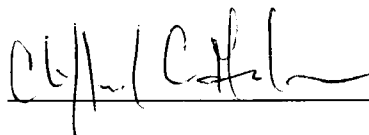


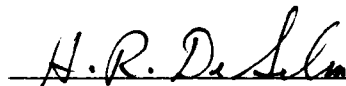
To the Graduate Council:

I am submitting herewith a dissertation written by James F. Rosson, Jr. entitled "An Analysis of the Temporal Dynamics in Tree Species Diversity for Major Tree Taxa of Two States in the Midsouth, USA." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology and Evolutionary Biology.



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and recommend its acceptance:



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Dr. Lou J. Gross; Mathematics



Dr. John C. Rennie; Forestry, Wildlife, and Fisheries

Accepted for the Council:



Associate Vice Chancellor and
Dean of The Graduate School

**AN ANALYSIS OF THE TEMPORAL DYNAMICS
IN TREE SPECIES DIVERSITY FOR MAJOR TREE
TAXA OF TWO STATES IN THE MIDSOUTH, USA**

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

James Forrest Rosson, Jr.
May 1999

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DEDICATION

This dissertation is dedicated to all those who have
given me the educational opportunities I have realized.

This process began in my early childhood and has
continued into my adult life.

I am appreciative and beholden to all.

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ABSTRACT

An analysis of the temporal dynamics of tree species diversity was made for empirical forests of the States of Arkansas and Mississippi, USA. These two states each had four comprehensive, variable radius plot measurements over a period of three decades. The data came from the Forest Survey, administered by the USDA Forest Service. An important factor contributing to the rigorousness of this study was that the same sample design, involving a minimum of 2,623 plots in Arkansas and 2,806 plots in Mississippi, was implemented in both states over these four survey measurements.

In addition to tree species data, the surveys provided three physiographic categories, three ownership categories, and five stand-size classes. Two measures of tree species diversity were applied to the survey data: (1) tree species richness; and (2) the McIntosh measure of evenness. The Sorensen quantitative index of similarity was used to contrast tree species changes between survey periods. Data treatment involved applying the two diversity measures and the plot similarity measure to each forested plot in each state for all four surveys. Summary statistics were then derived, along with graphs, to describe the trends of these three metrics through the four survey measurements.

Repeated measures ANOVA tests were conducted to test for significant differences in diversity measures across time and between specific group strata. All tests were conducted at the 0.05 probability level. The tests conducted were of statistical hypotheses. In all cases, the null hypothesis (no difference between respective means) was the subject of statistical testing.

Maps showing spatial distribution were created to show patterns of the three diversity measures across each state. The maps were constructed by aggregating plot-level data to the county level so that each county represented an average value for each diversity metric.

Major findings from this study showed tree species richness levels have declined at the state level for Arkansas and Mississippi. This was confirmed by examination of the empirical evidence and results from the repeated measures ANOVA test ($p \leq 0.0001$). Arkansas tree species richness declined by 3.4 percent since 1968, and Mississippi tree species richness declined 10.6 percent from its highest level in 1977.

An additional important revelation was the notable impact plantations were having on tree species richness at the state level. Tests were conducted to discern differences in species richness at the state level by contrasting data sets which included plantations with data sets that excluded plantations. The data showed that the increasing implementation of plantation forestry is having a negative impact on the overall average tree species richness for each state. As the areal extent of plantations continues to increase, their usual monotypic stand structure will continue to pull overall diversity measures of individual states downward. In 1995, plantations contributed to the decrease

of Arkansas' tree species richness by 14.1 percent, in contrast to the data set excluding plantations. Mississippi's 1994 tree species richness was reduced by 28.9 percent in a similar comparison.

The absence of harvesting allowed forest land to increase in tree species richness. Plots that had no harvesting activity over the four survey measurements (survivor plots), significantly increased in tree species richness. Arkansas tree species richness increased on these plots by 21.6 percent between 1968 and 1995 while Mississippi increased 43.8 percent from 1967 to 1994.

Tree species richness has declined in these two Midsouth states during four survey measurements covering the mid 1960's to the mid 1990's. The study did not use a causal inference design but did test statistical hypotheses to confirm real differences in the data. Corroborative evidence, supported by empirical evidence in the data, suggests that intense and increasing forestry practices (harvesting and plantation forestry) have attained a level high enough to contribute to the reduction in overall tree species diversity in Arkansas and Mississippi.

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CHAPTER I

INTRODUCTION

Questions, concerns, and interest in biological diversity have reached high levels of importance and research priority with research scientists, resource conservationists, political decision makers, and the general public concerned with the environment. This rapid expansion of interest began with awareness of the destruction of tropical rain forests; this destruction that stemmed from an intense level of harvesting and landclearing practices. These practices are continuing at a high level of intensity. Heightened awareness and focus on the decline of tropical forests culminated in the 1986 National Forum on Biodiversity and the introduction of the term, biodiversity, by Walter Rosen, forum organizer (Wilson and Peter 1988). Ten years after the forum, the term biodiversity has become a household word and research in this discipline has attained a significant level of interest, importance, and priority.

Anthropogenic disturbance on forest land is also receiving considerable attention in the United States (Kimmings 1997, Perry 1994, Kohm and Franklin 1997). This disturbance ranges from permanent forest clearing to intense levels of repeated harvesting activity. Such an increase in the timber harvest regimen in the Midsouth region of the United States has raised concerns about the-long term sustainability of the forest

resource. Increases in harvesting in the southern United States come primarily from heightened consumer demand combined with less public acreage being offered for contract sales. The latter follow from the decrease in the appropriated allowable cut (the amount of timber offered for sale on public lands by the United States Department of Agriculture, Forest Service), and sensitivity to habitat protection (as for the spotted owl in the northwestern United States). The South currently accounts for most of the timber removals in the United States, presently 55 percent, up from 45 percent in 1970 (Powell *et al.* 1993).

In addition to timber supply shortage issues are those related to the effects of continued harvesting activities on forest biology. These include, but are not limited to: soil deterioration; habitat destruction and alteration; changes in stand structure; successional interruption; stand fragmentation; old growth decline; changes in species composition; and impacts on biological diversity.

As harvesting pressures in the South continue to increase with no signs of abating, decision makers (and subsequent conservation strategies) will need reliable information that tracks the impact of harvesting on forest resources. Central to the long-term impact of timber harvest, and the focus of this study, is how tree species diversity and forest stand composition may be affected and what effect the continually increasing area of artificially regenerated forest lands will have on the species diversity of a large area, such as a state. Currently, it is not known if the tree species diversity of a southern state has declined, remained stable, or increased since harvest pressure began increasing in the 1960's. Additionally, species composition dynamics on these disturbed lands have not

been studied or documented. It is not clear if and to what degree tree species communities are changing in composition throughout forest ecosystems of the South. Pertinent documentation and studies are nonexistent in the literature. Research and conclusions based on probability sampling that rigorously defines the dynamics of tree species diversity and stand composition changes over time are urgently needed.

1. THE PROBLEM

Rationale for the Study and Statement of the Problem

As timber harvesting pressures increase in the Midsouth states, policy and decision makers will need accurate information to ensure sustainability of the timber resource. The sustainability issue has been raised, primarily by State Foresters, representatives of the forest industry, and those interested in environmental concerns. Other nontimber issues are of concern, such as the impact on the entire flora and fauna of the forest. Recent forest surveys by the United States Forest Service have shown the ratio of volume growth-to-removals narrowing and, in many cases, removals surpassing growth. An example is Louisiana, whose latest forest survey showed a volume removal-to-growth ratio of 1.27 to 1.00 for softwoods (Rosson 1995a). Two papers have addressed this concern. The first study documented harvesting over the last two survey measurements (Rosson 1994b). The second study documented the status of young, recently regenerated softwoods (Rosson 1994a). Another study (indirectly related to harvesting) documents, quantifies and provides analysis of the characteristics and

increasing occurrence of forest plantations in seven Midsouth states (Rosson 1995b). The establishment of forest plantations is an indirect impact of harvesting and most likely is important in affecting the overall species diversity of a state.

In addition to the timber supply issue, concerns have been raised for safeguarding the sustainability of the entire biotic and abiotic forest base. Several recent books have documented the need and urgency for altering forest management practices to achieve certain conservation goals (Kohm and Franklin 1997, Noss and Cooperrider 1994, Szaro and Johnston 1996, Huston 1994, Hunter 1980). The United States Forest Service has adopted and implemented the concept of ecosystem management in order to protect and provide sustainability for all attributes of the forest. Foremost in these new suggestions and approaches to forest management is the concept of managing forests in a way that protects and fosters the establishment of natural biodiversity. With the establishment of the Biosphere Initiative, the Ecological Society of America has brought the biodiversity problem to the public forum and to the attention of policymakers (Lubchenco *et al.* 1991). Additionally, the dialog has gone beyond the biology of the diversity issue to include and quantify the economic benefits of a diverse natural world (Freeman 1998).

Lacking are hard data and detailed analysis over large regions that describe the impact of the increasing intensity and frequency of harvesting on tree species diversity and stand composition. Currently, it cannot be stated with any scientific certainty and rigor whether or not any states in the Midsouth have had their tree species diversity impacted or overall tree stand composition altered during the last 20 to 30 years of increasing harvesting activity.

There has been much speculation on the effects of harvesting, most of it based on studies of small stands. Application of a probability-based sample would provide meaningful insight into the status of any state's forests. Some investigators have concluded that the status of species diversity in United States forests has improved dramatically during the last century (Salwasser *et al.* 1992). Others are convinced of continuing degradation of entire ecosystems (Noss *et al.* 1994). No studies or rigorous statistics are available that accurately document the status of biodiversity in the United States (United States Environmental Protection Agency 1990, LaRoe *et al.* 1995, Noss and Cooperrider 1994). Therefore, neither claim can be rigorously supported.

This study will provide important information on tree species diversity trends and changes in tree stand composition of two states in the region most heavily impacted by tree harvest in the United States, the Midsouth States. There is a unique opportunity here to explore the impact of harvesting across a large area with public, forest industry, and nonindustrial private ownership involved. The states of Arkansas and Mississippi were selected for study. Four survey measurements, covering the period of the 1960's through the 1990's, will be analyzed. Traditionally, the United States Forest Service forest surveys have been used as a source of information for timber supply and drain (harvest). However, these types of surveys have been criticized for spending money collecting data that is never fully utilized or put to good use (Thomas 1996). This study will demonstrate the potential use of forest survey data to address important biological issues surrounding and affected by anthropogenic disturbance throughout the forests of the United States.

Definition of Diversity Specific to the Dissertation Topic

Four primary levels of diversity studies have been recognized in the recent literature. These are ranked on a scale that covers very small to very large geographic regions (Szaro and Shapiro 1990, Szaro and Salwasser 1991, Noss and Cooperrider 1994, Ricklefs 1987). Included are: (1) genetic diversity; (2) community (and ecosystem) diversity; (3) landscape and regional diversity; (4) species diversity.

Genetic diversity relates to the genetic building blocks among individual species. The maintenance of genetic diversity is crucial for species survival. Protection and enhancement of genetic diversity are essential in order to provide resilience against environmental stressors.

Community and ecosystem diversity is concerned with both the variety of community types and ecosystem processes. Examples of such studies are the kinds and numbers of different ecosystems that occur across several abiotic settings.

Landscape diversity deals with the number of, and different kinds of, communities and ecosystems across large areas or regions. A landscape ecosystem composed of forest, grassland, meadow, streams, and shrubland would be considered more diverse than a landscape composed of only forest.

Species diversity defines the variety of living organisms found in a particular area or environment. Normally, three types of measures are recognized (Magurran 1988, Krebs 1989): (1) a count of the number of species (species richness); (2) a description of the relative abundance of these species (species evenness); and (3) a measure (index) that combines the number of species count and the relative abundance measure into one

number. These three measures usually represent species present on a defined area. The defined area can range in scale from a sample plot to a small forest stand, a county, a state, a country, or the planet.

Two measures of species diversity were used for analysis in this study, species richness and species evenness across three generalized physiographic designations. A formal definition of species richness is the number of species in a given sample, assemblage, community, biomass, or habitat (Lincoln *et al.* 1998). In this study, species richness is the number of species found on a sample plot. Species evenness is defined as the component of species diversity that measures the relative abundance of species (Lincoln *et al.* 1998). In this study, species evenness is the relative abundance of species on a sample plot. These two diversity measures were used to assess the dynamics of species numbers, abundance, and fluctuations in conjunction with anthropogenic disturbance over four survey measurements.

Additionally, a measure of change in sample plot stand composition between measurements will be applied (Wolda 1981). This is, in essence, a measure of similarity of species composition and abundance of a plot between measurement 1 and measurement 2 (Lincoln *et al.* 1998). In this study, stand similarity is the measure of species similarity between a sample plot at time 1 measurement and time 2 measurement.

Hypothesis and Research Questions

The primary objectives of this study are to describe, quantitatively, the dynamics of tree species richness, tree species evenness, and stand similarity between successive survey measurements. Both empirical and statistical evidence is presented.

The empirical evidence is presented in the form of statistical summaries.

Statistical tests were performed that compared species richness, evenness, and similarity among four survey measurements. Additional tests were conducted on species richness to discern the effects of ownership, physiography, and stand-size class. The year of the survey measurement was then assigned a label of T_1 (Time 1 measurement), T_2 (Time 2), T_3 (Time 3), and T_4 (Time 4):

	T_1	T_2	T_3	T_4
	----- Survey year -----			
Arkansas	1968	1978	1988	1995
Mississippi	1967	1977	1987	1994

Listed below are the primary hypotheses to be tested. These tests were conducted separately for both Arkansas and Mississippi.

Tests 1, 2, 3. H_0 : There is no difference in tree species richness, evenness, or stand similarity among survey measurement years for all forested plots. This test was conducted using all forested plots in each state.

1. Species richness : $T_1 = T_2 = T_3 = T_4$
2. Species evenness : $T_1 = T_2 = T_3 = T_4$
3. Similarity : $T_1 T_2 = T_2 T_3 = T_3 T_4$

Tests 4, 5, 6. H_0 : There is no difference in tree species richness, evenness, or stand similarity among survey measurement years for survivor plots. This test was done

on all forested survivor plots (defined in Research Procedures and Methodology) in each state.

$$4. \text{ Species richness} : T_1 = T_2 = T_3 = T_4$$

$$5. \text{ Species evenness} : T_1 = T_2 = T_3 = T_4$$

$$6. \text{ Similarity} : T_1 T_2 = T_2 T_3 = T_3 T_4$$

Test 7. H_0 : There is no difference in tree species richness among all plots (with plantations included) versus all plots (with plantations excluded). This test was conducted using all the respective forested plots in each state. Comparing all plots with all plots (minus plantations) could illustrate any impact of plantations across the state.

7. Species richness

$$\text{All plots} \quad T_1 = T_2 = T_3 = T_4$$

x

$$\begin{array}{l} \text{All plots (minus} \\ \text{plantations)} \end{array} \quad T_1 = T_2 = T_3 = T_4$$

Test 8. H_0 : There is no difference in species richness among survey measurement years and among public, forest industry, and nonindustrial private ownership groups.

8. Species richness

$$\text{Public} \quad T_1 = T_2 = T_3 = T_4$$

x

$$\text{Forest industry} \quad T_1 = T_2 = T_3 = T_4$$

x

Private nonindustrial $T_1 = T_2 = T_3 = T_4$

Test 9. H_0 : There is no difference in species richness among survey measurement years and among upland (pine), upland (hardwood), and bottomland hardwood physiographic groups.

9. Species richness

Upland (pine) $T_1 = T_2 = T_3 = T_4$

x

Upland (hardwood) $T_1 = T_2 = T_3 = T_4$

x

Bottomland hardwood $T_1 = T_2 = T_3 = T_4$

Test 10. H_0 : There is no difference in species richness among survey measurement years and among four stand-size classes.

10. Species richness

12.7-20.0 *cm* $T_1 = T_2 = T_3 = T_4$

x

20.0-30.0 *cm* $T_1 = T_2 = T_3 = T_4$

x

30.0-40.0 *cm* $T_1 = T_2 = T_3 = T_4$

x

≥ 40.0 *cm* $T_1 = T_2 = T_3 = T_4$

2. REVIEW OF THE LITERATURE

Historical Overview of the Theory and Research Literature

Early in the history of biological science, the concept of species diversity was regarded as an historical phenomenon, related to the accumulation of species over time (Wallace 1876, Willis 1922, Fischer 1960). Much of the interest and early work in species abundance was done by animal ecologists (Kingsland 1985). The early part of the twentieth century also saw the beginning of techniques development to describe plant communities in quantitative terms (McIntosh 1985). Oosting (1956) described the difference between two approaches to analysis, descriptive (analytical) statistics and qualitative (synthetic) statistics. The descriptive statistics involved measures of individual stands (the actual concrete community); qualitative statistics were estimates of several stands in aggregate (the abstract community). Implications of this concept to this study will be discussed in the methodology section.

By carefully counting species, several investigators were able to demonstrate that species were organized into predictable structures (Gleason 1922; Williams 1944, 1953; Preston 1948). Early work showed a majority of species were rare and less abundant while only a few were dominant or very abundant. Ecologists soon found it was not possible to census an entire biotic community and that patterns of species abundance would have to come from samples (Golley 1993). By graphing the cumulative species observed against the number of individuals on a logarithmic scale, it was shown that this

often produced a straight line. Supposedly, the slope of this line was a measure of the species diversity of the community (Fisher *et al.* 1943). Pielou (1977) states that the idea of species diversity was first introduced by Fisher in 1943. The work of Margalef (1958) was instrumental in the popularization of the term species diversity among ecologists (Green 1979).

Jaccard was the earliest to demonstrate that there was an increase in the number of species with an increase in area (Goodall 1952). This was later expressed mathematically by Arrhenius (1921). Coinage of the terms “rich” and “poor” is credited to Baker (1918) who recorded the number of species on lake bottoms. Thienemann, a limnologist in Europe, identified three important species-abundance principles: (1) the greater the variety of habitats, the larger the number of species; (2) the more that conditions deviate from the normal optima of most species, the smaller is the number of species that occur and the greater the number of individuals that do occur; and (3) the longer a habitat has been in the same condition, the richer and more stable is the community (Hynes 1970, Goodman 1975). The third principle that Thienemann identified is now known as the stability-diversity hypothesis, still studied and strongly debated today.

Elton (1927) and others realized that species numbers were most likely part of important principles in plant and animal ecology, however, he went on to state that it was not clear what these important principles were (McIntosh 1985). Thienemann's first two principles led to a long series of studies by other workers involving species-area relations. Cain (1938) and Preston (1948) were early investigators of species-area curves. All early mathematical properties of species-area relations have been reviewed by Connor and

McCoy (1979). The term diversity still had not come into popular usage. However, with the exception of Odum's textbook (1959), no ecology textbooks of the 1940's and 1950's even mentioned the term (Schluter and Ricklefs 1993).

In 1969, the famous Brookhaven Symposia in Biology maintained that a major means of assuring continuity and sustainability of life systems appeared to be the number of species per unit of area (Wolda *et al.* 1969). This meeting also ensured the popularization of the term diversity. By the late 1960's the study of diversity was expanding, involving not only the number of species but also the proportionate distribution of individuals (evenness) and the consequent development of a myriad of diversity indices. This period also marks the beginning of a significant number of diversity study contributions to the literature. Lloyd and Ghelardi (1964) are credited with introducing the term evenness (Krebs 1989).

The beginning of the modern era of quantitative ecology has been attributed to MacArthur (McIntosh 1985). Building on Preston's work (Preston 1948) concerning the canonical distribution of species, MacArthur and Wilson extended this idea as the basis for their seminal book, *Theory of Island Biogeography* (1967). Ideas put forth in this small book essentially set the stage for much of the ecological work over the next two to three decades. Many workers in either plant or animal ecology borrowed and built upon MacArthur's ideas and work related to species-area and species-distribution phenomena.

The literature related to species diversity studies and technique development is voluminous. Many papers in the literature have dealt with the development of new and improved measures of diversity. This pattern of work began in the early 1960's and

continued through the 1970's. Many papers and books are considered seminal and helped critique and resolve certain issues pertaining to the problems of measuring and analyzing species diversity. Examples are: Pielou 1969, 1975; Peet 1974, 1975; and Hurlbert 1971. A good summary of the diversity literature prior to 1979 has been put together by Dennis *et al.* (1979).

For a brief period, interest in species diversity declined; however, the onslaught of tropical forest landclearing and the environmental movement quickly brought to focus not only species diversity but also genetic diversity, habitat diversity, landscape diversity, and ecosystem diversity. Prominent biologists were quick to respond resulting in the National Forum on Biodiversity, held in Washington, D.C., September 21-24, 1986 (Wilson and Peter 1988). This meeting and published proceedings were important in bringing attention to the potential problem of declining species diversity and the ultimate loss of species through extinction. Since then, a second volume, *Biodiversity II*, has been published, concentrating on concept formation and technique (Reaka-Kudla *et al.* 1997).

Since the National Forum on Biodiversity, other important conferences have been held, including the symposium, Ecological Perspectives of Biodiversity, held in Kyoto, Japan in December 1993 (Abe *et al.* 1997); the Symposium of Biodiversity in Managed Landscapes held in Sacramento, California, in July 1992 (Szaro and Johnston 1996); the Sixth Cary Conference held in May 1995, at the Institute of Ecosystem Studies, Millbrook, New York (Pickett *et al.* 1997); and the proceedings of the plenary sessions of the 45th annual meeting of the American Institute of Biological Sciences held at Knoxville, Tennessee in August 1994, resulting in a supplementary issue of the

publication, *BioScience* (BioScience 1995). These meetings and published proceedings focused on educating the public about the importance of biodiversity, described the current state of knowledge in particular disciplines, and provided examples of failures and successes in managing ecosystems to preserve biological diversity while maintaining economic viability (Powledge 1998).

In addition to conferences and published proceedings, several books on diversity have been published over the last few years. Examples include *Species Diversity in Space and Time* (Rosenzweig 1995), *Species Diversity in Ecological Communities* (Ricklefs and Schluter 1993), and *Biological Diversity* (Huston 1994). All are comprehensive in scope and contain sizeable reference sections. Huston's reference section, alone, covers 98 pages.

The Theory and Research Literature Specific to the Dissertation Topic

Although much work has been completed on the theory and concepts of biological diversity, little has been done on the application of this theory to real world problems. The literature up to the present time is largely based on incidental observations or reports rather than detailed systematic and analytical evaluations. Studies dealing with comparative analysis are valuable and rare (Machlis and Forester 1996).

Most of the studies that have been undertaken were usually done on a small area that had attracted investigators because of some unusual biotic or abiotic characteristic. Additionally, the cost of sampling areas larger than a few hundred hectares becomes prohibitive. Some examples of plant pattern and response to anthropogenic disturbance in forests at a small scale can be found in Grime (1979), Oliver (1981), and Hunter

(1990). Other studies have implemented novel approaches to biodiversity studies, such as Sites and Crandall (1997) and Skov (1997). Quantitative studies using systematic and analytical techniques on a large regional scale (an area the size of a state or larger) are lacking (Langer and Flather 1994; LaRoe *et al.* 1995). There have also been calls for the establishment and application of rigorous sampling and analytical techniques in biodiversity assessments (Debinski and Humphrey 1997, Solomon 1979).

Because of the cost and complexity of sampling large, continuous geographic areas, very little, and very limited, data (usually addressing only specific resource and conservation issues) are available for large regional studies. To get around this problem, some investigators have taken several local studies and extrapolated the results to a larger area or continental region. One such example is a paper by Glenn-Lewin (1977) in which richness information from six temperate forest communities across North America were analyzed for correlations of species diversity within the environment and community structure. While filling a needed information gap, such studies lack rigor because they are based on non-probability samples and because they have too few plots (from a regional perspective). Additionally, the data come from studies that poorly represent the whole of vegetation conditions. The Great Smoky Mountains and Siskiyou Mountains are of great biological interest but they hardly represent the current range of conditions, sites, and vegetation characteristics across the North American continent. Other studies have also followed a similar approach, either by using a local study or by using abstract information from flora listings by county (Currie 1991; Monk 1967; Currie and Paquin 1987).

Little definitive work has been done describing temperate tree species diversity over areas as large as a state in relation to disturbance; only one study has attempted to evaluate these relationships over large geographic areas (Stapanian *et al.* 1997). They used USDA Forest Service Forest Health Monitoring plots but data were incomplete due to a lack of complete implementation over all areas of the United States. Only 14 states are in the program and less than 150 forested plots (on average) are present in a particular state. It is doubtful that this small number of initial sample plots is sufficient to represent an area as large and diverse as a state. Additionally, such a small number of primary plots would severely limit any attempt to post-stratify the data. Finally, since the Forest Health Monitoring Program has only recently begun implementation, there are no adequate historical data available. Therefore, trend analysis on species diversity cannot be conducted at this time with these data sets.

CHAPTER II

RESEARCH PROCEDURES AND METHODOLOGY

1. OVERVIEW

Methodology

The stated objectives for this study are to determine whether or not tree species richness, tree species evenness, and stand similarity (all determined from forest surveys) have declined, remained stable, or increased in the presence of rising harvesting activity over the last 20- to 30-year period. During this period harvesting activity has intensified in both Arkansas and Mississippi (Rosson 1998a, Rosson 1998b). This provided the opportunity to contrast changes in tree species richness, evenness, and plot similarity with this increase in harvesting.

One direct result of increased harvesting activity is the subsequent expansion in area of pine plantations (Rosson 1998c, Rosson 1998d). Many landowners plant pines to control temporal regeneration success and to establish the desired species composition. This provided an additional opportunity to assess the impact that artificially regenerated forest lands (plantations) were having on tree species richness, evenness and similarity

over large regions. Selected statistical tests were conducted to define the rigor and power of any conclusions.

Scheiner (1993) describes three types of ecological experiments: (1) the manipulative; (2) the observational; and (3) the natural. The manipulative experiment is the true classical experiment where the investigator has complete control of the variables. Ecology examples would be the manipulation of climate control in a greenhouse setting. An observational experiment arises where it is not feasible to manipulate variables, either because of ethical considerations or because it is not feasible, either economically and/or physically, due to the scale of the study. Hypotheses are tested by comparing altered conditions to conditions that are considered normal, *i.e.*, conditions that have not been changed by the specific phenomena of interest. In between manipulative and observational experiments are natural experiments. Here an attempt is made to predict the outcome of a naturally occurring event. Some authors group natural and observational experiments together (Hairston 1989). They follow the basic tenet that the control is a condition that is undisturbed (or not influenced) and the observation is a sample plot that falls into a condition that has been altered naturally or by some anthropogenic influence.

The approach in this study was inductive and the experimental design follows the concept of Scheiner's definition of a natural experiment. Most of the detailed analyses concerned a comparison of two or more populations or being able to detect diversity patterns. Causal inference cannot be determined with this type of experimental design and procedures because the treatment assignment is unknown. Natural experiments are

adequate for testing of hypotheses concerning pattern detection and comparisons but not for inference of mechanistic causal relationships (Gotelli and Graves 1996). The primary reason that natural experiments cannot be used to test for causality of the model and hypothesis proposed is because the investigator has no control of all the elements that may influence the change from before the test to after the test. Underwood (1997) calls this a confounded experiment and all of these uncontrolled elements, confounding influences.

The hypotheses tested in this study were statistical hypotheses. Loehle (1996) describes three types of hypotheses: (1) the working hypothesis; (2) the scientific hypothesis; and (3) the statistical hypothesis. The working hypothesis is based upon the intuition that a pattern or relationship in nature has been detected. A working hypothesis leads to a scientific hypothesis when a causal explanation is offered to explain the pattern in question. The statistical hypothesis can be empirical, descriptive, or used to test a scientific hypothesis (after suitable deduction and definitions of variables). It is primarily used to judge the comparison of two samples to determine whether or not the sample populations are indeed different.

Data

Data for this study came from forest surveys conducted by the United States Forest Service. These surveys have been conducted since the early 1930's under the direction of the McSweeney-McNary Act of 1928. The original survey mission was to estimate forest area, timber volume, timber growth, and timber removals. The survey was charged with reporting the findings and in assisting with the formulation of guiding

principles and policies for sustained forest use. Recently, the mission was expanded by the passage of three major legislative acts: (1) the Forest and Rangeland Renewable Resources Planning Act of 1974; (2) the National Forest Management Act of 1976; and (3) the Forest and Rangeland Renewable Resources Research Act of 1978.

The data used in this study were collected in the seven Midsouth states by the former Southern Forest Experiment Station (Figure A-1). The work unit administering the survey is housed in the Forestry Sciences Laboratory at Starkville, Mississippi. Recently, the Southern Forest Experiment Station merged with the former Southeastern Forest Experiment Station to form the new Southern Research Station, headquartered in Asheville, North Carolina.

Two states, Arkansas and Mississippi, were selected from the Midsouth for data analysis in this study. These states represent typical features of the landscape and the intensity of forestry practices in the Midsouth. The land area of Arkansas is 134,887 km^2 ; approximately 55 percent is in timberland (land available for commercial harvest) (Rosson 1998e). Arkansas is diverse in both physiography and in intensity of harvest activity. The southern portion has been impacted by an intense level of harvest activity (Rosson 1998a). The western and northern portions of the state are less productive, contain fewer and smaller commercial species and thus escape the most intense forms of harvesting activity. Physiographically, the southern portion of the state lies on the Coastal Plain and Mississippi Alluvial Plain. The western and northern portions are in the Ouachita and Ozark Plateaus Provinces, respectively (Figure A-2).

Mississippi lies on the Coastal Plain and Mississippi Alluvial Plain (Figure A-2). There are 122,331 km^2 of land area in the state; 60 percent of Mississippi is in timberland (73,396 km^2) (Rosson 1998f). Having only two major physiographic provinces means Mississippi presents a more homogeneous landscape for tree occupancy. Harvest activity has been intense in the central and southern portions of the state for the last 20 years. Activity has increased in northern Mississippi over the last ten years (Rosson 1998b).

Individual states are divided into forest survey units (Figure A-1). These divisions facilitate field work and data analysis. The unit boundaries, though following political (county) boundaries, are correlated fairly closely with the physiographic and vegetative regions of each respective state.

The forest survey uses a two-phase sampling scheme to derive periodic forest resource statistics. Phase I (to determine forest area) consists of a forest-versus-nonforest dot count classification system using aerial photography. Phase II (to determine tree and plot [stand] parameters) consists of sample plots at the intersection of a 4.8 km square grid. The grid is systematic but the starting point of the grid was randomly selected in each county. Therefore, the sample is considered probability-based. All phase II plots are monumented and revisited during each successive measurement. Figures A-3 and A-4 illustrate the distribution of forested sample plots for Arkansas and Mississippi, respectively. This also is a representation of the relative density of forest land in different regions of each state. The area with fewer forest plots is within the Mississippi Alluvial Plain. Here, the probability of a sample plot falling on forest land is less likely. The length of time between remeasurement of all plots has averaged eight to ten years.

All field measurements were made in English units by Forest Service field personnel. Conversions to metric units were done for all variables in this study.

Each forested 4.8- x 4.8-*km* sample plot consists of 10 satellite points spread over an area of approximately 0.4 hectares (Figure A-5). This design is used to improve portrayal of stand conditions by minimizing the effect that vegetation clumping or gaps would create if only one point or one fixed plot were installed at each location.

At each forested sample plot, trees ≥ 12.7 *cm* in diameter at breast height (*DBH*) were selected with an 8.6 Basal Area Factor (*BAF*) prism (m^2 per *ha*) on each of the 10 satellite points. Therefore, each tree selected with the prism represented 0.86 m^2 per hectare of basal area ($8.6/10 = 0.86$). Trees < 12.7 *cm* in *DBH* were tallied on 0.0015-hectare circular fixed plots on the first three variable radius points (Fig. A-6).

There were 18 variables collected by Forest Service field personnel that defined plot-area attributes and 27 additional variables describing attributes for each individual sample tree. Of these 45 variables, only 10 were needed for this study:

- (1) plot identification
- (2) tree species name
- (3) tree history of each tree
- (4) *DBH* of each tree
- (5) ownership of each plot
- (6) physiographic class of each plot
- (7) year each survey was conducted (survey year)
- (8) stand origin of each plot

(9) ground use of each plot

(10) latitude and longitude of each plot center.

Plot identification is a unique number assigned to each plot. It is a number that is made up of a combination of codes including the state code, the county code, and the plot code.

The tree species name is the botanical name of the tree. The nomenclature for field dendrology followed Little (1979). Adjustments were made to make the species lists compatible between surveys (see Treatment of the Data in Research Procedures and Methodology).

Tree history is a tracking code to account for trees through successive forest survey measurements. Tree history codes important for this study identify sample trees as: (1) a new tree (in growth); (2) a survivor tree (a tree that is still alive from the previous survey); (3) a mortality tree (a tree that was alive during the previous measurement and had died before the next measurement); and (4) a harvested tree (a tree that was alive during the previous measurement and was harvested before the next measurement).

Tree diameter is the diameter of each selected sample tree 1.37 *m* above the ground, commonly referred to as diameter at breast height (*DBH*). Tree diameter is a measurement useful in computing tree volume but it is also used to assign importance values (weighting) to trees. It is also useful in variable radius plot sampling to compute the number of trees per hectare (*TPH*).

Identification of plot ownership comes from information collected by field personnel from county courthouse records. The ownership assignment was divided into three categories: (1) public [this class includes all publicly owned forest lands (federal, state, municipal, etc.)]; (2) forest industry [this class includes all forest land owned by forest industry]; and (3) nonindustrial private forest (NIPF) [this includes all other forest land owned by private individuals or corporations that do not own and operate a wood-using facility (all lands other than public and forest industry)].

Physiographic class is a plot classification assigned to one of three categories: (1) upland pine (an upland site where pines occupy more than 25 percent of stand stocking); (2) upland hardwood (an upland site where hardwoods occupy more than 75 percent of stand stocking); and (3) bottomland hardwood (a bottomland site usually situated on a floodplain).

Stand origin defines how the stand became established. Field personnel assessed whether the plot location originated by natural or artificial means. It is not always easy to determine if a plot originated from artificial or natural regeneration. Many times the conspicuous indicators (rows of trees) become obscure over time (Rosson 1995b). Therefore, the estimate of artificially regenerated stands (plots) is usually conservative.

Ground use is a classification assigned to plots that describes the disposition of the land where the sample plot is located. The two classifications that were important to this study were whether a plot was in a forest or nonforest condition.

Some variables in this study were computed from field variables. Two computed variables that were important to this study are trees per hectare (*TPH*) and the quadratic

mean diameter (QMD). Since the computation of these two variables is not straightforward with variable radius plot sampling, the following documentation is offered. Trees per hectare was derived by the following formula:

$$TPH = ((BAF/0.00007854)/10)/DBH^2$$

where:

TPH = trees per hectare

BAF = basal area factor of the sampling prism = 8.6 m^2

10 = number of points on the sample plot

DBH = diameter of the tree at breast height (in cm)

0.0007854 = constant to convert trees measured in cm to cross section area in m^2 . It is derived by the following reasoning:

$$\text{Area} = \pi r^2 = (\pi DBH^2)/4 = cm^2 \text{ when}$$

diameter (instead of radius) is measured in cm .

$$\text{Area} = \pi r^2 = (\pi DBH^2)/(4(10000)) = m^2$$

when diameter is measured in cm .

$$\text{Therefore } \pi/(4(10000)) = 0.00007854.$$

For example, a sample tree selected with an 8.6 BAF prism and 16.3 cm in diameter would represent 41.2 TPH .

$$\begin{aligned} TPH &= ((8.6/0.00007854)/10)/16.3^2 \\ &= 10949.8/265.7 \\ &= 41.2 \text{ TPH} \end{aligned}$$

The diameter of the tree of mean basal area of the plot is thus 35.8 *cm*. The *QMD* of the plot will always be slightly larger than the arithmetic mean diameter (Avery and Burkhart 1996).

Survivor plots are defined as plots that survived the four survey measurements without undergoing harvesting disturbance. In this study, plots that had less than 5 percent of their basal area removed were classed as survivor plots. Five percent was chosen as the cutoff level in order to increase the plot population to a satisfactory level (for statistical purposes). It is difficult to find plots, with absolutely no evidence of harvest, across four survey measurements in the Midsouth states. Allowing a 5 percent threshold of harvest had no impact on the results of this study.

2. PROCEDURES

Treatment of the Data

The data for several forest surveys are present in an ORACLE database housed at the Southern Research Station laboratory in Starkville, MS. It was possible to go back to the 1960's (four survey measurements) in two states of the Midsouth survey region (Arkansas and Mississippi) without data consistency problems. Going back to surveys conducted before the 1960's would introduce significant sample design dissimilarities that would weaken the analysis and raise serious questions of integrity in analytical procedures. The primary cause for this dissimilarity was the procedural change from sampling with fixed plots to sampling with variable radius plots. Fixed plots of various

design were used from the early 1930's through the 1950's. The variable radius plot design was introduced in the 1962 survey of Alabama and has been used up to the latest completed state survey (Arkansas 1995). Eliminating sample inconsistency problems (all fixed plot designs) resulted in four survey measurements being available for species diversity analysis for both Arkansas and Mississippi. Only forested sample plots for each survey year were loaded into the data sets.

After data sets with consistent sample designs were selected, adjustments were made to the species lists that were collected for each survey year. This was necessary to ensure compatibility between the species lists for each survey for each respective state. In order to strengthen the analysis, it was important that the same eligible species were available for each survey through time. Earlier surveys had fewer species eligible for tally than the most recent surveys. The expansion of survey goals over the years has been the primary reason more species have been added to the field tally. Correcting for this meant collapsing all of the more recent species lists to make them compatible with older species lists. Some species (the *Carya*) were collapsed to the genus. The species changed to the name *Carya* spp. included:

Carya cordiformis

Carya glabra

Carya laciniosa

Carya myristiciformis

Carya ovata

Carya pallida

Carya texana

Carya tomentosa.

Others were eliminated as species and placed into the group of "other species."

Species in this category included:

Aleurites fordii

Amelanchier spp.

Paulownia tomentosa

Sapium sebiferrum.

All the species that were included in this study are defined as trees according to Little (1979). His definition states that trees are woody plants having one erect perennial stem at least 7.5 *cm* in *DBH*, a more or less definitely formed crown of foliage, and a minimum total height of 4 *m* at maturity. This means that many species are included which will probably not reach the upper canopy. Examples of these smaller understory trees include *Cornus florida*, *Cercis canadensis*, *Ostrya virginiana*, and *Carpinus caroliniana*. It is important to know that the target population in this study includes many understory trees.

Table A-1 lists all the species (and species groups) eligible for tally in this study. Any tree at least 12.7 *cm* in *DBH* but not on the eligible list was placed in the miscellaneous unidentified category. These miscellaneous trees were also included in the analysis after grouping them all together and treating them as one species.

Restricting the analysis to trees greater than 12.7 *cm* alleviated most of the concerns associated with the lack of a comprehensive species tally because many minor

constituents of southern forests rarely attain a diameter of 12.7 *cm*. Only a few plots in any of the survey years had trees that were in the unidentified category; Arkansas 1988 contained the fewest plots (35) and Mississippi 1967 had the most plots with unidentified species (80) (Tables A-2 and A-3). This was a very minor element of the study; there were $\approx 2,900$ sample plots per survey year and the small number of plots with unidentified species had no effect on the overall results of this study.

The final treatment applied to the data was the assignment of tree species diversity measures to each individual sample plot. Two were chosen for this study: (1) a species richness index; and (2) a species evenness index. Additionally, a plot similarity index was included. These three estimators provided the baseline data for the diversity assessments in this study.

The species richness measure is simply the number of species that occurred on the 10-point sample cluster. As applied to this study, it was the number of species tallied on one sample unit. The measure is an accurate assessment of the number of species occurring on each sample plot and it is easy to understand and comprehend. It was the most important index in this study and its value was used to determine if the number of tree species is increasing, remaining stable, or declining in the states of Arkansas and Mississippi. The number of species in a sample is the index that emphasizes the pure richness component of diversity most strongly (Huston 1994). However, there is no element of evenness in the species richness index, *i.e.*, there is no assessment concerning the distribution of individuals among species.

It is well recognized that the species richness index alone is not enough to detect the more subtle changes occurring in the diversity of a community. Even when the species richness index is unchanged over time there may be shifts in the distribution of abundance among species. Such information would be important in assessing declines in numbers of individuals before a major problem arises that would ultimately result in the loss of a species. Therefore, a measure of evenness is needed to detect these types of diversity dynamics.

The McIntosh index was selected as a measure of evenness for this study. McIntosh suggested that a sample of a community is a point in space and that the distance from the origin is an indication of diversity (McIntosh 1967). He called this distance U and defined it as:

$$U = \sqrt{(\sum n_i^2)}$$

where: n_i = the number of trees per hectare of the i th species.

This was not a measure of evenness, however. Pielou (1969) expanded upon McIntosh's distance measure to obtain an evenness measure. This is called the McIntosh evenness index (Mc_E) and is defined as:

$$Mc_E = \frac{N - \sqrt{(\sum n_i^2)}}{N - (N/\sqrt{S})}$$

where: Mc_E = the McIntosh evenness index

N = the total weighted number of individuals on a plot
(number of trees per hectare)

- n_i^2 = the square of weighted abundance of the i th species
(square of the number of trees per hectare) on a plot
- S = the number of species on a plot.

A worked example of the Mc_E index is shown in Figure A-7. The index is closely related to Simpson's index (Peet 1974). The range of the evenness index is 0 to 1.0. Plots that have all individual trees the same size and distributed equally among all species will have an evenness index of 1.0.

The similarity index selected for this study was the Sorensen coefficient of similarity. It was first used by Czekanowski in 1913 and reestablished by Sorensen in 1948 (Krebs 1989). The index was modified by Bray and Curtis (1957) to adopt it to quantitative data. It has since been called the Sorensen quantitative coefficient of similarity (Magurran 1988). Its index also ranges from 0 to 1.0 with 1.0 representing exact similarity. It is defined as:

$$C_N = 2jN / (aN + bN)$$

- where: C_N = Sorensen quantitative coefficient of similarity
- aN = the weighted number (trees per hectare) of individuals on a plot at time 1 measurement
- bN = the weighted number (trees per hectare) of individuals on the same plot at time 2 measurement
- jN = the sum of the minimum weighted number (trees per hectare) of individuals that occur on the plot at time 1 and time 2 measurement.

The similarity value was computed on a plot-by-plot basis among T_1 and T_2 , T_2 and T_3 , T_3 and T_4 , and T_1 and T_4 . A worked example, comparing two survey measurements, is shown in Figure A-8.

These three diversity measures were used to provide empirical assessments for individual plots. Controversy and debate in the literature continue to surround many of the diversity measures available. Important in any particular study is the ability to produce intuitively realistic results to the data to which they are applied. Clearly, the species richness number, McIntosh evenness, and the Sorensen coefficient of similarity measure all satisfy that role when assigned to individual plots. Also important is that these measures were applied consistently throughout these data for comparative purposes within the confines of this study. However, it would not be feasible to compare the results of this study with the results from another study that applied different diversity and similarity metrics.

The analysis of aggregated plots in this study follows Oosting's definition of qualitative (synthetic) statistics (Oosting 1956). Here, the analysis was done in an abstract mode where no actual concrete vegetation type was defined *a priori*, then sampled. The random nature and spatial arrangement of sampling makes it necessary to define these aggregated plots as abstract and not actual concrete entities that can be viewed on the ground.

Mention needs to be made of trees that died from natural causes, whether because of damage from insect, disease, weather, animal, or natural senescence. They were not distinctly isolated for analysis in this study. These mortality trees make up a minor

component of the disturbance element compared to the impact harvesting is having on southern forests. For example, Louisiana had a loss of volume from natural mortality that was 4.2 percent of total volume whereas the loss of volume through harvesting was 34.4 percent of total volume (Rosson 1995a). Based on such rates of mortality and harvest, it seemed likely that disturbance as a result of tree harvest activity would have the greatest impact on species diversity dynamics in this study. Recognizing that most natural mortality can have a significant impact locally, high levels of mortality would need to occur over large expanses to be significant in a large survey such as that used in this study. An example of such an event would be the Chestnut blight.

Analytical Procedures

The field data and computed data (see Treatment of the Data in Research Procedures and Methodology) were loaded into an ORACLE database to enhance and simplify data interrogation. Four data sets were created for each state, one for each survey year. The database was used to facilitate data editing and access. Once loaded, a structured query language, along with embedded FORTRAN programs, was used to process data for analytical purposes.

Three approaches to the analysis of this data were implemented: (1) empirical analysis; (2) spatial analysis; and (3) statistical analysis. Tables and accompanying graphs were created for the empirical analysis. Summary statistics were provided in each respective table for species richness, species evenness, and plot similarity estimators. The fiducial limits shown in the graphs represent upper and lower limits to ± 2 S.E.

The spatial resolution of the forest survey sample plot is limited by plot size and plot spacing. Plot sizes approximate 0.4 hectares and locations are systematically located across each state at a density of one sample plot per 5.8 km^2 . In order to make map distribution assessments beyond a single plot (stand) the plots would have to be aggregated into a spatial unit such as an ecoregion, state, or county. My approach was to aggregate plots to the county level. The county means of species richness, evenness, and plot similarity were then used to produce maps that illustrate the spatial attributes of the three diversity estimators across a state. All maps were produced with ATLAS GIS software.

There are two basic approaches that could be applied in analyzing data in a species diversity study. The traditional method is the cumulative species approach (Magurran 1988, Hayek and Buzas 1997). Here, each successive plot in the sample is checked for presence of species. As plot data is processed, any new species not previously tallied is added to the cumulative species list. After all sample plots are accounted for, a grand total of the number of unique species is produced (S), along with a total number of individuals (N). A shortcoming of this method is that only one estimator (or index) is derived for the number of species and the number of individuals for the entire sample collection. No statistical parameters can be assigned. One possible solution to this problem is to derive bootstrap estimators from the original sample pool. This would allow confidence intervals to be assigned and statistical tests of significance to be conducted (Efron and Tibshirani 1993, Hall and Wilson 1991). However, this approach proved impractical for this study both because of the magnitude of the sample

($\approx 2,900$ plots per state) and because of the inherent nature of the species list (see next paragraph). Bootstrapping a reasonable sample size from 2,900 plots would be complex. Additionally, the chance of losing species information while sampling with replacement would be very high.

The total number of species present in the cumulative species list in each state survey is fairly constant over time with the exception of the more minor species. Because of this phenomenon, species richness trends would be strongly influenced by the coming and going, in the sample, of species that were less abundant. It would not be possible to state definitively whether or not the loss of one species was a true biological event or an artifact of sampling. For example, it would be very difficult to rigorously state that species richness had declined in Arkansas because *Aesculus glabra* was present on one plot in 1968, but not present on any plots in 1978, 1988, or 1995 (Table A-2). A cumulative species list that declined from 106 species in 1968 to 105 species in 1978 would provide little conclusive power when taking into account the *Aesculus glabra* example above. Additionally, another situation involving the addition of one species and loss of another would go undetected because S would remain the same for both surveys.

The second method (the approach used in this study) analyzed the two diversity estimators and the plot similarity estimator using classical parametric statistical procedures. This was done by deriving and assigning a value for species richness (S), species evenness (Mc_E), and plot similarity (C_N) to each sample plot. Since each plot had a diversity measure, the mean, variance, and standard error of each state could be derived. This approach is intuitively appealing because measures of diversity change are not

heavily influenced by the loss or gain of one species as in the *Aesculus glabra* example above. Instead, the *Aesculus glabra* change would be represented in only one sample plot (out of $\approx 2,900$) and its loss from the sample would not be detected in species richness, species evenness, or plot similarity means. This is to be desired because the survey sample design is not adequate for making definitive statements about the decline of a species that naturally occurs less frequently or is considered rare or very localized in distribution.

The parametric statistical approach to diversity studies, as outlined above, is not sensitive to fluctuations in species numbers for species that are less common. Species fluctuations on a small number of plots will have little impact when pooled with all the other plots in a state. What is being reported in this study is the average measure of species richness, evenness, and plot similarity on a large number of sample plots in Arkansas and Mississippi. Significant shifts (gain or loss of species) in the average diversity measures in a state would indicate that a substantial number of sample plots have been impacted.

All statistical tests were done on the null hypothesis. This was the hypothesis of no difference among four populations from which samples were drawn. The population estimates came from sampling carried out during measurements from the four survey years, T_1 , T_2 , T_3 , and T_4 . Statistical tests were done with either a one-way ANOVA (analysis of variance) with one repeated-measure factor or with a factorial ANOVA with repeated-measure factors and between-groups factors. All tests were conducted at the 0.05 level of significance. Descriptive statistical convention follows Sokal and Rohlf

(1995): significant ($0.05 > p > 0.01$); very significant ($0.01 > p > 0.001$); highly significant ($p < 0.001$). The one-way ANOVA repeated measures design was used to test the differences in species richness, evenness, or similarity measures, individually, across the four survey years (T_1 , T_2 , T_3 , and T_4). Results of these tests (hypotheses 1 through 6) are presented in six ANOVA summary tables for Arkansas and six ANOVA summary tables for Mississippi.

The factorial ANOVA repeated measures design was used to test the null hypothesis (hypothesis 7) of the influence of plantations on species richness. This factorial design was also used to test for differences in species richness for three other strata in each state: between the three ownership categories across time (hypothesis 8); between the three physiographic categories across time (hypothesis 9); and between the stand-size classes across time (hypothesis 10).

The assumptions underlying the repeated measures ANOVA are similar to a normal ANOVA: (1) level of measurement should be assessed on an interval- or ratio-level of measurement; (2) observations are independent; (3) sampling is random; (4) population is normally distributed; and (5) groups should have equal variances.

The normal distribution and equal variance requirements were of most concern in a study such as this. Natural populations usually have a high amount of variation associated with their statistical distributions (Hayek and Buzas, 1997). However, the central limit theorem states that if the sample is large enough, the distribution of sample means is itself normally distributed (Sokal and Rohlf 1995). The major important benefit in this is for statistical inference. Usually, sample sizes of more than 50 plots per stratum

are considered large (Zar 1984, Sokal and Rohlf 1995). The large sample in this study alleviated the problem of analyzing data from a sample that did not follow a normal distribution pattern.

When sampling natural populations, it can also be difficult to satisfy the equal variance requirement. However, again, a large sample size per strata offsets this concern (Underwood 1997). When the number of sample plots becomes large, the expectation that many will fall out in the far end of the probability distribution curve becomes less and less likely (Underwood 1997). Green (1979) further adds that the most powerful argument for a large sample size is that most analyses tend to be robust even though it appears violations of basic assumptions may be present. This is, again, because of the influence of the central limit theorem. This factor helped eliminate many of the concerns that the analysis would be negatively impacted.

There was one more condition required by the repeated measures ANOVA that had to be addressed. The cell size (number of sample plots) between successive survey measurements had to be equal (Hatcher and Stepanski 1994). For example, the sample sizes for Arkansas were: 2,809 plots for 1968; 2,623 plots for 1978; 3,059 plots for 1988; and 3,127 plots for 1995. To overcome the unequal sample sizes, a randomization procedure was improvised to randomly select sample plots from the years with more plots (Manly 1991). In this case, 2,623 plots were established as the base; then 2,623 plots were randomly selected, without replacement, from the 1968, 1988, and 1995 survey years. Sampling without replacement in large data sets produces more accurate results than sampling with replacement (Krebs 1989, Caughley 1977). Not surprisingly, these

newly derived pseudo-means never departed more than 0.2 percent from the empirical mean. This is because of the large sample size and properties inherent in the central limit theorem. The repeated measures ANOVA tests were then run on these equal-sized samples among T_1 , T_2 , T_3 , and T_4 .

Summary statistics tables are presented for species richness, evenness, and plot similarity in Tables B-1 to B-19 and E-1 to E-19. Basic statistics are provided that describe the sample size, sample mean, standard deviation, variance, standard error of the mean, the coefficient of variation, and the range of each diversity estimator. These elements were considered the minimum presentation that should be given in a summary table (Zar 1984). With this information, it is possible for users of the information to draw their own conclusions about the variation and integrity of the data. Additionally, with the introduction of meta-analysis techniques in ecology, it is imperative that users are provided with basic statistical information that will aid in the synthesis of two independent data sets (Gurevitch *et al.* 1992).

It was not possible to conduct formal multiple comparison tests after initial repeated measures ANOVA processing of the ten formally declared hypotheses. This was because of the large number of combinations and comparisons possible with the data that were presented in the study. However, the statistical summary information can be used to test unplanned comparisons. Greig-Smith (1983) demonstrates a *t*-test procedure to do an unplanned comparison of two means, using the standard error from summary statistics. This can quickly and easily be carried out on a hand-held calculator. For example, one might wish to test the null hypothesis of no difference between 1978 species richness

(4.84) and 1995 species richness (4.56) in Arkansas. The standard error of the 1978 mean is 0.0491 and that of 1995 is 0.0491 (Table B-1). The standard error of their difference is

$$\sqrt{0.0491^2 + 0.0491^2} = 0.0694$$

The observed difference is $4.84 - 4.56 = 0.2800$. The *t*-statistic value of the sample (t_s) is thus $0.2800/0.0694 = 4.03$. This is larger than the *t*-critical value from standard statistical tables (2.576, $p < 0.01$) for samples where n is larger than 120 (Rohlf and Sokal 1995).

Since the t_s value is 4.03 the null hypothesis is rejected, the reason being that 4.03 is an unlikely value if the null hypothesis were true, *i.e.*, larger than 2.576. Cochran (1977) has provided an adjustment when n is unbalanced. However, as sample size increases, the adjustment becomes trivial in relation to the magnitude of the variance that usually accompanies data sets from natural populations (Greig-Smith 1983, Sokal and Rohlf 1995).

Zar (1984) discusses the problems of using a two-sample test in place of a formal multiple comparison test. The primary concern with the two-sample test is the increase in the chance of committing a Type I error as more and more means in a series are tested. To overcome this problem in this study, tests of significance for the unplanned comparisons were conducted at a conservative 0.01 level of significance instead of the traditional 0.05. As the number of means to be tested increases, the probability of committing a Type I error increases accordingly. Zar (1984) provides a table (developed by Pearson in 1942) that demonstrates the correlation of an increase in the number of means (to compare) with an increase in the probability of committing a Type I error. Conducting all unplanned tests at 0.01 on data with four means (such as T_1, T_2, T_3, T_4)

would set the actual probability of committing a Type I error at 0.05 (Zar 1984).

Additionally, the large sample size dramatically increased the robustness of the method, further lessening the concerns of a Type I error (Ott 1995). The best way to increase the power of a test is increase the sample size (Sokal and Rohlf 1995). The sample size in this study would be considered very large, even for the post-stratified classes.

Jones (1984) reviewed the debate over comparisons of multiple means versus simple two-mean tests. As discussed by Zar (above), one side of the debate is concerned with inflation of Type I error rates when using simple tests (Day and Quinn 1989). The other position, of whether two means are different, should not depend on what other samples are included in the analysis; this argument is against using multiple sample tests and promotes simple tests such as the *t*-test when comparing two means (Jones and Matloff 1986, Saville 1990). Scheiner (1993) contends both sides have valid positions and correct usage depends on the question being asked and the conservative level of the test.

CHAPTER III

RESULTS

1. ARKANSAS FINDINGS

Findings for Arkansas are presented in a species occurrence table (Table A-2), abundance (of individuals) tables (Tables A-4 and A-6), summary statistics tables (Tables B-1 to B-19), ANOVA test tables (Tables B-20 to B-29), graphs (Figs. C-1 to C-19), and spatial maps (Figs. D-1 to D-9). The ten hypotheses outlined in the research objectives were formally tested with the repeated measures ANOVA and results are presented below. The repeated measures ANOVA tests were based upon the smallest number of sample plots in each survey year (T_1 , T_2 , T_3 , and T_4) to satisfy the equal-size cell requirements of the design. The unplanned t -tests were based upon the actual number of sample plots in each survey year.

Species Frequency Attributes

In Arkansas, 97 species (including genus groups) occurred on sample plots over the four survey years. Table A-2 shows the number of sample plots on which each species occurred. The species occurring on the highest number of sample plots in 1968 were *Quercus alba*, *Pinus echinata*, *Carya* spp. and *Quercus stellata*, present on 1,142,

1,140, 1,136, and 1,135 sample plots, respectively. This was approximately 40 percent of the forest survey plots. By the time of the 1995 survey, these numbers had shifted slightly. *Carya* spp. occurrence increased to 1,373 plots, *Quercus alba* increased to 1,405 plots while *Pinus echinata* and *Quercus stellata* remained about the same. Additionally, two other species surpassed the 1,000-plot mark in 1995, *Liquidambar styraciflua* and *Pinus taeda*. There were 72 and 65 species, respectively, that occurred on less than 100 plots in 1968 and 1995.

The range of the number of species occurring on a single sample plot was 0 to 17 (Table A-4). Most of the sample plots had 3 to 6 species per plot (63 percent of all sample plots in 1968).

The number of individual trees on a sample plot ranged from 0 to 63 (Table A-6). However, 72 percent of the sample plots had a range of 8 to 22 individual trees per plot (1968 survey). Plots with more than 30 individuals were uncommon (only 4 percent of the plots in 1968). The number of sample plots with no trees ≥ 12.7 cm in DBH increased substantially, from 60 in 1968 to a high of 374 in 1988, dropping to 255 in 1995.

Species Richness for all Forested Plots: Hypothesis 1

Mean species richness averaged 4.72, 4.84, 4.37, and 4.56 for the 1968, 1978, 1988, and 1995 surveys, respectively (Table B-1, Fig. C-1). The standard deviations were approximately 50 percent of the mean (coefficient of variation ranges from 49.59 to 63.10) and the variances were approximately twice the mean. The smallest number of sample plots was 2,623 in 1977; the largest was 3,127 in 1995. Therefore, 2,623 plots were randomly selected from 1968, 1988, and 1995 for the repeated measures ANOVA tests.

Species richness declined across the state between 1968 and 1995 (Table B-1, Fig. C-1). The repeated measures ANOVA ($df = 2,622$) showed this decline to be highly significant ($p \leq 0.0001$) (Table B-20). The contrast between 1968 and each of the successive survey years was also significant (1968 versus 1978, $p = 0.0478$; 1968 versus 1988, $p \leq 0.0001$; 1968 versus 1995, $p \leq 0.0001$) (Table B-20).

Species Evenness for all Forested Plots: Hypothesis 2

Species evenness for all plots ranged from a high of 0.67 in 1968 and then fell to 0.60 in 1995 (Table B-2, Fig. C-2). The coefficient of variation was similar to species richness variation and was approximately 50 percent. The range was 40.37 to 55.84 percent. The repeated measures ANOVA showed the decline of species evenness over time to be highly significant ($df = 2,622$, $p \leq 0.0001$) (Table B-21). However, the ANOVA contrast between years showed no significant difference in the evenness index between 1968 and 1978 ($p = 0.1281$), but there was a highly significant difference between 1968 and 1988 ($p \leq 0.0001$) and 1968 and 1995 ($p \leq 0.0001$) survey years (Table B-21). Although the repeated measures ANOVA did not compare 1988 and 1995, the unplanned t -test showed no significant difference between these survey years ($t_s = 0.00$).

Plot Similarity for all Forested Plots: Hypothesis 3

Since plot similarity is a comparison of the same plot over time, the tables and graphs are constructed somewhat differently. For example, a single survey year does not have a similarity measure. Instead, a plot measured in successive surveys is compared. For example, a plot measured in 1968 is compared with its 1978 measurement (1968/1978). Thus there are three similarity measures for the four survey years

(Table B-3, Fig. C-3). The fourth measure is a comparison between the 1968 and 1995 survey. The largest change in plot similarity over the 30-year period was between 1968 and 1995 (Table B-3, Fig. C-3).

The similarity measure for the 1968/1978 comparison was 0.71, which dropped to 0.66 for 1978/1988, then increased to 0.70 for 1988/1995. The similarity dropped to 0.50 when comparing 1968/1995 (Table B-3, Fig. C-3). The coefficient of variation averages slightly less than 50 percent for the four comparisons. The range is 38.32 to 58.45 percent. The change in the plot similarity measure over time was highly significant in the repeated measures ANOVA test ($df = 2,500, p \leq 0.0001$) (Table B-22). The repeated measures ANOVA contrast between years was highly significant ($p \leq 0.0001$) for the 1968/1978 similarity measure compared with 1978/1988. The difference between 1968/1978 and 1988/1995 was not significant ($p = 0.05$).

Species Richness for all Forested Survivor Plots: Hypothesis 4

The plots that went through the four survey measurements without harvesting disturbance were named survivor plots. There were 772 of these plots in Arkansas. Mean species richness was 4.87 in 1968 and had increased to 5.92 in the 1995 survey (Table B-16, Fig. C-16). The repeated measures ANOVA, to test the null hypothesis of no difference between 1968 and 1995, was highly significant ($df = 771, p \leq 0.0001$) (Table B-23). The differences between 1968 and 1978, and between 1968 and 1988, were also highly significant ($p \leq 0.0001$).

Species Evenness for all Forested Survivor Plots: Hypothesis 5

Mean species evenness also increased over the four survey years. The lowest evenness was in 1968 (0.68) and highest was in 1988 (0.72) (Table B-17, Fig. C-17). The repeated measures ANOVA showed this difference to be significant ($df = 771, p \leq 0.0001$) (Table B-24). The differences between 1968 and 1978, and between 1968 and 1988, were also significant ($p = 0.0004, p = 0.0056$).

Plot Similarity for all Forested Survivor Plots: Hypothesis 6

Plot similarity also increased over the three survey comparisons (Table B-18, Fig. C-18). The repeated measures ANOVA test showed similarity between 1968/1978 versus 1978/1988 to be insignificant ($df = 771, p = 0.5327$) (Table B-25). However, the similarity value between 1968/1978 and 1988/1995 was highly significant ($p \leq 0.0001$).

Plantation Influence: Hypothesis 7

An analysis was done to determine what impact the increasing number of pine plantations would have on the overall tree species diversity of Arkansas. Adding plantations, with their lower species richness, to the forest land base could be enough to pull down the overall state species richness (Table B-19, Fig. C-19). As more and more plantations are added to the forest land base, species richness continues to decline. In 1995, there were 360 plantation plots in the survey data set, as compared to 1978, which had only 98 plantation plots. The factorial repeated measures ANOVA showed highly significant differences ($p \leq 0.0001$) between and among the plantations-excluded plots versus the plantations-included plots (Table B-29).

Species richness on plantations has steadily decreased over the four survey years (Table B-13, Fig. C-13). Starting with 3.73 species per plot in 1968, richness has decreased to 2.56 species per plot in 1995 (Table B-13, Fig. C-13). Based upon the unplanned t -test, the difference between 1988 and 1995 was not significant ($t_s = 0.20$) but the difference between 1978 to 1995, and 1968 to 1995 was significant, $t_s = 2.74$ and 6.03 , respectively. It was not possible to do the repeated measures ANOVA on the plantation plots because of the range in the number of plots for 1968 through 1995. All years would have to be equal in number to meet the equal cell size requirement. There were too few plots in which to conduct a randomization selection to create equal cell sizes.

Species evenness also declined across the survey years, dropping from 0.57 in 1968 to 0.36 in 1995 (Table B-14, Fig. C-14). The difference between 1988 and 1995 was not significant ($t_s = 0.66$) nor was the difference between 1978 and 1995 ($t_s = 2.48$). However the difference between 1968 and 1995 was significant ($t_s = 6.25$).

Mean plot similarity increased across the comparison groups (Table B-15, Fig. C-15). Beginning with 0.36 for the 1968/1978 comparison and ending in the 1988/1995 comparison with 0.56, the similarity measures between 1968/1978 and 1988/1995 were significantly different from each other ($t_s = 5.45$). However, the similarity measures comparing 1978/1988 and 1988/1995 were not significant ($t_s = 1.03$).

Ownership Influence: Hypothesis 8

One important characteristic that is impacting species diversity trends in the South is forest ownership. The most obvious trend is that concerning forest industry. Species richness, evenness, and plot similarity all decreased substantially across the four survey

years in that ownership class (Figs. C-4, C-5, C-6). The factorial repeated measures ANOVA test was only done on species richness. It showed a highly significant difference between the ownerships and across time for species richness ($df = 2,622, p \leq 0.0001$) (Table B-26). Unplanned tests are included below.

The nonindustrial private component began with 4.84 species per plot in 1968 (Table B-4, Fig. C-4). This was the highest species richness of all ownerships at this time. The nonindustrial private owner had the highest richness until the 1988 survey where public lands finally surpassed forest industry and nonindustrial private owners.

Forest industry richness decreased from an initial 4.60 species per plot in 1968 to 3.71 species per plot in 1995 (Table B-4, Fig. C-4). The number of sample plots in this post-strata class has remained fairly constant over the four survey years. Along with the richness decline was an evenness decline, from 0.64 to 0.49 (Table B-5, Fig. C-5). The t_s value between 1968 and 1995 was 9.09, making this a highly significant difference.

Public land richness was the lowest of the three ownership categories in 1968, 4.53 species per plot (Table B-4, Fig. C-4). The difference between public and forest industry richness was not significant ($t_s = 0.54$). By the end of the four survey years, public richness was highest, averaging 5.14 species per plot, and forest industry lowest averaging 3.71 species per plot (Table B-4, Fig. C-4). Plot similarity was highest on public land for every survey year, with 0.80 recorded for the 1988/1995 comparison (Table B-6, Fig. C-6). Forest industry had the lowest similarity for all three comparisons with the lowest similarity in the 1978/1988 comparison, 0.51 (Table B-6, Fig. C-6).

Physiographic Class Influence: Hypothesis 9

The highest average species richness for bottomland hardwoods over four survey years was 6.45 per plot in 1978 (Table B-7, Fig. C-7). The lowest average richness was 3.95 per plot in upland pine for 1988. Overall, the upland pine plots had the lowest species richness over all four survey years while bottomland hardwoods had the highest (Table B-7, Fig. C-7). The factorial repeated measures ANOVA between groups and among the survey years was highly significant ($df = 2,622, p \leq 0.0001$) (Table B-27).

Mean species evenness was highest for upland hardwood in 1968 and 1978 with 0.72 (Table B-8, Fig. C-8). The lowest evenness was 0.56 in 1988 for upland pine. The difference between 1968 and 1995 upland pine species evenness was highly significant ($t_s = 6.90$). The overall trend for evenness was a decline from the 1968 survey to the 1995 survey for all three physiographic classes (Table B-8, Fig. C-8).

Mean plot similarity was highest for upland hardwoods, followed by bottomland hardwoods, with lowest plot similarity in upland pine (Table B-9, Fig. C-9). The highest similarity average was upland hardwoods in the 1988/1995 comparison (0.80) with the lowest similarity average in the 1978/1988 comparison (0.62). The test of the means between the 1968/1978 and the 1988/1995 similarity comparisons was only significant for upland pine ($t_s = 2.98$). Upland hardwoods and bottomland hardwoods were both insignificant ($t_s = 1.34$ and 1.36 , respectively). The overall trend for the similarity measure was a slight decrease for upland pine and bottomland hardwoods and a slight increase for upland hardwoods (Fig. C-9).

Stand-size Class Influence: Hypothesis 10

The size class of 0 - 12.7 *cm* does not have a richness value since the arbitrarily assigned tree-size limit was a minimum of 12.7 *cm* in *DBH*. The highest average species richness over the four survey years was 5.79 per plot in 1995 for the 30.0 - 40.0 *cm* size class (Table B-10, Fig. C-10). Lowest richness was in the 1995 12.7 - 20.0 *cm* class with 3.10 species per plot. Two groupings are obvious in Fig. C-10, the 30.0 - 40.0 *cm* and 20.0 - 30.0 *cm* stand-size classes (where species richness is running between 5.0 to 6.0 species per plot) and the 12.7 - 20.0 *cm* and ≥ 40.0 *cm* size classes (where species richness is running between 3.0 to 4.0 species per plot). The factorial repeated measures ANOVA between the groups and among the survey years was highly significant ($df = 2,622$, $p \leq 0.0001$) (Table B-28).

Species evenness by stand-size classes also showed two distinct groupings among the same four classes (Table B-11, Fig. C-11). Highest evenness (0.71) was in the 30.0 - 40.0 *cm* size class for both 1988 and 1995 and in the 20.0 - 30.0 *cm* size class in 1968 and 1988. The lowest evenness was in the 12.7 - 20.0 *cm* size class in 1995 (0.48).

The two groupings were also prevalent in the similarity measure (Fig. C-12). Highest similarity was in the 20.0 - 30.0 *cm* diameter class (0.78) for the 1988/1995 comparisons (Table B-12, Fig. C-12). The lowest similarity was in the 1978/1988 survey comparison, 0.40 for the ≥ 40.0 *cm* size class.

Spatial Attributes of Diversity Measures

The maps in Figs. D-1 through D-9 illustrate spatial patterns of species diversity measures across the state. Four maps (Figs. D-1 through D-4) show species richness trends across the four survey years; four maps (Figs. D-5 through D-8) show evenness trends across the four survey measurements; and one map (Fig. D-9) shows the spatial attributes of the plot similarity measure comparing 1968 with 1995.

As previously discussed, species richness had declined between 1968 and 1995. In 1968, nine counties had an average of 2 to 4 species per plot. By 1988, there were 16 counties that averaged 2 to 4 species per plot. In 1995, 15 counties averaged 2 to 4 species per plot with a notable shift to the more southern part of the state. Most of these counties were in survey units 3 and 4 (Fig. A-1), units heavily impacted by intense forestry practices.

The more highly diversified bottomland hardwoods of the Mississippi Alluvial Plain (Fig. A-2) appeared relatively stable over the expanse of the four survey years. No other region in Arkansas had a county averaging such high numbers per plot with the exception of Conway County in central Arkansas (Fig. D-2). It is interesting to note that Conway County dropped from averaging > 6 species per plot in 1978 to 2 to 4 species per plot in 1988 (Figs. D-2, D-3).

The distribution of evenness patterns across Arkansas show little change between 1968 and 1978 (Figs. D-5, D-6). In 1968 and 1978, there were 9 and 11 plots, respectively with evenness averaging > 0.75 per plot. By 1988, that number had dropped to three counties in the northeast portion of the state (Fig. D-7). At the same time, nine counties

appeared with evenness averaging 0.25 - 0.50 per plot. By 1995, the number of counties averaging > 0.75 per plot increased to 5, along with a decrease in the number of counties averaging 0.25 - 0.50. Those counties dropped to a total of five by the 1995 survey (Fig. D-8).

A graphic that illustrates the dynamics of the southern forest is Fig. D-9. Most of the counties with low average plot similarity between 1968 and 1995 were in the southern portion of the state. This is the upper reach of the Coastal Plain Province and is prime habitat for *Pinus taeda*, the major timber tree of the state. Harvest activity, centered around *Pinus taeda*, had increased dramatically in this area of the state over the 1988 and 1995 survey years (Rosson 1998a). It appears that timber harvest has had a significant impact on forest composition dynamics in southern Arkansas.

2. MISSISSIPPI FINDINGS

Findings for Mississippi are presented in a species occurrence table (Table A-3), abundance (of individuals) tables (Tables A-5 and A-7), summary statistics tables (Tables E-1 to E-19), ANOVA test tables (Tables E-20 to E-29), graphs (Figs. F-1 to F-19), and spatial maps (Figs. G-1 to G-9). The ten hypotheses outlined in the research objectives were formally tested with the repeated measures ANOVA and results presented below. The repeated measures ANOVA tests were based upon the smallest number of sample plots in each survey year (T_1 , T_2 , T_3 , and T_4) to satisfy the equal-size cell

requirements of the design. Any unplanned *t*-tests were based upon the actual number of sample plots in each survey year.

Species Frequency Attributes

Mississippi had 96 species (including genus groups) occurring on sample plots over the four survey years. The distribution of species occurrence on the survey sample plots is illustrated in Table A-3. Species of highest occurrence in 1967 were *Pinus taeda* and *Liquidambar styraciflua*. These were the only species in Mississippi that occurred on 1,000 plots or more in 1967. By 1994, only *Quercus nigra* had joined the ranks of species occurring on more than 1,000 sample plots. Meanwhile, *Pinus echinata* and *Quercus falcata* dropped below 1,000 plots after being above that mark during the 1977 and 1987 surveys. *Quercus falcata* and *Pinus echinata* were closest to the 1,000-plot threshold with 937 and 900 plots, respectively. There were 60 and 51 species, respectively, that occurred on less than 100 plots in 1967 and 1994.

Mississippi had forested sample plots that ranged from 0 species to 17 species per plot (Table A-5). The distribution of plots by number of species per plot fell mostly in the range of 2 to 6 species (Table A-5). There were 180 plots in 1967 with no trees on them larger than 12.7 *cm* in *DBH*. By the 1994 survey, this number had jumped to 466 plots, 14.6 percent of all forested plots in the state.

The number of trees > 12.7 *cm* in *DBH* on a plot ranged from 0 to 85 (Table A-7). There were very few plots with more than 30 trees per plot. The data show that there was a shift to more trees per plot with each successive survey measurement. For example, in 1967 there were many more trees in the 7 to 9 trees-per-plot range than in 1994.

Conversely, in the 21 to 32 trees-per-plot range, there were more trees in this category in 1994 than in 1967.

Species Richness for all Forested Plots: Hypothesis 1

Mean species richness has averaged 4.53, 5.02, 4.82, and 4.49 species per plot for 1967, 1977, 1987, and 1994, respectively (Table E-1, Fig. F-1). From 1977 to 1994 there was a decline in species richness (Fig. F-1). The smallest number of sample plots was 2,806 in 1977; the largest was 3,180 in 1994. Therefore, 2,806 plots were selected from each survey year for the repeated measures ANOVA test. The repeated measures ANOVA showed this decline to be highly significant ($df = 2,805$, $p \leq 0.0001$) (Table E-20). There was a significant difference in species richness between 1967 and 1977 and between 1967 and 1987 ($p = 0.001$ and $p = 0.0067$). However, there was no difference between 1967 and 1994 species richness ($p = 0.0617$) (Table E-20). The coefficient of variation was slightly over 50 percent for the four survey years. The range was 59.09 to 74.44 percent.

Species Evenness for all Forested Plots: Hypothesis 2

Species evenness has also declined across the four surveys, starting with 0.63 in 1967, then falling to 0.56 in 1994 (Table E-2, Fig. F-2). The repeated measures ANOVA test showed the change in evenness across time to be highly significant ($df = 2,805$, $p \leq 0.0001$) (Table E-21). The ANOVA contrast between years showed the difference between 1967 and 1977 as not significant ($p = 0.2814$) but differences between 1967 and 1987, and between 1967 and 1994 evenness were highly significant ($p \leq 0.0001$) (Table E-21). The coefficient of variation was approximately 50 percent and ranged from 47.81 to 63.79.

Plot Similarity for all Forested Plots: Hypothesis 3

Plot similarity for the 1967/1977, 1977/1987, and 1987/1994 comparison was 0.61 (Table E-3, Fig. F-3). Significance tests with the repeated measures ANOVA showed no significant differences between the survey comparisons across time ($df = 2,669$, $p = 0.99$) (Table E-22). Also, there was no difference between any of the individual comparisons: 1967/1977 versus 1977/1987 ($p = 0.98$); and 1967/1977 versus 1987/1994 ($p = 0.98$). However, there was a big drop in the similarity measure when the comparison spanned a longer period of time. Such was the case when the plot similarity measure was derived for the comparison between plots measured in 1967 and 1994. In this instance the similarity value was 0.39. The unplanned t -test was highly significant ($t_s = 27.05$) when compared with the similarity value between 1967/1977.

Species Richness for all Forested Survivor Plots: Hypothesis 4

Survivor plots increased substantially in species richness across the survey measurement periods. There were 553 of these plots in Mississippi, beginning with 4.73 species per plot in 1967, species richness rose to 5.86 in 1977, 6.49 in 1987, and 6.80 by the time of the 1995 survey (Table E-16, Fig. F-16). The repeated measures ANOVA showed the increases in 1977 and 1987 both highly significant ($df = 552$, $p \leq 0.0001$) (Table E-23). Also, the change between 1967 and 1994 was highly significant ($p \leq 0.0001$) The unplanned t -test showed the increase from 1987 to 1994 to be insignificant ($t_s = 1.76$).

Species Evenness for all Forested Survivor Plots: Hypothesis 5

Species evenness also increased across the four surveys. Evenness in 1967 was 0.63, then rose to 0.69 in 1977, 0.71 in 1987, and 0.72 in 1994 (Table E-17, Fig. F-17). The change between 1967 and 1977 was significant ($df = 552, p \leq 0.0001$) (Table E-24); as was the change between 1967 and 1994 ($p \leq 0.0001$). However, the changes between 1977 and 1987, and between 1987 and 1994 were not significant by the unplanned t -test ($t_s = 1.39$ and 0.76 , respectively).

Plot Similarity for all Forested Survivor Plots: Hypothesis 6

Plot similarity increased from a low of 0.64 for the 1967/1977 comparison to 0.83 for the 1977/1987 comparison, then dropped slightly to 0.73 for the 1987/1994 comparison (Table E-18, Fig. F-18). The repeated measures ANOVA showed the change between 1967/1977 and 1977/1987, and between 1967/1977 and 1987/1994 to be significant ($df = 552, p \leq 0.0001$) (Table E-25). Likewise, the change from 1977/1987 to 1987/1994 was also significant ($p \leq 0.0001$).

Plantation Influence: Hypothesis 7

An important component of this study was to determine the impact that plantations may have in decreasing species diversity across a state (Table. E-19). Fig. F-19 illustrates this trend. The effect of plantations became more noticeable as the number of plantations increased. In 1967, there were only 262 plantation plots so there was little distinction between plots without plantations and plots with plantations. However, the difference was still significant ($t_s = 7.15$). The groups tracked fairly closely to 1977 but then, as more and more plantations were added, the trend lines diverged. In 1994, there were 491 plantation

plots. The factorial repeated measures ANOVA showed a highly significant difference among the groups and across time ($p \leq 0.0001$) (Table E-29).

Species richness in plantation plots has decreased across time, from 3.26 species per plot in 1967 to 2.82 species per plot in 1994 (Table E-13, Fig. F-13). Even though this stratum of plots was lower than any other stratum average, there were still many plots in the data sets with a higher number of species than one would intuitively expect. The maximum richness showed 13, 12, 10, and 11 species for the respective survey years. These range values indicated many plantation plots with more than the average number of species. The change in species richness, from 3.26 to 2.82 species per plot, between 1967 and 1994 was significant ($t_s = 2.70$).

Evenness decreased substantially across time (Table E-14, Fig. F-14). The evenness measure started off at 0.52 in 1967 and had decreased to 0.38 in 1994. The change between 1967 and 1977 was not significant ($t_s = 0.97$). However, the change between 1967 and 1994 was significant ($t_s = 5.09$).

The plot similarity measures for plantation plots are shown in Table E-15 and Fig. F-15. There was a large increase in similarity between 1967/1977 and 1977/1987, from 0.38 to 0.52. This change was significant ($t_s = 4.79$). The change in similarity between 1967/1977 and 1987/1994 was also significant ($t_s = 5.44$) but the change between 1977/1987 and 1987/1994 was not significant ($t_s = 0.35$).

Ownership Influence: Hypothesis 8

The factorial repeated measures ANOVA test was significant for the ownership strata. The impact of all ownerships on species richness was highly significant

($df = 2,805$, $p \leq 0.0001$) (Table E-23). Also, the effect of ownership across time was highly significant ($df = 2,805$, $p \leq 0.0001$) (Table E-26). Unplanned tests were done below.

The obvious ownership trend in Mississippi was the species richness decline on forest industry lands across the four survey years. Species richness was 4.21 in 1967 and dropped to 3.58 in 1994 (Table E-4, Fig. F-4). The change was significant between 1967 and 1994 ($t_s = 3.43$). By 1994, public lands had the highest richness (5.32), followed by nonindustrial private (4.56), then by forest industry (3.58).

Species evenness showed a pattern similar to species richness. Forest industry lands decreased in evenness from 1967 to 1994. The difference was significant ($t_s = 5.03$). Public lands had an evenness decline in 1987 but recovered by 1994. The difference between 1967 and 1994 was not significant ($t_s = 0.41$). Nonindustrial forest lands declined between 1967 and 1994 from 0.64 to 0.57. This change was significant ($t_s = 6.95$). The rank of ownerships in 1994 showed public lands with the highest evenness, 0.63, followed by nonindustrial private lands, 0.57, and forest industry lands last with 0.46. The differences were all significant ($t_s = 3.47$ [public versus NIPF], 6.21 [NIPF versus forest industry], and 7.63 [public versus forest industry]).

Although the aggregated plot similarity measures were equal for all three comparisons (0.61), the ownership stratum in each one was not. For instance, the 1967/1977 comparison resulted in 0.66 for public, 0.53 for forest industry, and 0.62 for nonindustrial private (Table E-6, Fig. F-6). The difference between public lands and forest industry lands was significant ($t_s = 5.65$) but the difference between public and

nonindustrial private lands was not significant ($t_s = 2.17$). The difference between forest industry and NIPF lands was also significant ($t_s = 5.41$). The trend lines for each ownership stratum did not intersect each other over the three comparison years (Fig. F-6). Public lands showed an increase in plot similarity, nonindustrial private lands remained about the same, and forest industry lands declined. The difference between the public 1967/1977 comparison and the 1987/1994 comparison was significant ($t_s = 2.62$). The change in forest industry between 1967/1977 and 1987/1994 was significant ($t_s = 2.70$). The change between nonindustrial private for 1967/1977 and 1987/1994 was not significant ($t_s = 1.03$)

Physiographic Class Influence: Hypothesis 9

Mean species richness by physiographic class is presented in Table E-7 and Fig. F-7. Richness is highest on upland hardwood stands and lowest on upland pine stands across the four measurements. In 1967, mean species richness was 7.53, 5.79, and 3.89 for upland hardwoods, bottomland hardwoods, and upland pine, respectively. The trend lines across the four measurement years do not cross each other. The factorial repeated measures ANOVA showed the interaction between time and groups to be highly significant ($df = 2,805$, $p \leq 0.0001$) (Table E-27).

The evenness measure patterns are very similar to those of species richness. Upland hardwoods have the highest evenness (0.73 for 1994) and upland pines the lowest (0.52 for 1994); bottomland hardwoods fall in between (0.65) (Table E-8, Fig. F-8). The differences in 1994 were all significant between upland hardwoods and bottomland

hardwoods ($t_s = 3.67$), between bottomland hardwoods and upland pine ($t_s = 7.96$), and between upland pine and upland hardwoods ($t_s = 10.43$).

The similarity measures also tracked closely with species richness and evenness (Table E-9, Fig. F-9). One difference was the convergence of the upland hardwood and the bottomland hardwood measures for the 1987/1994 comparison (Fig. F-9). Upland pines were substantially lower than upland and bottomland hardwoods. The difference in upland pine between the 1967/1977 and 1987/1994 survey was not significant ($t_s = 1.93$).

Stand-size Class Influence: Hypothesis 10

The lowest species richness was in the 12.7 - 20.0 *cm* and ≥ 40.0 *cm* stand sizes (Table E-10, Fig. F-10). The highest richness was in the 30.0 - 40.0 *cm* stand-size class (6.28 in 1994); the lowest in the 12.7 - 20.0 *cm* stand size (2.84 in 1994) (Table E-10, Fig. F-10). The 30.0 - 40.0 *cm* and 20.0 - 30.0 *cm* track very closely together, their widest divergence occurring in 1994. The 12.7 - 20.0 *cm* and ≥ 40.0 *cm* classes tracked together also. Their widest divergence was in 1994. The factorial repeated measures ANOVA showed there to be high significance between the groups ($df = 2,805, p \leq 0.0001$) (Table E-25). The ANOVA also showed there to be a highly significant difference between groups across time ($p \leq 0.0001$) (Table E-28).

The evenness measure tracked the same as species richness; the 20.0 - 30.0 *cm* and 30.0 - 40.0 *cm* classes are highest in evenness; the ≥ 40.0 *cm* and 12.7 - 20.0 *cm* classes are the lowest (Table E-11, Fig. F-11). The highest evenness measure was 0.72 for the 30.0 - 40.0 *cm* class in 1977 and for the 20.0 - 30.0 *cm* class in 1987. The evenness measure for the 20.0 - 30.0 and 30.0 - 40.0 *cm* classes remained stable between 1967 and

1994. The ≥ 40.0 cm class oscillated over time, starting at 0.57 in 1967 and settling not far from the initial value in 1994 (0.53); the difference was not significant ($t_s = 0.47$). The 12.7 - 20.0 cm class showed the foremost trend, a steady decline culminating in an evenness measure of 0.47 in 1994. This proved highly significant ($t_s = 4.81$).

The plot similarity measure repeated the above trends (Table E-12, Fig. F-12). The 30.0 - 40.0 cm and 20.0 - 30.0 cm stand sizes were very similar in trend. Similarity values for these two classes did not change across the four survey measurements. The highest similarity values were in the 20.0 - 30.0 cm and 30.0 - 40.0 cm classes (0.73 and 0.74, respectively). The lowest similarity measure in the ≥ 40.0 cm class was in the 1967/1977 comparison (0.33).

Spatial Attributes of Diversity Measures

A set of maps was generated for spatial analysis of diversity trends. Figures G-1 through G-4 show species richness trends across the state, Figs. G-5 through G-8 show evenness trends; and one map (Fig. G-9) shows the spatial attributes of the plot similarity measure comparing 1967 with 1995.

The number of counties in Mississippi averaging more than 6 species per plot increased from 6 in 1967 to 18 in 1978 (Figs. G-1, G-2). Along with that increase was a decrease in the number of plots averaging 2 to 4 species per plot, dropping from 16 in 1967 to 9 in 1978. By the time of the 1987 survey, counties averaging more than 6 species per plot declined to a total of 11 counties in the Mississippi Alluvial Plain. The 1994 survey showed these bottomland hardwoods remaining stable for the present. However, the number of counties averaging 2 to 4 species increased to a total of 18.

The species evenness measure declined across the four survey years. Starting with only 6 counties in 1967 (with evenness averaging 0.25 - 0.50) in the southern part of the state, the count increased to a total of 15 counties with this low level of evenness by the time of the 1994 survey. Only one county in the Mississippi Alluvial Plain had an evenness average falling in the range of 0.75 - 1.0 in 1994.

An exception to the declining species richness and evenness was in the southeastern portion of the state. Here, *Pinus palustris* was the predominant species and it is normal for this forest type to have few overstory trees (Burns and Honkala 1990a). Therefore, probably fewer than three overstory trees (on average) would ever be tallied on a plot in the best of circumstances.

As in Arkansas, the most dramatic depiction of forest dynamics was in Fig. G-9. All of the counties, with the exception of the 11 in the northwestern portion of the state, were very dissimilar to the 1967 survey. One reason for this was because of the large upswing in harvesting activity on the Coastal Plain Province (Rosson 1998b).

CHAPTER IV

DISCUSSION AND CONCLUSION

1. PRINCIPAL OBSERVATIONS

Analysis

Tree species richness for all forested plots has declined significantly in Arkansas over the last thirty years. Although the average difference between 1968 and 1995 is only 0.16 species per plot, the large sample size ($n \approx 2,900$ per survey year) increased the precision of the estimate markedly, as denoted by the small standard error of the mean (Table B-1). An important aspect of this study was not so much to identify the magnitude of species diversity change, but to detect trends over time, *i.e.*, test the null hypothesis of no change in tree species diversity among T_1 , T_2 , T_3 , and T_4 .

Although the size of the change between 1968 and 1995 seemed small (0.16 species per plot), it represented a 3.4 percent change; the change between 1968 and 1988 was 7.4 percent. A species population change of 3.4 percent should be considered biologically significant in this study, because the magnitude of the sample size, together with the fact that these were remeasured plots, made this level of change important and noteworthy. Remeasured plots help eliminate much of the noise (variation) that is common in natural populations. These high levels of variation may mask some true biological differences (Hayek and Buzas 1997, Husch *et al.* 1982). The alternative,

sampling each survey year with a completely new set of randomly selected sample plots, would have required many more plots to sufficiently reduce the variation to an acceptable level. This has been particularly true for trend parameters in forest science, such as growth (Loetsch *et al.* 1973). Some long-term ecological studies have used this same approach, *i.e.*, remeasure the same plots after a certain time period has elapsed. The best estimates of density and basal area in monitoring studies is provided by the use of permanent, remeasured sample plots (Bonham 1989).

Mississippi's species richness also declined, but after an increase between 1967 and 1977. The difference between 1977 and 1994 was a 10.6 percent decrease and the change between 1967 and 1977 was a 10.8 percent increase. This increase and decrease offset each other when comparing 1967 and 1994, resulting in a 0.88 percent net decrease. This was not significant in the repeated measures ANOVA test.

The trend in Mississippi (Fig. F-1) illustrates a concern that arises when investigators arbitrarily select endpoints in temporal analysis studies. The interpretation of the trend would be much different (a significant decline in species richness), if 1977 and 1994 were the starting and ending points. Instead, 1967 is not significantly different from 1994, as evidenced by the arched curve (Table E-20, Fig. F-1). One possible explanation of this humped distribution in Fig. F-1 is that the increase in high levels of harvesting, currently typical of all Midsouth states, did not become evident in Mississippi until after the 1977 survey (Rosson 1998b).

Another important finding in the study was the pattern found on survivor plots. These are the plots that went from the 1960's measurement through the 1990's

measurement without harvesting disturbance. Both Arkansas and Mississippi showed substantial increases in tree species richness on these plots (Figs. C-16, F-16). Arkansas increased from 4.87 to 5.92 species per plot, a 21.6 percent increase; Mississippi richness increased even more, from 4.73 to 6.80 species per plot, a 43.8 percent increase.

The survivor plots served as a control in the natural experiment of the study, comparing disturbed and undisturbed plots. The control provided information on the status and dynamics of the group of plots over time that did not experience harvesting practices for the four survey measurements. They are important to this study because they illustrated a trend of increasing species diversity that developed in the absence of harvesting even before the first survey. They could also serve as a benchmark with which to compare other findings as well: successional trends, species composition, stand development, and stand growth characteristics.

There were some concerns with the survivor plots. First, they were not stratified by physiographic class, ownership, or stand size. Proportionately there could be an unusually high number of plots in a stratum that influences diversity strongly in one direction or the other. Examples are plots of public ownership or bottomland hardwood plots where diversity is higher (Figs. C-4, C-7, F-4, F-7). Another concern was that the survivor plots themselves had come from a past that included disturbance of an unknown kind and magnitude. Some of these plots probably began their undisturbed state around the start of the 1960's survey but many did not. Therefore, a variety of plots, ranging from small seedling/sapling-sized plots to larger log-sized plots, were most likely to be in the survivor plot group the first survey year of this study. A high number of plots in an early

developmental stage could account for the steeply rising trend lines. Plots in the early stages of recovery from disturbance would show the greatest rate of improvement. There may be reasons (unknown in this study) that these survivor plots escaped harvesting activity. These could be personal decisions of owners to simply not harvest their timber. These plots can best be described as having a past history of disturbance and should not be confused with having characteristics and stature typical of old growth stands, as defined in Davis (1996). At best the survivor plots were a very conservative depiction of the possible potential species richness in each respective state; however they did serve as the only, and applicable, benchmark in this study.

The next important finding in the study was the decrease of species richness on plantation plots in both Arkansas and Mississippi. The change in Arkansas was substantial between 1968 and 1995, a 31 percent decline in average species richness per plot. Mississippi showed a 13.5 percent decline between 1967 and 1994. However, the humped distribution was also present in the plantation data (Fig. F-13). The change between 1977 and 1994 was a 17.3 percent decline.

Declines in plantation species richness over time may be attributed to more intensive site preparation procedures and stand treatment after establishment. For example, prescribed burning, spraying, or thinning to reduce competitive vegetation is more commonly applied in the 1980's and 1990's than was done in the 1960's. One reason for this is that plantation management intensifies as rotations become shorter (DeBell, *et al.* 1997). This is important because it appears that management practices after planting

are further decreasing richness on plantations. This means that such actions will impact overall species richness for the state even more.

Another comparison was done using plantation plots. Two data sets were constructed: one consisting of all the forested plots in a respective state minus plantations; the other data set consisting of all the forested plots including plantations (Figs. C-19, F-19). The comparison of these two data sets showed very similar trends for Arkansas and Mississippi. The impact was not as great in Arkansas because the majority of the plantations were established in the southern part of the state whereas Mississippi experienced plantation establishment throughout the state. This meant that Mississippi had much more overall forest land in plantations compared to Arkansas, 1,743,245 hectares compared to 1,038,055 hectares, respectively (Rosson, 1998c, 1998d).

The increasing establishment of plantations has impacted both Arkansas and Mississippi tree species richness. Arkansas' overall tree species richness for the state was 14.1 percent lower when plantations were included, 4.56 species per plot compared to 5.31. In Mississippi, the impact was even greater, 4.49 versus 5.79, a 22.5 percent decline (Tables B-19, E-19). Additionally, with the establishment of more and more plantations as a silvicultural practice, it appears that Arkansas and Mississippi overall species richness will continue to decline. Between 1987 and 1994, Mississippi went from 1,306,047 hectares in plantations to 1,743,245 hectares (a 437,197-hectare increase) (Rosson 1998d). Arkansas also increased its plantation area over the last survey, but at a lower rate of increase, from 775,203 hectares to 1,038,056 hectares, a 262,853-hectare increase (Rosson 1998c).

Mean species richness was significantly affected by ownership in both Arkansas and Mississippi. Forest industry lands had the greatest rate of decline in species richness which resulted in the lowest richness of all three ownerships by the mid-1990's (Figs. C-4, F-4). This empirical evidence gave support to the impacts of harvesting on tree species richness over time. Forest industry lands simply had higher amounts of harvesting activity (Rosson 1994b, 1998a, 1998b). However, this by itself may not result in lower species richness. After the establishment of plantations, continued intensive management of these plantations could reduce overall species diversity beyond that of the initial harvesting act alone.

Mean species richness was also significantly related to physiographic class. Upland pine sites had the lowest species richness per plot. This was expected since this is where the important pines are better developed and most productive. The amount of disturbance from harvesting on these sites was high since most of the harvest activity in the south takes place on these upland pine sites (Rosson 1998a, 1998b). An interesting difference between Arkansas and Mississippi was the ranking of bottomland hardwoods and upland hardwoods in terms of species richness. In Arkansas, bottomland hardwoods ranked highest in richness, followed by upland hardwoods. However, upland hardwoods ranked highest in Mississippi followed by bottomland hardwoods. Closer inspection of Figs. C-7 and F-7 shows that bottomland hardwoods richness was approximately the same for both states (approximately six species per plot). The real difference was the much higher richness of the upland hardwoods stratum in Mississippi than its counterpart in Arkansas. The more favorable habitat conditions in Mississippi compared to Arkansas are

offered as an explanation. In Mississippi, there were fewer numbers of harsh sites where upland hardwoods are under stress. This is not so in Arkansas where the probability is much higher for a site to exhibit less than optimum growing conditions. Outside of the Coastal Plain, upland hardwoods were restricted to the much drier Ouachita and Ozark Plateaus Provinces where the expected number of species was much lower (Fig. A-2). The highly productive Coastal Plain is found only in the southern portion of the state whereas, in Mississippi, the Coastal Plain extends north to south along the entire length of the state (Fig. A-2).

Another interesting pattern was observed in the stand-size strata. In both states, the 20.0 - 30.0 and 30.0 - 40.0 *cm* size classes have the highest degree of species richness, whereas the 12.7 - 20.0 and the ≥ 40.0 *cm* size classes have the lowest species richness (Figs. C-10, F-10). The patterns suggested adherence to the theory that richness is highest at intermediate levels of successional development and lowest at the beginning and ending stages of stand development (Huston 1994, 1979). Also, studies have shown that species diversity may even be enhanced by disturbance as long as it is intermediate in intensity and frequency (*i.e.*, these factors do not exceed the capacity of the site to recover) (Petraitis *et al.* 1989).

The species evenness measure was important to this study in illustrating the dynamics of stand composition across the four survey measurements. Decreasing stand evenness implied that fewer species show niche overlap in the stand; occupancy was being shared by fewer and fewer individuals.

Conceptually, one would expect evenness to decrease along with decreases in species richness. This would be especially so in highly disturbed systems where there has been little time for recovery. Highly competitive, early successional species would fill the first available voids (Palmer and Maurer 1997). An example of these stand composition dynamics can be seen in Table A-3. A few species have increased dramatically in Mississippi. *Liquidambar styraciflua* went from occurrence on 1,119 plots in 1967 to 1,589 plots in 1994. Similarly, *Pinus taeda* increased from 1,284 plots in 1967 to 1,814 plots in 1994; this represents occupancy on 57 percent of Mississippi's forested sample plots. *Quercus nigra* also had a substantial increase, from 636 to 1,065 plots. In the case of *Pinus taeda*, much of its increase has come in the form of pine plantations where species evenness is lowest (Figs. C-14, F-14). Additionally, both *Liquidambar styraciflua* and *Pinus taeda* are species of wide ecological amplitude and they are opportunistic in filling a wide variety of sites (Burns and Honkala 1990a, 1990b).

If the disturbance factor and plantation influence were removed, one would expect species evenness to increase. This is exactly what has happened on the survivor plots (Figs. C-17, F-17). They showed a steady rate of increase in evenness over the four measurements.

Mean species evenness closely followed the trends and patterns of mean species richness. It seemed reasonable that, as richness declines, evenness should decline also. Likewise, increases in richness should cause evenness to increase. For example, Fig. F-4 shows forest industry lands with long-term declines in richness. The evenness measure

showed a similar decline (Fig. F-5). In contrast, when species richness increased over time (Fig. F-16), species evenness also increased (Fig. F-17).

An important conclusion of these patterns is that species richness (S) and evenness (Mc_E) both provided similar results in depicting trend information over time. Nowhere in any of the contrasts and comparisons did Mc_E diverge from S to the degree that the trend information produced a different outcome. This suggests that either S or Mc_E might be used to study temporal trends of diversity dynamics. However, further research needs to be done on this topic.

No studies were found in the literature with which to directly compare these findings. Only Stapanian *et al.* (1997) reported species richness on a per plot basis. For the Southeast United States they showed a mean of 7.94 species per plot for undisturbed plots ($n = 114$), 4.74 species per plot for disturbed plots ($n = 161$), and 6.07 species per plot for all plots combined ($n = 275$). In addition, they showed a total of 86 species tallied in their sample region which was composed of the states of Alabama and Georgia. It was unclear how they delineated between disturbed and undisturbed plots but their sample design probably included the selection of plots in various phases of succession and stand development.

In contrast, my study showed species richness averaging 4.56 species per plot for all plots combined and 5.92 species per plot for survivor plots (perhaps comparable to their undisturbed plots) for Arkansas. Mississippi species richness averaged 4.49 species per plot for all plots combined and 6.80 for survivor plots. All of these averages were based upon the most recent survey, dates most comparable to data from Stapanian *et al.*

(1997). My study also showed 97 total species in Arkansas and 96 species in Mississippi. This is higher than the 86 species reported by Stapanian *et al.*, but expected, given the larger sample sizes in my study.

It is not possible to rigorously declare differences in species richness between my study and Stapanian *et al.* as significant. This is largely due to the differences in sample design. They used a fixed plot design; my study was based upon a variable radius plot design. Additionally, the differences in the size of the sample was very large. Some of my post-stratified classes were equal to their total sample size, and that was just for one state in my study compared to their two, together. However, given the above, the numbers from their study are within a reasonable range of the numbers from this study. They just cannot be compared rigorously, *i.e.*, it cannot be stated conclusively that Alabama and Georgia have higher richness values than either Arkansas or Mississippi.

The description of species diversity measures across all types of forest land, as presented in this study, needs to be emphasized. This approach was different from studies that have traditionally sampled unique and rare areas such as The Great Smoky Mountains and Joyce Kilmer Wilderness Area. Valuable insights can be gained from these undisturbed (or relatively undisturbed) areas but they cannot be expected to represent stand conditions of large areas of disturbed forest land. In contrast, many of the forests in this study, which represent or reflect the whole of the landscape, have been disturbed by harvesting three or more times and certainly prior to the surveys evaluated here. The natural diversity dynamics of these stands can be described as complex (Williamson 1973).

Demonstrating a significant difference between means without considering ecological relevance may be trivial if magnitudes of change are not considered. I consider the differences in species richness, evenness, and similarity to be both biologically and statistically significant in this study. I base this on the magnitudes of change (usually more than 3 percent) together with the size of the sample ($\approx 2,900$ plots per year) and a very low standard error. Recent material in the literature has emphasized the importance of the distinction between biological and statistical significance (Krebs 1989, Hilborn and Mangel 1997, Scheiner 1993). However, no guidelines are given except to use personal judgment based upon magnitudes of change, sample size, and the size of the standard error.

The relevance of this study needs to be re-emphasized because it is the last that can be done in such a manner. Beginning with the Tennessee survey in 1996, the Southern Research Station Forest Inventory and Analysis unit has changed its primary sample design from a variable radius plot to a fixed plot. The relevance of a similar sample plot design for species richness (and other diversity indices) comparisons cannot be overemphasized. The ability to continue trend analysis in a rigorous manner as outlined in this study has ended. There are no other organizations in the United States that have a continuous data set describing woody plants as detailed as that used in this study; moreover, none cover areas as large as a state that contain forest measurements spanning three or more decades. It will be many years before another data set is assembled which can be used for rigorous trend analysis such as was done here. This is unfortunate because it has come at a time when the science of ecology is at the threshold of exploring holistic

lines of inquiry. This includes studies on a large scale in which consistent detailed data, collected over a long period of time, are lacking (Schluter and Ricklefs 1993). Schluter and Ricklefs (1993) have also advocated an empirical approach to provide data and trend information needed to resolve diversity issues and problems.

Perhaps it is not realistic to expect a sample design to go unchanged over a period of decades. Administrators move on or retire, employees come and go, new employees bring fresh new ideas, objectives change. However, trend information is seriously violated when designs change. To be able to test trends rigorously, a continuous, unchanging sample design is a necessity. In light of this, it would be best to accept any faults or shortcomings of an original design but continue to implement it in order to maintain rigorous trend analysis. Many times, improvements in design are statistically trivial (bias corrections of less than 2 percent) while field measurement errors, in all likelihood, are higher than 5 or even 10 percent.

2. ADDITIONAL STUDY DISCUSSION

Limitations of the Study

The species list adopted for this study was not a comprehensive one. The problems dealing with sampling efficiency, detail, and practicality were addressed in formulating the list. Based on these considerations, species that occurred infrequently were not included on the list. Little (1979) claims 679 native woody species (defined as trees) in the continental United States. His broad definition of a tree permits the inclusion of 70

species that are usually shrubs but in some conditions reach tree size. Not all of these will be tall enough at maturity to reach the forest canopy. He further states that important (economically) and influentially dominant forest trees number less than 200. My study had a minimum threshold size of 12.7 *cm DBH* which eliminated many of the more minor woody species that fall under Little's definition. His minimum *DBH* threshold is 7.5 *cm DBH*.

Several species that occurred in the sample were not provided an individual species code by the forest survey because of their minor importance and infrequent occurrence in the Midsouth Region. It is impractical to strive for a completely comprehensive species tally in such a large survey. The number of plots with these unidentified species was small (Tables A-2, A-3); the maximum was 2.7 percent of all forested plots for any one survey year. These species were all lumped together, given a dummy species code of 999, and treated as one species in the analysis. If a sample plot had one or more unidentified species, it (they) would count as one species. The same procedure was used in deriving the evenness and similarity measures. Given the sample size of this study and the procedures used to analyze the data, these minor species had no impact on the results presented.

The minimum threshold size of 12.7 *cm DBH* also eliminated the inclusion of seedling/sapling-size stands from the analysis. Therefore, there were many stands without trees ≥ 12.7 *cm* in *DBH*. The richness and evenness estimators were zero for these plots. This means that these stands pulled the respective means downward. Excluding these stands would bias the results since it would be desirable to know if harvesting had taken

place to the extent that there were no stands with trees ≥ 12.7 DBH. If disturbance were to occur to this extent, species richness would be zero in a state. This would be important information so these plots were used to derive mean plot estimates of richness, evenness, and similarity. They provided valuable trend information on the status of tree species diversity across all forest lands, with intimations of sexually mature sizes. Eliminating them from the analysis would not provide information on the status of all forest lands, only the forest lands that meet the criteria of having trees ≥ 12.7 cm in DBH.

It is important to be aware of taxonomy problems in large surveys such as this. The data were collected over several decades by many different people. The dendrological skill levels of these field personnel ranged from excellent to poor. In addition, these data were collected throughout all seasons of the year. Field personnel did not have the luxury of returning to questionable trees to obtain key components (such as flowers or fruits) necessary for accurate identification. Quality assurance/quality control procedures are used but do not assure catching and correcting all problems. In reality, it is not possible to positively identify all specimens but errors are held to a minimum through thorough training and the selection of qualified field personnel. It was not possible to determine directly the proportion of species identified incorrectly nor the impact incorrect species identification had on this study.

An important component lacking in this study was baseline data with which to compare these findings. For instance, it was not known what the range of the number of tree species per plot was or should be for natural undisturbed stands. It is uncertain how much higher a species richness curve would rise in correlation with optimum site

conditions or the absence of harvesting (Figs. C-16, F-16). We do know that the two Midsouth states averaged approximately 4.50 species per plot in their most current surveys while the survivor plots averaged 5.92 and 6.80 species per plot for Arkansas and Mississippi, respectively.

The sample design of the forest survey restricted, somewhat, the analysis and interpretation of the data for specific purposes. The design did not capture adequate information about species that are sporadic, rare, and infrequent in their distribution habits. The 4.8 *km* spatial resolution (plot spacing) was inadequate for this. This is contrary to what most workers are accustomed to in biodiversity studies, where much effort in sampling and results is directed at species with known problems or potential problems. The forest survey design did provide excellent information on tree species that make up the important and influentially dominant components of forest ecosystems throughout a particular state. This study did address the impact that harvesting is having on the target population, *i.e.*, the important species that make up and biologically characterize the majority of forest ecosystems of a state.

The temporal frame of the forest survey also presented problems. The main concern was plots on the 4.8 x 4.8 *km* sample grid changing land use, from forest to nonforest and vice versa. An ongoing phenomenon in the Midsouth is the loss and gain of forest land across time (Rosson 1995a). This appears as a change in the number of sample plots between surveys (for example, see *n* in Table B-1).

The immediate impact of a change in plot ground use was in conducting the repeated measures ANOVA tests and the similarity assessments. Some plots were not

used in the repeated measures ANOVA because the sample size had to be equal in all survey years. The only way to obtain equal sample sizes, given the loss and addition of plots over time, was to implement a randomization procedure that selected plots (without replacement) from the survey years with the higher number of plots to make them equal to the survey year with the smallest number of plots. Of most concern was the loss of information from the excluded plots, but this had little impact since the pseudo-means varied very little (if at all) from the empirical means. When deriving the similarity measure, plots were compared to themselves by sequential survey years. If a plot happened to be lost to a nonforest land use (some form of landclearing) then that plot had a similarity measure of 0.0. The richness and evenness indices were not affected by the changes in plot ground use (from forest to nonforest or vice versa); these two estimators were applied to all plots that were considered forest for their respective survey year.

Using repeated measures ANOVA or simple unplanned tests exhibited no conflict in analytical interpretation. Both performed equally well and the results were consistent whether using the *t*-test or ANOVA. However, the repeated measures ANOVA presented problems in the requirement of equal-sized samples. Forcing this requirement meant giving up information, in some cases 200 or 300 plots when successive surveys varied because of land use changes. When sample size of the smallest component became exceptionally small, the test had to be abandoned altogether because the pseudo-means were so different from the empirical means. This was the case with the plantation plot group.

Implications

The central questions to this study have been answered. Species richness has been declining in these two states in the Midsouth since the 1960's. Furthermore, when disturbed plots were contrasted with undisturbed plots over the same 30-year period, disturbed plots decreased in richness, evenness, and stand similarity while undisturbed plots increased in these respective measures. The similarity measure showed large changes in stand composition between beginning and ending periods of this study. Plantations showed the lowest measures and appear to be headed for continued decline, though it is doubtful they can go much lower.

The largest impact appeared to be from land-use decisions. Although no causal inference was possible with this study, the strong empirical evidence showed that harvesting has negatively impacted species richness and evenness of the target population (definitive trees ≥ 12.7 cm in *DBH*).

The study helped confirm, indirectly, other findings that even though forest area may be increasing in certain regions of the United States, forest stands that are older or undisturbed continue to decrease in area (Spies 1997). Although size-class structure was not analyzed in my study, the downward trend in diversity is of concern and correlated with decreasing amounts of undisturbed (or older) stands.

Given the fact that species diversity is declining, what to do to change this trend over an area as large as a state is another matter. Ownership is diverse and fragmented. There is a lack of complete knowledge about stand structure and an even poorer understanding of forest management effects on biodiversity and long-term ecosystem

function. No one knows how long viable ecosystem functions can be maintained while providing for the increasing demand of commodity resources. One ongoing debate is what amount (or level) of diversity is necessary to maintain stable ecosystem function (Perry and Amaranthus 1997). In the case of my results, how low would species richness have to fall before action is taken? Because forests are economically mature long before they are biologically mature, certain functions pertaining to older stands are never realized. Scientists do not know what impact this has on species diversity over a long period of time. Additionally, with the pressure the southern forests are under, another unforeseen biological facet of the ecosystem may become even more important. For instance, Hunter (1990) has suggested that nutrient depletion may become a serious problem long before species losses become a concern.

These data rigorously define the status of species richness and evenness trends for two representative Midsouth states for the past 30 years. Additionally, stand dynamics have been defined with a plot similarity measure. The study was important because harvesting impacts on species diversity over large areas has been quantified. Previous work has dealt mostly with very localized studies.

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APPENDICES

APPENDIX A

MISCELLANEOUS MAPS, TABLES, AND FIGURES

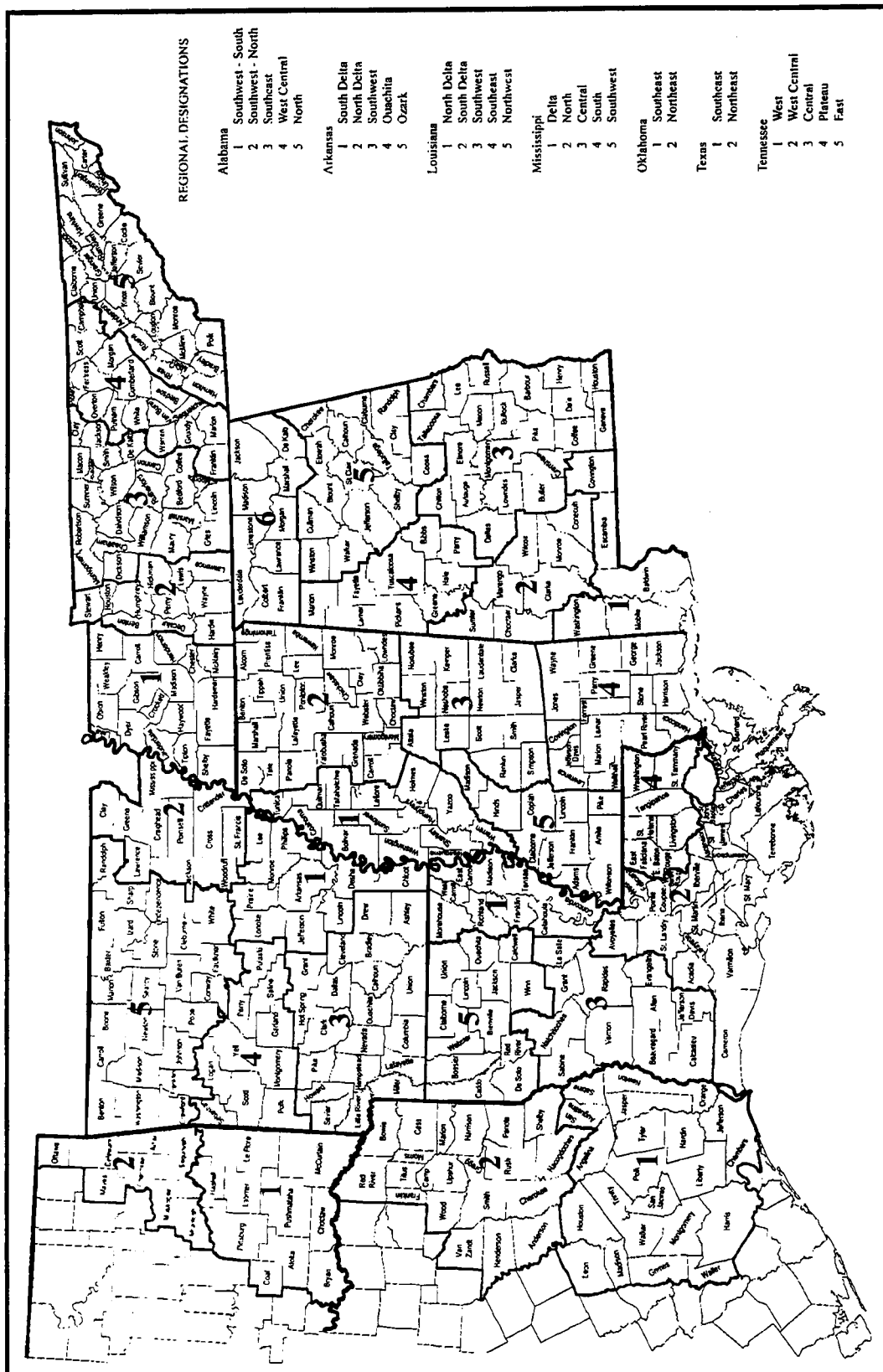


Figure A-1. Survey regions of Midsouth, USA.

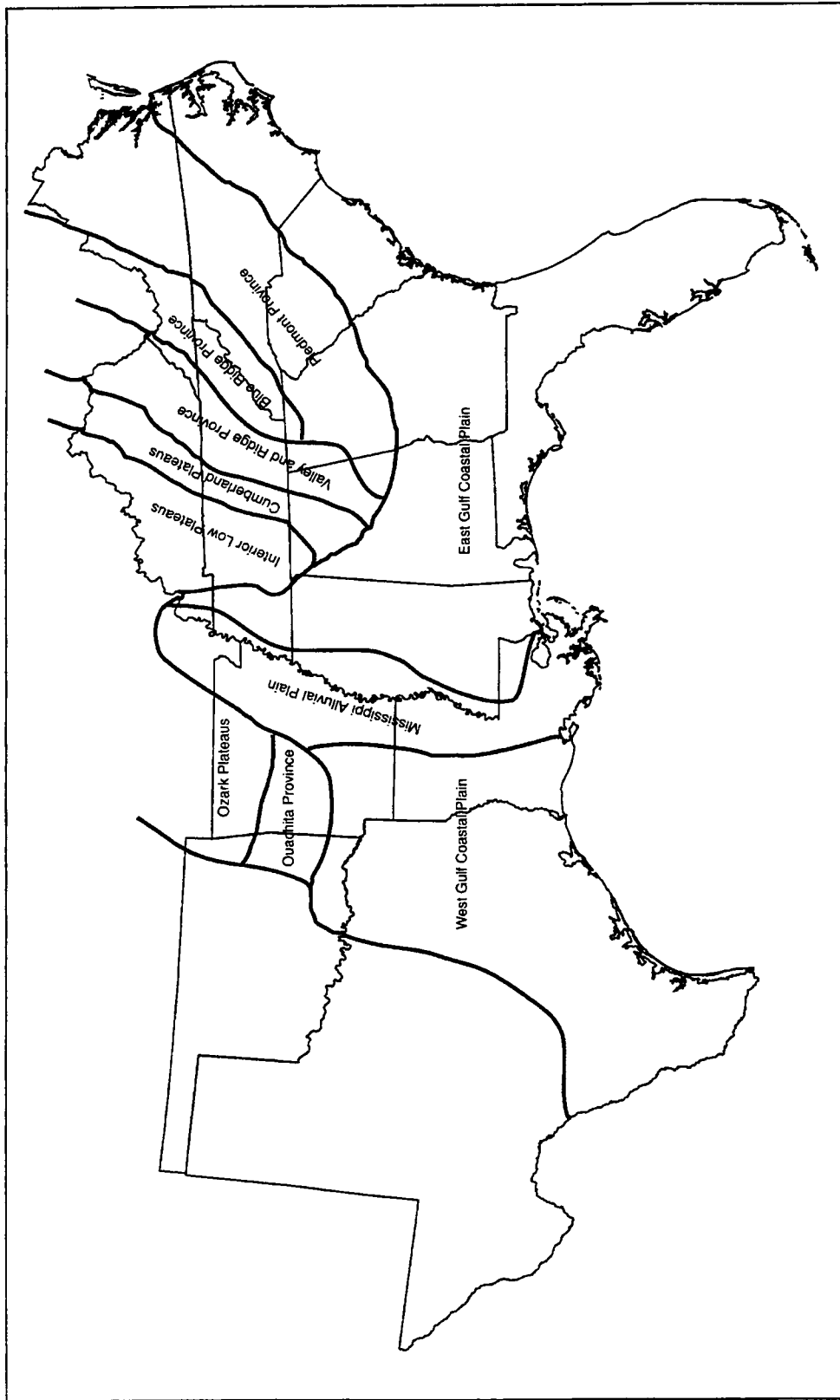


Figure A-2. Major physiographic regions of the Southern United States.
After Fenneman and Johnson, 1946

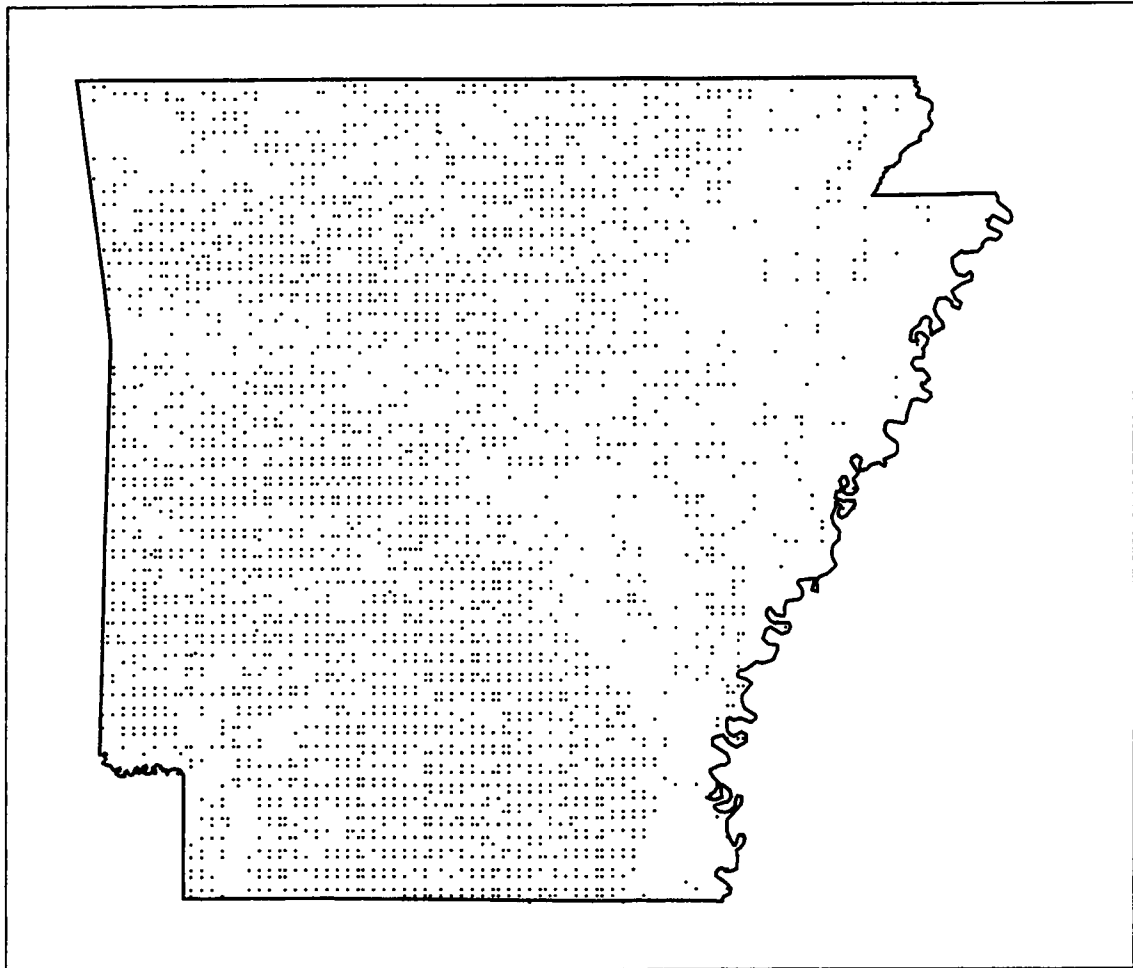


Figure A-3. Distribution of sample plots across Arkansas, 1995. Each dot represents a forest plot location.

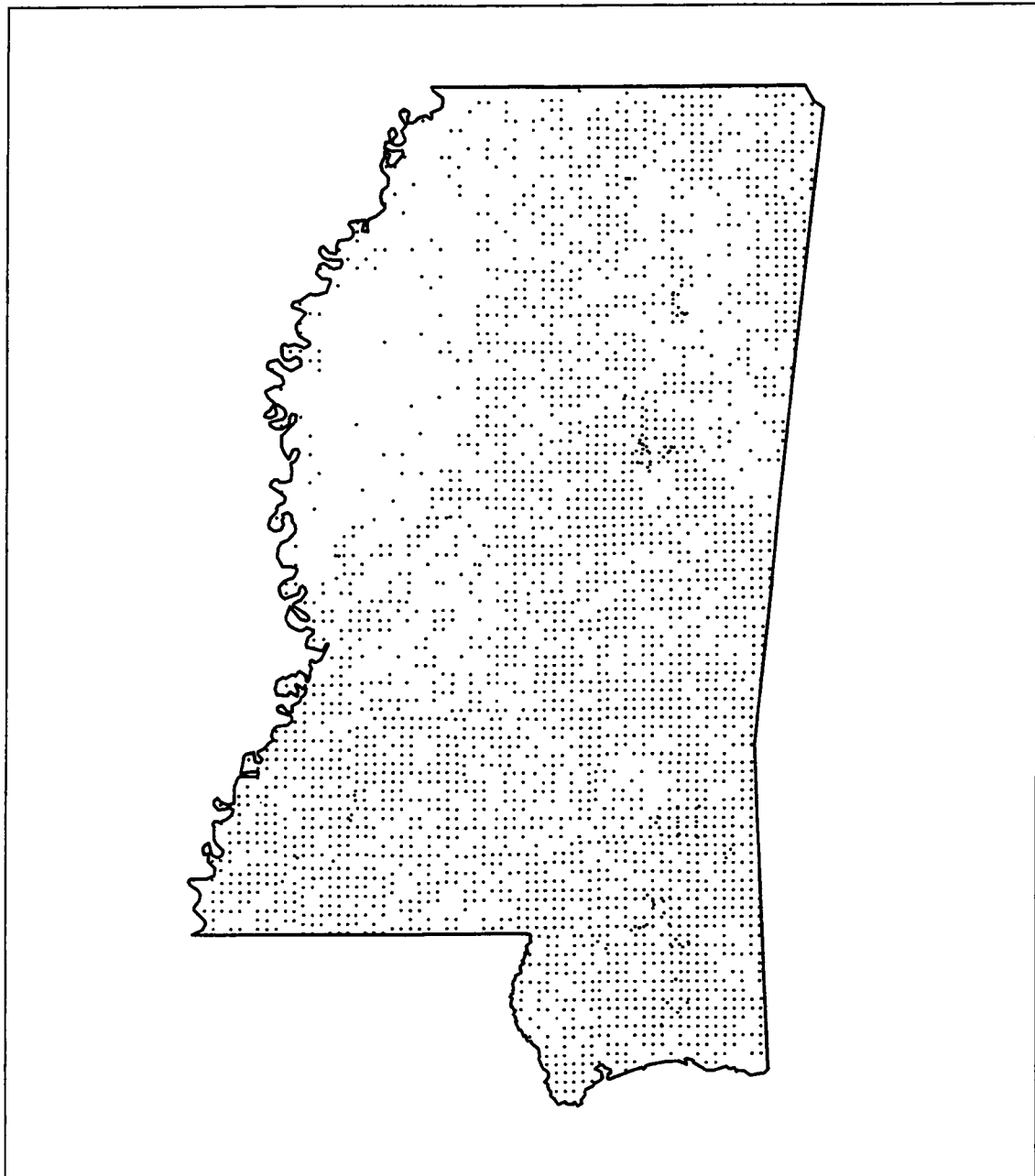


Figure A-4. Distribution of sample plots across Mississippi, 1994. Each dot represents a forest plot location..

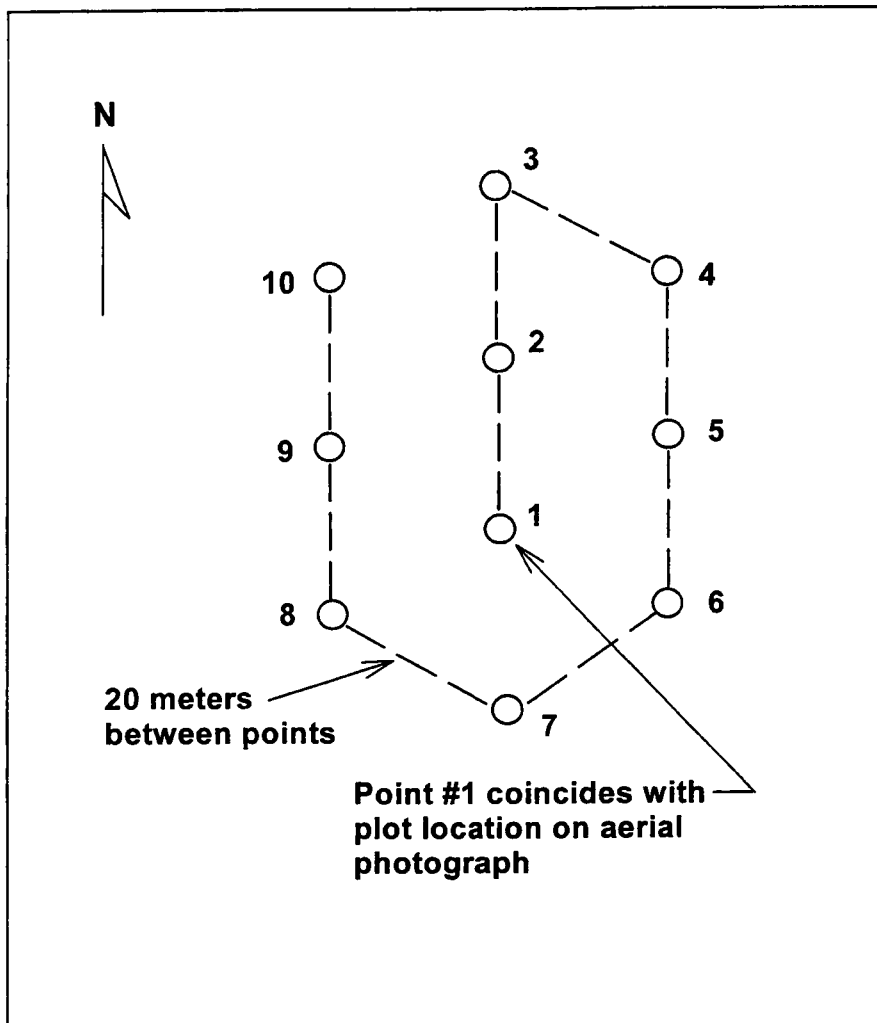


Figure A-5. Ten point sample cluster used at each 4.8 x 4.8 *km* sample location.

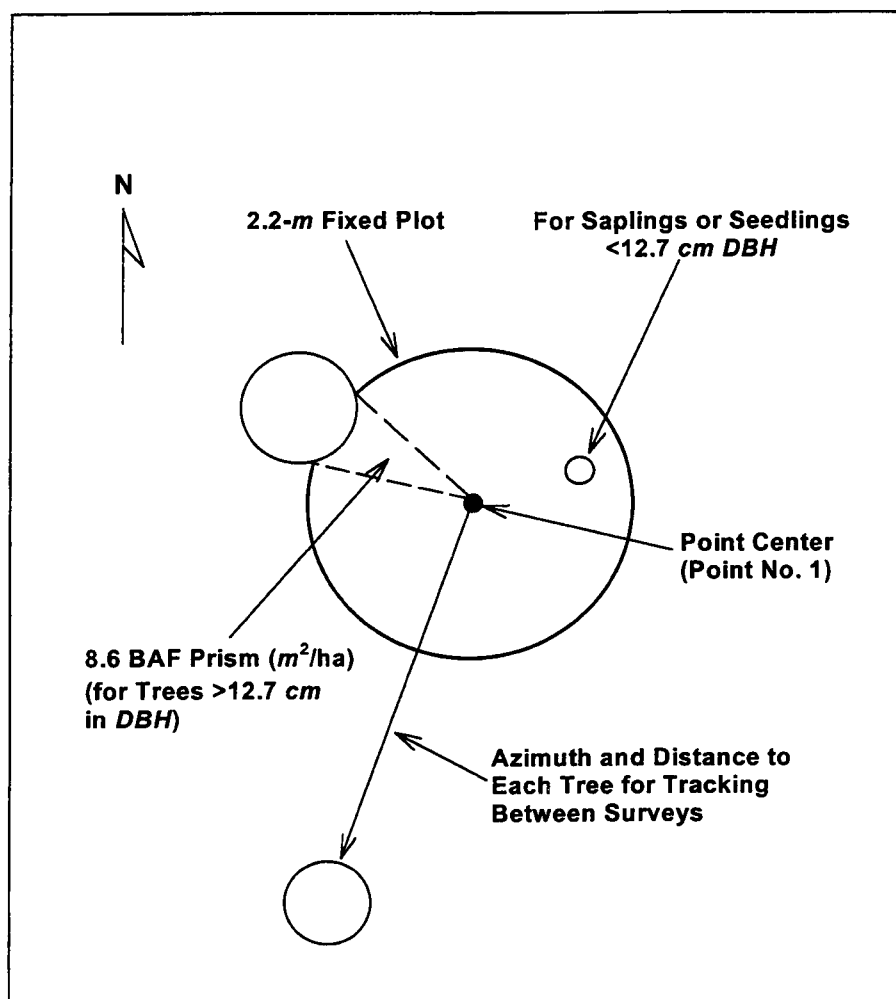


Figure A-6. Satellite point configuration used on sample plot. Ten of these are laid out at each location as shown in Figure A-5.

Figure A-7.—Calculation of the McIntosh evenness index. The example illustrates the computations for one sample unit. This sample unit has 10 individual trees distributed among 5 species.

Species (s)	Tree number	Tree diameter at breast height (cm)	Trees per hectare (n)	n ²
<i>Quercus alba</i>	1	33.8	9.6	
	2	26.4	15.7	
	3	28.2	13.8	
			<u>Σ=39.1</u>	1,528.8
<i>Quercus nigra</i>	4	18.8	31.0	961.0
<i>Quercus falcata</i>	5	25.4	17.0	
	6	20.6	25.8	
			<u>Σ=42.8</u>	1,831.8
<i>Nyssa sylvatica</i>	7	39.6	7.0	49.0
<i>Pinus echinata</i>	8	40.9	6.6	
	9	21.1	24.6	
	10	20.1	27.2	
			<u>Σ=58.4</u>	3,410.6

$$S = \sum s = 5$$

$$N = \sum n = 178.3$$

$$\sum n^2 = 7,781.2$$

$$Mc_E = \frac{N - \sqrt{(\sum n^2)}}{N - (N/\sqrt{S})} = \frac{178.3 - \sqrt{7781.2}}{178.3 - (178.3/\sqrt{5})} = \frac{90.1}{98.6} = 0.9138$$

Where:

- s = species
- S = total number of species
- N = total number of individual trees per hectare
- n² = the square of the trees per hectare for each individual species
- n = the representative trees per hectare for each individual tree
- Mc_E = the McIntosh evenness index

Figure A-8.—Calculation of the Sorensen quantitative coefficient of similarity. The example illustrates the comparison for one sample unit between measurement periods 1 and 2. This sample unit has 8 trees distributed among 3 species. Between measurement periods, tree numbers 1, 3, 5, 6, and 7 increased in DBH; trees 2 and 4 died; tree 8 is new ingrowth for period 2.

Species	Tree number	Measurement period 1			Measurement period 2		
		Tree diameter at breast height (cm)	Trees per hectare	Total trees per hectare by species	Tree diameter at breast height (cm)	Trees per hectare	Total trees per hectare by species
<i>Quercus alba</i>	1	33.5	9.8		35.1	8.9	
	2	26.4	15.7		Dead	0.0	
	3	28.2	13.8		31.7	10.9	
			$\Sigma=39.3$	39.3		$\Sigma=19.8$	19.8*
<i>Quercus nigra</i>	4	18.8	31.0	31.0	Dead	0.0	0.0*
<i>Nyssa sylvatica</i>	5	23.4	20.0		28.9	13.1	
	6	18.3	32.7		20.0	27.4	
	7	13.5	60.2		17.9	34.2	
	8				15.1	48.1	
			$\Sigma=112.9$	112.9*		$\Sigma=122.8$	122.8

*Denotes lowest value between the 2 measurement periods used to calculate jN .

$$C_N = 2(jN)/(aN + bN)$$

$$jN = 19.8 + 0.0 + 112.9 = 132.7$$

$$aN = 39.3 + 31.0 + 112.9 = 183.2$$

$$bN = 19.8 + 0.0 + 122.8 = 142.6$$

$$C_N = 2(132.7)/(183.2 + 142.6) = 265.4/325.8 = 0.8146$$

where:

jN

= the sum of the lowest values of abundance between periods 1 and 2

aN

= the sum of individuals abundance for period 1

bN

= the sum of individuals abundance for period 2

C_N

= Sorensen quantitative coefficient of similarity

Table A-1.—Tree species available for data collection entry in Arkansas and Mississippi for four survey periods from 1967 to 1995. A tree had to be ≥ 12.7 cm in DBH to qualify. Nomenclature follows Little (1979). Note that some species are identified only to the genus.

Acer barbatum Michx.
A. negundo L.
A. nigrum Michx. f.
A. rubrum L.
A. saccharinum L.
Aesculus spp. L. .
A. glabra Willd.
A. octandra Marsh.
Ailanthus altissima (Mill.) Swingle
Betula nigra L.
Bumelia spp. Sw.
Carpinus caroliniana Walt.
Carya spp. (Nutt.)
C. aquatica (Michx. f.) Nutt.
C. illinoensis (Wangenh.) K. Koch
Castanea spp. Mill.
C. dentata (Marsh.) Borkh.
C. pumila Mill.
Catalpa spp. Scop.
Celtis laevigata Willd.
C. occidentalis L.
Cercis canadensis L.
Chamaecyparis thyoides (L.) B.S.P.
Cornus florida L.
Crataegus spp. L.
Diospyros virginiana L.
Fagus grandifolia Ehrh.
Fraxinus americana L.
F. pennsylvanica Marsh.
F. profunda (Bush) Bush
F. quadrangulata (Michx.)
Gleditsia aquatica Marsh.
G. triacanthos L.
Gymnocladus dioicus (L.) K. Koch
Halesia carolina L.
Ilex opaca Ait.
Juglans cinerea L.
J. nigra L.
Juniperus silicicola (Small) Bailey

Table A-1.—Tree species available for data collection entry in Arkansas and Mississippi for four survey periods from 1967 to 1995. A tree had to be ≥ 12.7 cm in DBH to qualify. Nomenclature follows Little (1979). Note that some species are identified only to the genus (continued).

J. Virginiana L.
Liquidambar styraciflua L.
Liriodendron tulipifera L.
Maclura pomifera (Raf.) Schneid.
Magnolia acuminata L.
M. grandiflora L.
M. macrophylla Michx.
M. virginiana L.
Melia azedarach L.
Morus alba L.
M. rubra L.
Nyssa aquatica L.
N. sylvatica Marsh.
N. sylvatica var. *biflora* (Walt.) Sarg.
Ostrya virginiana (Mill.) K. Koch
Oxydendrum arboreum (L.) DC.
Persea borbonia (L.) Spreng.
Pinus echinata Mill.
P. elliotii Engelm.
P. glabra Walt.
P. palustris Mill.
P. taeda L.
P. virginiana Mill.
Planera aquatica J. F. Gmel.
Platanus occidentalis L.
Populus spp. L.
Prunus spp. L.
P. serotina Ehrh.
Quercus alba L.
Q. coccinea Muenchh.
Q. durandii Buckl.
Q. falcata Michx.
Q. falcata var. *pagodaefolia* Ell.
Q. imbricaria Michx.
Q. incana Bartr.
Q. laevis Walt.
Q. laurifolia Michx.
Q. lyrata Walt.
Q. macrocarpa Michx.

Table A-1.—Tree species available for data collection entry in Arkansas and Mississippi for four survey periods from 1967 to 1995. A tree had to be ≥ 12.7 cm in DBH to qualify. Nomenclature follows Little (1979). Note that some species are identified only to the genus (continued).

Q. marilandica Muenchh.
Q. michauxii Nutt.
Q. muehlenbergii Engelm.
Q. nigra L.
Q. nuttallii Palmer
Q. palustris Muenchh.
Q. phellos L.
Q. prinus L.
Q. rubra L.
Q. shumardii Buckl.
Q. stellata Wangenh.
Q. stellata var. *paludosa* Sarg.
Q. velutina Lam.
Q. virginiana Mill.
Robinia pseudoacacia L.
Salix spp. L.
Sassafras albidum (Nutt.) Nees
Taxodium distichum (L.) Rich.
Tilia spp.
T. americana L.
Ulmus alata Michx.
U. americana L.
U. crassifolia Nutt.
U. pumila L.
U. rubra Muhl.
U. serotina Sarg.
U. Thomasii Sarg.
Vaccinium arboreum Marsh.
Other unidentified species

Table A-2.—Number of sample plots where species occurred by survey year, Arkansas. A species had to be ≥ 12.7 cm in DBH to qualify as occurring on a sample plot.

Species	Survey year			
	1968	1978	1988	1995
	----- Number of plots -----			
<i>Acer barbatum</i> Michx.	44	5	78	83
<i>A. negundo</i> L.	47	56	64	69
<i>A. rubrum</i> L.	258	320	379	409
<i>A. saccharinum</i> L.	12	11	18	28
<i>Aesculus glabra</i> Willd.	1	0	0	0
<i>Ailanthus altissima</i> (Mill.) Swingle	0	0	2	2
<i>Betula nigra</i> L.	25	27	32	33
<i>Bumelia</i> spp. Sw.	1	1	5	6
<i>Carpinus caroliniana</i> Walt.	110	134	151	134
<i>Carya</i> spp. (Nutt.)	1,136	1,184	1,447	1,373
<i>C. aquatica</i> (Michx. f.) Nutt.	129	124	113	106
<i>C. illinoensis</i> (Wangenh.) K. Koch	27	32	44	52
<i>Castanea</i> spp. Mill.	0	0	2	1
<i>C. dentata</i> (Marsh.) Borkh.	4	4	3	0
<i>C. pumila</i> Mill.	4	4	2	1
<i>Catalpa</i> spp. Scop.	1	2	1	1
<i>Celtis laevigata</i> Willd.	125	138	165	173
<i>C. occidentalis</i> L.	41	42	38	34
<i>Cercis canadensis</i> L.	5	12	22	28
<i>Cornus florida</i> L.	42	65	88	82
<i>Crataegus</i> spp. L.	11	13	14	11
<i>Diospyros virginiana</i> L.	89	97	109	108
<i>Fagus grandifolia</i> Ehrh.	76	77	89	87
<i>Fraxinus americana</i> L.	162	182	249	252
<i>F. pennsylvanica</i> Marsh.	179	205	239	253
<i>F. profunda</i> (Bush) Bush	1	1	2	2
<i>F. quadrangulata</i> (Michx.)	2	2	3	3
<i>Gleditsia aquatica</i> Marsh.	39	34	26	28
<i>G. triacanthos</i> L.	60	57	59	64
<i>Halesia carolina</i> L.	0	0	1	0
<i>Ilex opaca</i> Ait.	60	71	79	74
<i>Juglans cinerea</i> L.	2	2	4	1
<i>J. nigra</i> L.	58	61	80	98
<i>J. virginiana</i> L.	125	144	278	340
<i>Liquidambar styraciflua</i> L.	930	1,049	1,143	1,098
<i>Liriodendron tulipifera</i> L.	6	7	16	16
<i>Maclura pomifera</i> (Raf.) Schneid.	2	6	6	14
<i>Magnolia acuminata</i> L.	5	6	9	10

Table A-2.—Number of sample plots where species occurred by survey year, Arkansas. A species had to be ≥ 12.7 cm in DBH to qualify as occurring on a sample plot (continued).

Species	Survey year			
	1968	1978	1988	1995
	----- Number of plots -----			
<i>M. virginiana</i> L.	19	21	19	18
<i>M. macrophylla</i> Michx.	1	1	1	2
<i>Melia azedarach</i> L.	0	0	2	3
<i>Morus alba</i> L.	5	6	5	1
<i>M. rubra</i> L.	28	48	63	65
<i>Nyssa aquatica</i> L.	23	27	26	26
<i>N. sylvatica</i> Marsh.	602	640	753	736
<i>N. sylvatica</i> var. <i>biflora</i> (Walt.) Sarg.	0	0	4	5
<i>Ostrya virginiana</i> (Mill.) K. Koch	35	46	75	68
<i>Oxydendrum arboreum</i> (L.) DC.	0	0	0	1
<i>Persea borbonia</i> (L.) Spreng.	0	0	0	1
<i>Pinus echinata</i> Mill.	1,140	1,220	1,251	1,123
<i>P. taeda</i> L.	837	925	1,001	1,092
<i>Planera aquatica</i> J. F. Gmel.	19	20	29	36
<i>Platanus occidentalis</i> L.	79	98	122	135
<i>Populus</i> spp. L.	49	49	45	37
<i>Prunus</i> spp. L.	4	5	6	7
<i>P. serotina</i> Ehrh.	59	80	133	172
<i>Quercus alba</i> L.	1,142	1,254	1,454	1,405
<i>Q. coccinea</i> Muenchh.	7	9	10	1
<i>Q. durandii</i> Buckl.	0	0	1	2
<i>Q. falcata</i> Michx.	713	802	850	773
<i>Q. falcata</i> var. <i>pagodaefolia</i> Ell.	306	395	397	360
<i>Q. imbricaria</i> Michx.	0	0	1	1
<i>Q. incana</i> Bartr.	0	0	2	0
<i>Q. laevis</i> Walt.	0	0	1	0
<i>Q. laurifolia</i> Michx.	0	0	1	6
<i>Q. lyrata</i> Walt.	200	201	196	187
<i>Q. macrocarpa</i> Michx.	2	2	6	6
<i>Q. marilandica</i> Muenchh.	202	199	286	235
<i>Q. michauxii</i> Nutt.	78	85	98	78
<i>Q. muehlenbergii</i> Engelm.	53	56	84	104
<i>Q. nigra</i> L.	353	436	472	443
<i>Q. nuttalli</i> Palmer	102	113	110	100
<i>Q. palustris</i> Muenchh.	14	16	15	10
<i>Q. phellos</i> L.	329	345	337	311
<i>Q. prinus</i> L.	0	0	1	0
<i>Q. rubra</i> L.	358	399	561	591

Table A-2.—Number of sample plots where species occurred by survey year, Arkansas. A species had to be ≥ 12.7 cm in DBH to qualify as occurring on a sample plot (continued).

Species	Survey year			
	1968	1978	1988	1995
	----- Number of plots -----			
<i>Q. shumardii</i> Buckl.	54	58	61	67
<i>Q. stellata</i> Wangenh.	1,135	1,124	1,261	1,126
<i>Q. stellata</i> var. <i>paludosa</i> Sarg.	8	9	7	4
<i>Q. velutina</i> Lam.	510	563	786	731
<i>Robinia pseudoacacia</i> L.	35	42	50	52
<i>Salix</i> spp. L.	75	79	73	76
<i>Sassafras albidum</i> (Nutt.) Nees	26	31	49	55
<i>Taxodium distichum</i> (L.) Rich.	95	101	103	107
<i>Tilia americana</i> L.	22	24	32	31
<i>Ulmus alata</i> Michx.	334	361	447	474
<i>U. americana</i> L.	239	241	281	269
<i>U. crassifolia</i> Nutt.	42	40	28	32
<i>U. pumila</i> L.	0	0	3	0
<i>U. rubra</i> Muhl.	61	68	77	102
<i>U. serotina</i> Sarg.	0	1	4	4
<i>U. Thomasii</i> Sarg.	1	1	2	1
<i>U. serotina</i> Sarg.	0	0	1	0
<i>U. thomasii</i> Sarg.	4	5	2	0
<i>Robinia pseudoacacia</i> L.	35	42	50	52
<i>Salix</i> spp. L.	75	79	73	76
Other unidentified species	52	38	35	42

Table A-3.—Number of sample plots where species occurred by survey year, Mississippi. A species had to be ≥ 12.7 cm in DBH to qualify as occurring on a sample plot.

Species	Survey year			
	1967	1977	1987	1994
	----- Number of plots -----			
<i>Acer barbatum</i> Michx.	19	24	28	35
<i>A. negundo</i> L.	70	94	109	106
<i>A. rubrum</i> L.	308	416	526	581
<i>A. saccharinum</i> L.	13	18	13	13
<i>Aesculus</i> spp. L.	0	1	1	1
<i>A. octandra</i> Marsh.	0	0	1	1
<i>Betula nigra</i> L.	29	35	31	33
<i>Bumelia</i> spp. Sw.	0	0	0	1
<i>Carpinus caroliniana</i> Walt.	148	202	209	202
<i>Carya</i> spp. (Nutt.)	685	789	816	762
<i>C. aquatica</i> (Michx. f.) Nutt.	94	84	75	76
<i>C. illinoensis</i> (Wangenh.) K. Koch	35	52	64	76
<i>Castanea pumila</i> Mill.	3	4	2	0
<i>Catalpa</i> spp. Scop.	2	2	6	5
<i>Celtis laevigata</i> Willd.	150	187	208	221
<i>C. occidentalis</i> L.	1	2	3	4
<i>Cercis canadensis</i> L.	5	15	20	16
<i>Chamaecyparis thyoides</i> (L.) B.S.P.	1	1	2	2
<i>Cornus florida</i> L.	119	213	277	270
<i>Crataegus</i> spp. L.	2	3	3	4
<i>Diospyros virginiana</i> L.	71	85	109	107
<i>Fagus grandifolia</i> Ehrh.	180	203	226	214
<i>Fraxinus americana</i> L.	89	120	130	118
<i>F. pennsylvanica</i> Marsh.	194	244	278	290
<i>Gleditsia aquatica</i> Marsh.	12	9	5	6
<i>G. triacanthos</i> L.	37	45	39	32
<i>Ilex opaca</i> Ait.	51	58	54	57
<i>Juglans nigra</i> L.	17	19	20	24
<i>Juniperus silicicola</i> (Small) Bailey	1	1	0	0
<i>J. virginiana</i> L.	74	114	169	197
<i>Liquidambar styraciflua</i> L.	1,119	1,382	1,582	1,589
<i>Liriodendron tulipifera</i> L.	304	443	539	563
<i>Maclura pomifera</i> (Raf.) Schneid.	8	8	12	16
<i>Morus alba</i> L.	3	8	7	4
<i>M. rubra</i> L.	55	78	88	90
<i>Nyssa aquatica</i> L.	27	28	33	35
<i>N. sylvatica</i> Marsh.	628	698	742	722
<i>N. sylvatica</i> var. <i>biflora</i> (Marsh.)	49	54	71	67

Table A-3.—Number of sample plots where species occurred by survey year, Mississippi. A species had to be ≥ 12.7 cm in DBH to qualify as occurring on a sample plot (continued).

Species	Survey year			
	1967	1977	1987	1994
	----- Number of plots -----			
<i>Ostrya virginiana</i> (Mill.) K. Koch	58	74	99	102
<i>Oxydendrum arboreum</i> (L.) DC.	44	100	153	163
<i>Persea borbonia</i> (L.) Spreng.	0	7	12	17
<i>Pinus echinata</i> Mill.	985	1,123	1,079	900
<i>P. elliotii</i> Engelm.	207	270	301	293
<i>P. glabra</i> Walt.	104	118	125	125
<i>P. palustris</i> Mill.	345	385	342	287
<i>P. taeda</i> L.	1,284	1,546	1,703	1,814
<i>Platanus occidentalis</i> L.	97	128	158	171
<i>Populus</i> spp. L.	55	64	58	57
<i>Prunus</i> spp. L.	1	0	2	2
<i>P. serotina</i> Ehrh.	96	174	236	295
<i>Quercus alba</i> L.	620	719	803	763
<i>Q. coccinea</i> Muenchh.	84	115	106	89
<i>Q. durandii</i> Buckl.	2	2	5	5
<i>Q. falcata</i> Michx.	846	1,011	1,012	937
<i>Q. falcata</i> var. <i>pagodaefolia</i> Ell.	356	454	558	547
<i>Q. incana</i> Bartr.	17	18	12	6
<i>Q. laevis</i> Walt.	3	7	11	7
<i>Q. laurifolia</i> Michx.	56	72	117	141
<i>Q. lyrata</i> Walt.	149	148	144	129
<i>Q. marilandica</i> Muenchh.	186	215	173	132
<i>Q. michauxii</i> Nutt.	133	129	146	137
<i>Q. muehlenbergii</i> Engelm.	7	9	9	14
<i>Q. nigra</i> L.	636	833	1,016	1,065
<i>Q. nuttallii</i> Palmer	89	91	84	79
<i>Q. palustris</i> Muenchh.	5	3	6	3
<i>Q. phellos</i> L.	255	279	288	272
<i>Q. prinus</i> L.	13	20	13	10
<i>Q. rubra</i> L.	19	30	37	46
<i>Q. shumardii</i> Buckl.	130	169	169	143
<i>Q. stellata</i> Wangenh.	682	764	757	672
<i>Q. stellata</i> var. <i>paludosa</i> Sarg.	8	6	3	0
<i>Q. velutina</i> Lam.	226	290	285	224
<i>Q. virginiana</i> Mill.	3	6	8	12
<i>Robinia pseudoacacia</i> L.	8	14	21	23
<i>Salix</i> spp. L.	82	100	93	97
<i>Sassafras albidum</i> (Nutt.) Nees	51	67	94	99

Table A-3.—Number of sample plots where species occurred by survey year, Mississippi. A species had to be ≥ 12.7 cm in DBH to qualify as occurring on a sample plot (continued).

Species	Survey year			
	1967	1977	1987	1994
	----- Number of plots -----			
<i>Taxodium distichum</i> (L.) Rich.	87	85	82	85
<i>Tilia americana</i> L.	0	0	5	5
<i>T. heterophylla</i> Vent.	21	27	25	24
<i>Ulmus rubra</i> Muhl.	40	41	66	93
<i>U. serotina</i> Sarg.	0	0	1	0
<i>U. thomasi</i> Sarg.	4	5	2	0
<i>Vaccinium arboreum</i> Marsh.	4	4	6	6
<i>Melia azedarach</i> L.	1	3	6	7
<i>Planera aquatica</i> J. F. Gmel.	7	11	15	15
Other unidentified species	80	71	68	71

Table A-4.—Sample plot frequency by number of species occurring on a sample plot by survey year, Arkansas. The table is based on all trees ≥ 12.7 cm in DBH.

Number of species	Survey year			
	1968	1978	1988	1995
	----- <i>Number of plots</i> -----			
0	60	143	374	255
1	149	102	176	256
2	261	204	236	268
3	396	324	350	339
4	521	421	422	386
5	466	429	463	456
6	378	358	368	415
7	248	279	290	304
8	147	164	177	225
9	95	99	98	112
10	46	55	59	57
11	28	28	24	26
12	6	12	11	13
13	4	4	8	11
14	3		2	2
15	1			1
16			1	1
17		1		

Table A-5.—Sample plot frequency by number of species occurring on a sample plot by survey year, Mississippi. The table is based on all trees ≥ 12.7 cm in DBH.

Number of species	Survey year			
	1967	1977	1987	1994
	----- <i>Number of plots</i> -----			
0	180	189	433	466
1	247	166	176	286
2	347	238	201	308
3	398	320	261	300
4	411	357	324	326
5	360	346	298	289
6	330	342	350	300
7	258	270	271	282
8	207	214	217	211
9	111	157	175	143
10	73	101	112	115
11	34	57	63	76
12	24	22	40	50
13	7	18	21	16
14	3	4	11	9
15		3	5	1
16		1		2
17		1		

Table A-6.—Sample plot frequency by number of trees ≥ 12.7 cm in DBH occurring on a sample plot by survey year, Arkansas.

Number of trees	Survey year			
	1968	1978	1988	1995
	----- <i>Number of plots</i> -----			
0	60	143	374	255
1	23	21	47	37
2	39	29	43	26
3	57	32	29	35
4	45	35	39	50
5	57	29	53	43
6	76	47	51	52
7	79	51	72	64
8	96	56	67	70
9	119	64	72	67
10	101	75	83	83
11	128	102	84	109
12	138	83	93	108
13	153	90	83	101
14	146	99	102	144
15	126	112	123	105
16	127	114	119	139
17	133	105	114	111
18	137	116	124	109
19	131	128	124	133
20	124	128	106	117
21	120	118	130	117
22	99	100	125	95
23	78	98	104	116
24	78	94	106	105
25	72	82	94	115
26	39	77	68	92
27	39	73	59	83
28	38	59	70	60
29	26	42	47	65
30	22	43	48	61
31	26	32	43	47
32	17	31	29	33
33	11	28	24	37
34	8	20	27	23
35	7	18	23	26
36	9	8	12	17

Table A-6.—Sample plot frequency by number of trees ≥ 12.7 cm in DBH occurring on a sample plot by survey year, Arkansas (continued).

Number of trees	Survey year			
	1968	1978	1988	1995
	----- <i>Number of plots</i> -----			
37	7	8	10	16
38	4	8	8	15
39	2	3	4	10
40	4	4	4	7
41	1	4	4	4
42	2	4	7	4
43		2	2	2
44	1	3	1	4
45	1	1	1	1
46	1	1	2	4
47			1	2
48			1	3
49	2	2	1	1
50				
51				1
52				
53				
54				1
55				1
56				
58		1		
59				
60			1	
62			1	
63				1

Table A-7.—Sample plot frequency by number of trees ≥ 12.7 cm in DBH occurring on a sample plot by survey year, Mississippi.

Number of trees	Survey year			
	1967	1977	1987	1994
	----- <i>Number of plots</i> -----			
0	180	189	433	466
1	58	39	65	83
2	79	48	48	81
3	93	48	43	90
4	95	62	45	81
5	94	62	57	76
6	92	53	50	80
7	109	63	52	80
8	121	66	74	66
9	130	88	68	69
10	145	79	77	92
11	154	88	74	88
12	114	92	71	92
13	150	84	66	91
14	141	109	96	88
15	140	108	84	81
16	126	111	90	89
17	125	110	117	98
18	112	108	108	88
19	118	104	106	89
20	111	125	92	82
21	84	115	96	104
22	65	95	99	96
23	64	99	92	93
24	47	91	96	89
25	45	78	92	75
26	36	65	84	65
27	26	75	66	59
28	31	60	64	68
29	19	45	51	56
30	14	46	54	49
31	11	32	40	51
32	13	26	40	48
33	6	33	32	31
34	7	23	20	24
35	8	23	25	21
36	5	9	13	13

Table A-7.—Sample plot frequency by number of trees ≥ 12.7 cm in DBH occurring on a sample plot by survey year, Mississippi (continued).

Number of trees	Survey year			
	1967	1977	1987	1994
	----- <i>Number of plots</i> -----			
37	2	6	18	15
38	3	9	9	13
39	2	9	10	9
40	1	7	9	12
41	2	5	3	10
42	2	4	4	4
43		5	6	5
44		1	3	5
45	2	3	3	1
46	2	2	2	1
47		1	2	1
48	2	1	1	1
49			1	3
50			1	3
51	1		2	
52			1	1
53		1	1	
54	1			1
55			1	
56			1	
59	1			
60				2
65				1
84		1		
85	1			

APPENDIX B

ARKANSAS DIVERSITY TABLES

Table B-1.—Species richness statistics for all plots, Arkansas, 1968–1995. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1968	2,809	4.72	2.3404	5.4775	0.0442	49.59	15	0
1978	2,623	4.84	2.5158	6.3291	0.0491	52.02	17	0
1988	3,059	4.37	2.7582	7.6075	0.0499	63.10	16	0
1995	3,127	4.56	2.7456	7.5383	0.0491	60.15	16	0

Table B-2.—Species evenness statistics for all plots, Arkansas, 1968–1995. Number of species is from trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (see page 32 in text for explanation).

Survey year	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1968	2,809	0.67	0.2696	0.0727	0.0051	40.37	1	0
1978	2,623	0.65	0.2810	0.0789	0.0055	43.03	1	0
1988	3,059	0.60	0.3323	0.1105	0.0060	55.84	1	0
1995	3,127	0.60	0.3248	0.1055	0.0058	53.95	1	0

Table B-3.—Plot similarity statistics for all plots, Arkansas, 1968-1995. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (see page 33 in text for explanation).

Survey years compared	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1968/1978	2,562	0.71	0.2722	0.0741	0.0054	38.32	1	0
1978/1988	2,501	0.66	0.2996	0.0897	0.0060	45.48	1	0
1988/1995	2,920	0.70	0.2909	0.0846	0.0054	41.54	1	0
1968/1995	2,471	0.50	0.2938	0.0863	0.0059	58.45	1	0

Table B-4.—Species richness statistics for all plots by ownership, Arkansas, 1968-1995. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.									
Survey year	Ownership class	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1968	Public	533	4.53	2.1146	4.4715	0.0916	46.71	14	0
	Forest industry	753	4.60	2.4534	6.0190	0.0894	53.30	14	0
	Nonindustrial private forest	1,523	4.84	2.3549	5.5454	0.0603	48.64	15	0
	Total	2,809	4.72	2.3404	5.4775	0.0442	49.59	15	0
1978	Public	502	4.77	2.0484	4.1958	0.0914	42.92	13	0
	Forest industry	753	4.33	2.6815	7.1905	0.0977	62.00	12	0
	Nonindustrial private forest	1,368	5.14	2.5314	6.4080	0.0684	49.24	17	0
	Total	2,623	4.84	2.5158	6.3291	0.0491	52.02	17	0
1988	Public	566	4.47	2.4814	6.1573	0.1043	55.56	11	0
	Forest industry	787	3.81	2.8540	8.1451	0.1017	74.94	14	0
	Nonindustrial private forest	1,706	4.60	2.7655	7.6480	0.0670	60.13	16	0
	Total	3,059	4.37	2.7582	7.6075	0.0499	63.10	16	0
1995	Public	587	5.14	2.3422	5.4858	0.0937	45.53	13	0
	Forest industry	778	3.71	2.7778	7.7163	0.0996	74.96	15	0
	Nonindustrial private forest	1,762	4.75	2.7710	7.6787	0.0660	58.33	16	0
	Total	3,127	4.56	2.7456	7.5383	0.0491	60.15	16	0

Table B-5.—Species evenness statistics for all plots by ownership, Arkansas, 1968-1995. Evenness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (see page 32 in text for explanation).									
Survey year	Ownership class	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1968	Public	533	0.65	0.2695	0.0726	0.0117	41.52	1	0
	Forest industry	753	0.64	0.2814	0.0792	0.0103	43.89	1	0
	Nonindustrial private forest	1,523	0.69	0.2621	0.0687	0.0067	38.12	1	0
	Total	2,809	0.67	0.2696	0.0727	0.0051	40.37	1	0
1978	Public	502	0.66	0.2484	0.0617	0.0111	37.62	1	0
	Forest industry	753	0.59	0.3207	0.1028	0.0117	54.36	1	0
	Nonindustrial private forest	1,368	0.68	0.2627	0.0690	0.0071	38.36	1	0
	Total	2,623	0.65	0.2810	0.0789	0.0055	43.03	1	0
1988	Public	566	0.60	0.3152	0.0993	0.0132	52.51	1	0
	Forest industry	787	0.51	0.3574	0.1278	0.0127	70.02	1	0
	Nonindustrial private forest	1,706	0.63	0.3187	0.1016	0.0077	50.39	1	0
	Total	3,059	0.60	0.3323	0.1105	0.0060	55.84	1	0
1995	Public	587	0.65	0.2658	0.0706	0.0110	40.72	1	0
	Forest industry	778	0.49	0.3598	0.1294	0.0129	73.68	1	0
	Nonindustrial private forest	1,762	0.64	0.3146	0.0990	0.0075	49.52	1	0
	Total	3,127	0.60	0.3248	0.1055	0.0058	53.95	1	0

Table B-6.—Plot similarity statistics for all plots by ownership, Arkansas, 1968-1995. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (see page 33 in text for explanation).									
Survey year compared	Ownership class	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1968/1978	Public	495	0.79	0.2193	0.0481	0.0099	27.75	1	0
	Forest industry	747	0.63	0.3211	0.1031	0.0117	51.08	1	0
	Nonindustrial private forest	1,320	0.73	0.2472	0.0611	0.0068	34.03	1	0
	Total	2,562	0.71	0.2722	0.0741	0.0054	38.32	1	0
1978/1988	Public	495	0.76	0.2486	0.0618	0.0112	32.59	1	0
	Forest industry	768	0.51	0.3489	0.1217	0.0126	67.93	1	0
	Nonindustrial private forest	1,238	0.71	0.2480	0.0615	0.0070	35.07	1	0
	Total	2,501	0.66	0.2996	0.0897	0.0060	45.48	1	0
1988/1995	Public	571	0.80	0.2323	0.0539	0.0097	28.88	1	0
	Forest industry	766	0.56	0.3449	0.1190	0.0125	61.96	1	0
	Nonindustrial private forest	1,583	0.73	0.2534	0.0642	0.0064	34.61	1	0
	Total	2,920	0.70	0.2909	0.0846	0.0054	41.54	1	0

Table B-7.—Species richness statistics for all plots by physiographic class, Arkansas, 1968-1995. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	Physiographic class	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1968	Upland (pine)	1,819	4.27	2.0889	4.3634	0.0490	48.95	12	0
	Upland (hardwood)	427	4.67	2.1368	4.5660	0.1034	45.80	13	0
	Bottomland	563	6.22	2.6217	6.8731	0.1105	42.15	15	0
	Total	2,809	4.72	2.3404	5.4775	0.0442	49.59	15	0
1978	Upland (pine)	1,764	4.35	2.3171	5.3691	0.0552	53.26	12	0
	Upland (hardwood)	355	4.96	2.0813	4.3318	0.1105	41.96	12	0
	Bottomland	504	6.45	2.7719	7.6832	0.1235	42.99	17	0
	Total	2,623	4.84	2.5158	6.3291	0.0491	52.02	17	0
1988	Upland (pine)	1,878	3.95	2.5535	6.5206	0.0589	64.57	13	0
	Upland (hardwood)	695	4.42	2.6607	7.0795	0.1009	60.22	14	0
	Bottomland	486	5.91	3.0901	9.5489	0.1402	52.27	16	0
	Total	3,059	4.37	2.7582	7.6075	0.0499	63.10	16	0
1995	Upland (pine)	2,000	4.11	2.5212	6.3567	0.0564	61.35	14	0
	Upland (hardwood)	582	4.97	2.5730	6.6203	0.1067	51.80	13	0
	Bottomland	545	5.80	3.2273	10.4154	0.1382	55.61	16	0
	Total	3,127	4.56	2.7456	7.5383	0.0491	60.15	16	0

Table B-8.—Species evenness statistics for all plots by physiographic class, Arkansas, 1968-1995. Evenness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (see page 32 in text for explanation).

Survey year	Physiographic class	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1968	Upland (pine)	1,819	0.64	0.2854	0.0815	0.0067	44.44	1	0
	Upland (hardwood)	427	0.72	0.2388	0.0570	0.0116	33.16	1	0
	Bottomland	563	0.71	0.2225	0.0495	0.0094	31.28	1	0
	Total	2,809	0.67	0.2696	0.0727	0.0051	40.37	1	0
1978	Upland (pine)	1,764	0.62	0.2995	0.0897	0.0071	48.02	1	0
	Upland (hardwood)	355	0.72	0.2252	0.0507	0.0120	31.34	1	0
	Bottomland	504	0.71	0.2286	0.0523	0.0102	32.25	1	0
	Total	2,623	0.65	0.2810	0.0789	0.0055	43.03	1	0
1988	Upland (pine)	1,878	0.56	0.3434	0.1180	0.0079	60.97	1	0
	Upland (hardwood)	695	0.63	0.3245	0.1053	0.0123	51.77	1	0
	Bottomland	486	0.67	0.2790	0.0778	0.0127	41.47	1	0
	Total	3,059	0.60	0.3323	0.1105	0.0060	55.84	1	0
1995	Upland (pine)	2,000	0.57	0.3378	0.1141	0.0076	59.37	1	0
	Upland (hardwood)	582	0.67	0.2833	0.0803	0.0117	42.21	1	0
	Bottomland	545	0.65	0.2998	0.0899	0.0128	46.16	1	0
	Total	3,127	0.60	0.3248	0.1055	0.0058	53.95	1	0

Table B-9.—Plot similarity statistics for all plots by physiographic class, Arkansas, 1968-1995. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (see page 33 in text for explanation).									
Survey years compared	Physiographic class	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1968/1978	Upland (pine)	1,729	0.69	0.2915	0.0850	0.0070	42.49	1	0
	Upland (hardwood)	344	0.78	0.2164	0.0468	0.0117	27.85	1	0
	Bottomland	492	0.75	0.2204	0.0486	0.0099	29.44	1	0
	Total	2,562	0.71	0.2722	0.0741	0.0054	38.32	1	0
1978/1988	Upland (pine)	1,656	0.62	0.3223	0.1039	0.0079	52.04	1	0
	Upland (hardwood)	410	0.78	0.2117	0.0448	0.0105	27.30	1	0
	Bottomland	435	0.70	0.2413	0.0582	0.0116	34.53	1	0
	Total	2,501	0.66	0.2496	0.0897	0.0060	45.48	1	0
1988/1995	Upland (pine)	1,889	0.66	0.3140	0.0986	0.0072	47.25	1	0
	Upland (hardwood)	531	0.80	0.2094	0.0438	0.0091	26.31	1	0
	Bottomland	500	0.73	0.2441	0.0596	0.0109	33.28	1	0
	Total	2,920	0.70	0.2909	0.0846	0.0054	41.54	1	0

Table B-10.—Species richness statistics for all plots by stand-size class, Arkansas, 1968-1995. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	Stand-size class	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum Richness per plot
1968	0 - 12.7 cm	60	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	580	3.72	1.7476	3.0541	0.0726	46.95	10	1
	20.0 - 30.0 cm	1,837	5.16	2.2393	5.0146	0.0522	43.43	15	1
	30.0 - 40.0 cm	292	5.04	2.5272	6.3869	0.1479	50.17	14	1
	≥ 40.0 cm	40	3.85	2.3918	5.7205	0.3782	62.12	12	1
	Total	2,809	4.72	2.3404	5.4775	0.0442	49.59	15	1
1978	0 - 12.7 cm	143	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	417	3.94	1.8672	3.4865	0.0914	47.42	10	1
	20.0 - 30.0 cm	1,722	5.35	2.2402	5.0186	0.0540	41.89	17	1
	30.0 - 40.0 cm	304	5.54	2.5196	6.3483	0.1445	45.48	13	1
	≥ 40.0 cm	37	4.05	2.7783	7.7192	0.4568	68.53	12	1
	Total	2,623	4.84	2.5158	6.3291	0.0491	52.02	17	1
1988	0 - 12.7 cm	374	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	485	3.57	2.0056	4.0226	0.0911	56.20	10	1
	20.0 - 30.0 cm	1,805	5.25	2.2391	5.0138	0.0527	42.65	16	1
	30.0 - 40.0 cm	355	5.72	2.6857	7.2130	0.1425	46.94	13	1
	≥ 40.0 cm	40	3.30	2.1025	4.4205	0.3324	63.71	8	1
	Total	3,059	4.37	2.7582	7.6075	0.0499	63.10	16	1
1995	0 - 12.7 cm	255	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	426	3.10	1.9829	3.9319	0.0961	64.04	10	1
	20.0 - 30.0 cm	1,946	5.24	2.2978	5.2797	0.0521	43.83	14	1
	30.0 - 40.0 cm	444	5.79	2.7500	7.5623	0.1305	47.51	16	1
	≥ 40.0 cm	56	3.27	2.6662	7.1088	0.3563	81.59	10	1
	Total	3,127	4.56	2.7456	7.5383	0.0491	60.15	16	1

Table B-11.—Species evenness statistics for all plots by stand-size class, Arkansas, 1968-1995. Evenness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	Stand-size class	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1968	0 - 12.7 cm	60	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	580	0.60	0.3025	0.0915	0.0126	50.03	1	0
	20.0 - 30.0 cm	1,837	0.71	0.2282	0.0521	0.0053	32.28	1	0
	30.0 - 40.0 cm	292	0.69	0.2624	0.0689	0.0154	38.01	1	0
	≥ 40.0 cm	40	0.64	0.2765	0.0765	0.0437	43.43	1	0
Total		2,809	0.67	0.2696	0.0727	0.0510	40.37	1	0
1978	0 - 12.7 cm	143	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	417	0.65	0.2998	0.0899	0.0147	46.70	1	0
	20.0 - 30.0 cm	1,722	0.70	0.2202	0.0485	0.0053	31.41	1	0
	30.0 - 40.0 cm	304	0.70	0.2319	0.0538	0.0133	33.35	1	0
	≥ 40.0 cm	37	0.61	0.3420	0.1170	0.0562	56.47	1	0
Total		2,623	0.65	0.2810	0.0789	0.0055	43.03	1	0
1988	0 - 12.7 cm	374	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	485	0.56	0.3412	0.1164	0.0155	60.51	1	0
	20.0 - 30.0 cm	1,805	0.71	0.2286	0.0523	0.0054	32.41	1	0
	30.0 - 40.0 cm	355	0.71	0.3462	0.0606	0.0131	34.59	1	0
	≥ 40.0 cm	40	0.53	0.3849	0.1482	0.0609	72.67	1	0
Total		3,059	0.60	0.3323	0.1105	0.0060	55.84	1	0
1995	0 - 12.7 cm	255	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	426	0.48	0.3703	0.1371	0.0179	77.50	1	0
	20.0 - 30.0 cm	1,946	0.69	0.2481	0.0616	0.0056	36.22	1	0
	30.0 - 40.0 cm	444	0.71	0.2395	0.0573	0.0114	33.50	1	0
	≥ 40.0 cm	56	0.50	0.3744	0.1402	0.0500	74.37	1	0
Total		3,127	0.60	0.3248	0.1055	0.0058	53.95	1	0

Table B-12.—Plot similarity statistics for all plots by stand-size class, Arkansas, 1968-1995. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).

Survey years compared	Stand-size class	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1968/1978	0 - 12.7 cm	82	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	417	0.58	0.2961	0.0877	0.0145	51.20	1	0
	20.0 - 30.0 cm	1,722	0.77	0.2103	0.0442	0.0051	27.24	1	0
	30.0 - 40.0 cm	304	0.75	0.2378	0.0566	0.0136	31.72	1	0
	≥ 40.0 cm	37	0.56	0.3129	0.0979	0.0514	55.42	1	0
Total		2,562	0.71	0.2722	0.0741	0.0054	38.32	1	0
1978/1988	0 - 12.7 cm	119	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	435	0.46	0.3278	0.1075	0.0157	72.02	1	0
	20.0 - 30.0 cm	1,577	0.75	0.2097	0.0440	0.0053	27.85	1	0
	30.0 - 40.0 cm	334	0.74	0.2176	0.0474	0.0119	29.37	1	0
	≥ 40.0 cm	36	0.40	0.3527	0.1244	0.0588	87.61	1	0
Total		2,501	0.66	0.2996	0.0897	0.0060	45.48	1	0
1988/1995	0 - 12.7 cm	80	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	423	0.42	0.3572	0.1276	0.0174	84.65	1	0
	20.0 - 30.0 cm	1,923	0.78	0.2063	0.0425	0.0047	26.47	1	0
	30.0 - 40.0 cm	438	0.77	0.1991	0.0396	0.0095	25.78	1	0
	≥ 40.0 cm	56	0.53	0.3315	0.1099	0.0443	63.04	1	0
Total		2,920	0.70	0.2909	0.0846	0.0054	41.54	1	0

Table B-13.—Species richness statistics for all plantation plots, Arkansas, 1968-1995. Richness is based on trees ≥ 12.7 cm in DBH. *n* is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	<i>n</i>	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1968	147	3.73	1.9970	3.9879	0.1676	53.60	10	1
1978	159	3.20	2.0955	4.3909	0.2117	65.40	9	1
1988	329	2.53	1.7061	2.9109	0.1161	67.49	8	1
1995	422	2.56	1.8530	3.4336	0.0977	72.35	10	1

Table B-14.—Species evenness statistics for all plantation plots, Arkansas, 1968-1995. Evenness is based on trees ≥ 12.7 cm in DBH. *n* is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	<i>n</i>	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1968	147	0.57	0.3358	0.1127	0.0282	59.35	1	0
1978	159	0.46	0.3553	0.1262	0.0359	77.65	1	0
1988	329	0.38	0.3565	0.1271	0.0243	93.63	1	0
1995	422	0.36	0.3455	0.1194	0.0182	96.72	1	0

Table B-15.—Plot similarity statistics for plantation plots, Arkansas, 1968-1995. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).									
Survey years compared	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot	
1968/1978	147	0.36	0.3628	0.1316	0.0304	101.79	1	0	
1978/1988	155	0.52	0.3171	0.1009	0.0327	61.46	1	0	
1988/1995	327	0.56	0.3019	0.0912	0.0206	53.66	1	0	
1968/1995	422	0.33	0.2995	0.0897	0.0256	89.87	1	0	

Table B-16.—Species richness statistics for survivor plots, Arkansas, 1968-1995. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Year of survey	n	Mean number of species per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1968	772	4.87	2.3260	5.4102	0.0837	47.79	14	0
1978	772	5.38	2.1874	4.7848	0.0787	40.69	13	0
1988	772	5.63	2.2760	5.1800	0.0819	40.42	14	0
1995	772	5.92	2.3297	5.4274	0.0838	39.33	15	

Table B-17.—Species evenness statistics for survivor plots, Arkansas, 1968-1995. Number is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Year of survey	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1968	772	0.68	0.2625	0.0689	0.0094	38.38	1	0
1978	772	0.71	0.2153	0.0463	0.0077	30.25	1	0
1988	772	0.72	0.2089	0.0436	0.0075	29.21	1	0
1995	772	0.71	0.2084	0.0434	0.0075	29.35	1	0

Table B-18.—Plot similarity statistics for survivor plots, Arkansas, 1968-1995. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).

Survey year compared	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1968/1978	772	0.78	0.2294	0.0526	0.0083	29.44	1	0
1978/1988	772	0.79	0.1921	0.0369	0.0069	24.37	1	0
1988/1995	772	0.85	0.1485	0.0221	0.0054	17.41	1	0
1968/1995	772	0.63	0.2576	0.0663	0.0093	40.65	1	0

Table B-19.—Summary statistics for contrast of mean species richness, Arkansas, 1968-1995. Comparison is between all forested plots (including plantations) versus all forested plots (excluding plantations). Species richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year compared	Plot Grouping*	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1968	with	2,809	4.72	2.3404	5.4775	0.0442	49.59	15	0
1968	without	2,662	4.90	2.2460	5.0455	0.0456	45.85	15	1
1978	with	2,623	4.84	2.5158	6.3291	0.0491	52.02	17	0
1978	without	2,464	5.19	2.2690	5.1484	0.0465	43.69	17	1
1988	with	3,059	4.37	2.7582	7.6075	0.0499	63.10	16	0
1988	without	2,730	5.19	2.3025	5.3017	0.0463	44.33	16	1
1995	with	3,127	4.56	2.7456	7.5383	0.0491	60.15	16	0
1995	without	2,705	5.31	2.3747	5.6392	0.0474	44.68	16	1

*Denotes all forested plots with or without plantations.

Table B-20.-Summary test table for changes in species richness using ANOVA repeated measures design. Data includes all forested plots, Arkansas, 1968 to 1995.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	2,622				
Within years	7,869				
Change	3	12.04	4.01	43.87	0.0001
Residual	7,866	719.65	0.09		
Total	10,491				
----- Contrast between years -----					
Comparisons					
1968 vs. 1978				3.92	0.0478
1968 vs. 1988				87.90	0.0001
1968 vs. 1995				72.34	0.0001

Table B-21.-Summary test table for changes in the species evenness index using ANOVA repeated measures design. Data includes all forested plots, Arkansas, 1968 to 1995.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	2,622				
Within years	7,869	52,847.30			
Change	3	371.20	123.73	18.55	0.0001
Residual	7,866	52,476.10	6.67		
Total	10,491				
----- Contrast between years -----					
Comparisons					
1968 vs. 1978			2.32	0.1281	
1968 vs. 1988			31.51	0.0001	
1968 vs. 1995			7.41	0.0001	

Table B-22.-Summary test table for changes in plot similarity using ANOVA repeated measures design. Data includes all forested plots, Arkansas 1968 to 1995.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	2,500				
Within years	2,501	403.23			
Change	2	3.39	1.69	21.21	0.0001
Residual	5,000	399.84	0.08		
Total	5,001				
----- Contrast between years -----					
Comparisons					
1968/1978 vs. 1978/1988				41.52	0.0001
1968/1978 vs. 1988/1995				3.88	0.05

Table B-23.-Summary test table for changes in species richness for survivor plots using ANOVA repeated measures design. Data includes all forested survivor plots, Arkansas 1968 to 1995.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	771				
Within years	2,316	3,282.75			
Change	3	465.42	155.14	127.37	0.0001
Residual	2,313	2,817.33	1.22		
Total	3,087				
----- Contrast between years -----					
Comparisons					
1968 vs. 1978				112.19	0.0001
1968 vs 1988				132.33	0.0001
1968 vs. 1995				208.63	0.0001

Table B-24.-Summary test table for changes in species evenness for survivor plots using ANOVA repeated measures design. Data includes all forested survivor plots, Arkansas 1968 to 1995.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	771				
Within years	2,316	50.34			
Change	3	0.47	0.16	7.31	0.0001
Residual	2,313	49.87	0.02		
Total	3,087				
----- Contrast between years -----					
Comparisons					
1968 vs. 1978				12.74	0.0004
1968 vs. 1988				11.45	0.0008
1968 vs. 1995				7.71	0.0056

Table B-25.-Summary test table for changes in plot similarity for survivor plots using ANOVA repeated measures design. Data includes all forested survivor plots, Arkansas 1968 to 1995.					
Source	df	SS	MS	F	P
----- Test of the overall effect of time -----					
Among years	771				
Within years	1,544	55.98			
Change	2	1.79	0.90	25.51	0.0001
Residual	1,542	54.19	0.04		
Total	2,315				
----- Contrast between years -----					
Comparisons					
1968/1978 vs. 1978/1988				0.39	0.5327
1968/1978 vs. 1988/1995				37.30	0.0001

Table B-26.-Summary test table for comparing changes in species richness by ownership classes. Test is factorial ANOVA design with repeated measures and between group factors, Arkansas, 1968 to 1995.

Source	df	SS	MS	F	p
Among subjects	2,622	17,191.38			
Group	2	331.13	165.56	24.23	0.0001
Residual between	2,620	16,860.25	6.83		
Within subjects	7,869	49,601.14			
Time	3	185.40	61.80	9.36	0.0001
Time x group	6	552.90	92.15	13.96	0.0001
Residual within	7,860	48,862.84	6.60		
Totals	10,491	66,792.52			

Table B-27.--Summary test table for comparing changes in species richness by physiographic classes. Test is factorial ANOVA design with repeated measures and between group factors, Arkansas, 1968 to 1995.					
Source	df	SS	MS	F	p
Among subjects	2,622	18,347.97			
Group	2	291.71	145.86	21.16	0.0001
Residual between	2,620	18,056.26	6.89		
Within subjects	7,869	52,875.30			
Time	3	399.24	133.08	20.27	0.0001
Time x group	6	881.36	146.89	22.38	0.0001
Residual within	7,860	51,594.70	6.56		
Totals	10,491	71,223.27			

Table B-28. -Summary test table for test comparing changes in species richness by stand-size class classes. Test is factorial ANOVA design with repeated measures and between group factors, Arkansas, 1968 to 1995.

Source	df	SS	MS	F	p
Among subjects	2,622	27,218.47			
Group	3	1,296.25	432.08	46.70	0.0001
Residual between	2,619	25,922.22	9.25		
Within subjects	7,869	80,437.88			
Time	3	435.14	145.05	15.65	0.0001
Time x group	9	2,098.48	233.16	25.16	0.0001
Residual within	7,857	77,904.26	9.27		
Totals	10,491	107,656.35			

Table B-29.-Summary test table for test comparing species richness in all forest plots (with plantations included) versus all forest plots (with plantations excluded). Test is factorial ANOVA design with repeated measures and between group factors, Arkansas, 1968 to 1995.

Source	df	SS	MS	F	p
Among subjects	5,092	34,932.78			
Group	1	298.42	298.42	43.86	0.0001
Residual between	5,091	34,634.36	6.80		
Within subjects	15,279	100,090.42			
Time	3	415.93	138.64	21.26	0.0001
Time x group	3	83.59	27.86	4.27	0.0051
Residual within	15,273	99,590.90	6.52		
Totals	20,371	135,023.20			

APPENDIX C

ARKANSAS DIVERSITY GRAPHS

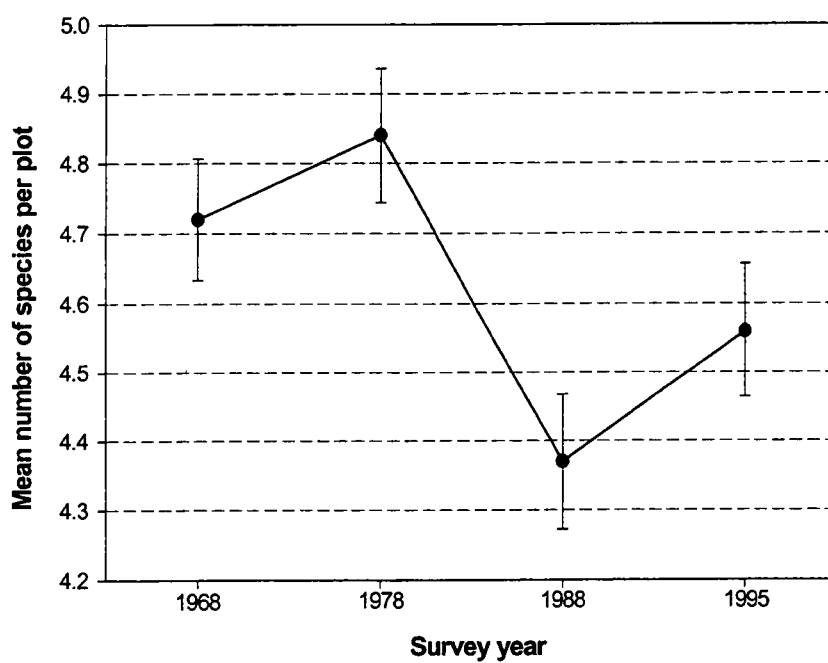


Figure C-1. Mean species richness per plot, Arkansas, 1968-1995, all plots. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-1.

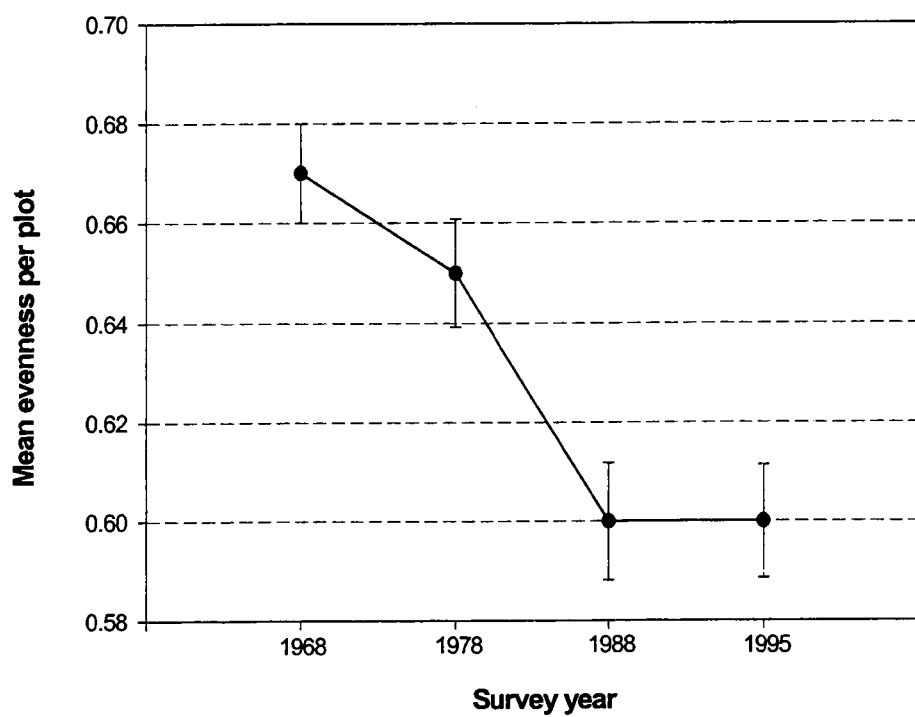


Figure C-2. Mean species evenness per plot, Arkansas, 1968-1995, all plots. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-2.

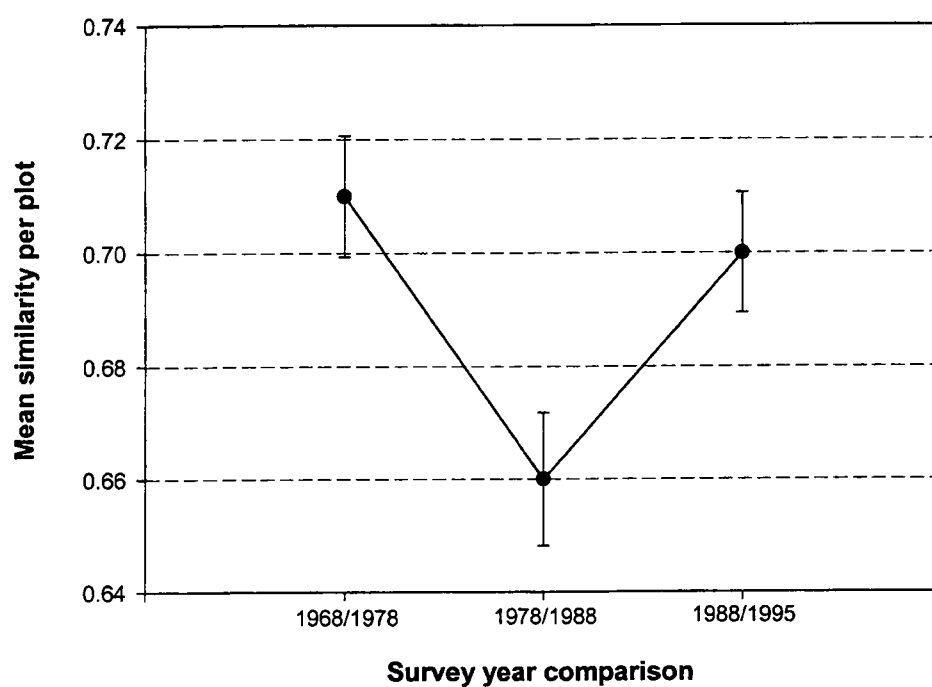


Figure C-3. Mean plot similarity, Arkansas, 1968-1995, all plots.
The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-3.

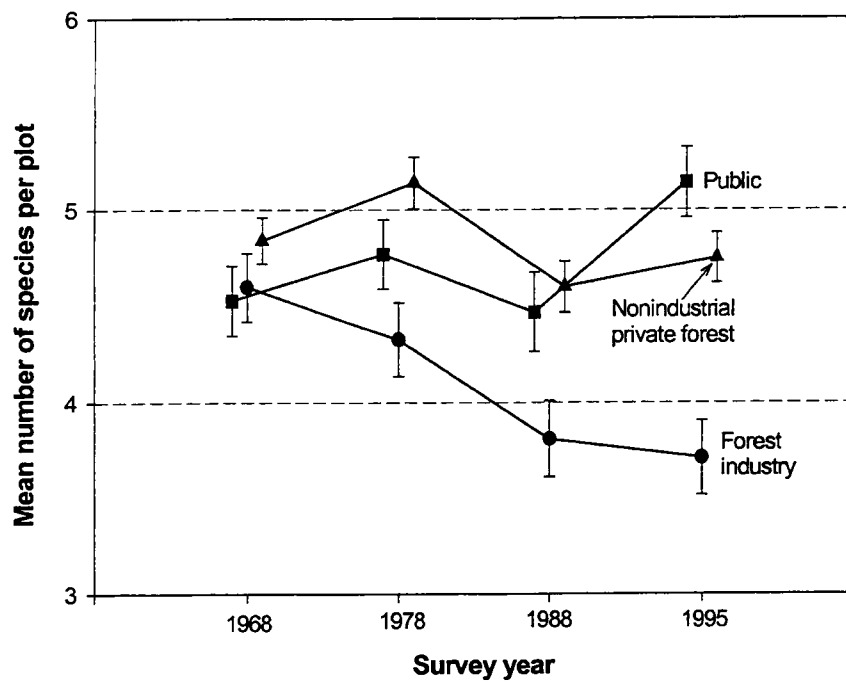


Figure C-4. Mean species richness per plot by ownership, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-4.

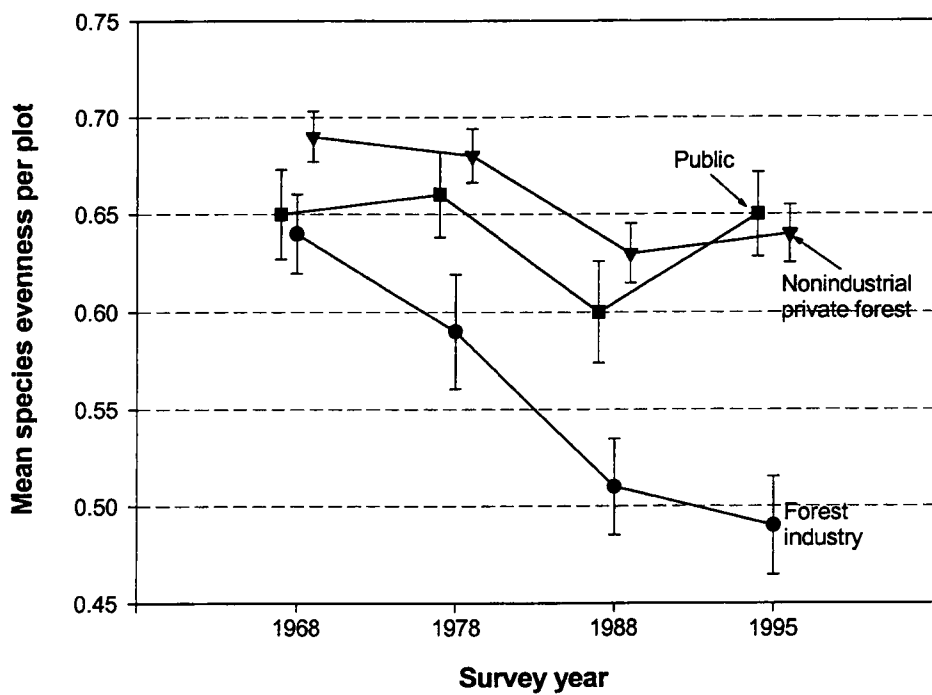


Figure C-5. Mean species evenness per plot by ownership, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-5.

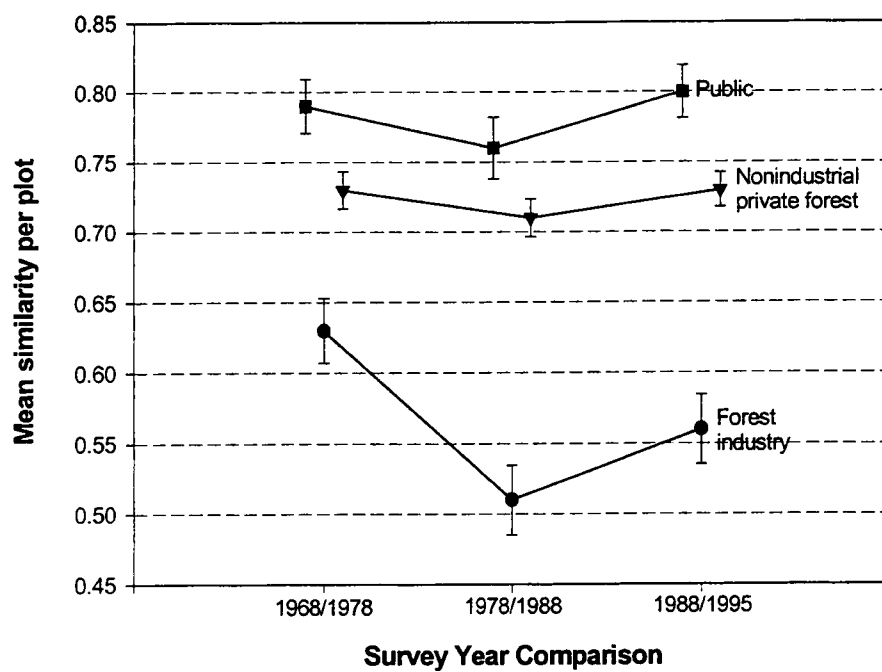


Figure C-6. Mean plot similarity by ownership, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-6.

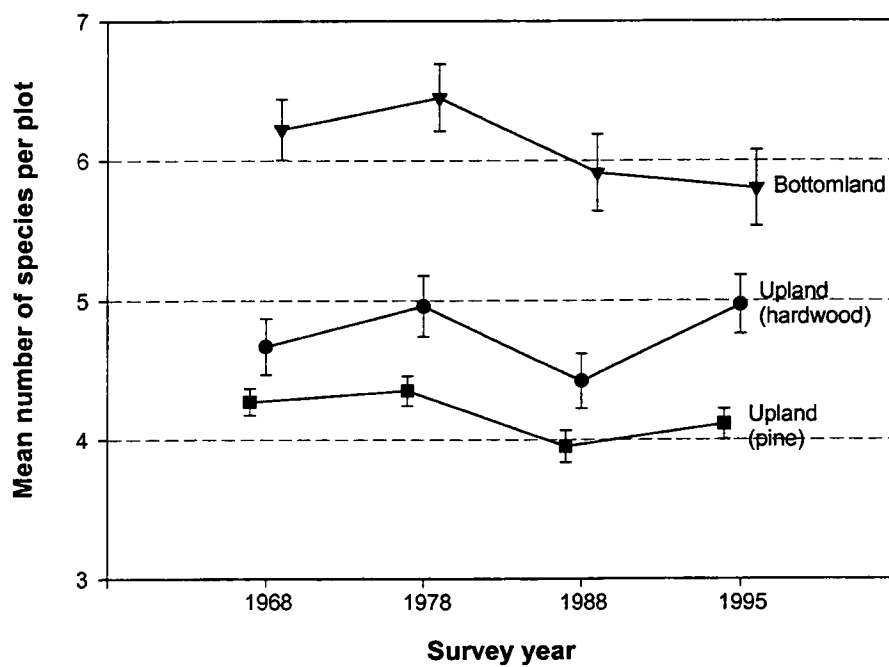


Figure C-7. Mean species richness per plot by physiographic class, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-7.

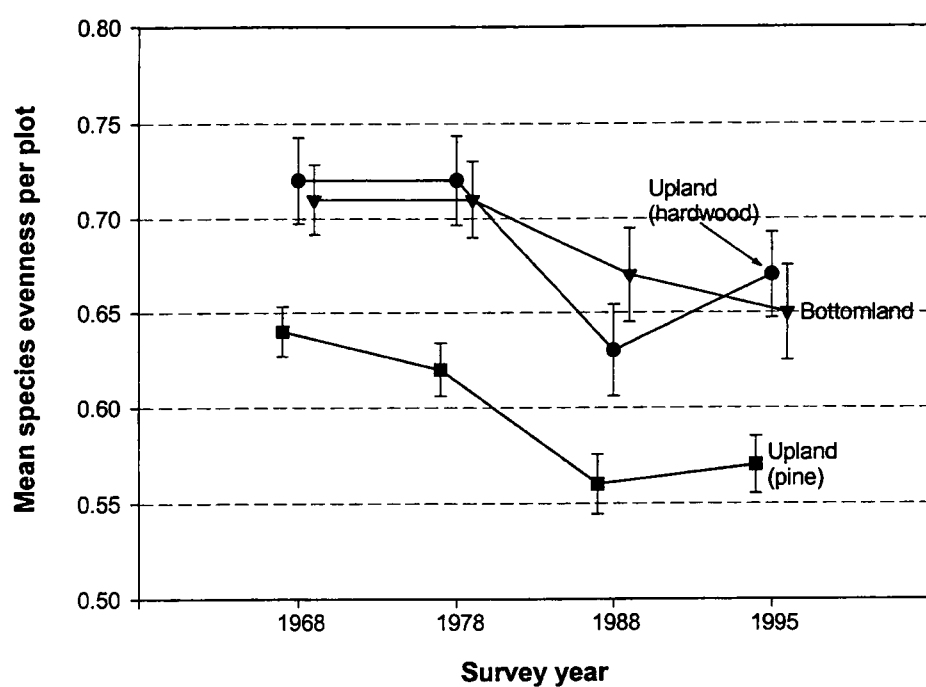


Figure C-8. Mean species evenness per plot by physiographic class, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-8.

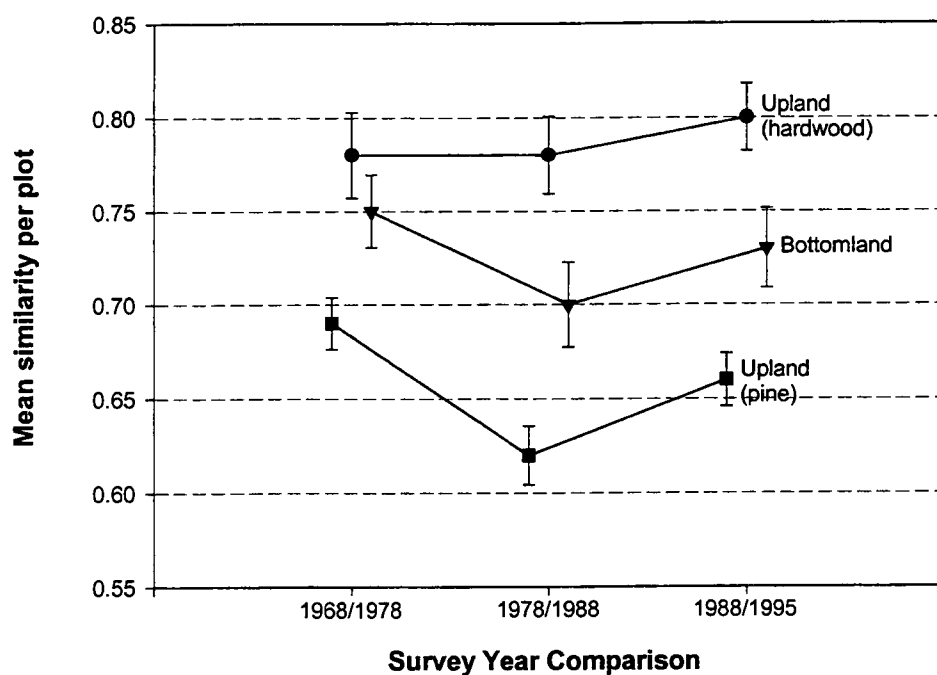


Figure C-9. Mean plot similarity by physiographic class, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-9.

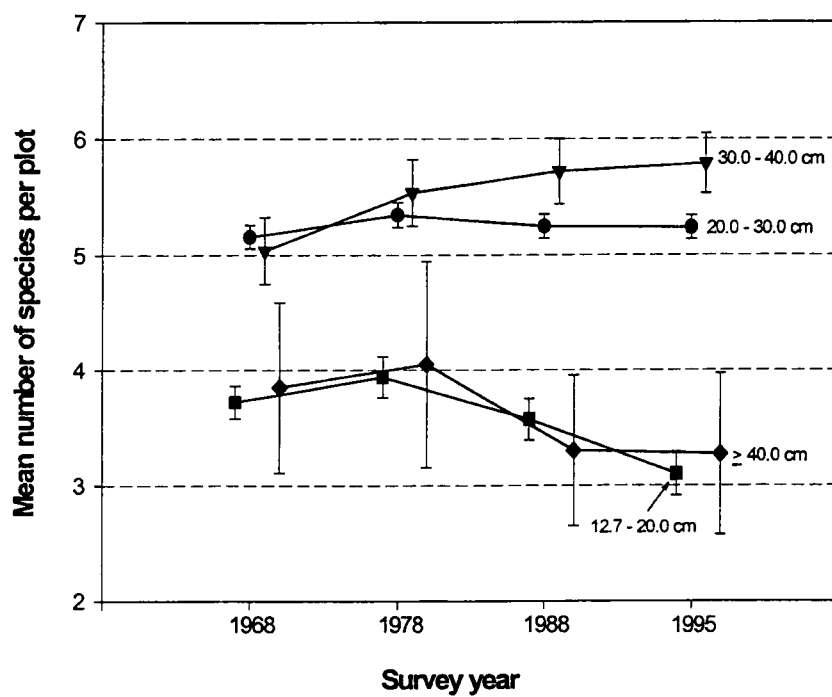


Figure C-10. Mean species richness per plot by stand-size class, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-10.

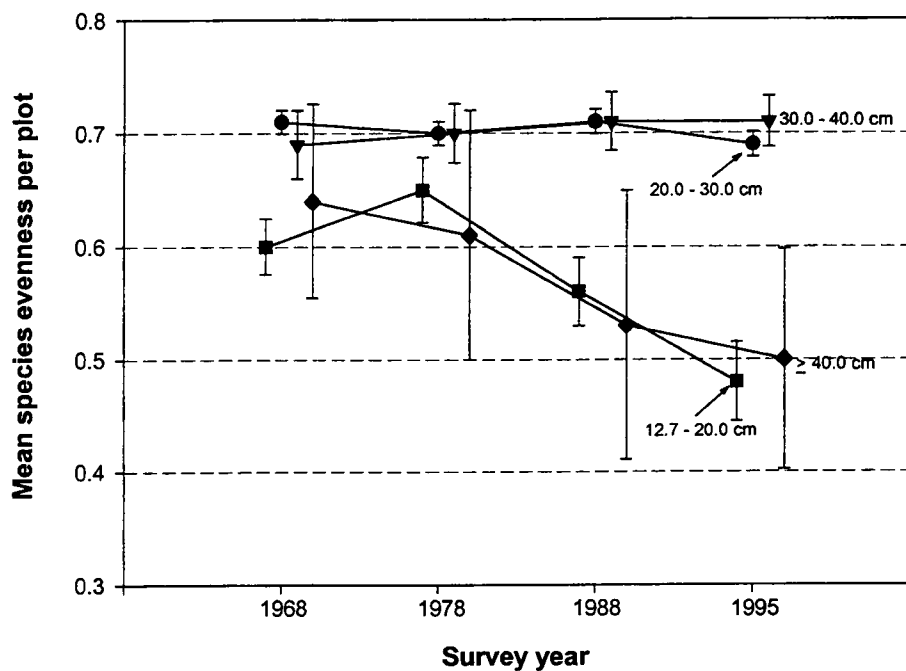


Figure C-11. Mean species evenness per plot by stand-size class, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-11.

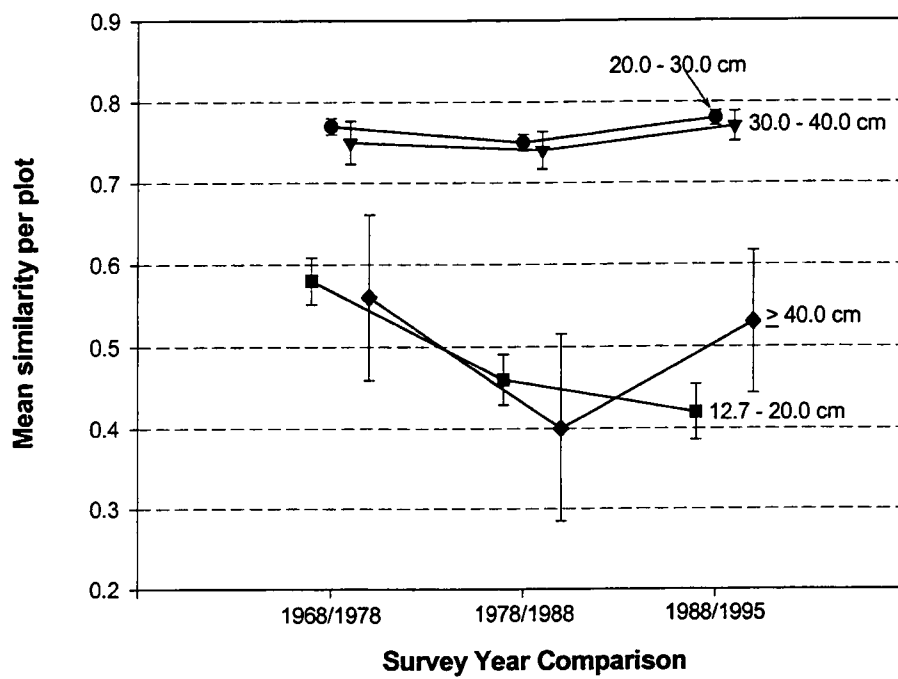


Figure C-12. Mean plot similarity by stand-size class, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-12.

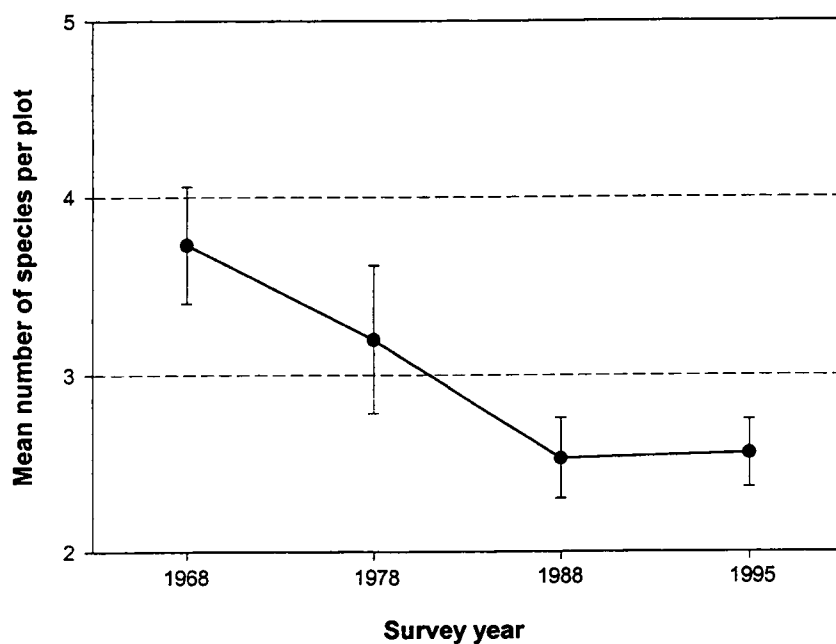


Figure C-13. Mean species richness per plot for plantation plots, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-13.

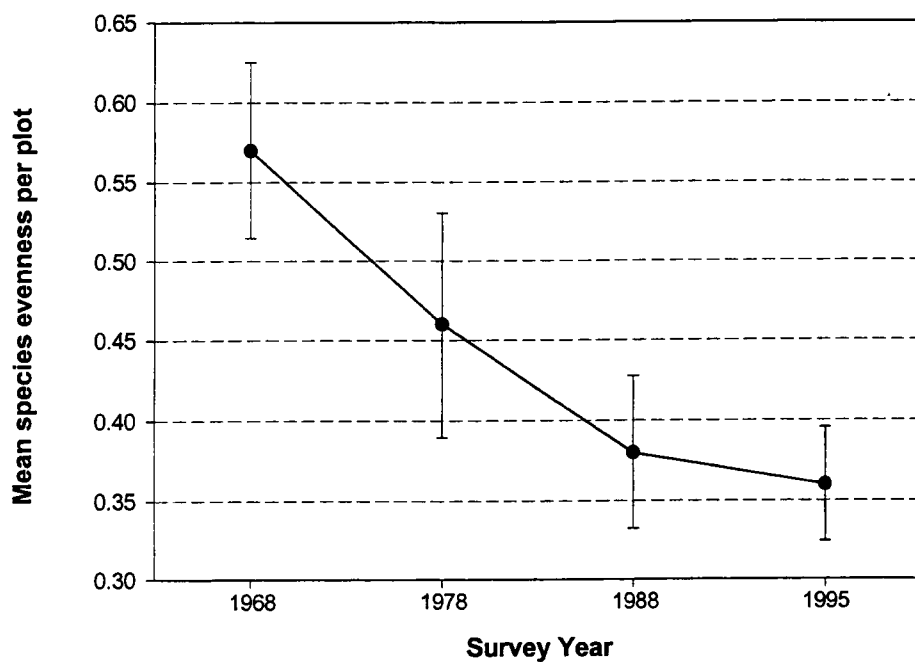


Figure C-14. Mean species evenness per plot for plantation plots, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-14.

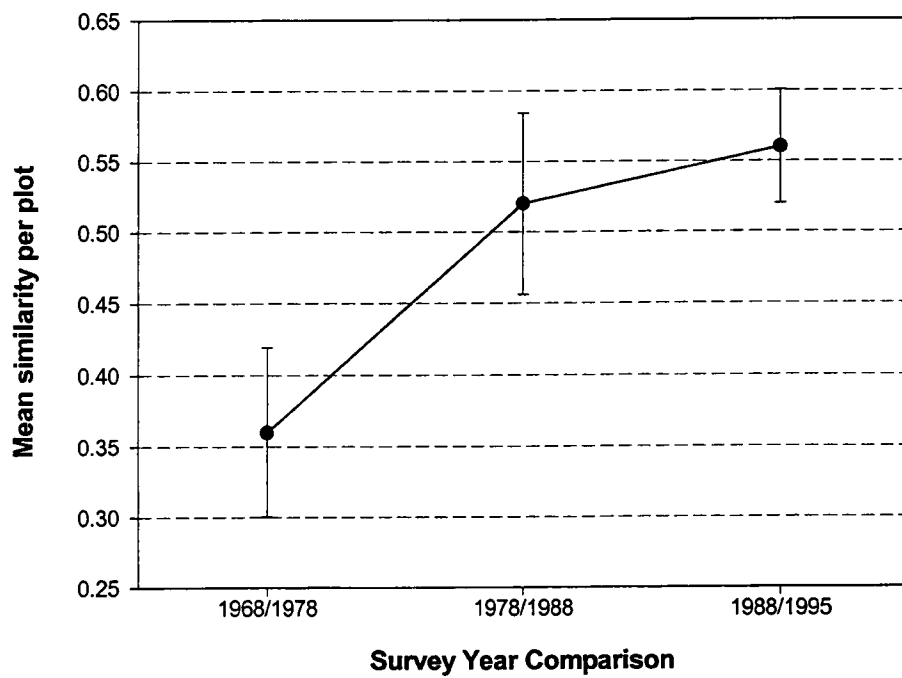


Figure C-15. Mean plot similarity for plantation plots, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-15.

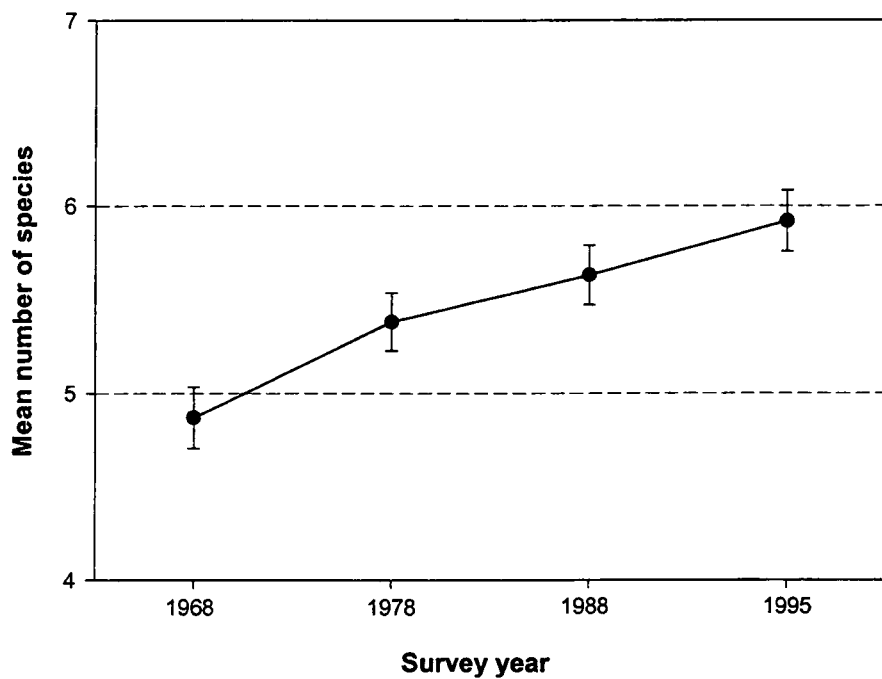


Figure C-16. Mean species richness per plot for survivor plots, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-16.

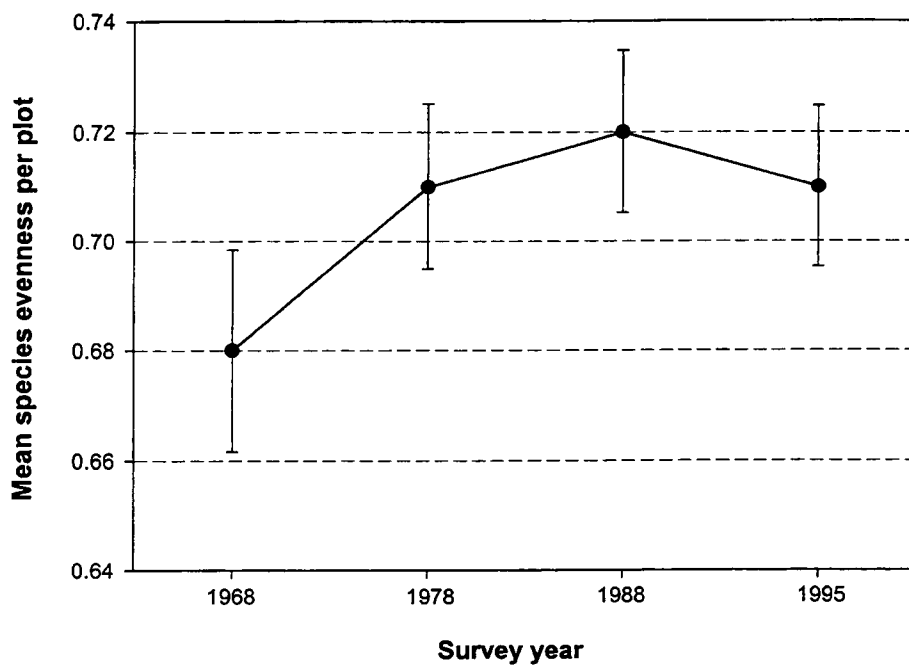


Figure C-17. Mean species evenness per plot for survivor plots, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-17.

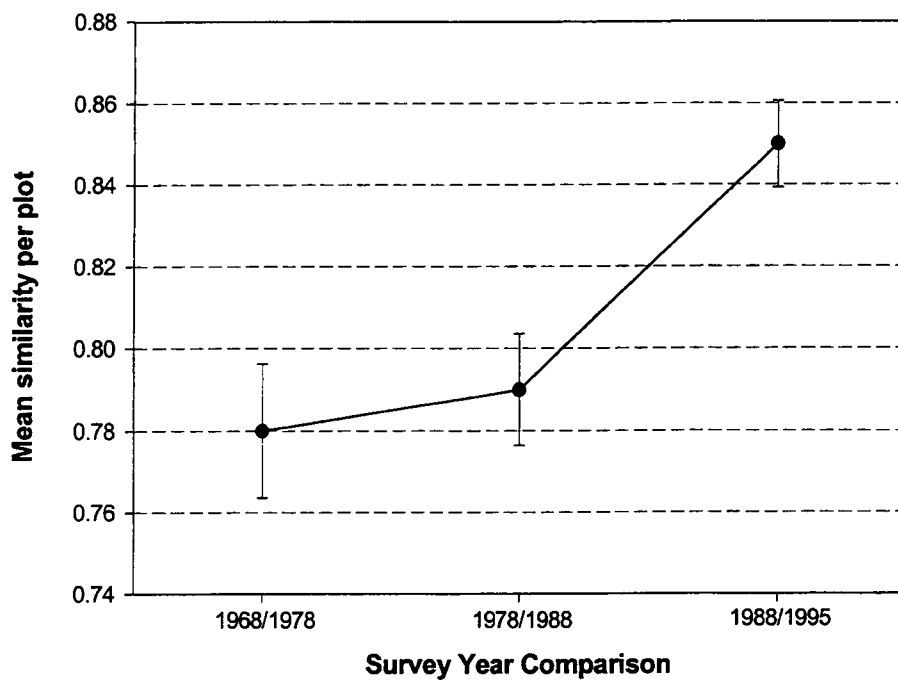


Figure C-18. Mean plot similarity for survivor plots, Arkansas, 1968-1995. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-18.

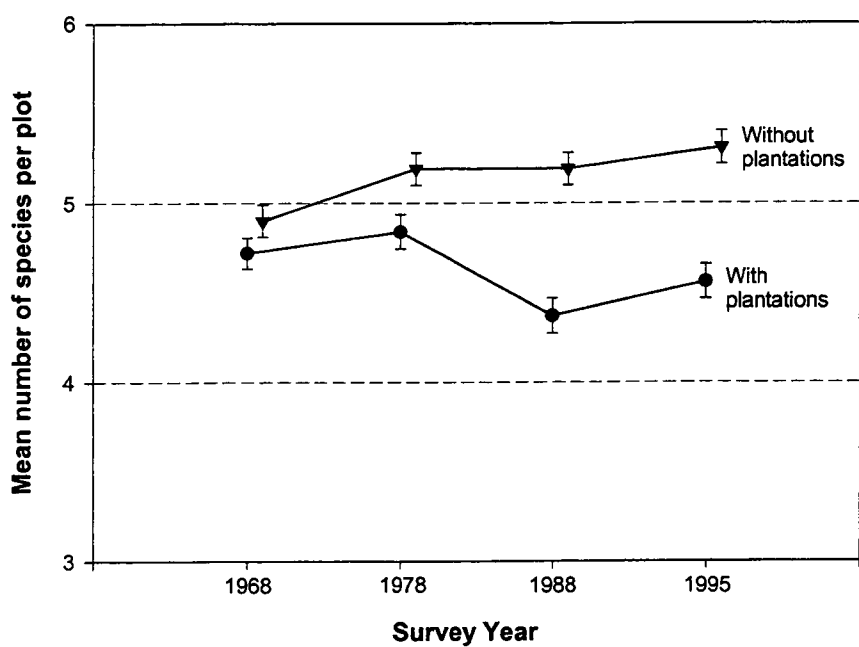


Figure C-19. Contrast of mean species richness per plot, Arkansas, 1968 to 1995. Comparison is between all forest plots (including plantations) versus all forest plots (excluding plantations). The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table B-19.

APPENDIX D

ARKANSAS DIVERSITY MAPS

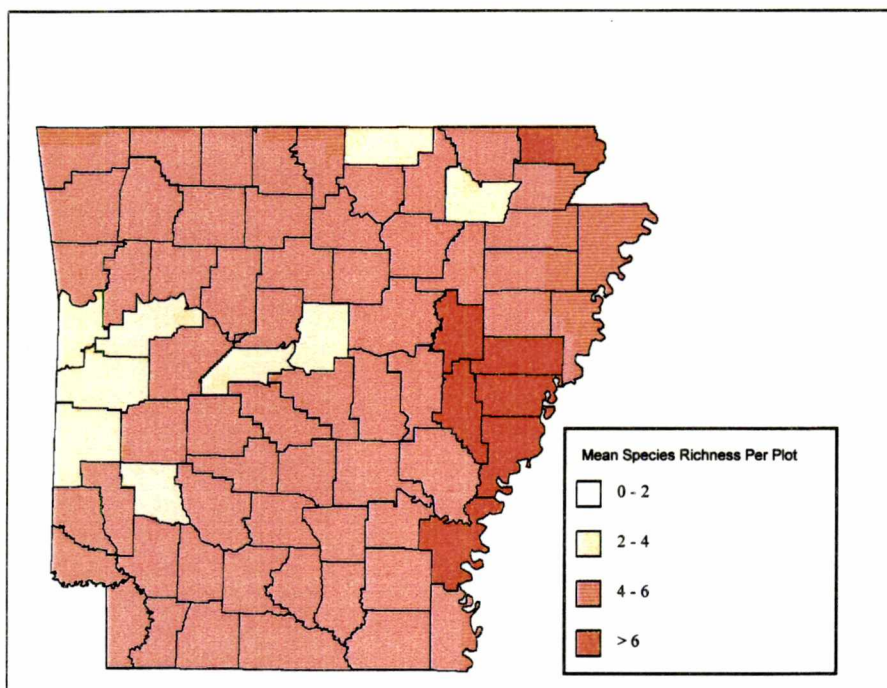


Figure D-1. Distribution of species richness across Arkansas, 1968. Species richness is the mean of plots aggregated to the county level.

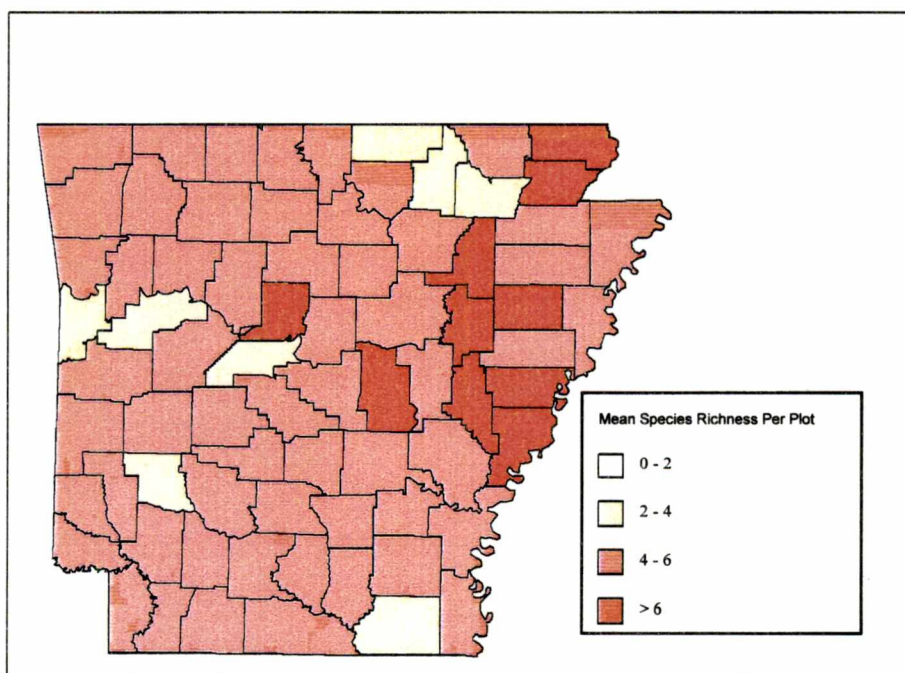


Figure D-2. Distribution of species richness across Arkansas, 1978. Species richness is the mean of plots aggregated to the county level.

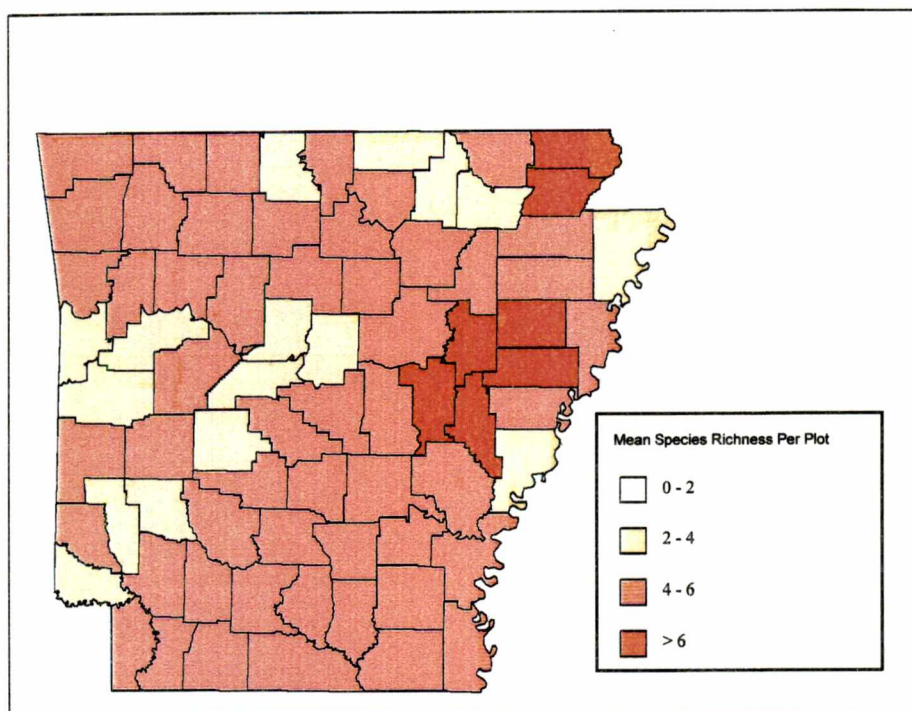


Figure D-3. Distribution of species richness across Arkansas, 1988. Species richness is the mean of plots aggregated to the county level.

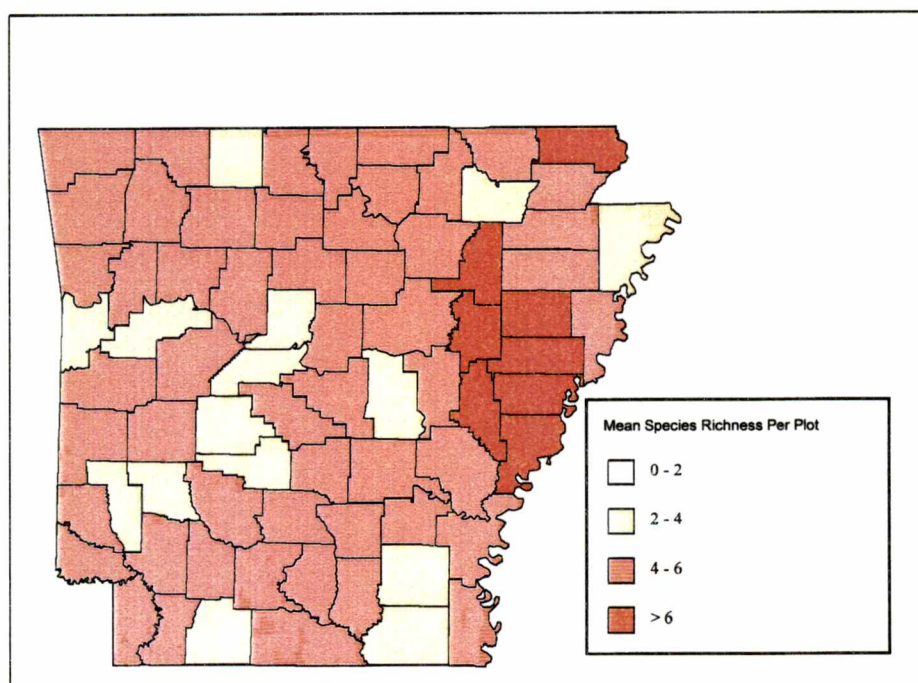


Figure D-4. Distribution of species richness across Arkansas, 1995. Species richness is the mean of plots aggregated to the county level.

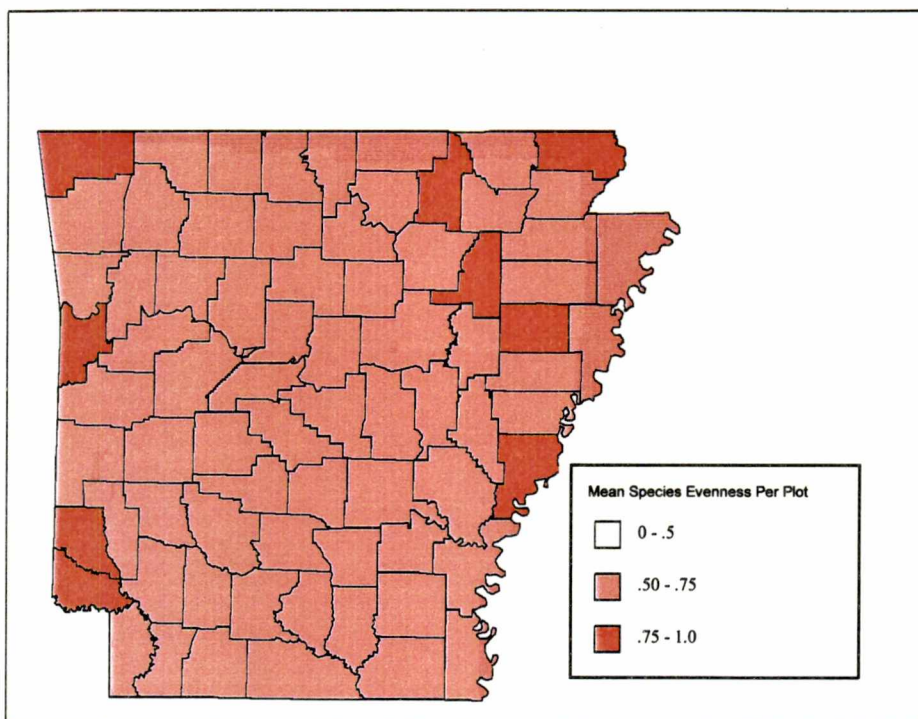


Figure D-5. Distribution of species evenness across Arkansas, 1968. Species evenness is the mean of plots aggregated to the county level.

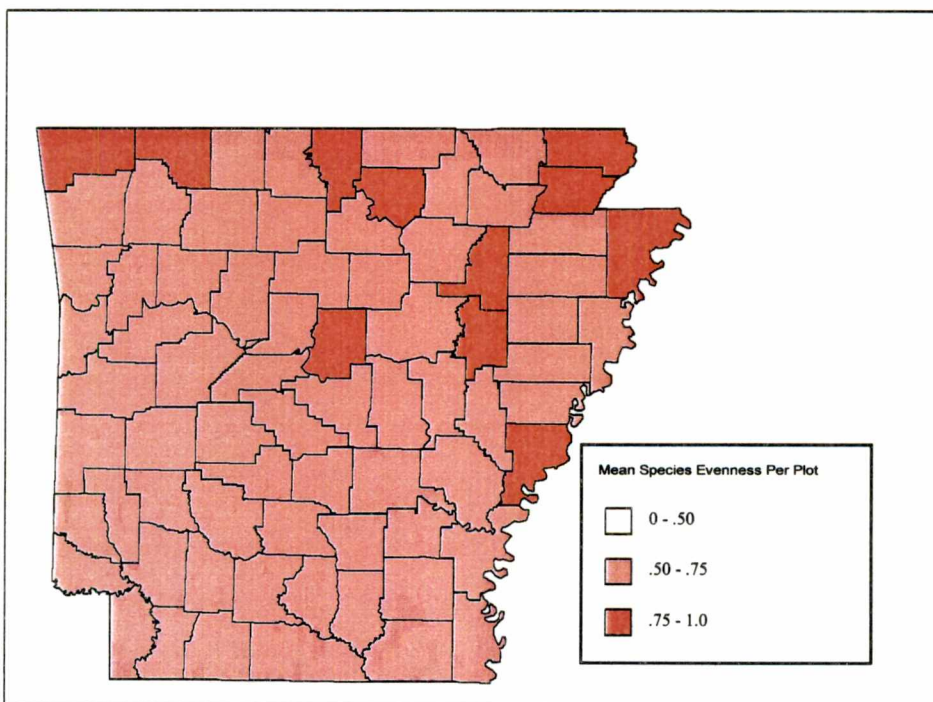


Figure D-6. Distribution of species evenness across Arkansas, 1978. Species evenness is the mean of plots aggregated to the county level.

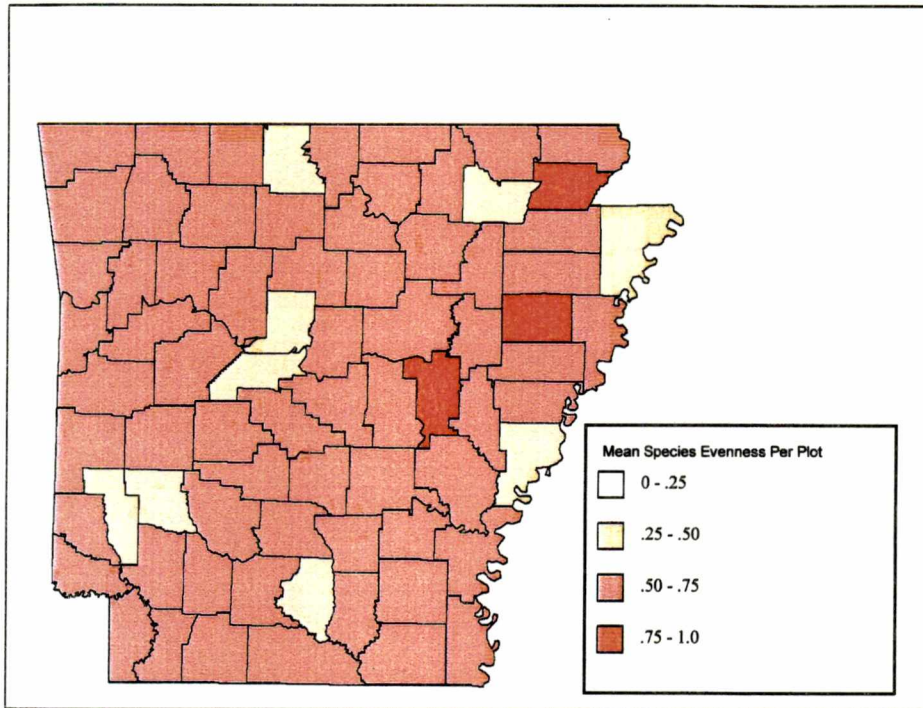


Figure D-7. Distribution of species evenness across Arkansas, 1988. Species evenness is the mean of plots aggregated to the county level.

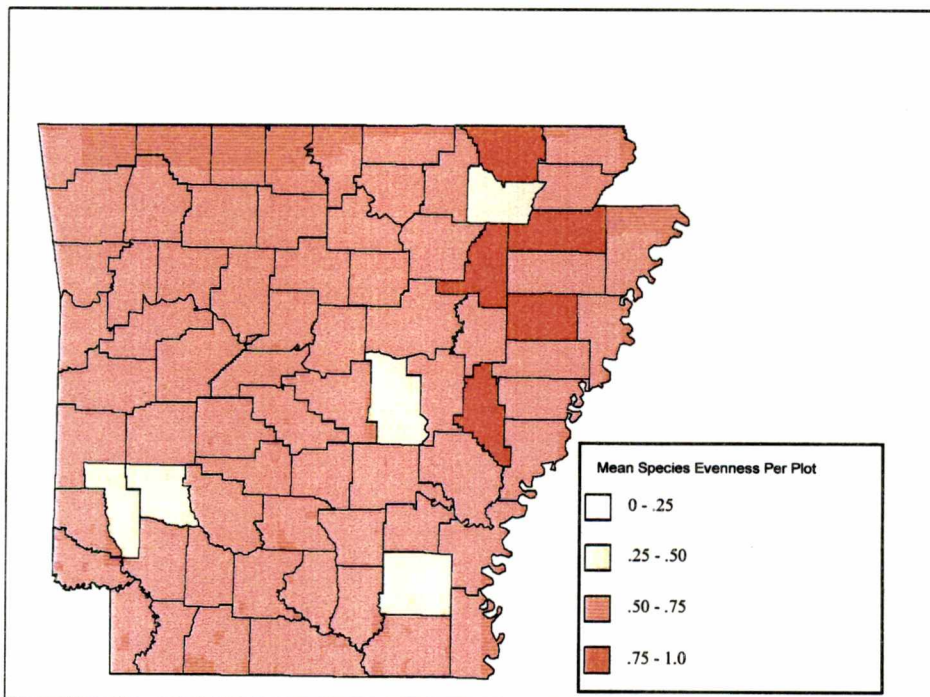


Figure D-8. Distribution of species evenness across Arkansas, 1995. Species evenness is the mean of plots aggregated to the county level.

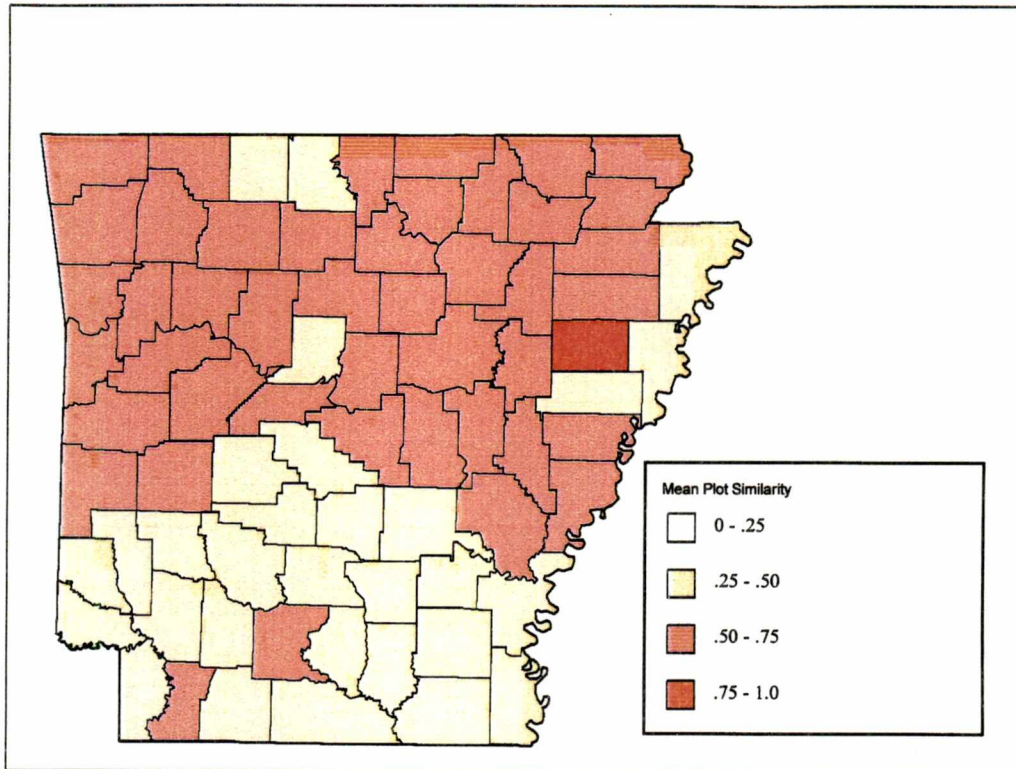


Figure D-9. Distribution of plot similarity across Arkansas. Plot similarity is the mean of plots aggregated to the county level. Comparisons were between the 1968 and 1995 survey years.

APPENDIX E

MISSISSIPPI DIVERSITY TABLES

Table E-1.—Species richness statistics for all plots, Mississippi, 1967-1994. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1967	2,990	4.53	2.7629	7.6335	0.0505	60.96	14	0
1977	2,806	5.02	2.9683	8.8109	0.0560	59.09	17	0
1987	2,958	4.82	3.3232	11.0437	0.0611	68.94	15	0
1994	3,180	4.49	3.3397	11.1533	0.0592	74.44	16	0

Table E-2.—Species evenness statistics for all plots, Mississippi, 1967-1994. Number of species is from trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1967	2,990	0.63	0.3155	0.0995	0.0058	50.42	1	0
1977	2,806	0.64	0.3043	0.0926	0.0057	47.81	1	0
1987	2,958	0.58	0.3412	0.1164	0.0063	58.35	1	0
1994	3,180	0.56	0.3579	0.1281	0.0063	63.79	1	0

Table E-3.—Plot similarity statistics for all plots, Mississippi, 1967-1994. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).

Survey years compared	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1967/1977	2,700	0.61	0.3001	0.0901	0.0058	49.21	1	0
1977/1987	2,670	0.61	0.3100	0.0961	0.0060	50.96	1	0
1987/1994	2,879	0.61	0.3347	0.1120	0.0062	54.88	1	0
1967/1994	2,626	0.39	0.2915	0.0850	0.0057	74.22	1	0

Table E-4.—Species richness statistics for all plots by ownership, Mississippi, 1967-1994. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	Ownership class	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1967	Public	296	4.35	2.6565	7.0568	0.1544	61.00	11	0
	Forest industry	514	4.21	2.8251	7.9814	0.1246	67.04	13	0
	Nonindustrial private forest	2,180	4.63	2.7566	7.5987	0.0590	59.52	14	0
	Total	2,990	4.53	2.7629	7.6335	0.0505	60.96	14	0
1977	Public	296	4.98	2.6476	7.0098	0.1539	53.17	11	0
	Forest industry	510	4.32	3.0616	9.3731	0.1356	70.88	15	0
	Nonindustrial private forest	2,000	5.21	2.9633	8.7810	0.0663	56.88	17	0
	Total	2,806	5.02	2.9683	8.8109	0.0560	59.09	17	0
1987	Public	390	4.63	3.4129	11.6480	0.1728	73.74	15	0
	Forest industry	550	3.81	3.2968	10.8688	0.1406	86.55	15	0
	Nonindustrial private forest	2,018	5.13	3.2561	10.6021	0.0725	63.44	15	0
	Total	2,958	4.82	3.3232	11.0437	0.0611	68.94	15	0
1994	Public	408	5.32	3.2933	10.8457	0.1630	61.95	13	0
	Forest industry	546	3.58	3.1445	9.8877	0.1346	87.78	15	0
	Nonindustrial private forest	2,226	4.56	3.3463	11.1980	0.0709	73.45	16	0
	Total	3,180	4.49	3.3397	11.1533	0.0592	74.44	16	0

Table E-5.—Species evenness statistics for all plots by ownership, Mississippi, 1967-1994. Evenness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	Ownership class	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1967	Public	296	0.62	0.3192	0.1019	0.0186	51.81	1	0
	Forest industry	514	0.57	0.3368	0.1134	0.0149	59.21	1	0
	Nonindustrial private forest	2,180	0.64	0.3083	0.0950	0.0066	48.14	1	0
	Total	2,990	0.63	0.3155	0.0995	0.0058	50.42	1	0
1977	Public	296	0.66	0.2903	0.0843	0.0169	43.86	1	0
	Forest industry	510	0.56	0.3433	0.1178	0.0152	61.06	1	0
	Nonindustrial private forest	200	0.65	0.2928	0.0857	0.0065	44.93	1	0
	Total	2,806	0.64	0.3043	0.0926	0.0057	47.81	1	0
1987	Public	390	0.57	0.3535	0.1250	0.0179	62.03	1	0
	Forest industry	550	0.47	0.3667	0.1344	0.0156	78.24	1	0
	Nonindustrial private forest	2,018	0.62	0.3242	0.1051	0.0072	52.34	1	0
	Total	2,958	0.58	0.3412	0.1164	0.0063	58.35	1	0
1994	Public	408	0.63	0.3136	0.0984	0.0155	49.99	1	0
	Forest industry	546	0.46	0.3737	0.1397	0.0160	81.49	1	0
	Nonindustrial private forest	2,226	0.57	0.3568	0.1273	0.0076	62.15	1	0
	Total	3,180	0.56	0.3579	0.1281	0.0063	63.79	1	0

Table E-6.—Plot similarity statistics for all plots by ownership, Mississippi, 1967-1994. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).										
Survey year	Ownership class	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot	
1967/	Public	287	0.66	0.2914	0.0849	0.0172	44.33	1	0	
1977	Forest industry	502	0.53	0.3419	0.1169	0.0153	64.20	1	0	
	Nonindustrial private forest	1,911	0.62	0.2860	0.0818	0.0065	45.91	1	0	
	Total	2,700	0.61	0.3001	0.0901	0.0058	49.21	1	0	
1977/	Public	311	0.69	0.2555	0.0653	0.0145	37.22	1	0	
1987	Forest industry	537	0.45	0.3695	0.1366	0.0159	82.04	1	0	
	Nonindustrial private forest	1,822	0.64	0.2829	0.0801	0.0066	44.10	1	0	
	Total	2,670	0.61	0.3100	0.0961	0.0060	50.96	1	0	
1987/	Public	392	0.72	0.2992	0.0895	0.0151	41.37	1	0	
1994	Forest industry	535	0.47	0.3755	0.1410	0.0162	80.19	1	0	
	Nonindustrial private forest	1,952	0.63	0.3168	0.1004	0.0072	50.62	1	0	
	Total	2,879	0.61	0.3347	0.1120	0.0062	54.88	1	0	

Table E-7.—Species richness statistics for all plots by physiographic class, Mississippi, 1967-1994. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	Physiographic class	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1967	Upland (pine)	2,098	4.04	2.5292	6.3967	0.0552	62.68	14	0
	Upland (hardwood)	102	6.63	3.0795	9.4836	0.3049	46.47	14	0
	Bottomland	790	5.58	2.8963	8.3886	0.1030	51.92	14	0
	Total	2,990	4.53	2.7629	7.6335	0.0505	60.96	14	0
1977	Upland (pine)	1,984	4.60	2.7866	7.7650	0.0626	60.57	15	0
	Upland (hardwood)	100	7.21	3.6551	13.3595	0.3655	50.69	17	0
	Bottomland	722	5.88	3.0316	9.1903	0.1128	51.53	16	0
	Total	2,806	5.02	2.9683	8.8109	0.0560	59.09	17	0
1987	Upland (pine)	2,135	4.21	3.1337	9.8200	0.0678	74.52	15	0
	Upland (hardwood)	227	6.88	3.6042	12.9902	0.2392	52.38	15	0
	Bottomland	596	6.23	3.1238	9.7581	0.1280	50.13	15	0
	Total	2,958	4.82	3.3232	11.0437	0.0611	68.94	15	0
1994	Upland (pine)	2,332	3.89	3.1089	9.6652	0.0644	79.85	14	0
	Upland (hardwood)	158	7.53	3.5381	12.5181	0.0282	46.98	16	0
	Bottomland	690	5.79	3.2992	10.8844	0.0126	56.95	15	0
	Total	3,180	4.49	3.3397	11.1533	0.0592	74.44	16	0

Table E-8.—Species evenness statistics for all plots by physiographic class, Mississippi, 1967-1994. Evenness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	Physiographic class	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1967	Upland (pine)	2,098	0.60	0.3285	0.1079	0.0072	54.51	1	0
	Upland (hardwood)	102	0.72	0.2609	0.0681	0.0258	36.26	1	0
	Bottomland	790	0.67	0.2768	0.0766	0.0098	41.07	1	0
	Total	2,990	0.63	0.3155	0.0995	0.0058	50.42	1	0
1977	Upland (pine)	1,984	0.62	0.3142	0.0987	0.0071	50.66	1	0
	Upland (hardwood)	100	0.70	0.2805	0.0787	0.0281	40.09	1	0
	Bottomland	722	0.67	0.2743	0.0752	0.0102	40.82	1	0
	Total	2,806	0.64	0.3043	0.0926	0.0057	47.81	1	0
1987	Upland (pine)	2,135	0.54	0.3566	0.1272	0.0077	65.70	1	0
	Upland (hardwood)	227	0.70	0.2828	0.0800	0.0188	40.18	1	0
	Bottomland	596	0.69	0.2637	0.0696	0.0108	38.25	1	0
	Total	2,958	0.58	0.3412	0.1164	0.0063	58.35	1	0
1994	Upland (pine)	2,332	0.52	0.3726	0.1388	0.0077	71.22	1	0
	Upland (hardwood)	158	0.73	0.2339	0.0547	0.0186	32.05	1	0
	Bottomland	690	0.65	0.2992	0.0895	0.0114	45.98	1	0
	Total	3,180	0.56	0.3579	0.1281	0.0063	63.79	1	0

Table E-9.—Plot similarity statistics for all plots by physiographic class, Mississippi, 1967-1994. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).									
Survey year compared	Physiographic class	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1967/1977	Upland (pine)	1,913	0.59	0.3053	0.0932	0.0070	51.86	1	0
	Upland (hardwood)	90	0.68	0.2456	0.0603	0.0259	36.00	1	0
	Bottomland	697	0.66	0.2850	0.0812	0.0108	43.27	1	0
	Total	2,700	0.61	0.3001	0.0901	0.0058	49.21	1	0
1977/1987	Upland (pine)	1,905	0.57	0.3253	0.1058	0.0075	56.87	1	0
	Upland (hardwood)	205	0.71	0.2248	0.0505	0.0157	31.66	1	0
	Bottomland	560	0.69	0.2534	0.0642	0.0107	36.47	1	0
	Total	2,670	0.61	0.3100	0.0961	0.0060	50.96	1	0
1987/1994	Upland (pine)	2,090	0.57	0.3485	0.1214	0.0076	61.18	1	0
	Upland (hardwood)	152	0.72	0.2311	0.0534	0.0187	32.08	1	0
	Bottomland	637	0.72	0.2756	0.0760	0.0109	38.50	1	0
	Total	2,879	0.61	0.3347	0.1120	0.0062	54.88	1	0

Table E-10.—Species richness statistics for all plots by stand-size class, Mississippi, 1967-1994. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.									
Survey year	Stand-size class	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1967	0 - 12.7 cm	180	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	676	3.44	2.0814	4.3322	0.0801	60.57	13	1
	20.0 - 30.0 cm	1,848	5.31	2.5572	6.5393	0.0595	48.15	14	1
	30.0 - 40.0 cm	252	5.13	2.7475	7.5485	0.1731	53.55	14	1
	≥ 40.0 cm	34	3.35	2.2681	5.1444	0.3890	67.65	11	1
Total		2,990	4.53	2.7629	7.6335	0.0505	60.96	14	1
1977	0 - 12.7 cm	189	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	506	3.75	2.1050	4.4309	0.0936	56.06	11	1
	20.0 - 30.0 cm	1,806	5.80	2.6884	7.2276	0.0633	46.37	17	1
	30.0 - 40.0 cm	272	5.99	2.8518	8.1328	0.1729	47.59	14	1
	≥ 40.0 cm	33	2.91	2.2272	4.9602	0.3877	76.56	8	1
Total		2,806	5.02	2.9683	8.8109	0.0560	59.09	17	1
1987	0 - 12.7 cm	433	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	453	3.54	2.1660	4.6915	0.1018	61.21	11	1
	20.0 - 30.0 cm	1,684	6.14	2.7188	7.3919	0.0663	44.26	15	1
	30.0 - 40.0 cm	354	6.15	3.1191	9.7291	0.1658	50.74	15	1
	≥ 40.0 cm	34	3.71	2.7910	7.7897	0.4787	75.31	10	1
Total		2,958	4.82	3.3232	11.0437	0.0611	68.94	15	1
1994	0 - 12.7 cm	466	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	568	2.84	1.9753	3.9020	0.0829	69.56	12	1
	20.0 - 30.0 cm	1,625	5.85	2.8133	7.9149	0.0698	48.07	16	1
	30.0 - 40.0 cm	463	6.28	3.0829	9.5045	0.1433	49.10	15	1
	≥ 40.0 cm	58	4.07	3.0999	9.6092	0.4070	76.18	12	1
Total		3,180	4.49	3.3397	11.1533	0.0592	74.44	16	1

Table E-11.—Species evenness statistics for all plots by stand-size class, Mississippi, 1967-1994. Evenness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	Stand-size class	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1967	0 - 12.7 cm	180	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	676	0.57	0.3349	0.1121	0.0129	58.47	1	0
	20.0 - 30.0 cm	1,848	0.70	0.2491	0.0620	0.0058	35.67	1	0
	30.0 - 40.0 cm	252	0.69	0.2773	0.0769	0.0175	40.44	1	0
	≥ 40.0 cm	34	0.57	0.3930	0.1545	0.0674	68.84	1	0
	Total	2,990	0.63	0.3155	0.0995	0.0058	50.42	1	0
1977	0 - 12.7 cm	189	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	506	0.59	0.3264	0.1065	0.0145	55.79	1	0
	20.0 - 30.0 cm	1,806	0.71	0.2311	0.0534	0.0054	32.65	1	0
	30.0 - 40.0 cm	272	0.72	0.2318	0.0537	0.0141	32.25	1	0
	≥ 40.0 cm	33	0.48	0.4004	0.1603	0.0697	83.45	1	0
	Total	2,806	0.64	0.3043	0.0926	0.0057	47.81	1	0
1987	0 - 12.7 cm	433	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	453	0.55	0.3489	0.1217	0.0164	63.48	1	0
	20.0 - 30.0 cm	1,684	0.72	0.2149	0.0462	0.0052	29.80	1	0
	30.0 - 40.0 cm	354	0.70	0.2544	0.0647	0.0135	36.59	1	0
	≥ 40.0 cm	34	0.58	0.3785	0.1432	0.0649	65.72	1	0
	Total	2,958	0.58	0.3412	0.1164	0.0063	58.35	1	0
1994	0 - 12.7 cm	466	0.00	0.0000	0.0000	0.0000	0.00	0	0
	12.7 - 20.0 cm	568	0.47	0.3889	0.1512	0.0163	82.40	1	0
	20.0 - 30.0 cm	1,625	0.71	0.2333	0.0544	0.0058	32.76	1	0
	30.0 - 40.0 cm	463	0.71	0.2379	0.0566	0.0111	33.58	1	0
	≥ 40.0 cm	58	0.53	0.3854	0.1485	0.0506	72.86	1	0
	Total	3,180	0.56	0.3579	0.1281	0.0063	63.79	1	0

Table E-12.—Plot similarity statistics for all plots by stand-size class, Mississippi, 1967-1994. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).

Survey year compared	Stand-size class	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1967/	0 - 12.7 cm	83	0.00	0.0000	0.0000	0.0000	0.00	0	0
1977	12.7 - 20.0 cm	506	0.43	0.2922	0.0854	0.0130	67.34	1	0
	20.0 - 30.0 cm	1,806	0.68	0.2566	0.0658	0.0060	37.91	1	0
	30.0 - 40.0 cm	272	0.71	0.2504	0.0627	0.0152	35.19	1	0
	≥ 40.0 cm	33	0.33	0.3610	0.1303	0.0628	107.83	1	0
	Total	2,700	0.61	0.3001	0.0901	0.0058	49.21	1	0
1977/	0 - 12.7 cm	179	0.00	0.0000	0.0000	0.0000	0.00	0	0
1987	12.7 - 20.0 cm	448	0.40	0.3083	0.0950	0.0146	78.03	1	0
	20.0 - 30.0 cm	1,660	0.72	0.2194	0.0481	0.0054	30.62	1	0
	30.0 - 40.0 cm	349	0.70	0.2382	0.0568	0.0128	34.16	1	0
	≥ 40.0 cm	34	0.43	0.3675	0.1350	0.0630	86.05	1	0
	Total	2,670	0.61	0.3100	0.0961	0.0060	50.96	1	0
1987/	0 - 12.7 cm	178	0.00	0.0000	0.0000	0.0000	0.00	0	0
1994	12.7 - 20.0 cm	572	0.37	0.3342	0.1117	0.0140	89.83	1	0
	20.0 - 30.0 cm	1,613	0.73	0.2404	0.0578	0.0060	32.93	1	0
	30.0 - 40.0 cm	459	0.74	0.2474	0.0612	0.0115	33.57	1	0
	≥ 40.0 cm	57	0.48	0.3610	0.1303	0.0478	75.13	1	0
	Total	2,879	0.61	0.3347	0.1120	0.0062	54.88	1	0

Table E-13.—Species richness statistics for all plantation plots, Mississippi, 1967-1994. Richness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1967	294	3.26	2.1588	4.6603	0.1334	66.23	13	1
1977	311	3.41	2.0476	4.1928	0.1314	60.09	12	1
1987	487	3.27	2.1754	4.7322	0.1212	66.58	10	1
1994	709	2.82	2.0687	4.2795	0.0934	73.23	11	1

Table E-14.—Species evenness statistics for all plantation plots, Mississippi, 1967-1994. Evenness is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1967	294	0.52	0.3590	0.1289	0.0222	68.48	1	0
1977	311	0.49	0.3347	0.1120	0.0215	67.90	1	0
1987	487	0.44	0.3411	0.1164	0.0190	77.14	1	0
1994	709	0.38	0.3583	0.1284	0.0162	93.62	1	0

Table E-15.—Plot similarity statistics for plantation plots, Mississippi, 1967-1994. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).

Survey years compared	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1967/1977	294	0.38	0.3275	0.1073	0.0202	85.21	1	0
1977/1987	304	0.52	0.3248	0.1055	0.0211	62.36	1	0
1987/1994	480	0.53	0.3333	0.1111	0.0188	63.19	1	0
1967/1994	571	0.29	0.2647	0.0701	0.0166	92.06	1	0

Table E-16.—Species richness statistics for survivor plots, Mississippi, 1967-1994. Richness on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. Richness is the total number of species present on a sample plot.

Survey year	n	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1967	553	4.73	2.9027	8.4255	0.1234	61.36	13	0
1977	553	5.86	2.8193	7.9485	0.1199	48.09	15	0
1987	553	6.49	2.8950	8.3811	0.1232	44.59	15	0
1994	553	6.80	2.9678	8.8078	0.1262	43.67	15	0

Table E-17.—Species evenness statistics for survivor plots, Mississippi, 1967-1994. Number is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The evenness measure comes from the McIntosh formula (See page 32 in text for explanation).

Survey year	n	Mean evenness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum evenness per plot	Minimum evenness per plot
1967	553	0.63	0.3189	0.1017	0.0136	50.48	1	0
1977	553	0.69	0.2548	0.0649	0.0108	36.80	1	0
1987	553	0.71	0.2213	0.0490	0.0094	31.04	1	0
1994	553	0.72	0.2138	0.0457	0.0091	29.74	1	0

Table E-18.—Plot similarity statistics for survivor plots, Mississippi, 1967-1994. Plot similarity is based on trees ≥ 12.7 cm in DBH. n is number of sample plots per stratum. The similarity measure comes from the Sorensen quantitative formula (See page 33 in text for explanation).

Survey years compared	n	Mean similarity per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum similarity per plot	Minimum similarity per plot
1967/1977	553	0.64	0.3027	0.0916	0.0129	47.20	1	0
1977/1987	553	0.83	0.1865	0.0348	0.0080	22.60	1	0
1987/1994	553	0.73	0.2269	0.0515	0.0097	30.94	1	0
1967/1994	553	0.51	0.2843	0.0808	0.0122	55.76	1	0

Table E-19.—Summary statistics for contrast of mean species richness per plot, Mississippi, 1967-1994. Comparison is between all forested plots (including plantations) versus all forested plots (excluding plantations). Species richness is based on trees ≥ 12.7 cm DBH. <i>n</i> is number of sample plots per stratum. Richness is the total number of species present on a sample plot.									
Survey year compared	Plot grouping*	<i>n</i>	Mean richness per plot	Standard deviation	Variance	Standard error of mean	Coefficient of variation (%)	Maximum richness per plot	Minimum richness per plot
1967	with	2,990	4.53	2.7629	7.6335	0.0505	60.96	14	0
1967	without	2,696	5.06	2.5939	6.7285	0.0543	51.29	14	1
1977	with	2,806	5.02	2.9683	8.8109	0.0560	59.09	17	0
1977	without	2,495	5.59	2.7185	7.3901	0.0558	48.64	17	1
1987	with	2,958	4.82	3.3232	11.0437	0.0611	68.94	15	0
1987	without	2,471	5.99	2.8024	7.8537	0.0597	46.78	15	1
1994	with	3,180	4.49	3.3397	11.1533	0.0592	74.44	16	0
1994	without	2,471	5.79	2.9106	8.4715	0.0617	50.23	16	1

*Denotes all forested plots with or without plantations.

Table E-20.--Summary test table for changes in species richness using ANOVA repeated measures design. Data includes all forested plots, Mississippi, 1967 to 1994.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	2,805				
Within years	8,418	80,621.25			
Change	3	618.51	206.17	21.69	0.0001
Residual	8,415	80,002.74	9.51		
Total	11,223				
----- Contrast between years -----					
Comparisons					
1967 vs. 1977				38.21	0.0001
1967 vs. 1987				7.38	0.0067
1967 vs. 1994				3.49	0.0617

Table E-21.-Summary test table for changes in the species evenness index using ANOVA repeated measures design. Data includes all forested plots, Mississippi, 1967 to 1994.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	2,805				
Within years	8,418	929.57			
Change	3	11.08	3.69	33.85	0.0001
Residual	8,415	918.49	0.11		
Total	11,223				
----- Contrast between years -----					
Comparisons					
1967 vs. 1977				1.16	0.2814
1967 vs. 1987				25.19	0.0001
1967 vs. 1994				56.85	0.0001

Table E-22.-Summary test table for changes in plot similarity using ANOVA repeated measures design. Data includes all forested plots, Mississippi 1967 to 1994.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	2,669				
Within years	5,340	532.31			
Change	2	0.00018	0.00009	0.00	0.99
Residual	5,338	532.30	0.099		
Total	8,009				
----- Contrast between years -----					
Comparisons					
1967/1977 vs. 1977/1987				0.00	0.98
1967/1977 vs. 1987/1994				0.00	0.98

Table E-23.-Summary test table for changes in species richness for survivor plots using ANOVA repeated measures design. Data includes all forested survivor plots, Mississippi, 1967 to 1994.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	552				
Within years	1,659	5,980.50			
Change	3	1,377.29	459.10	165.16	0.0001
Residual	1,656	4,603.21	2.78		
Total	2,211				
----- Contrast between years -----					
Comparisons					
1967 vs. 1977			200.05		0.0001
1967 vs. 1987			199.11		0.0001
1967 vs. 1994			323.70		0.0001

Table E-24.-Summary test table for changes in species evenness for survivor plots using ANOVA repeated measures design. Data includes all forested survivor plots, Mississippi, 1967 to 1994.					
Source	df	SS	MS	F	p
----- Test of the overall effect of time -----					
Among years	552				
Within years	1,659	64.76			
Change	3	2.60	0.87	23.11	0.0001
Residual	1,656	62.16	0.04		
Total	2,211				
----- Contrast between years -----					
Comparisons					
1967 vs. 1977				24.78	0.0001
1967 vs. 1987				32.29	0.0001
1967 vs. 1994				41.65	0.0001

Table E-25.-Summary test table for changes in plot similarity for survivor plots using ANOVA repeated measures design. Data includes all forested survivor plots, Mississippi, 1967 to 1994.					
Source	df	SS	MS	F	P
----- Test of the overall effect of time -----					
Among years	552				
Within years	1,106	71.18			
Change	2	8.45	4.23	74.38	0.0001
Residual	1,104	62.73	0.06		
Total	1,658				
----- Contrast between years -----					
Comparisons					
1967/1977 vs. 1977/1987				30.52	0.0001
1967/1977 vs. 1987/1994				121.80	0.0001

Table E-26.-Summary test table for comparing changes in species richness by ownership classes. Test is factorial ANOVA design with repeated measures and between group factors, Mississippi, 1967 to 1994.

Source	df	SS	MS	F	p
Among subjects	2,805	17,037.61			
Group	2	177.36	88.68	9.18	0.0001
Residual between	2,803	25,313.42	9.66		
Within subjects	8,418	74,509.40			
Time	3	344.17	114.72	12.23	0.0001
Time x group	6	424.73	70.78	7.55	0.0001
Residual within	8,409	73,740.50	9.38		
Totals	11,223	100,000.18			

Table E-27.-Summary test table for comparing changes in species richness by physiographic classes. Test is factorial ANOVA design with repeated measures and between group factors, Mississippi, 1967 to 1994.						
Source	df	SS	MS	F	p	
Among subjects	2,805	27,218.46				
Group	2	611.54	305.77	32.21	0.0001	
Residual between	2,803	26,606.92	9.49			
Within subjects	8,418	80,494.85				
Time	3	492.11	164.04	17.69	0.0001	
Time x group	6	2,040.25	340.04	36.68	0.0001	
Residual within	8,409	77,962.49	9.27			
Totals	11,223	107,713.31				

Table E-28.-Summary test table for test comparing changes in species richness by stand-size classes. Test is factorial ANOVA design with repeated measures and between group factors, Mississippi, 1967 to 1994.					
Source	df	SS	MS	F	p
Among subjects	2,805	18,347.97			
Group	3	653.13	217.71	32.22	0.0001
Residual between	2,803	17,694.84	6.76		
Within subjects	8,418	52,715.39			
Time	3	239.34	79.78	12.20	0.0001
Time x group	9	1,095.58	121.73	18.61	0.0001
Residual within	8,409	51,380.47	6.54		
Totals	11,223	71,063.36			

Table E-29.--Summary test table for test comparing species richness in all forest plots (with plantations included) versus all forest plots (with plantations excluded). Test is factorial ANOVA design with repeated measures and between group factors, Mississippi, 1967 to 1994.

Source	df	SS	MS	F	p
Among subjects	5,275	52,370.10			
Group	1	1,121.21	1,121.21	115.38	0.0001
Residual between	5,274	51,248.88	9.72		
Within subjects	15,828	150,215.89			
Time	3	925.92	308.64	32.78	0.0001
Time x group	3	310.89	103.63	11.01	0.0001
Residual within	15,822	148,979.08	9.42		
Totals	21,103	202,585.98			

APPENDIX F

MISSISSIPPI DIVERSITY GRAPHS

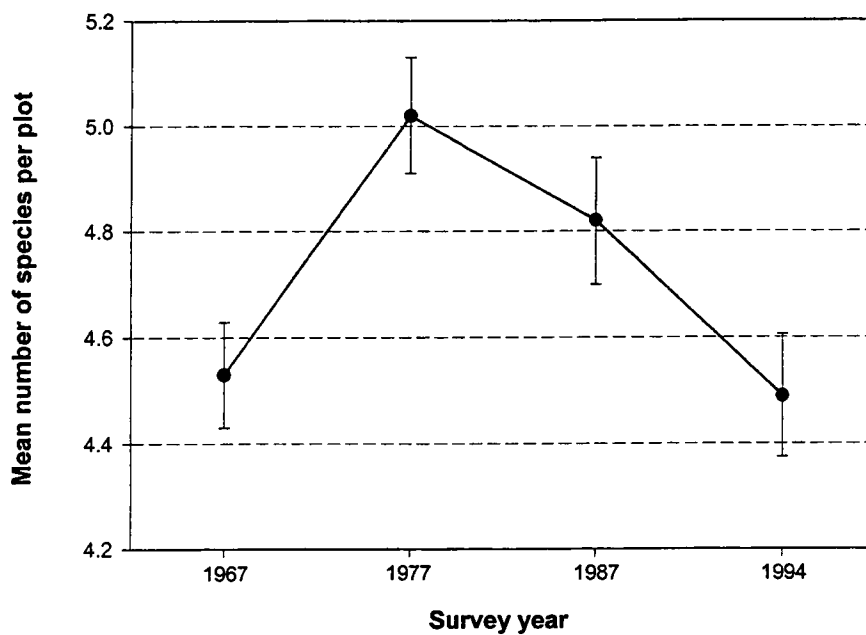


Figure F-1. Mean species richness per plot, Mississippi, 1967 to 1994, all plots. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-1.

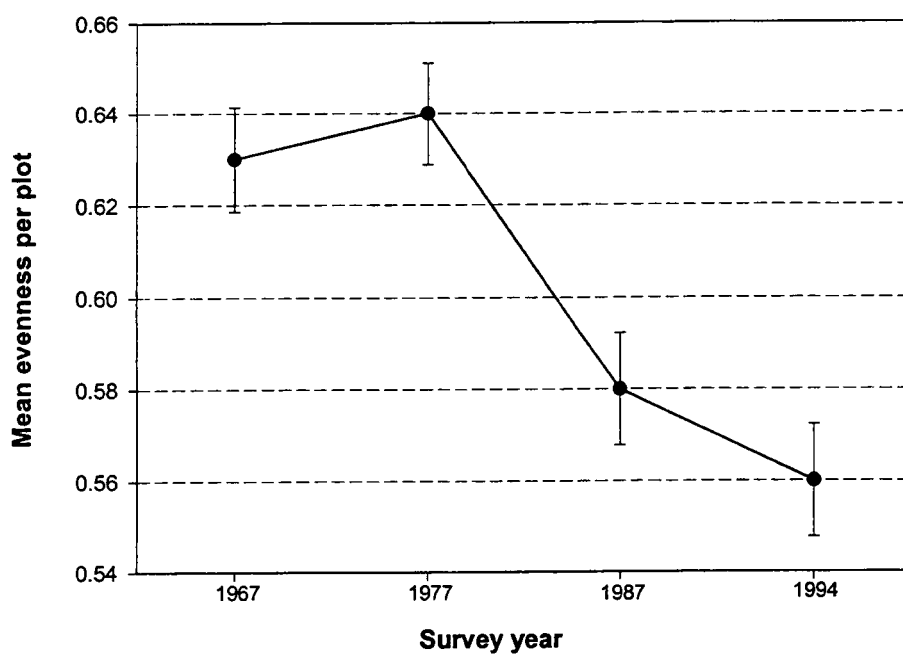


Figure F-2. Mean species evenness per plot, Mississippi, 1967-1994, all plots.
The error bars are ± 2 S.E. The number of sample plots in
each stratum can be found in Table E-2.

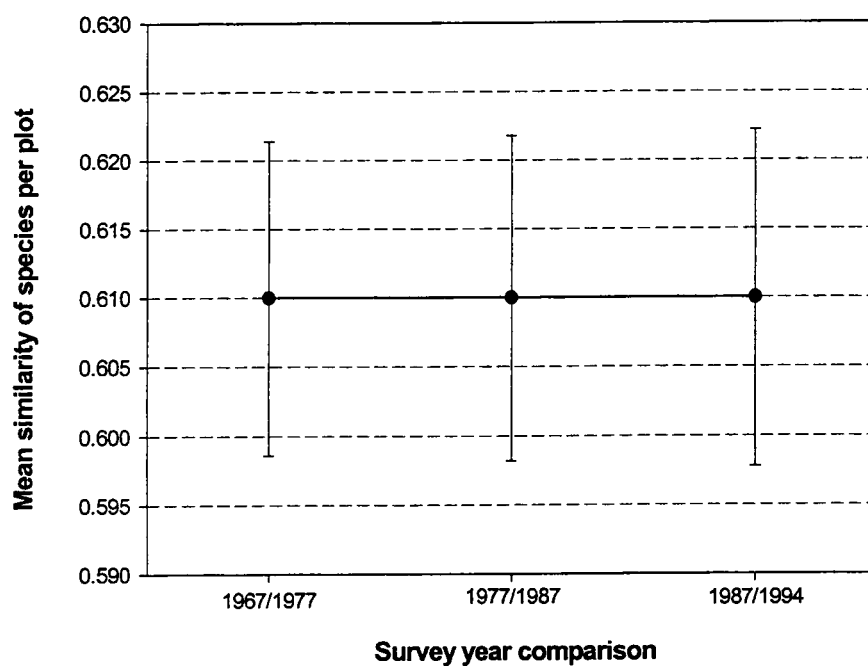


Figure F-3. Mean plot similarity, Mississippi, 1967-1994, all plots.
The error bars are ± 2 S.E. The number of sample plots
in each stratum can be found in Table E-3.

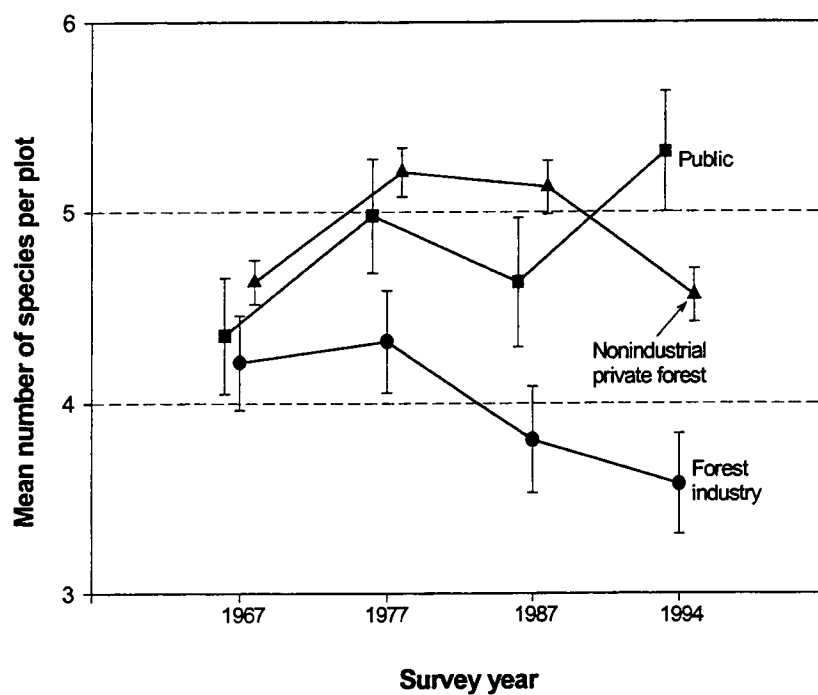


Figure F-4. Mean species richness per plot by ownership, Mississippi, 1967-1994
 The error bars are ± 2 S.E. The number of sample plots in each stratum
 can be found in Table E-4.

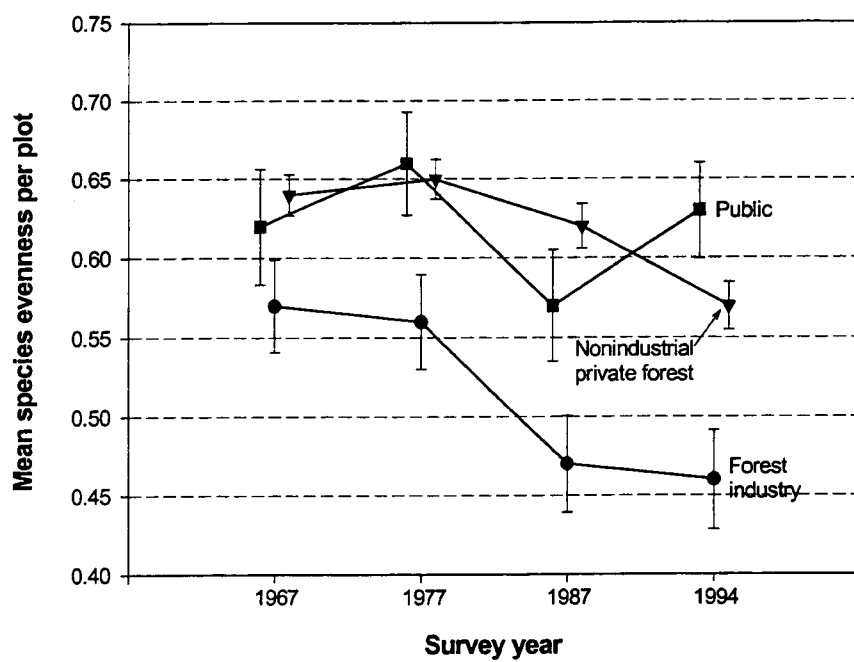


Figure F-5. Mean species evenness per plot by ownership, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-5.

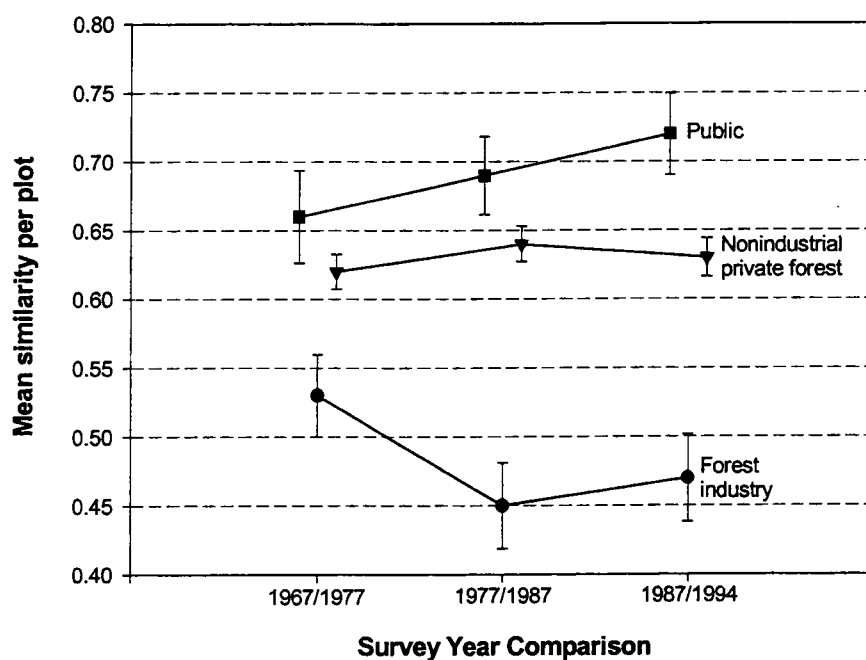


Figure F-6. Mean plot similarity by ownership, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-6.

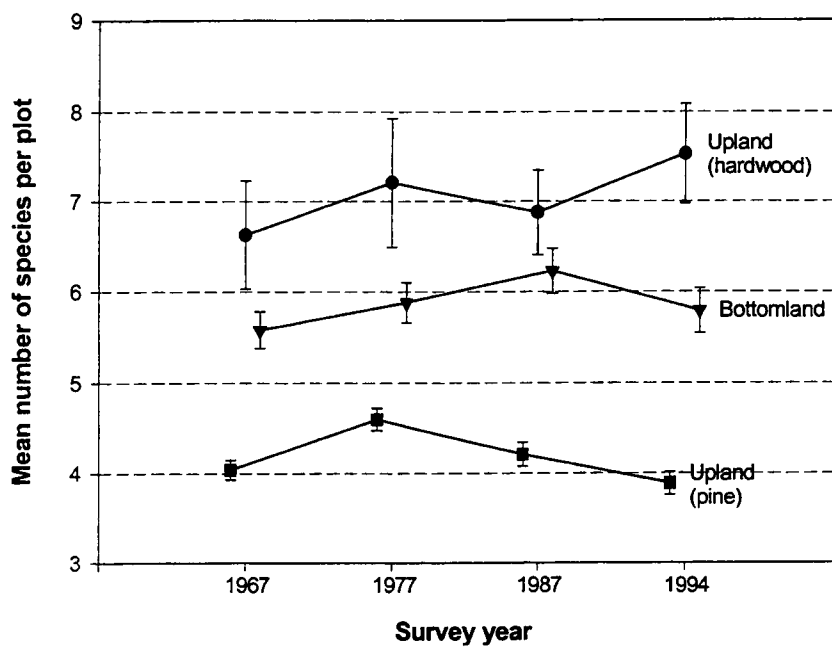


Figure F-7. Mean richness per plot by physiographic class, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Appendix E-7.

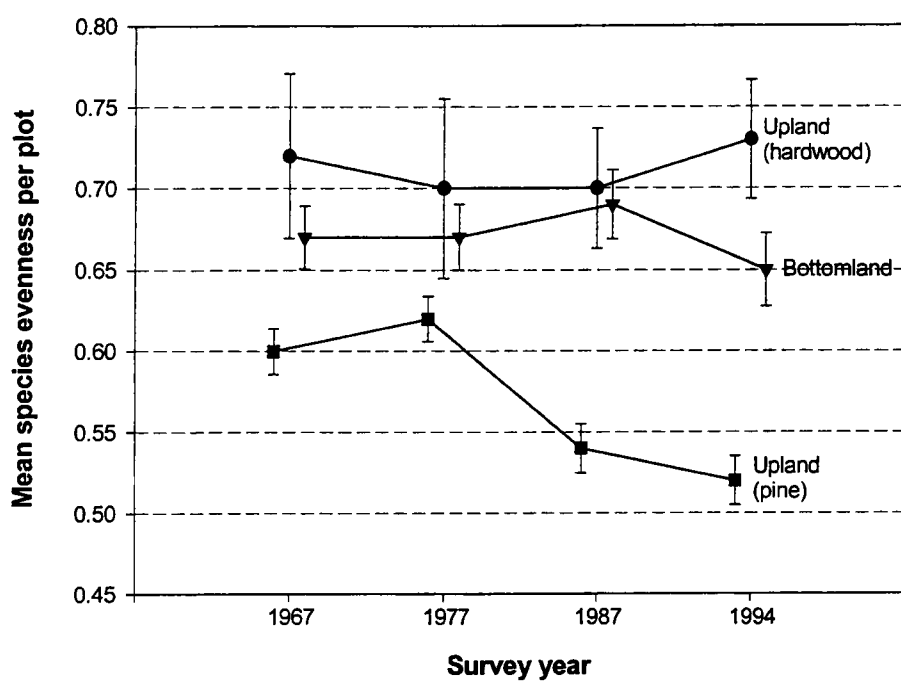


Figure F-8. Mean species evenness per plot by physiographic class, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-8.

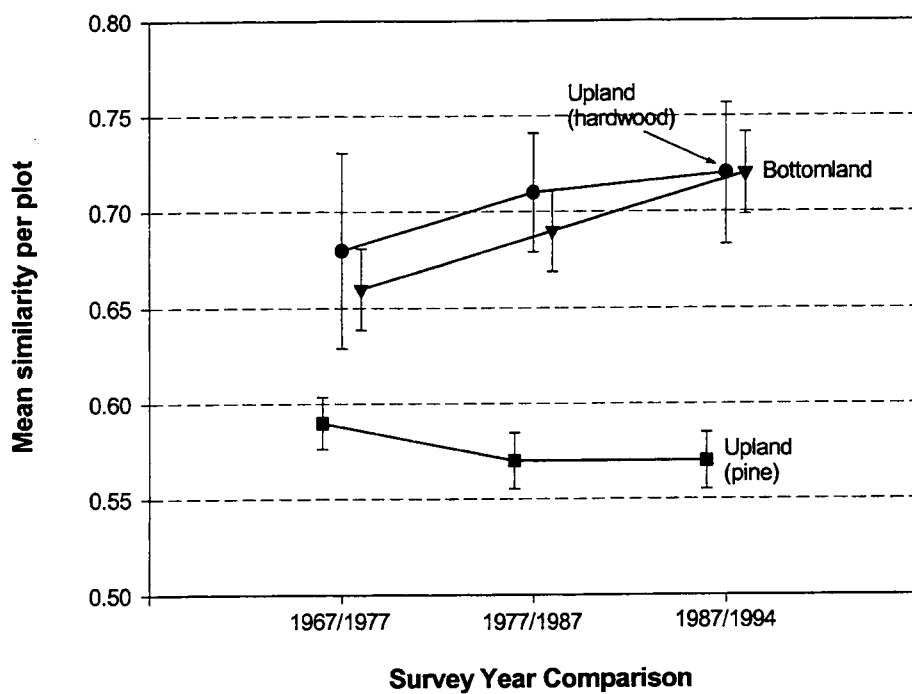


Figure F-9. Mean plot similarity by physiographic class, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-9.

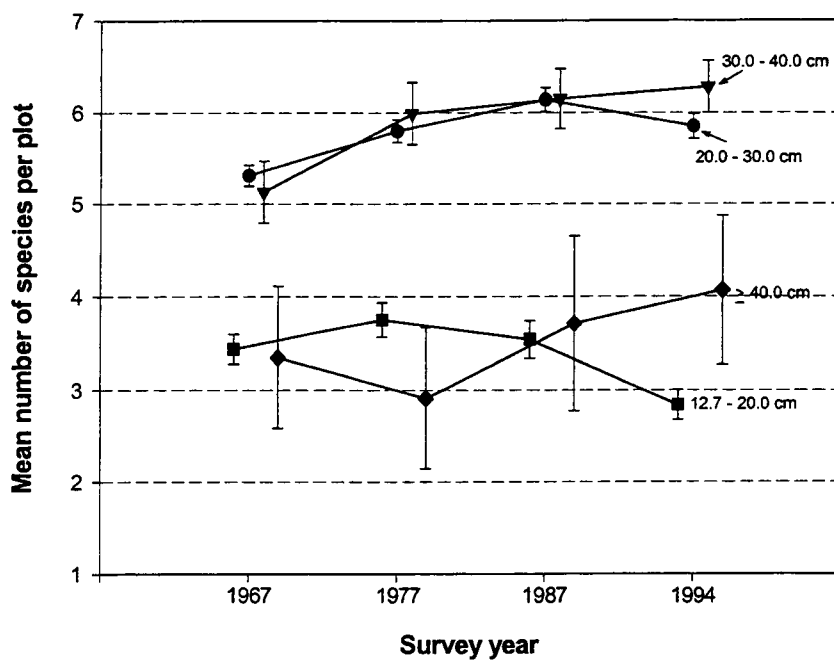


Figure F-10. Mean species richness per plot by stand-size class, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-10.

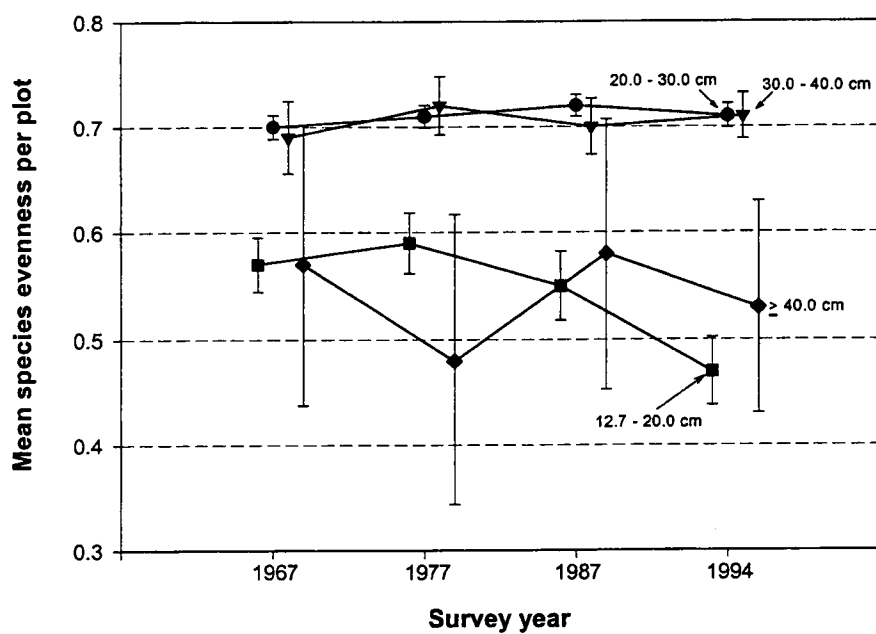


Figure F-11. Mean species evenness per plot by stand-size class, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-11.

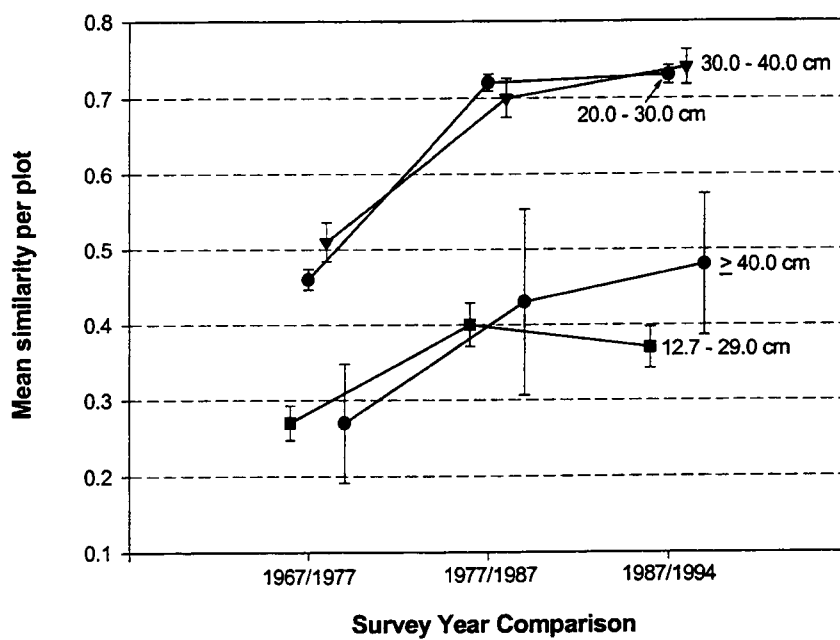


Figure F-12. Mean plot similarity by stand-size class, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-12.

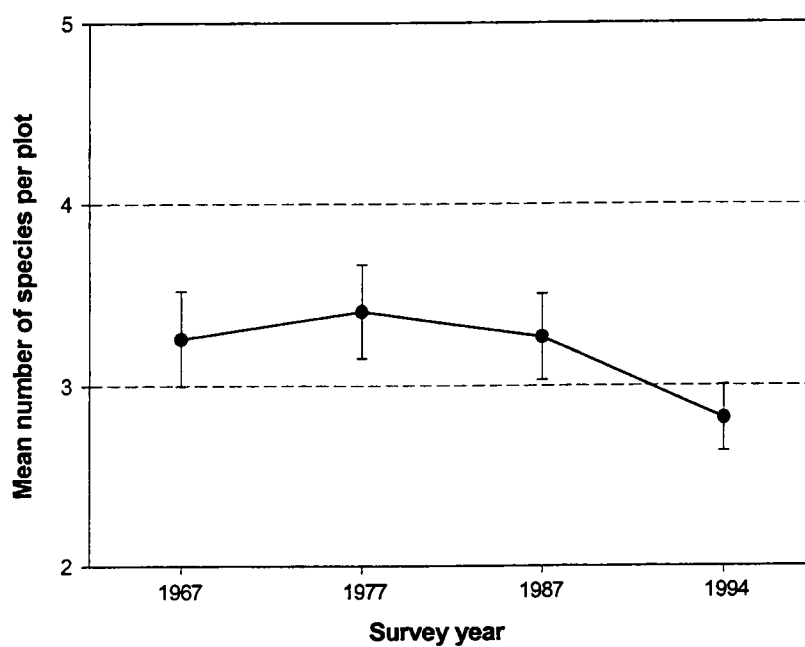


Figure F-13. Mean species richness per plot for plantation plots, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-13.

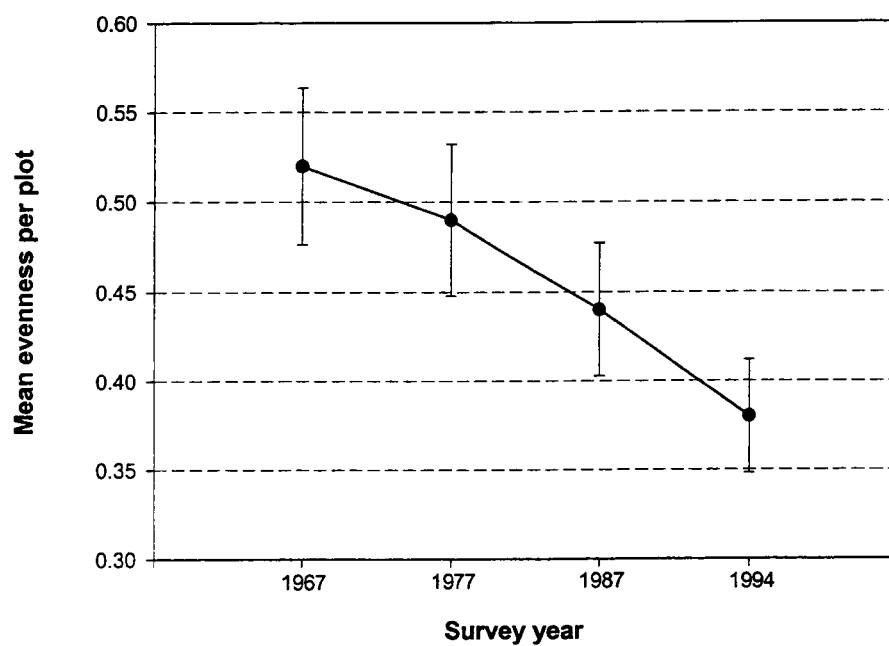


Figure F-14. Mean species evenness per plot for plantation plots, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-14.

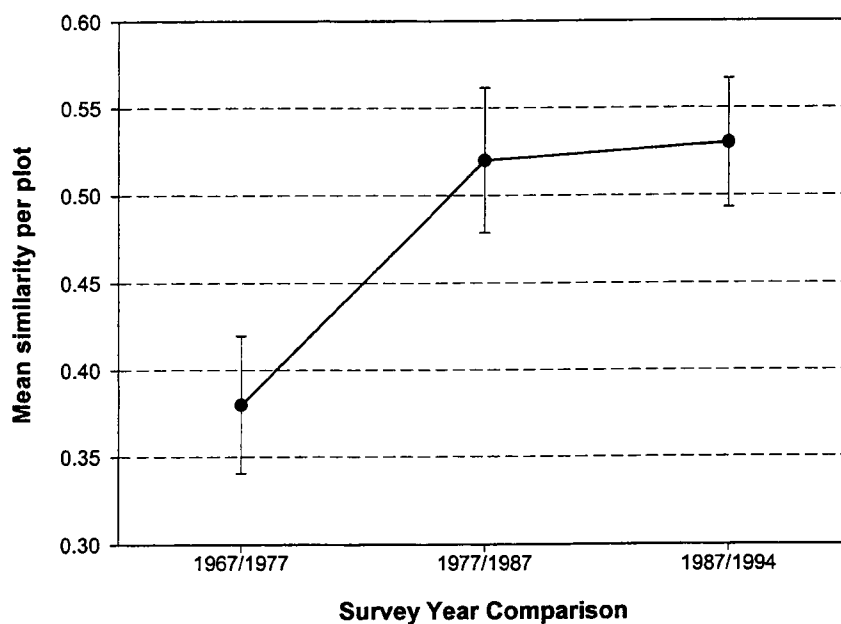


Figure F-15. Mean plot similarity for plantation plots, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-15.

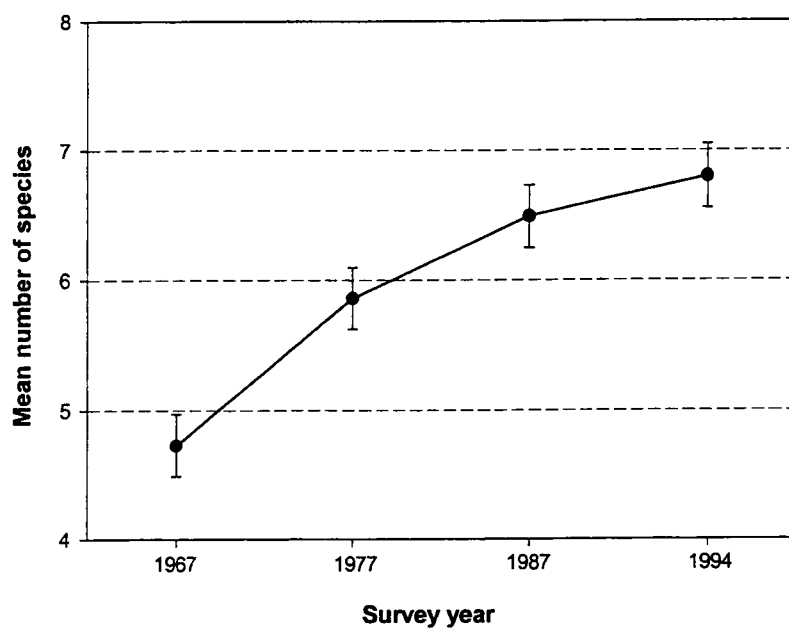


Figure F-16. Mean species richness per plot for survivor plots, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-16.

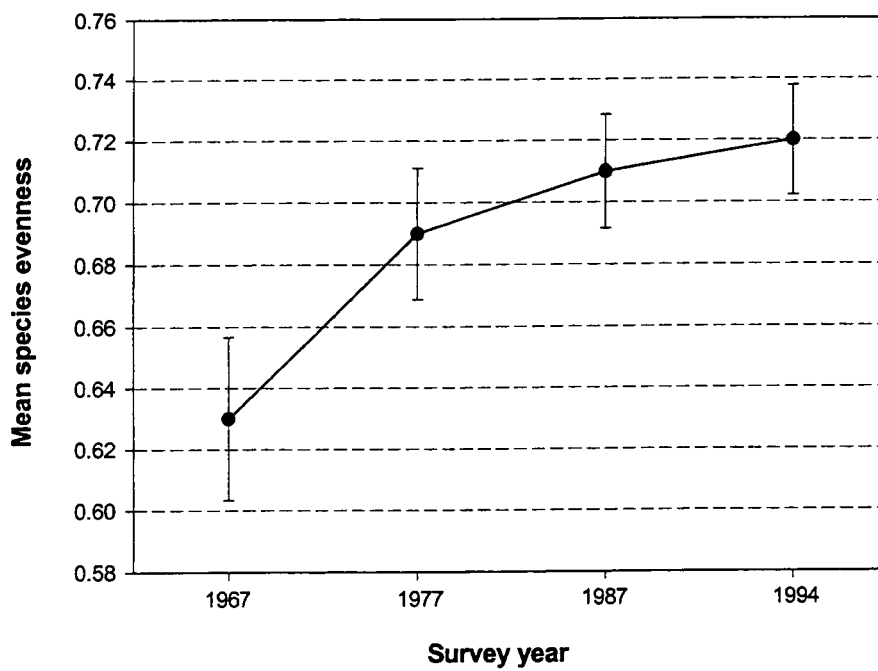


Figure F-17. Mean species evenness per plot for survivor plots, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-17.

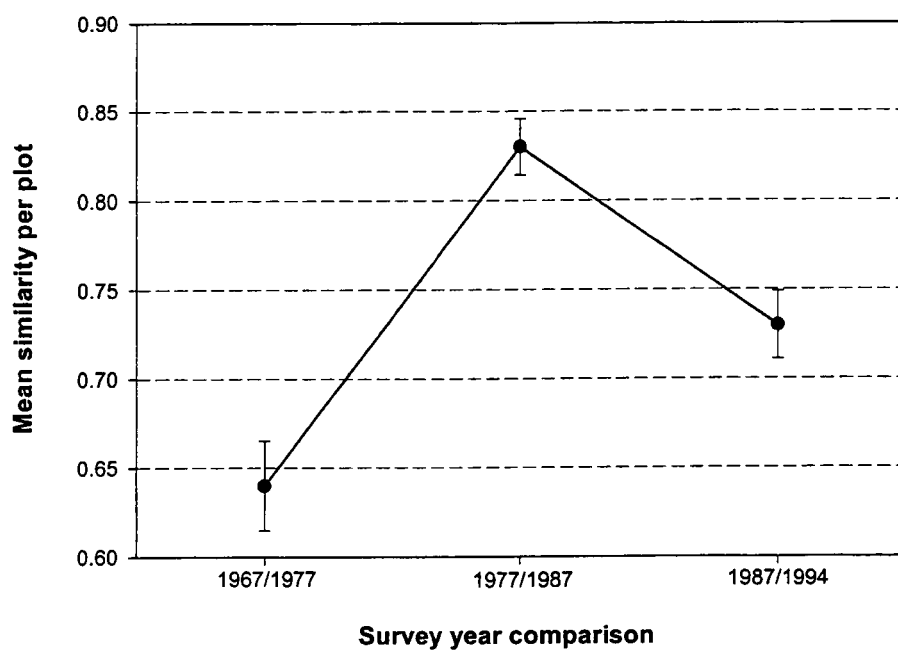


Figure F18. Mean plot similarity for survivor plots, Mississippi, 1967-1994. The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-18.

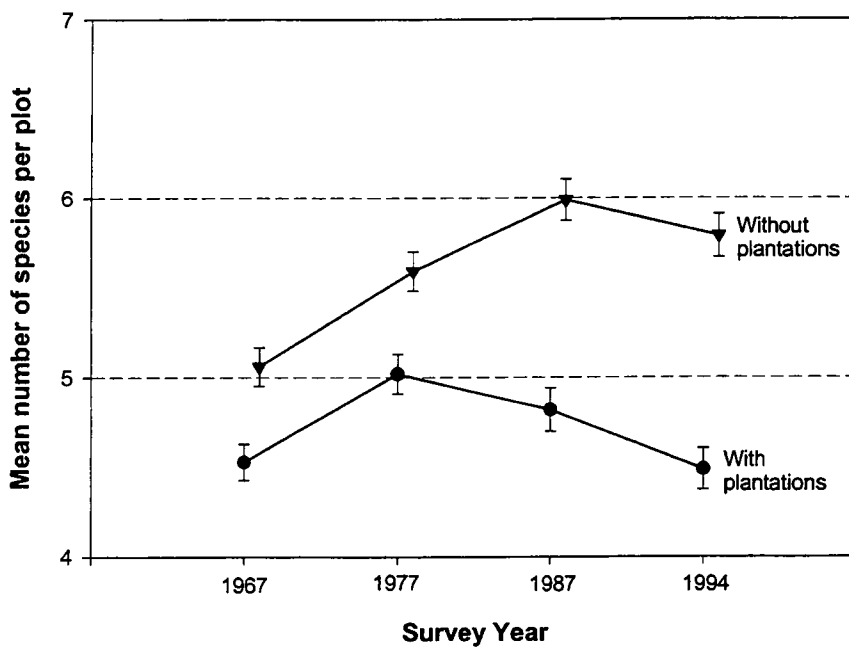


Figure F-19. Contrast of mean species richness per plot, Mississippi, 1967 to 1994. Comparison is between all forest plots (including plantations) versus all forest plots (excluding plantations). The error bars are ± 2 S.E. The number of sample plots in each stratum can be found in Table E-19.

APPENDIX G

MISSISSIPPI DIVERSITY MAPS

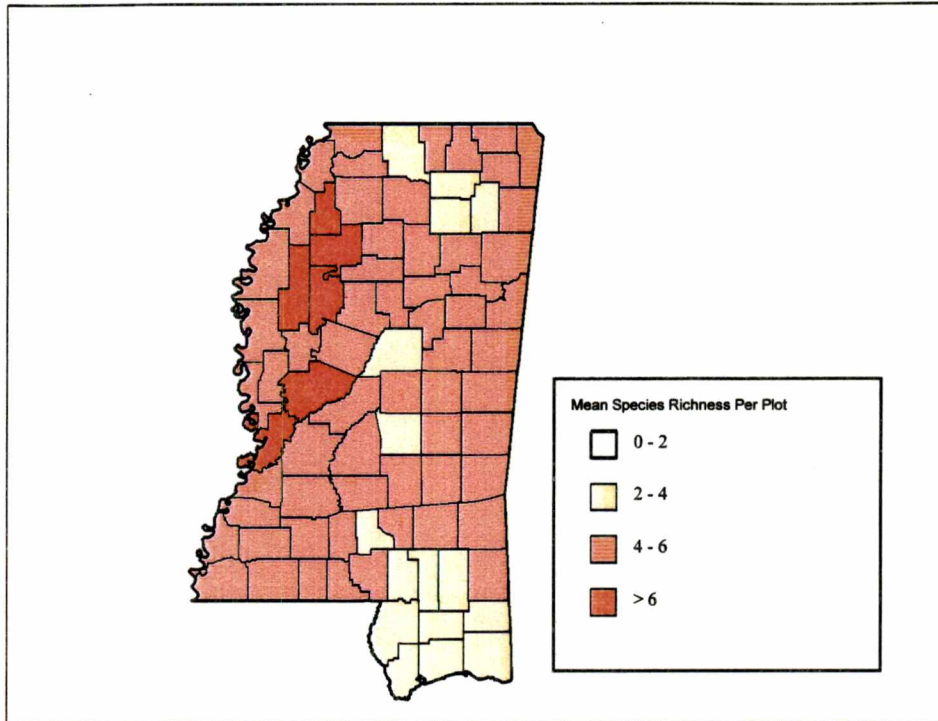


Figure G-1. Distribution of species richness across Mississippi, 1967. Species richness is the mean of plots aggregated to the county level.

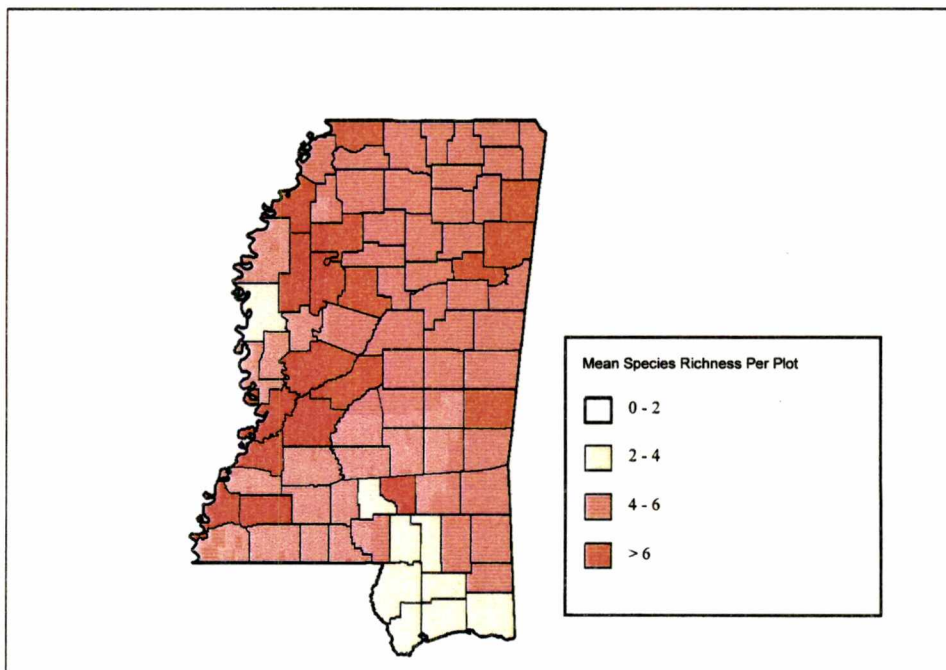


Figure G-2. Distribution of species richness across Mississippi, 1977. Species richness is the mean of plots aggregated to the county level.

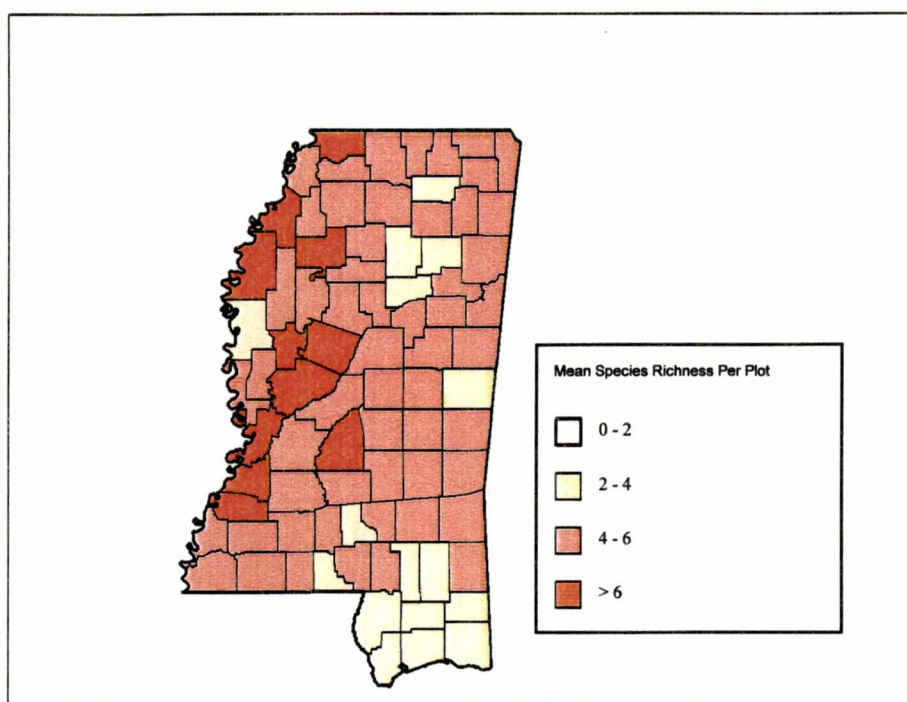


Figure G-3. Distribution of species richness across Mississippi, 1987. Species richness is the mean of plots aggregated to the county level.

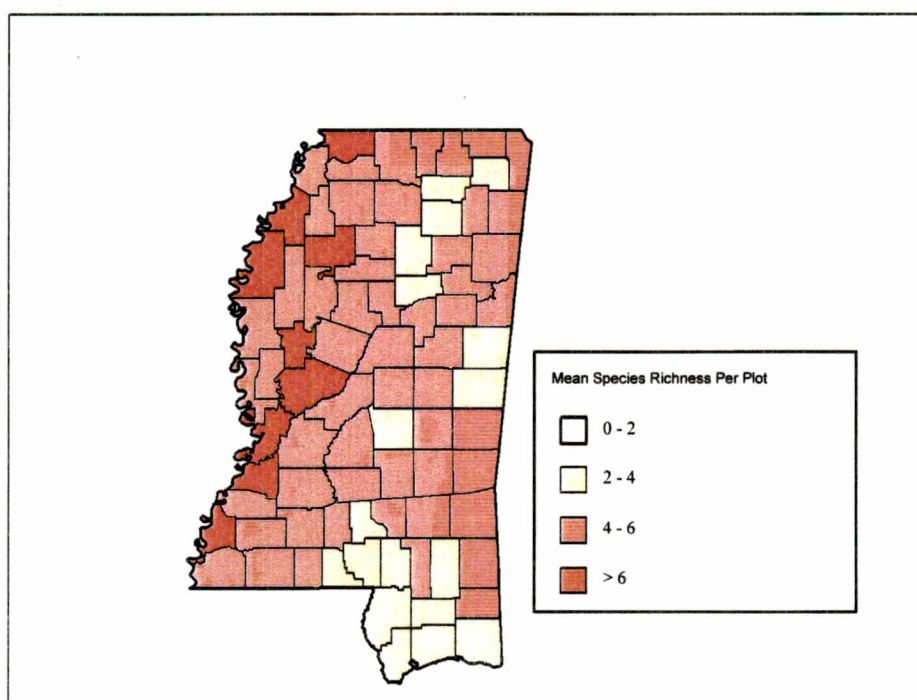


Figure G-4. Distribution of species richness across Mississippi, 1994. Species richness is the mean of plots aggregated to the county level.

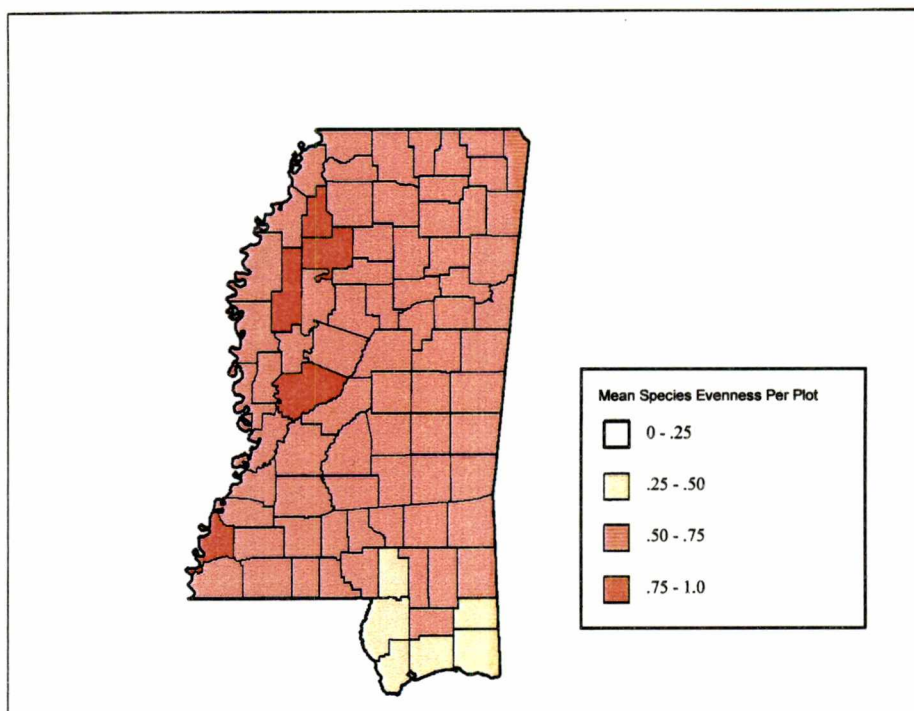


Figure G-5. Distribution of species evenness across Mississippi, 1967. Species evenness is the mean of plots aggregated to the county level.

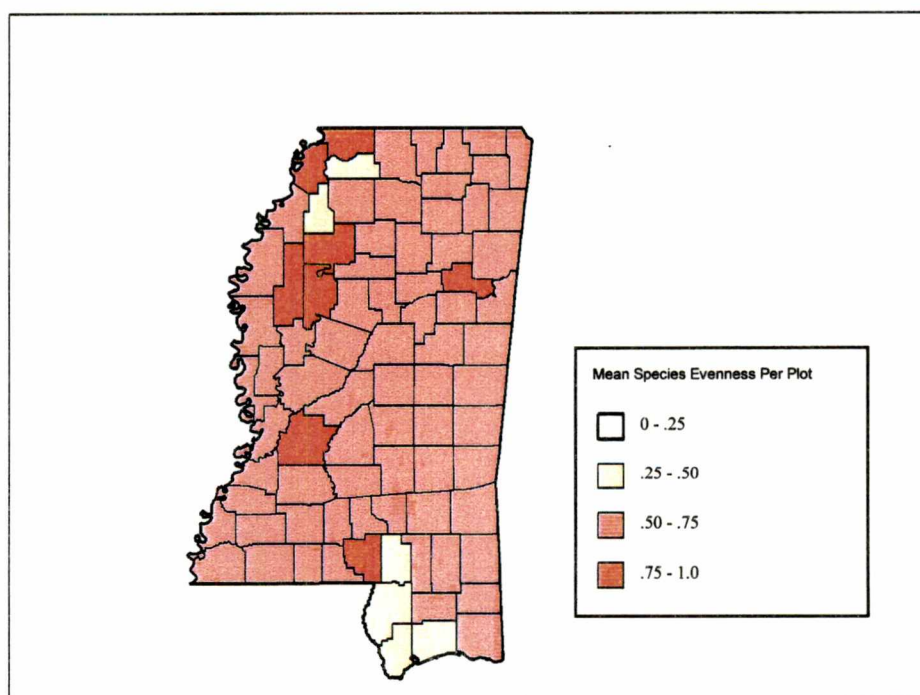


Figure G-6. Distribution of species evenness across Mississippi, 1977. Species evenness is the mean of plots aggregated to the county level.

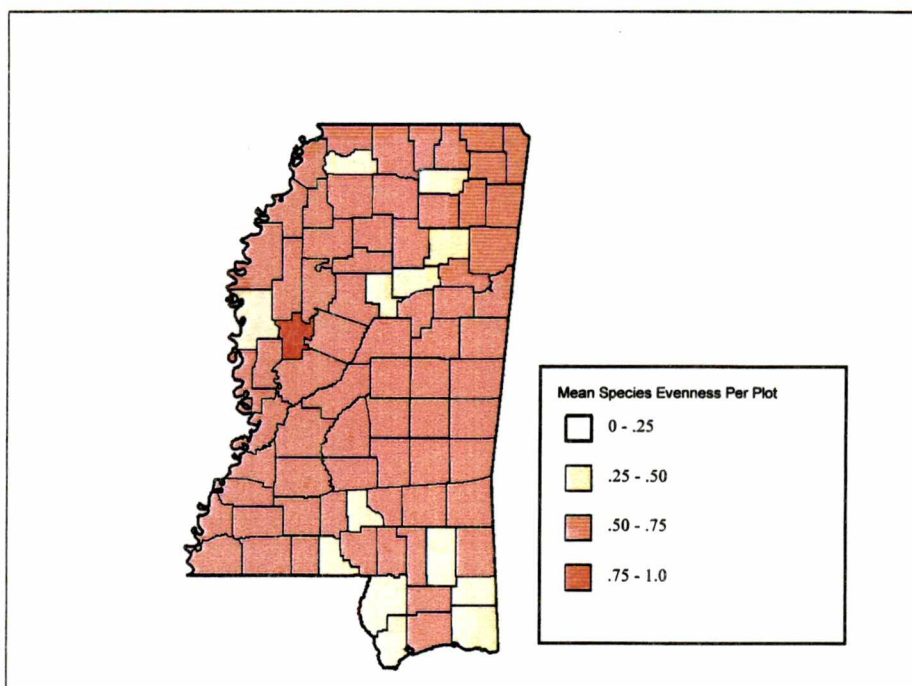


Figure G-7. Distribution of species evenness across Mississippi, 1987. Species evenness is the mean of plots aggregated to the county level.

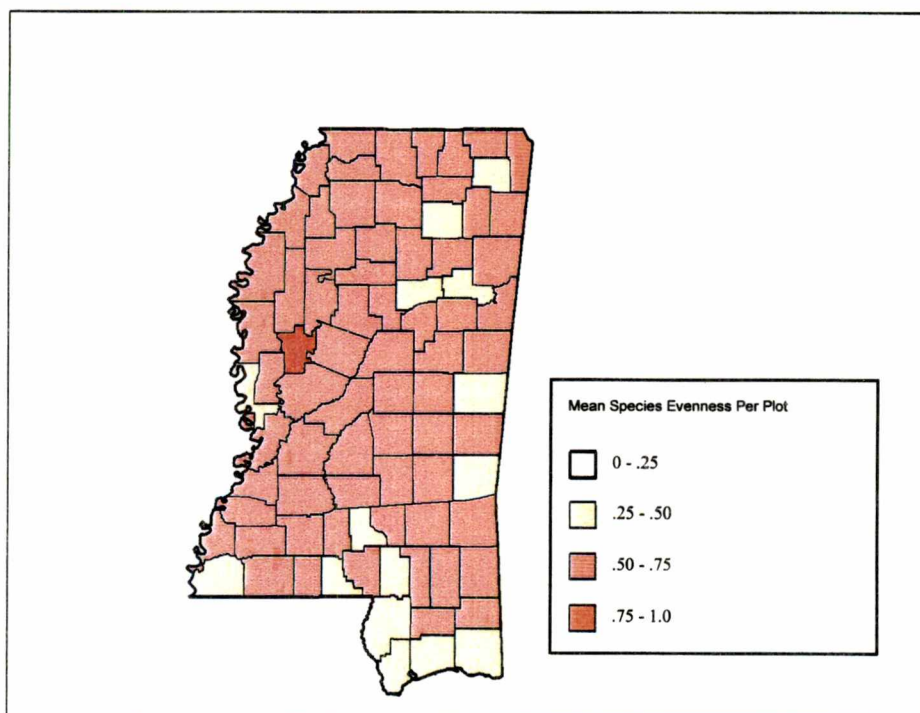


Figure G-8. Distribution of species evenness across Mississippi, 1994. Species evenness is the mean of plots aggregated to the county level.

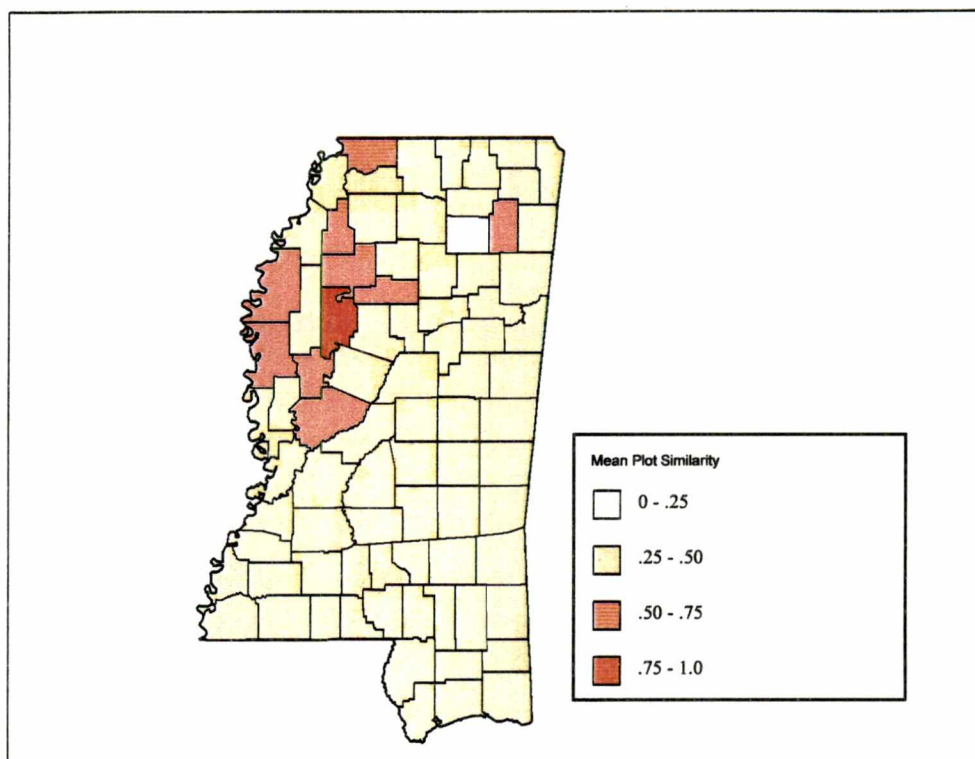


Figure G-9. Distribution of plot similarity across Mississippi. Plot similarity is the mean of plots aggregated to the county level. Comparisons were between the 1967 and 1994 survey years.

VITA

VITA

James F. Rosson, Jr., received a B.S. in forestry and an M.S. in forest ecology from Southern Illinois University. He has worked for the USDA Forest Service, Forest Inventory and Analysis, in Starkville, MS for the past 20 years. During this time he returned to school to complete the requirements for the degree of Doctor of Philosophy in the Ecology and Evolutionary Biology Program at the University of Tennessee.

He is presently stationed at the Forestry Sciences Laboratory in Starkville, MS, where he is working on research involving: (1) the impacts of harvesting on forest ecosystems, species diversity, and resource sustainability in the Southern United States; (2) forest resource trends; (3) forest regeneration after harvest; and (4) characterization of forest plantations in the South.