.677	11.065
Bois d’arc	94	6939.778	0.694	1.102	0.060	7	11.111	0.872	5	2.688	1.207
Hackberry	2367	4398482.810	439.848	698.172	38.219	85	134.921	10.585	32	17.204	22.003
Snag	1096	943432.840	94.343	149.751	8.198	52	82.540	6.476	35	18.817	11.164
Chittamwood	33.5	881.413	0.088	0.140	0.008	1	1.587	0.125	1	0.538	0.223
Red Mulberry	193	29255.296	2.926	4.644	0.254	9	14.286	1.121	9	4.839	2.071
Bur oak	655	336955.447	33.696	53.485	2.928	13	20.635	1.619	9	4.839	3.128
Honey locust	25	490.874	0.049	0.078	0.004	1	1.587	0.125	1	0.538	0.222
Slippery elm	128.5	12968.691	1.297	2.059	0.113	404	641.270	50.311	4	2.151	17.525
Shumard oak	215.5	36474.087	3.647	5.790	0.317	8	12.698	0.996	3	1.613	0.975
Box Elder	549.5	237151.172	23.715	37.643	2.061	28	44.444	3.487	9	4.839	3.462
Pecan	207.5	33816.300	3.382	5.368	0.294	4	6.349	0.498	3	1.613	0.802
American elm	1557	1902778.044	190.278	302.028	16.533	53	84.127	6.600	25	13.441	12.192
Cottonwood	146.5	16856.412	1.686	2.676	0.146	3	4.762	0.374	3	1.613	0.711
Black willow	89	6221.139	0.622	0.987	0.054	5	7.937	0.623	3	1.613	0.763
Sycamore	107.5	9076.258	0.908	1.441	0.079	3	4.762	0.374	1	0.538	0.330
Mesquite	13.5	143.139	0.014	0.023	0.001	1	1.587	0.125	1	0.538	0.221
Chinaberry	27.5	593.957	0.059	0.094	0.005	1	1.587	0.125	1	0.538	0.222
vine	11	95.033	0.010	0.015	0.001	1	1.587	0.125	1	0.538	0.221
Sum	**10516**	**11508667.3**	**1150.8667**	**1826.77258**	**100**	**803**	**1274.603**	**100**	**186**	**100**	**100**

Avian Plot Forest Survey Data

Station	Stand Type	Seral Stage	Edge	Edge Type	# Can. Layers	Ground	Shrub	Understory	Midstory	Canopy Ht	Emergents	FHD	Canopy Cover	Corr/Patch
1 E	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.9	1.9	2.6	10.3	27.7		0.4222	0.9	C
2 E	mixed/even	stem exclusion	Y	abrupt/dense	4	0.8	1.4		6	16.6		0.3944	0.95	C
3 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.8	1.5	4	11.1	22.2		0.5150	0.8	C
4 W	mixed/uneven	stem exclusion	Y	transtnl/dense	4	1		1.5	4	19.7		0.2985	0.8	C
5 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.9	1.5	2.9	9.6	23.3		0.4601	0.65	C
6 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.8	1.4		5	18.6		0.3443	0.75	C
7 W	mixed/uneven	old growth	N		5	1	1.4	3.9	6.9	22.6		0.4230	0.75	C
8 E	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.9		3	9.2	24.8		0.4202	0.65	C
9 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.6	1.8	4.9	15.3	24.7		0.5340	0.75	P
10 W	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.7	1.2	2.9	7.7	22.2		0.4345	0.65	C
11E	mixed/uneven	undrstry reinit	N		4	0.9		2.9	6.7	24.4		0.3688	0.8	P
12 E	mixed/uneven	stem exclusion	Y	transtnl/dense	4	0.9		2.7	6.3	17.1		0.4387	0.85	P
13 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.8	1.5	4.4	8.3	20.8		0.4925	0.75	P
14 W	mixed/even	stand initiation	Y	abrupt/dense	3	0.8	1.2			5.6		0.2849	0.95	P
15 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.7	1.6	3.2	6	19.3		0.4370	0.85	P
16 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.3	3.8	8.7	19.4		0.5048	0.35	C
17 E	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.6	1.1	2.3	4.4	12		0.4807	0.85	C
18 E	mixed/uneven	stem exclusion	Y	transtnl/dense	4	0.6	1.1	3.2		9		0.4186	0.55	C
19 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1.1		3.6	6	13.7		0.4959	0.6	C
20 E	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.6		6.3	11.3	21.7		0.4956	0.55	C
21 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.8	1	2.3	10.8	13.8		0.4687	0.6	C
22 E	mixed/uneven	old growth	Y	abrupt/dense	5	0.9	1.8	4.8	7.8	22.2		0.4697	0.8	C
23 W	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.9	4.4	12.7	13.3		0.4886	0.85	C
24 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1.2	1.6		5.1	23.8		0.3000	0.8	C
25 E	mixed/uneven	old growth	Y	abrupt/dense	5	0.7	1.7	4	7.7	27.7		0.4011	0.6	C
26 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.4	3.4	9.6	15		0.5576	0.65	C
27 W	mixed/uneven	undrstry reinit	Y	abrupt/open	4	1.1		2.3	5.3	29.3		0.2827	0.85	C
28 E	mixed/uneven	undrstry reinit	Y	abrupt/open	3	0.8		4.7		20.2		0.2817	0.55	C
29 W	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.4	4.2	10.2	26.5		0.4614	0.75	C
30 W	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.7		5.7	10.8	17.1		0.5294	0.75	C
31 E	mixed/even	stem exclusion	N		3	0.8			6.7	20.2		0.3286	0.8	C
32 E	mixed/uneven	stem exclusion	N		4	0.8	0.8		8.9	12.8	20.8	0.5098	0.85	P
33 E	mixed/even	stand initiation	Y	abrupt/dense	4	0.3	0.5		7.5	9.7		0.3298	0.7	C
34 W	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.8	3	6.9	25.5		0.3896	0.75	C
35 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1	1.6		6.5	15.1		0.4316	0.75	C
36 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1		2.9	7.1	19		0.4395	0.7	C
37 W	mixed/uneven	old growth	Y	abrupt/dense	5	0.9	1.4	3.7	4.9	28		0.2959	0.9	C
38 W	mixed/uneven	undrstry reinit	N		4	0.9		3.6	9.6	16.5		0.5156	0.85	P
39 W	mixed/uneven	undrstry reinit	N		4	0.8		2.1	5.8	17		0.4114	0.7	P
40 W	mixed/uneven	undrstry reinit	N		4	0.7		2.5	6.6	14.5		0.4748	0.7	P
41 W	mixed/uneven	undrstry reinit	N		4	1		1.9	7.3	18.2		0.4237	0.5	P
42 W	mixed/uneven	undrstry reinit	N		3	0.7			5.8	22.1		0.2920	0.7	P
43 W	mixed/uneven	undrstry reinit	N		4	0.8		1.7	7.1	18.8		0.4053	0.75	P
44 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.8	1.2	3.5	5.2	20.8		0.3758	0.75	C
45 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.9	1	2.7		22.5		0.2000	0.75	C

46 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.8	1.4	2.5	4	21.5		0.3161	0.6	C
47 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	1.2	1.5	3.1	6.6	18.3		0.4610	0.75	C
48 E	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.9	1.2	2.5		9.3	22.2	0.4483	0.7	C
49 E	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.9	1.4	2.5	4.3	15		0.4209	0.8	C
50 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	1	1.4	3	9.3	30.4		0.3926	0.9	C
51 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.7	1.3	4.2	8	30.2		0.3809	0.85	C
52 E	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.9	1.4	3.9	7.3	19.7		0.4737	0.75	P
53 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.9	1.3	2.9	6.4	15.7		0.4929	0.8	C
54 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	1.1	1.4	2.6	11	41.2		0.3420	0.75	C
55 E	mixed/even	stem exclusion	N		6	0.7	1.2	2.7	6.5	15.6	21.3	0.6127	0.75	P
56 W	mixed/uneven	undrstry reinit	N		5	0.3	1.1	2.6	11.2	18.9		0.4885	0.75	P
57 E	pure/even	stand initiation	Y	transtnl/dense	4	1.1	1.8	5.8		16.9		0.4025	0.3	C
58 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.7	1.5	5.3	9.5	34.8		0.3883	0.85	C
59 E	mixed/uneven	stem exclusion	N		5	1	1.3	4.7	6.9	18.1		0.4756	0.8	C
60 E	mixed/uneven	undrstry reinit	N		5	0.6	1.1	4.8	9.1	39.1		0.3427	0.85	P
61 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.6	1.3	4.7	7.4	30.1		0.3652	0.75	P
62 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	1	1.6	5.8	13	39		0.4258	0.75	P

Random Plot Forest Survey Data

Station	Stand Type	Seral Stage	Edge	Edge Type	# Can. Layers	Ground	Shrub	Understory	Midstory	Canopy Ht	Emergents	FHD	Canopy Cover
R 1	mixed/even	stand initiation	Y	abrupt/dense	3		1.5			5.4	25.8	0.2718	85%
R 2	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.6	1.2	3.6	8.1	23.7		0.4441	95%
R 3	pure/even	stem exclusion	Y	transtnl/dense	4	0.9	2	5.5		22.3		0.3568	80%
R 4	mixed/uneven	stem exclusion	Y	abrupt/open	4	0.6	1.4		7.9	20.1		0.3652	85%
R 5	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	0.5	1.7	4.6		28.6		0.2795	75%
R 6	mixed/uneven	stem exclusion	Y	abrupt/dense	4	0.4	1.3		5.4	15.9		0.3597	90%
R 7	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.2	2.2	8.1	21.2		0.4315	80%
R 8	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.6	1.3	5.1		23.1		0.3117	95%
R 9	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.3	1.4	3.7	10.4	29		0.4205	90%
R 10	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.3	3.1	7.1	24.5		0.4226	80%
R 11	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.7	3.6	7.3	22.2		0.4590	70%
R 12	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.5	1.7	3.9	7.3	23.3		0.4555	80%
R 13	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.2	4.2	7.5	20.6		0.4670	85%
R 14	mixed/uneven	stand initiation	Y	abrupt/dense	4	0.4	1.3			8.7	10.1	0.3485	80%
R 15	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.4	1.5	3.9	7.8	13.5		0.5242	80%
R 16	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.4	1.8	3.7	8	17		0.5014	65%
R 17	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.5	1.4	3.7		19.3		0.3132	70%
R 18	pure/uneven	stem exclusion	Y	abrupt/open	5	0.2	0.9		4.7	17	23.7	0.3849	90%
R 19	pure/uneven	stem exclusion	Y	abrupt/open	4	0.3	1.4		4.7	16.5		0.3426	95%
R 20	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.3	1.2	3.8	9.5	14.8		0.5000	90%
R 21	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	0.5	1.3		5.9	24.4		0.3103	85%
R 22	mixed/uneven	stem exclusion	Y	abrupt/open	5	0.9	1.5	4.8	7.5	17.4		0.5208	75%
R 23	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.7	2	4.4	9.8	23.9		0.4836	70%
R 24	mixed/uneven	stem exclusion	Y	abrupt/open	5	1	1.8	4.4	7.4	22.2		0.4894	65%
R 25	mixed/uneven	undrstry reinit	Y	abrupt/open	4	1	1.7		6.7	17		0.4048	70%
R 26	mixed/uneven	stem exclusion	Y	abrupt/open	4	0.6	1.2		5.1	23.3		0.3068	75%

R 27	mixed/uneven	stem exclusion	Y	abrupt/open	4	0.6	1.4		5.8	26.3		0.3057	75%
R 28	mixed/uneven	undrstry reinit	Y	transtnl/open	5	0.5	1.4	3.8	7.7	25.3		0.4357	80%
R 29	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.3	1.6	5.1	9.2	17.6		0.5062	80%
R 30	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.9	1.4	4.4	11.5	27		0.4640	75%
R 31	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.6	1.4	3.9	10.1	20.4		0.4832	90%
R 32	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.6	1.3	3.6	5.3	15		0.5009	70%
R 33	pure/uneven	stem exclusion	N		5	0.4	1.4	3.5	7.3	13.1		0.5193	75%
R 34	pure/even	stand initiation	Y	abrupt/dense	5	0.2	1		4	8.4	13.4	0.4306	80%
R 35	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	0.2	1.4		5.2	18.2		0.3291	90%
R 36	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.2	1.8	3.9	9.2	25.7		0.4409	85%
R 37	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.1	1.4	4.7	7.6	20.7		0.4596	75%
R 38	mixed/uneven	old growth	Y	abrupt/dense	5	0.2	1.6	3.1	8.1	26.1		0.4146	85%
R 39	mixed/uneven	old growth	Y	abrupt/dense	5	0.1	1.3	3	7.5	23.7		0.4103	85%
R 40	mixed/uneven	old growth	Y	abrupt/dense	5	0.1	1.5	2.8	10.8	22.2		0.4374	70%
R 41	mixed/uneven	undrstry reinit	N		5	0.1	1.2	2.5	5.5	18.8		0.4161	75%
R 42	mixed/uneven	undrstry reinit	N		3	0.1			5.4	16.8		0.2523	60%
R 43	mixed/uneven	undrstry reinit	N		5	0.1	1.7	3.4	5.2	15.3		0.4781	70%
R 44	mixed/uneven	undrstry reinit	Y	transtnl/open	5	0.3	1.6	3.5	10.8	28		0.4292	80%
R 45	mixed/uneven	stem exclusion	Y	abrupt/open	5	0.2	1.3	4.6	8.9	17		0.4919	75%
R 46	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.8	1.4		7.1	16		0.3977	80%
R 47	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.2	1.2	7.5	13	33.5		0.4423	80%
R 48	mixed/uneven	old growth	Y	abrupt/dense	4	0.5	1.9		7.5	22.9		0.3548	80%
R 49	mixed/uneven	stand initiation	Y	transtnl/dense	5	0.2	1.6	4.3	13.4	18.8		0.4874	60%
R 50	mixed/even	stand initiation	Y	transtnl/open	2	0.1				10.8		0.0227	75%
R 51	mixed/uneven	stand initiation	Y	transtnl/dense	4	0.1	1.2		6.9	14.8		0.3573	60%
R 52	mixed/uneven	stem exclusion	N		5	0.1	1.2	2.4	7.3	18.8		0.4284	90%
R 53	mixed/uneven	undrstry reinit	N		4	0.2		2.5	5	28		0.2958	70%
R 54	mixed/uneven	undrstry reinit	Y	abrupt/dense	3	0.1			6.4	30.9		0.2066	75%
R 55	mixed/even	stem exclusion	Y	transtnl/dense	4	0.1	1.7		5.9	16.5		0.3537	65%
R 56	pure/even	stem exclusion	N		3	0.2			5.6	14.6		0.2778	50%
R 57	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.2	1.5	4	6.1	13.9		0.5068	80%
R 58	mixed/uneven	stem exclusion	Y	abrupt/dense	4	0.5	1.3		4.9	17		0.3495	75%
R 59	mixed/uneven	stand initiation	Y	abrupt/dense	3	0.3			4	11.7		0.2823	80%
R 60	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.6		3	4.8	19.5		0.3802	85%
R 61	mixed/even	stand initiation	Y	transtnl/dense	4	0.2	1.3		5.8	15.8		0.3517	60%
R 62	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.3		3.6	6.9	25.3		0.3627	50%
R 63	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.3	1.3	2.8	5.1	25.8		0.3786	65%

APPENDIX C

ZELIG INPUT FILES

ZELIG Control Driver File

```
ZELIG version 2.3.
   1     * MODE
   0     * INDATA
  10     * NROWS
  10     * NCOLS
 500     * NYRS
  50     * IPRT
  50     * IPCH
  10     * ITRX
  50     * ILAI
  50     * ILOG
```

ZELIG Species Driver File

```
5  Species parameters for Greenbelt  (under testing)
FRpe  Fraxinus pennsylvanica  Green ash
  220 130 37.000 -0.0188 0.6110 1100  9  1950 5500  350 3  5 5  25
ULcr  Ulmus crassifolia       Cedar elm
  200 102 32.000 -0.0266 1.1100 1100  9  4200 6500  460 3  5 5  20
CEsp  Celtis spp.             Hackberry
  260  95 35.000 -0.0216 0.8210 1100  9  3400 5500  450 1  1 3  25
QUma  Quercus macrocarpa      Bur oak
  400 163 50.000 -0.0127 1.1000 1100  8  1950 5500  430 1  1 1  30
CAil  Carya illinoensis       Pecan
  300 160 45.000 -0.0132 1.0900 1100  9  3400 5500  227 3  3 3  20
```

ZELIG Site Driver File

```
Greenbelt bottomland forest
33.0  97.00 180.0
 0.65  0.42 0.58
0.400
150  25
    2
   10 20.00   Ovan clay
 10.00  4.5  2.5
 10.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
   10 20.00   Clay Loam
 10.00  3.83 2.10
 10.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 7.0  8.9 13.5 18.1 22.3 26.6 28.8 28.9 25.1 19.2 12.8  8.2
 2.4  2.4  2.3  1.4  1.2  1.2  1.1  1.2  1.4  1.5  1.8  1.9
 7.2  8.4  9.6  14.0  18.0  12.8  8.7  7.7  12.0  12.6  9.5  8.7
 4.0  3.9  4.1  6.6  6.5  6.3  4.0  4.3  5.9  7.0  5.5  4.5
249.5 318.4 404.4 481.8 533.5 593.7 602.3 550.7 447.4 361.4 266.7 232.3
  23.4  35.8
1111111111
1111111111
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1111111111
```

APPENDIX D

ZELIG OUTPUT FILES

These files show ZELIG output for a 200-year simulation. Print intervals are indicated with each file. Only the print, log, and tracer files are shown; the punch and LAI files were omitted, because they were not important for this project.

ZELIG Output File Z.pri (printed at 100-yr intervals**)**

```
ZELIG version 2.3.

    ZELIG is in interactive-grid mode
    Max zone-of-influence:   600.0 sq. m (4 plots)
    Vertical step size through leaf profile:   9 m

Location:  Greenbelt bottomland for

    Lat:  33.0     Long:  97.0
    Elevation:  180.0 m

Number of soil types:    3

  Soil type:    1      Ovan clay

    Fertility:  20.0 Mg/ha/yr

    Depth, FC, and WP per layer:
      1   10.00    4.50  2.50
      2   10.00    4.50  2.50
      3   14.00    4.50  2.50
      4   14.00    4.50  2.50
      5   14.00    4.50  2.50
      6   14.00    4.50  2.50
      7   14.00    4.50  2.50
      8   14.00    4.50  2.50
      9   14.00    4.50  2.50
     10   14.00    4.50  2.50

  Soil type:    2      Sandy Loam

    Fertility:  20.0 Mg/ha/yr

    Depth, FC, and WP per layer:
      1   10.00    2.80  .90
      2   10.00    2.80  .90
      3   10.00    2.80  .90
      4   10.00    2.80  .90
      5   10.00    2.80  .90
      6   10.00    2.80  .90
      7   10.00    2.80  .90
      8   10.00    2.80  .90
      9   10.00    2.80  .90
     10   10.00    2.80  .90

  Soil type:    3      Clay Loam

    Fertility:  20.0 Mg/ha/yr

    Depth, FC, and WP per layer:
      1   10.00    3.83  2.10
      2   10.00    3.83  2.10
      3   18.00    3.83  2.10
      4   18.00    3.83  2.10
      5   18.00    3.83  2.10
      6   18.00    3.83  2.10
      7   18.00    3.83  2.10
      8   18.00    3.83  2.10
      9   18.00    3.83  2.10
     10   18.00    3.83  2.10

Number of plots:  100 (10 rows, 10 columns)
    Output samples are  1.50-ha aggregates

Soils map for grid:

    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111

Number of species in driver file:    5

  Species names and mnemonics:

  1  FRpe  Fraxinus pennsylvanica    Green ash
  2  ULcr  Ulmus crassifolia         Cedar elm
  3  CEsp  Celtis spp.               Hackberry
  4  QUma  Quercus macrocarpa        Bur oak
  5  CAil  Carya illinoensis         Pecan

Number of species available for simulation:    5

Tree life-history parameters ...
  Species max Age, Dbh, Ht; G, Form; GDDs; L, M, N; Seeds, Sprouts:

  1  FRpe  220.0 130.0  37.0  1100.0  9  1950.0 5500.0  350 3   5.0 5
  2  ULcr  200.0 102.0  32.0  1100.0  9  4200.0 6500.0  460 3   5.0 5
```

```
 3  CEsp  260.0  95.0  35.0  1100.0  9  3400.0 5500.0  450 1   1.0 3
 4  QUma  400.0 163.0  50.0  1100.0  8  1950.0 5500.0  430 1   1.0 1
 5  CAil  300.0 160.0  45.0  1100.0  9  3400.0 5500.0  227 3   3.0 3

Simulation initiated from bare ground


Simulation year:  100

Stand Structure by Species:

  Species Dbh Distribution (#/ha, in 10-cm classes),

     FRpe  236.0 165.3  59.3    .7    .0   .0   .0   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     ULcr   35.3   8.0  40.0  52.7   2.0   .0   .0   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     CEsp   58.0  26.0  24.0  31.3  45.3  8.7   .0   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     QUma   25.3    .0   4.0   8.0  14.0  8.0   .0   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     CAil    4.7    .0   6.7  12.7  14.0   .0   .0   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

     All:  359.3 199.3 134.0 105.3  75.3 16.7   .0   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

Species Composition:

  Species Density, Rel. D;   BA, Rel. BA;  IV200; Frequency:

     FRpe      461.3  51.8     6.1  16.9    34.39      .98
     ULcr      138.0  15.5     7.4  20.6    18.05      .85
     CEsp      193.3  21.7    13.9  38.6    30.14      .92
     QUma       59.3   6.7     4.9  13.7    10.16      .57
     CAil       38.0   4.3     3.7  10.2     7.26      .42

Stand Aggregates:

     Total Density:   890.00/ha     >10 cm:  530.67/ha
     Basal Area:  36.048 sq.m/ha
     Mean Dbh:  17.63 cm, with s.d.  14.33
     Total woody biomass:  253.683 Mg/ha
     Leaf-area index:  6.246
     Average canopy height:  22.7 m


Simulation year:  200

Stand Structure by Species:

  Species Dbh Distribution (#/ha, in 10-cm classes),
```

```
     FRpe  268.7  12.7   4.7   8.0   8.0  4.0   .0   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     ULcr  656.0 118.7  18.0   1.3   2.0  2.0  3.3   .0   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     CEsp  366.7 104.0  22.7  12.0   6.7  2.0  4.0  8.0  3.3   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     QUma   42.7  22.7  20.7   9.3    .7  1.3  2.7  2.7  4.0  2.7
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
     CAil   14.7    .0    .0    .0   1.3  2.0  2.0  1.3   .0   .0
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

     All: 1348.7 258.0  66.0  30.7  18.7 11.3 12.0 12.0  7.3  2.7
              .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

Species Composition:

  Species Density, Rel. D;   BA, Rel. BA;  IV200; Frequency:

     FRpe      306.0  17.3     3.9  11.6    14.47      .72
     ULcr      801.3  45.3     5.9  17.7    31.52      .97
     CEsp      529.3  30.0    12.7  38.1    34.04      .97
     QUma      109.3   6.2     8.9  26.6    16.42      .81
     CAil       21.3   1.2     2.0   5.9     3.56      .21

Stand Aggregates:

     Total Density:  1767.33/ha     >10 cm:  418.67/ha
     Basal Area:  33.429 sq.m/ha
     Mean Dbh:   9.42 cm, with s.d.  12.34
     Total woody biomass:  277.896 Mg/ha
     Leaf-area index:  6.423
     Average canopy height:  24.5 m
```

ZELIG Output File Z.log (printed at 100-yr intervals)

```
Simulation year:  100

   Growing season begins on day   1.0, ends on 340.4
   and has a total length of 340.4 days.

   Total growing degree-days:  4698.8
   Total precipitation:  105.8 cm
   Total as rain:  105.8 cm
     and as snow:     .0 cm

 Soil water balance for plot (1,1), soil type:    1

   Total annual PET:  146.4     Annual AET:   80.1
   Cumulative runoff:     .0 cm
   Total interception:  19.6 cm
   Dry-days over seedling rooting zone:     .15
   and integrated over all soil layers:    .46
   Dry-days per layer:
         1     .16
         2     .14
         3     .16
         4     .44
         5     .56
         6     .96
         7     .96
         8     .96
         9     .96
        10     .00

 Mortality in plot (1,1), by 10-cm size classes:


      Alive:   1   1   2   1   1   0   0   0   0   0   0   0   0   0   0
      NDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
      SDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

      Total number of trees dead:    0

 Growth factor trace:

   plot (1,1)     Number of trees:    6

        I, Spp, Dbh, Ht, Hc;  ALF, SMF, SFF, DDF, GF;  Dinc, NoGro:

        1 FRpe  20.38 18  8   .71  .29 1.00  .70   .14    .07  0
        2 CAil  35.47 15  9   .60  .00 1.00  .94   .00    .00  1
        3 CEsp  48.70 25  5   .80  .29 1.00  .94   .22    .18  0
        4 ULcr  25.97 15  5   .66  .48 1.00  .68   .22    .18  0
        5 FRpe  12.98 15  8   .65  .29 1.00  .70   .13    .04  0
        6 FRpe   8.07 11  8   .54  .29 1.00  .70   .11    .01  0
```

```
 Regeneration in plot (1,1):

   NPoss: 144   NSStot:   0   NSS:   0
  NPoss2: 144    NStot:   1    NS:   1

      Species, RF; Seedling Cohorts; Sprouts; Saplings:

       1 FRpe   .07     .4   .4   .4   .0              .0   0
       2 ULcr   .14     .7   .6   .7   .3   .2          .0   0
       3 CEsp   .18     .2   .2   .2   .1   .1          .0   0
       4 QUma   .11     .1   .2   .2   .1   .1          .0   0
       5 CAil   .02     .1   .0   .1                  .0   1

      Total number of stems planted:    1

 Light regime for plot (1,1):

   Actual LAI and light profile, from top of canopy:

    25    .11   1.00
    24    .11    .96
    23    .11    .91
    22    .11    .87
    21    .11    .84
    20    .11    .80
    19    .11    .77
    18    .14    .73
    17    .14    .69
    16    .14    .66
    15    .29    .63
    14    .29    .58
    13    .29    .54
    12    .29    .49
    11    .30    .44
    10    .30    .39
     9    .30    .34
     8    .21    .29
     7    .17    .26
     6    .17    .22
     5    .17    .20
     4    .00    .18
     3    .00    .17
     2    .01    .16
     1    .01    .15
     0          .14


Simulation year:  200

   Growing season begins on day   1.0, ends on 365.0
   and has a total length of 365.0 days.
```

```
   Total growing degree-days:  4623.2
   Total precipitation:  260.5 cm
   Total as rain:  260.5 cm
     and as snow:     .0 cm

Soil water balance for plot (1,1), soil type:    1

   Total annual PET:  146.2     Annual AET:   61.2
   Cumulative runoff:    8.7 cm
   Total interception:  86.3 cm
   Dry-days over seedling rooting zone:     .00
   and integrated over all soil layers:    .05
   Dry-days per layer:
         1     .00
         2     .00
         3     .05
         4     .03
         5     .00
         6     .08
         7     .26
         8     .14
         9     .00
        10     .00

Mortality in plot (1,1), by 10-cm size classes:


       Alive:   0   1   2   2   0   0   0   1   0   0   0   0   0   0   0
       NDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
       SDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

       Total number of trees dead:    0

Growth factor trace:

   plot (1,1)     Number of trees:    6

         I, Spp, Dbh, Ht, Hc;  ALF, SMF, SFF, DDF, GF;  Dinc, NoGro:

         1 CAil  75.79 27  9   .54  .90 1.00  .97   .47    .40  0
         2 FRpe  33.54 23  8   .49  .95 1.00  .74   .35    .24  0
         3 FRpe  12.04 14  8   .26  .95 1.00  .74   .18    .05  0
         4 ULcr  23.77 14  3   .25  .96 1.00  .60   .15    .15  0
         5 ULcr  20.21 12  3   .20  .96 1.00  .60   .11    .11  0
         6 QUma  34.30 16  3   .31  .91 1.00  .74   .21    .32  0

Regeneration in plot (1,1):

    NPoss: 144   NSStot:   0   NSS:   0
   NPoss2: 144    NStot:   0    NS:   0
```

```
       Species, RF; Seedling Cohorts; Sprouts; Saplings:

        1 FRpe   .00     .0   .0   .0   .0              .0   0
        2 ULcr   .04     .2   .3   .3   .3   .1         .0   0
        3 CEsp   .06     .1   .1   .1   .1   .0         .0   0
        4 QUma   .05     .0   .0   .0   .1   .0         .0   0
        5 CAil   .00     .0   .0   .0                 .0   0

       Total number of stems planted:    0

Light regime for plot (1,1):

   Actual LAI and light profile, from top of canopy:

      27    .21   1.00
      26    .21    .92
      25    .21    .85
      24    .21    .78
      23    .27    .72
      22    .27    .64
      21    .27    .58
      20    .27    .51
      19    .27    .45
      18    .27    .40
      17    .27    .37
      16    .38    .35
      15    .38    .32
      14    .45    .29
      13    .45    .26
      12    .49    .23
      11    .49    .20
      10    .49    .16
       9   .49    .13
       8   .28    .11
       7   .21    .09
       6   .21    .09
       5   .21    .08
       4   .21    .07
       3   .21    .07
       2   .00    .07
       1   .00    .07
       0          .07
```

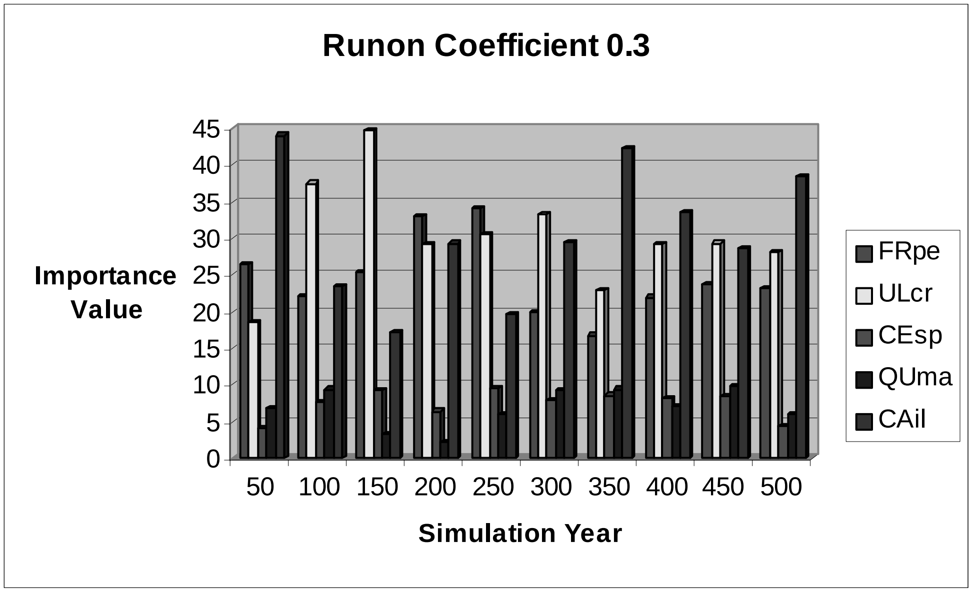
ZELIG Output File Z.tra (printed at 10-yr intervals)

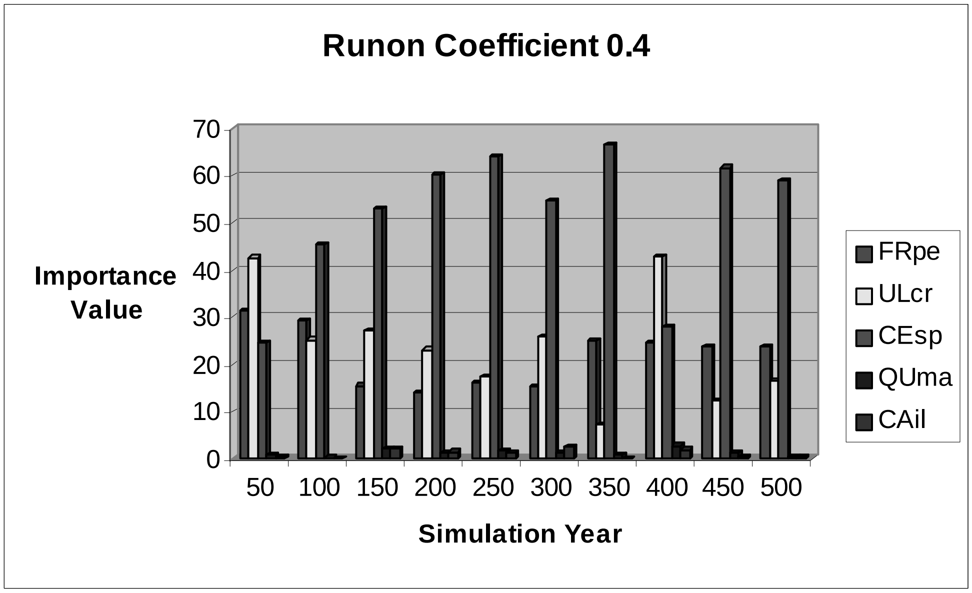
```
 10   3244.00   17.13    2.31    6.88    2.05    8.60    1.28  2.19   .47   .36  2.58
 20   7062.00   83.86    4.88   26.76    7.22   11.11    4.24 11.52  2.62  1.77  6.61
 30   6555.33  131.73   10.71   35.53    6.88   13.43    6.84 14.03  5.13  2.64  6.91
 40   5799.33  162.36   15.22   38.93    7.13   15.38    8.68 13.58  7.15  3.05  6.47
 50   3900.00  187.45   19.45   39.49    7.06   17.10    8.80 11.75  8.74  3.66  6.55
 60   2447.33  202.56   27.06   38.60    6.85   18.43    8.04 11.39  9.89  3.90  5.38
 70   1872.00  225.89   35.62   39.35    6.85   19.88    7.69 10.65 11.66  4.20  5.17
 80   1360.00  236.77   41.27   38.19    6.63   21.05    6.88  9.60 12.39  4.74  4.59
 90   1060.67  250.26   58.41   37.54    6.49   21.95    6.48  8.37 13.31  5.07  4.30
100    890.00  253.68   69.94   36.05    6.25   22.72    6.10  7.43 13.90  4.93  3.69
110    958.00  260.29   84.06   35.11    6.09   23.33    5.57  6.84 13.88  5.23  3.60
120    972.67  270.90   90.25   34.80    6.01   24.26    5.25  6.56 14.32  5.19  3.47
130   1084.00  281.83  101.99   34.81    6.06   24.74    4.99  6.63 14.20  5.52  3.48
140   1277.33  277.92  128.09   33.73    5.94   24.79    5.05  5.81 13.56  6.32  2.98
150   1518.67  286.87  151.09   34.45    6.16   25.10    5.03  5.63 13.65  7.36  2.79
160   1566.00  291.36  152.19   34.48    6.26   25.43    5.02  5.10 13.71  7.92  2.72
170   1618.00  288.30  169.83   34.09    6.27   25.33    4.83  4.90 13.81  7.85  2.70
180   1812.00  287.12  181.11   34.35    6.41   25.18    4.95  5.14 13.44  8.30  2.51
190   1756.67  295.64  184.76   35.05    6.61   25.14    4.71  5.47 13.19  9.37  2.31
200   1767.33  277.90  192.29   33.43    6.42   24.47    3.88  5.91 12.75  8.91  1.97
```

APPENDIX E

RUNON EXPERIMENT ADDITIONAL GRAPHS

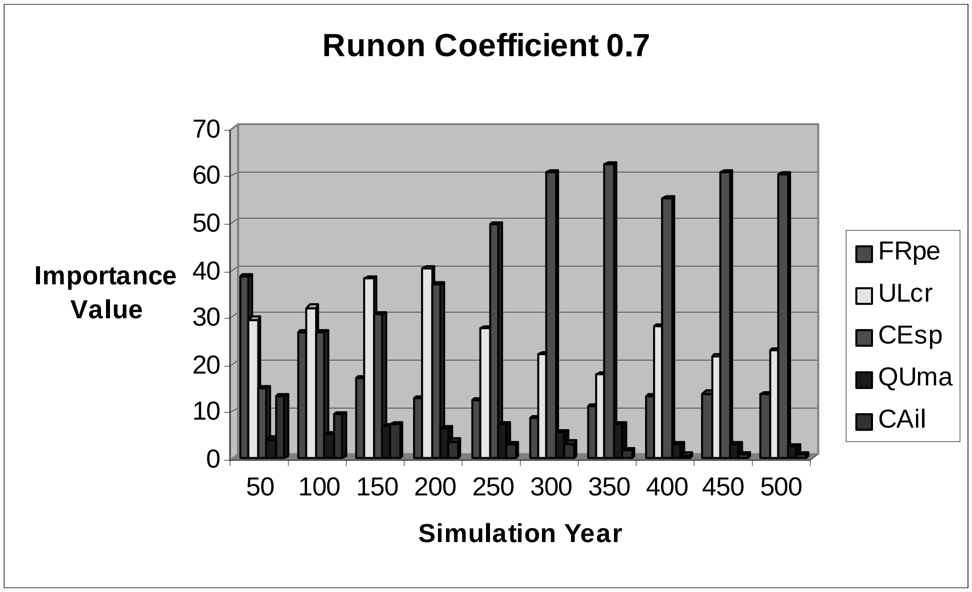
Comparison of Importance Values over Entire Simulation for Significant Runon Coefficients





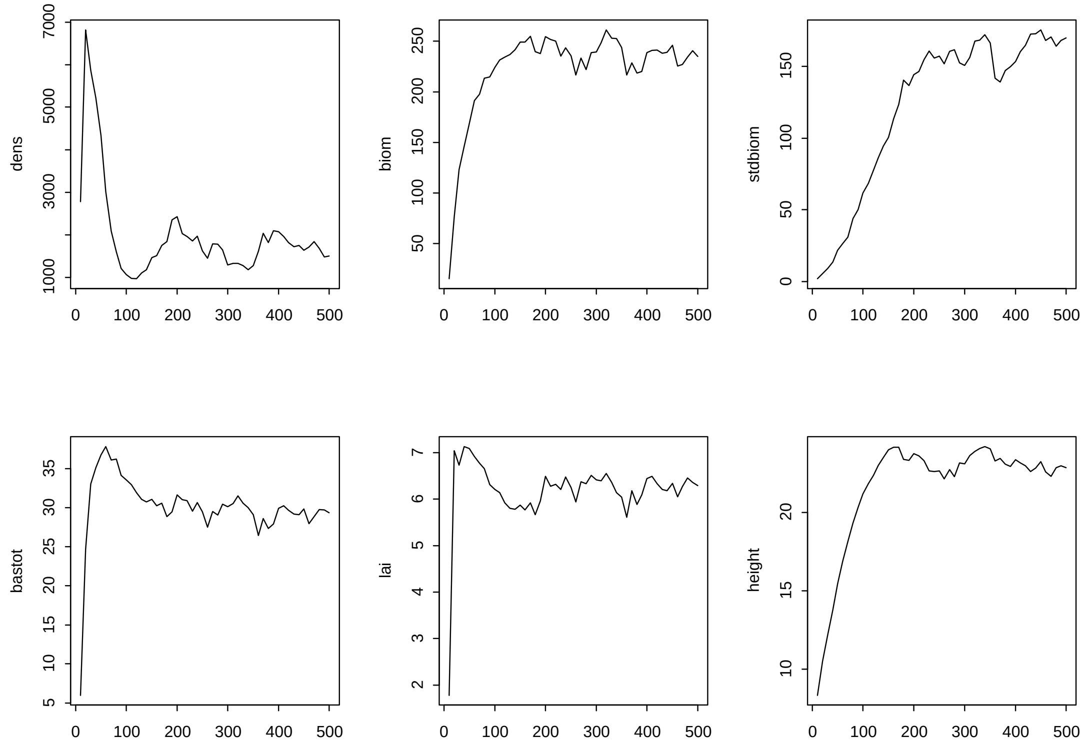
Tree growth of greater than 20 cm dbh was not achieved until the runon coefficient was raised to 0.4. Note the change in species composition between coefficients 0.3 and 0.4.

Best run- runon experiment



Results closest to those found in the Barry and Kroll study (1999) were achieved at year 400, with a runon coefficient of 0.7.

Tracer file graphs for runon experiment, coefficient 0.7



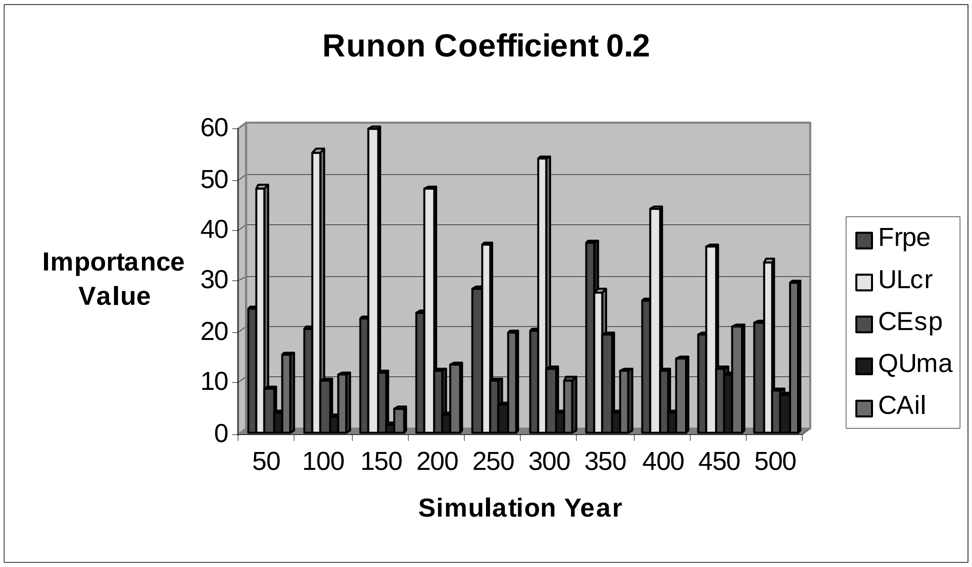
Note that although this run achieved results close to the observed species composition, a large drop remains at around year 350. More experimentation would need to be conducted to discover the reason for this.

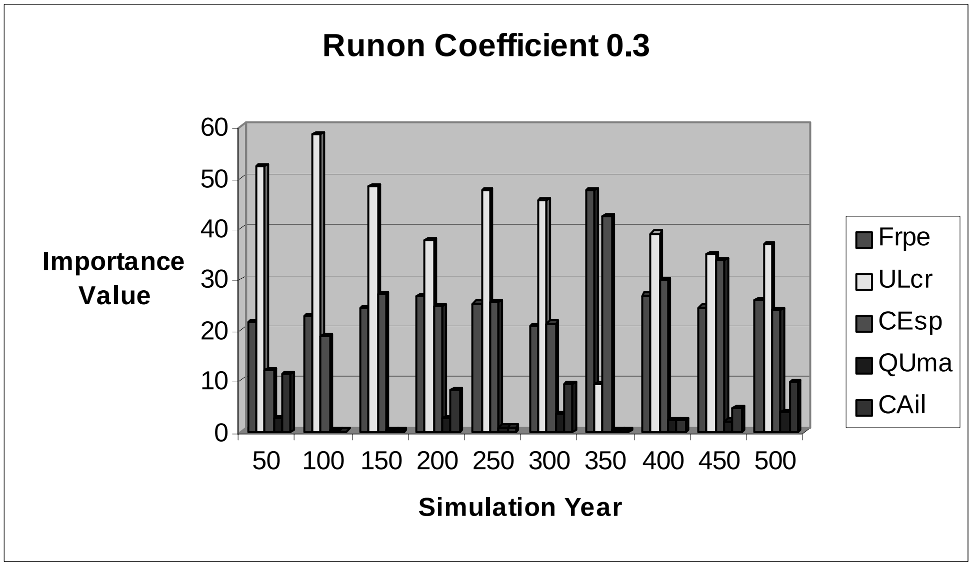
APPENDIX F

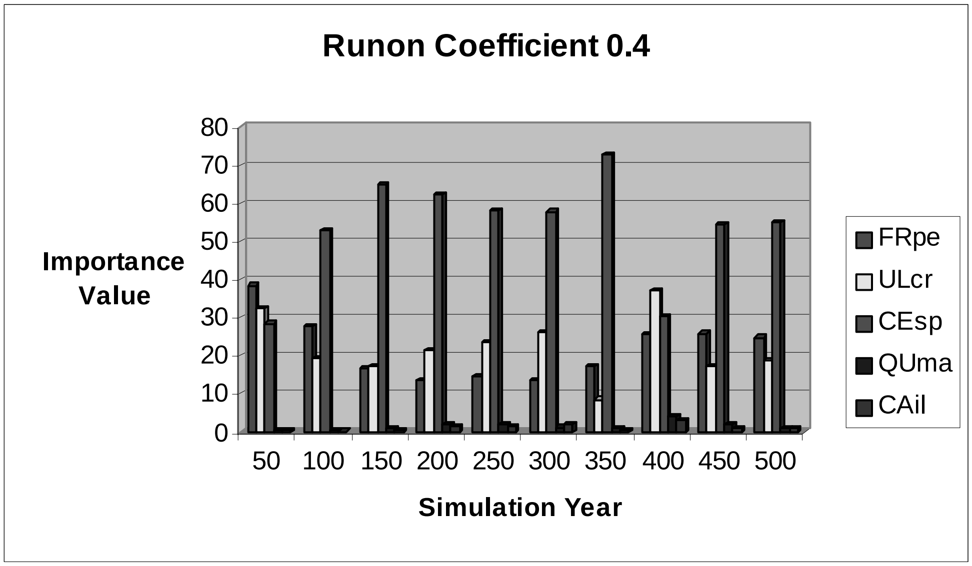
POND EXPERIMENT ADDITIONAL GRAPHS

Comparison of Importance Values over Entire Simulation for Significant Runon Coefficients, With Ponding Function Added

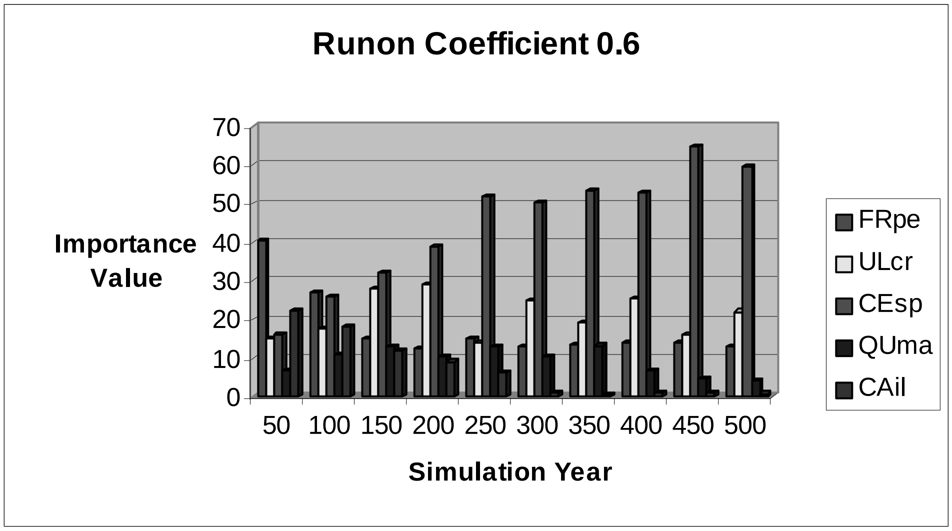
Some tree growth above 20 cm dbh occurred at runon coefficient 0.2 with the ponding function, but consistent tree growth above 20 cm dbh did not occur until the coefficient was raised to 0.4. Thus, the threshold seen in the previous runon experiment was apparent, but not as stark as before.



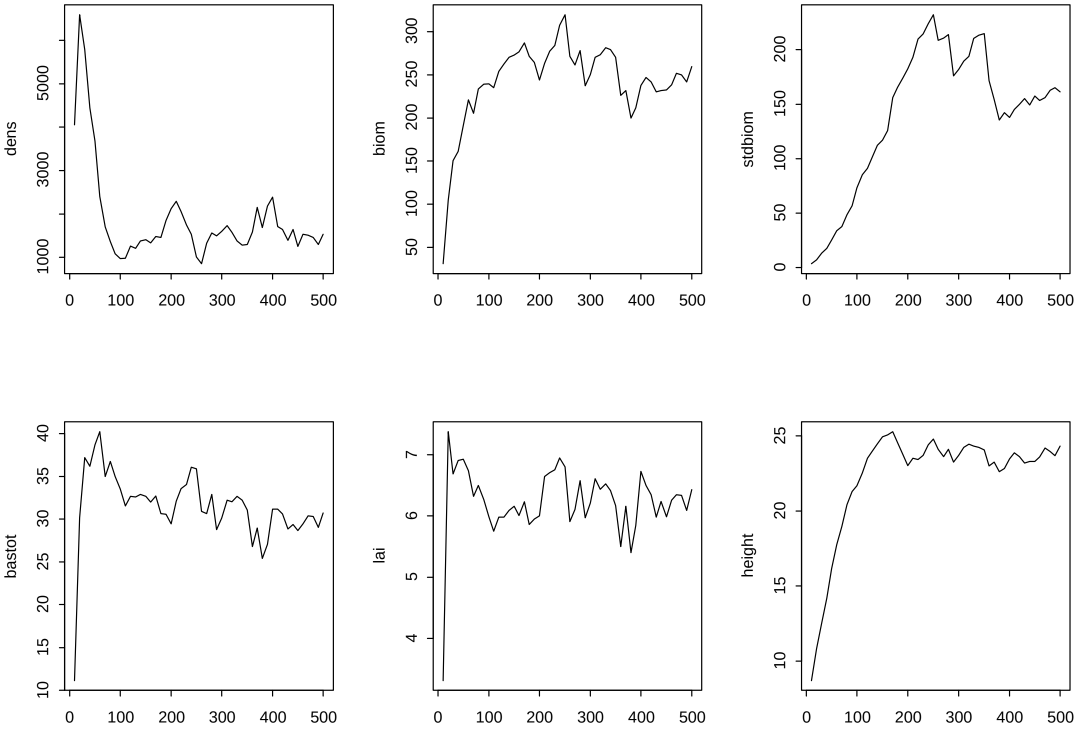




Results closest to those found in the Barry and Kroll study (1999) were achieved at year 400, with a runon coefficient of 0.6, slightly lower than the previous runon experiment.



Tracer File Graphs for Runon Coefficient 0.6



Note that, despite optimal results with regard to species composition and other metrics at 50-year intervals, some oscillations have reappeared in the tracer file graphs. Further experimentation would need to be made to discover the reason for this.