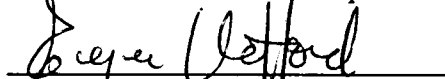
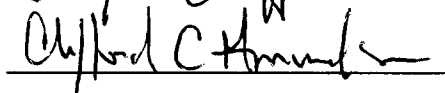


To the Graduate Council:

I am submitting herewith a thesis written by Jennifer Marie Hart entitled "Impacts of Nonpoint Source Agricultural Pollution on A Riparian Forest Community of Herrings Marsh Run Watershed in Duplin County, North Carolina." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Botany.


J. Frank McCormick, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor
and Dean of The Graduate School

IMPACTS OF NONPOINT SOURCE AGRICULTURAL
POLLUTION ON A RIPARIAN FOREST COMMUNITY OF HERRINGS
MARSH RUN WATERSHED IN DUPLIN COUNTY, NORTH CAROLINA

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Jennifer Marie Hart

May 1994

ACKNOWLEDGMENTS

First, I would like to thank the USDA Agricultural Research Service in Florence, SC for funding my research project.

Ten million thanks to Dr. Frank McCormick for his guidance and support. I am also extremely thankful to Dr. B.E. Wofford, Dr. V.E. McNeilus, Dr. H.R. Deselm, Dr. L. Swails and Allen Risk for their help in the identification of my plants. Thanks to Dr. Cliff Amundsen for being an invaluable source of practical information on field research. Thanks also to Bob Meunchen for sharing his statistical knowledge with me.

I would like to thank Drs. Patrick Hunt and Michael Kasperbauer at the USDA for their continued encouragement and support and Dr. Julia Krebs for stimulating my interest in ecology and for being an excellent role model.

Many thanks to Jennifer Maxwell for keeping me sane during my summer in Warsaw, NC and to all of my wonderful friends for making graduate school fun. Special thanks go to my family, whose never-ending unconditional support keeps me going.

And finally, to Chris, for giving me love, encouragement, and inspiration, I am forever thankful.

ABSTRACT

Two riparian forest communities were compared on the basis of community structure and composition. Parameters included species dominance, diversity, and richness, and community similarity, biomass, and plant density. These communities are close to each other and are similar in topography, elevation, aspect, soil types, and land use practices. The major abiotic difference between the communities is the level of nutrient inputs from nonpoint agricultural runoff; one community has high input levels (experimental community) and the other has relatively low levels (control community). It was hypothesized that community structure and composition would differ due to nutrient loading. The purpose of this study was to determine if differences exist, and, if so, to evaluate the differences and develop management options which would optimize forest removal of nutrients from water sources. Canopy, subcanopy, shrub, herb, and groundcover strata were analyzed.

Most differences between communities were not statistically significant. The canopy stratum of the control community was more diverse than that of the experimental community, but species richness and density were not significantly different. Subcanopy species richness was significantly higher in the control community, but plant density did not differ significantly. Woody biomass of canopy and subcanopy strata taxa was significantly higher in the control community. Species diversity was higher in the experimental community, but species richness of shrubs and herbs was quite similar in the two communities. Densities of shrubs and herbs

were significantly higher in the experimental community. Groundcover species richness was higher but percent coverage was lower in the experimental community. Highest community similarity of species composition was between the canopy strata (75%) with progressively less similarity between the subcanopy, shrub, groundcover, and herb strata. Overall coefficient of community similarity was 44%.

The experimental community is less nutrient limited, is less light limited (more open canopy) than the control community, and favors faster growing, shade intolerant species. Highest species diversity occurred in upper strata of the control community where light was not limiting but nutrients were probably limiting. Significantly greater biomass in the canopy and subcanopy of the control community was probably due to less recent logging and fewer treefalls. Higher species diversity and the presence of shade intolerant species in lower strata reflect the influence of intermediate levels of disturbance in the experimental community. Higher plant density in two of three lower strata of the experimental community are consistent with expectations of increased plant growth under conditions of relatively greater light and nutrient availability.

Based upon results of this study, the preferred management practice for riparian forest communities of Herrings Marsh Run is to:

1. maintain a riparian forest at least 24 m wide along all stream banks
2. maintain an economically productive agroforestry zone between riparian forest and contiguous land used for traditional purposes
3. on a 40 to 50 year rotation, harvest timber from 24 x 21m plots in the riparian forest according to strip shelter belt procedure.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. SITE DESCRIPTION	4
Location	4
Geology and Soils	4
Background Information	5
Description of Forest Communities	7
Hypothesis	9
III. MATERIALS AND METHODS	11
Experimental Design and Data Collection	11
Parameters of Structure and Composition	13
Importance Values	13
Community Similarity	14
Species Diversity	14
Species Richness	15
Woody Vegetative Biomass	15
Density	16
Data Analysis	16
Species Richness, Density, and Biomass	16
Extraneous Data	17

CHAPTER	PAGE
IV. RESULTS AND DISCUSSION	18
Canopy	18
Subcanopy	21
Shrubs	23
Herbs	25
Groundcover	26
Predictions of Future Canopy Dominance	27
Conclusions	28
Management Options for Riparian Communities	30
Research Limitations	35
BIBLIOGRAPHY	36
APPENDICES	41
APPENDIX A	42
Tables and Figures	43
APPENDIX B	62
Location of Data and Plant Vouchers	63
VITA	64

LIST OF TABLES

TABLE	PAGE
1. Importance Values of Canopy Species in Control and Experimental Communities	43
2. Importance Values of Subcanopy Species in Control and Experimental Communities	44
3. Importance Values of Shrub Species in Control and Experimental Communities	46
4. Importance Values of Herb Species in Control and Experimental Communities	50
5. Importance Values of Groundcover species in Control and Experimental Communities	53
8. Mean $\pm$ Standard Error for Species Richness for Each Stratum in Control and Experimental Communities.	58
7. Percent Similarity of Species Composition in Control and Experimental Communities Subdivided by Stratum	58
8. Importance Values for Canopy Dominants in Various Strata	59

LIST OF FIGURES

FIGURE	PAGE
1. Duplin County is Located in the Coastal Plain Physiographic Province of North Carolina	4
2. Study Area Showing the Western Control Community and Eastern Experimental Community	8
3. Differences in Levels of Nitrate in Stream Water, Average Levels of Nitrate in Groundwater (1991-1994), and Levels of Phosphate and Ammonium for Stream Water in the Control and Experimental Communities	10
4. Diversity Index Values for Stratum in Control and Experimental Communities	60
5. Plant Density for Each Stratum in Control and Experimental Communities	61

CHAPTER I

INTRODUCTION

As agriculture continues to increase in scale and intensity, more attention is being paid to effects that agricultural practices have on islands and strips of natural ecosystems they surround. Of special concern are riparian forest communities which lie between streams and cultivated land. Riparian ecosystems have high water tables and occur as an ecotone between aquatic and terrestrial systems (Baker et al. 1978). Although it is environmentally expensive in terms of water quality and loss of habitat to cultivate these streamside sites, pressure to increase area of productive farm land draws this land into agricultural production. Clearcutting for timber yield adds to the devastation of these communities.

As of 1984, it was estimated that at least 70% of the area occupied by original riparian ecosystems in the United States had been cleared (Swift 1984). Riparian ecosystems warrant special consideration and conservation because they serve as corridors and habitats to a great diversity of plant and animal species. In fact, 3/4 of all breeding birds and 1/2 of all mammals are in some way dependent on these systems and they provide habitat for over 100 endangered plant and animal species combined (McCormick 1979). These ecosystems are also extremely important because they protect water quality by acting as natural filters and sinks for sediments and excess nutrients that would otherwise contaminate stream waters (Todd 1983). The major sources of nutrient loading to riparian forest communities from

agricultural activities, as studied here, are mineral fertilizers and animal waste. Fertilizer N use in North Carolina alone has increased 400% from 1945-1983 (Anonymous, 1945-1983). Several studies have shown that riparian vegetation is effective in reducing amounts of nutrient pollutants that reach stream waters by assimilating these nutrients (Todd et al. 1983, Lowrance et al. 1984, Jacobs et al. 1985, Kuenzler 1988). Specifically, Todd et al. (1983) found that several riparian ecosystems of the coastal plain of Georgia filtered 82% of N and 54% of P and Kuenzler (1988) found a 64% uptake of N and 43% uptake of P by riparian ecosystems from upland nonpoint sources.

Riparian forests are very holistic and dynamic communities where biological structure is determined by a complex web of biotic and abiotic interactions (Gregory 1991). Because of this complexity, all of the factors contributing to the forests' structure cannot be examined in the present study. However, nutrients and light are commonly significant limiting factors which affect plant community structure (Tilman 1988). Because N and P are usually limiting nutrients in a forested ecosystem, the excess availability of these nutrients might be expected to have a marked affect on riparian forest community structure (Albrektson et al. 1977).

One purpose of this study is to identify and evaluate structural and compositional differences between two highly disturbed riparian forest communities which receive significantly different levels of uncontrolled, agriculturally applied, nonpoint source nutrients. A second purpose is to recommend forest management

options which will optimize the following goals:

1. Maintain riparian forest communities and their value as wildlife habitats.
2. Maximize their ability to reduce nutrient levels in streams.
3. Provide a sustainable source of income to land owners.

CHAPTER II

SITE DESCRIPTION

Location

The study area is located within Herrings Marsh Run research watershed. Herrings Marsh Run is located in northwestern Duplin County which lies in the coastal plain physiographic province of North Carolina (Figure 1). This watershed is contained within the Goshen Swamp watershed which in turn, is situated within the Northeast Cape Fear River Basin.

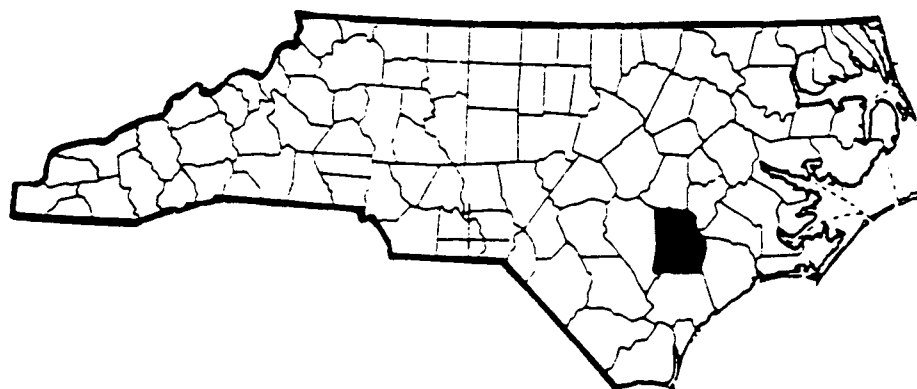


Figure 1. Duplin County in the Coastal Plain Physiographic Province of North Carolina.

Geology and Soils

Soils in the watershed are mostly coastal plain sands with the most dominant type being Autryville sand on slopes from 0 to 6%. Norfolk loamy sand on 2 to 6% slopes, Marvyn loamy sand on 6 to 15% slopes, and Blanton sand on 1 to 5% slopes are secondary soil types. Most of these soils are well drained and do not retain

nutrients effectively due to the porous qualities of the soil types present. The Sunderland geologic formation underlies the soil which has parent materials consisting of marine and fluvial sediments of the Atlantic Coastal Plain (USDA Annual Progress Report 1991).

The water table is relatively high within and around the forested riparian communities of the county and ranges from 0-4 feet at the stream/forest interface to 8-12 feet at forest/field interface. Groundwater for the project area consists of an unconfined, Surficial aquifer and a confined, Cretaceous aquifer. The Surficial aquifer is the saturated portion of the sediments from the upper surface down to the first confining layer. This depth tends to range from 6-15 meters and is the aquifer that is especially susceptible to nutrient contamination. The Cretaceous aquifer can start at depths from 30 to 182 meters and can be 122 or more meters thick. This aquifer exists in extremely old sediments and lies directly over the basement rock.

Background Information

Within the 2,040-hectare watershed there are approximately 1,091 hectares of cropland, 30 hectares of highways and roads, 212 hectares of homesites, farmsteads, poultry and swine facilities, and 707 hectares of woodland (USDA Annual Progress Report 1991). Approximately 210 hectares (30%) of this woodland area were evaluated in this research project.

In the late 1970's Duplin County started production of both turkey and swine. The county now has a higher estimated gross agricultural revenue than any other

county in North Carolina and produces more turkey than any other county in North Carolina. There are 20 poultry units within the watershed which, in total, produce approximately 350,000 birds per year. Beef cattle production consists of six operations with herds ranging from 10 to 50 head of cattle per farm. Duplin County has the fourth highest production of swine in the United States which consists of three finishing units with a total capacity of 5,550 head, one farrow-to-finish unit with a capacity of 100 head, and a farrow-to-feeder unit carrying 700 head. This swine production accounts for approximately 77% of the total agricultural revenue for the county. Crops produced in the watershed average around 93 hectares of tobacco, 323 hectares of corn, 202 hectares of soybean, 93 hectares of cotton, 210 hectares of wheat, 162 hectares of vegetables, and 28 hectares of bermuda sod grass (USDA Annual Progress Report 1991).

Although there is enough animal waste produced in the county to supply over one-half of the 132 tons of nitrogen, 58 tons of phosphorous, and 221 tons of potassium currently used for agriculture, close to 90% of the nutrients applied to farmland are purchased in the form of mineral fertilizers. For over 50 years, Duplin County has been using these mineral fertilizers to increase crop production. Animal waste is usually stored in large lagoons. Prior to the initiation of the project, some of the lagoons were not large enough to hold the amount of waste accumulated and there was some direct leaching into the surrounding area. Nonpoint source nutrient contamination to the riparian communities includes leaching of nutrients from waste lagoons and runoff from the application of the mineral fertilizers to crops (USDA

Annual Progress Report 1991).

Presently, there is a cooperative Water Quality Demonstration Project in the county that includes the North Carolina Agricultural Extension Service, USDA-Soil Conservation Service, and the USDA-Agricultural Research Service. This project was established to evaluate water quality status within Herrings Marsh Run watershed, to develop best management practices and waste management systems, and to monitor the effect that these new practices have on water quality. The goal of the project is to reduce inputs to surface waters by 90% for phosphorous and 60% for nitrogen. Herrings Marsh Run watershed was chosen by the ARS-USDA as a water quality demonstration project because it has been designated as "support threatened" by the North Carolina water quality agency. This classification is due to BOD (Biological Oxygen Demand), nutrient, and sediment nonpoint source inputs from the intensive agricultural activities practiced in the area.

Description of Forest Communities

Within the demonstration watershed there are twin tributaries and associated riparian forest communities (Figure 2) which are similar in size (control=127 ha, experimental=85 ha), soil type (US SCS 1954), topography, aspect, and elevation (USGS Summerlins Crossroads Quadrangle 1980). Water quality in both tributaries and surrounding groundwater has been monitored by Coastal Plains Soil and Water Conservation Research Center (USDA) for the past four years. The eastern most tributary and groundwater of its surrounding riparian forest community have

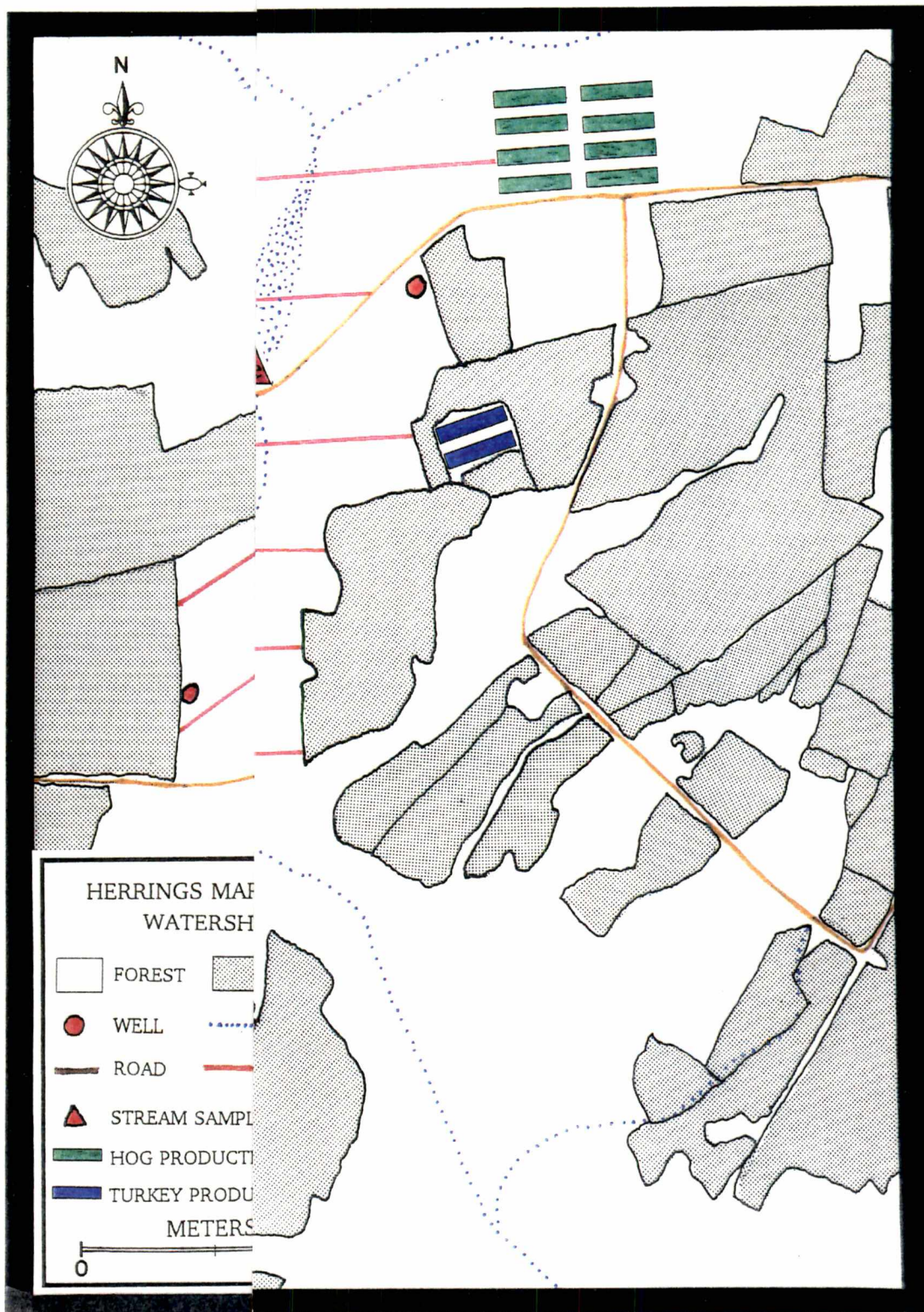


Figure 2. Study Area
 Experimental Comm

consistently shown extremely high levels of nitrate, phosphate, and ammonium inputs (Figure 3). This community is surrounded not only by intensive row crops but also by hog and turkey production units. This community is designated as the experimental community for this study and surrounds stream sampler e (Figure 2). The western most tributary and groundwater of its surrounding riparian forest community is referred to as the control site because of low input, stream, and groundwater levels of nitrate, phosphate, and ammonium. This community surrounds stream sampler c (Figure 2). Although this forest community is also surrounded by row crops, there are no adjacent hog or turkey production units.

Factors affecting community structure and species composition of forests are very interconnected and interdependent. Distribution and abundance of plants in forested systems are determined by a complex web of interactions. However, it is generally accepted that the two main factors affecting forest growth are nutrients and light (Tilman 1982).

Hypothesis

Because nitrogen and phosphorous are usually limiting nutrients in forested ecosystems, excessive inputs of nutrients from both mineral fertilizers and animal waste can be expected to affect forest function, composition, and structure. It is therefore hypothesized that there will be differences in structure and species composition between the control and the experimental communities.

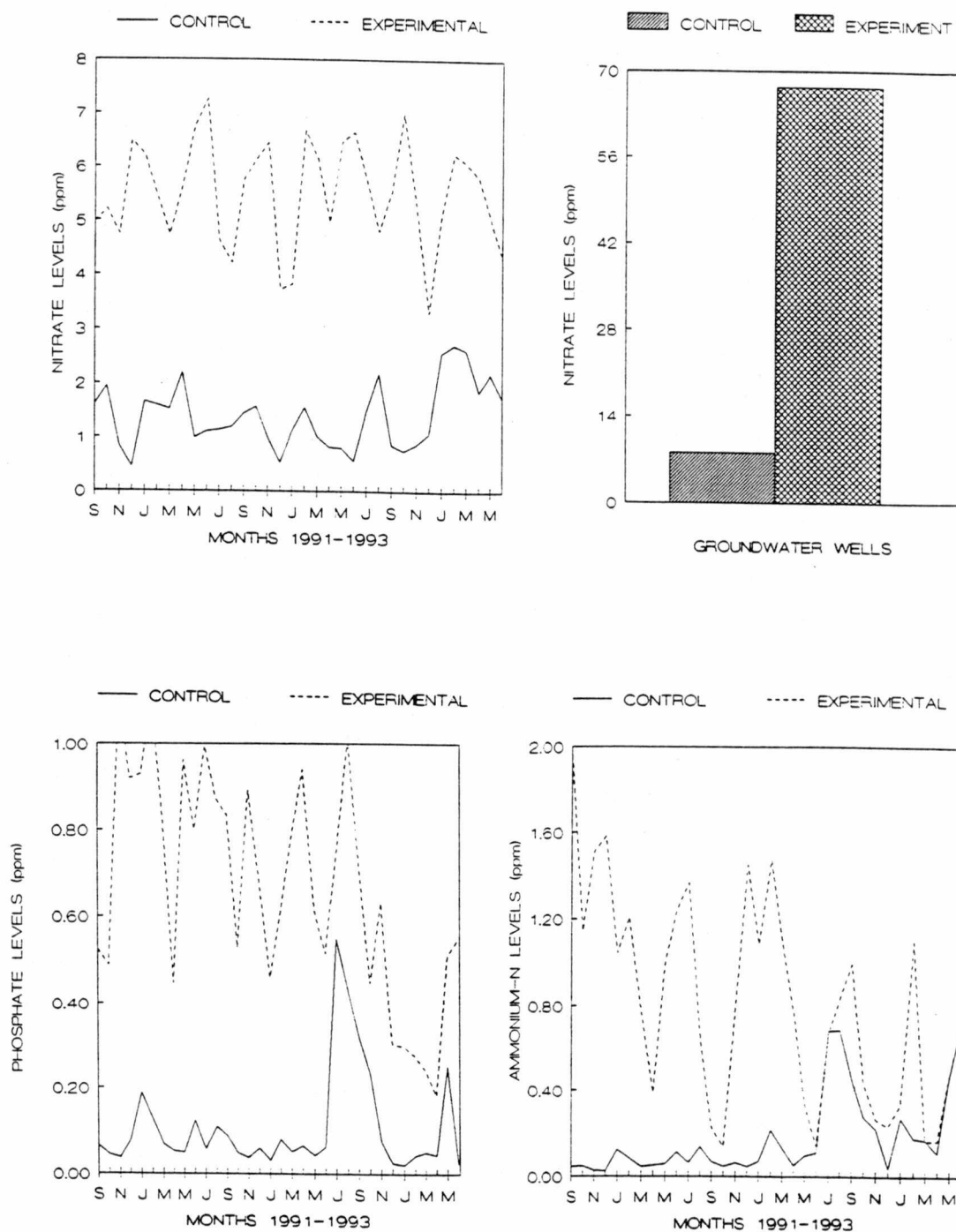


Figure 3. Differences in Levels of Nitrate in Stream Water, Average Levels of Nitrate in Groundwater (1991-1994), and Levels of Phosphate and Ammonium for Stream Water in the Control and Experimental Communities.

CHAPTER III

MATERIALS AND METHODS

Experimental Design and Data Collection

To determine if there are structural and compositional differences between experimental and control communities, the following parameters were evaluated: species importance values, community diversity, species richness, woody vegetative biomass, plant density, and community similarity.

Data were collected from May to August of 1994 from a series of transects, employing methods that are an adaptation of the line-strip method of Cain (1959). Transects, 2 meters in width, ran perpendicular to a compass line which ran parallel with the stream (Figure 2). Starting at the stream/forest edge, data were aggregated within 10 meter intervals. The longitudinal traverse from the first to the last transect of each riparian community sampled was 960 meters. Within each community, a total of 6 transects was sampled; they were separated by 160 meters. A total of 362 plots was evaluated, 251 in the control and 111 in the experimental community. Total area within plots sampled for the control community was 5020 m² canopy and subcanopy, 1255 m² shrubs and herbs, and 251 m² groundcover. Total area sampled for the experimental community was 2220 m² canopy and subcanopy, 555 m² shrubs and herbs, and 111 m² groundcover.

The forests were stratified into five vertical strata based only upon physical dimensions of height and/or dbh. These strata included canopy, subcanopy, shrubs,

herbs, and groundcover. Canopy data were collected within each 2 x 10 m plot and included all individuals with a DBH greater than 22.7 cm. Subcanopy data were also collected within each 2 x 10m plot and included all individuals with a height of greater than 3.0 meters and/or a DBH less than 22.7 m but greater than 12.6 cm. Species name, DBH, and height were recorded for every tree within the 20 m² plot. Height was measured with a Sunuto clinometer. Visual estimations of percent canopy closure were recorded for each plot.

Data collected for the designated shrub stratum included all woody vegetation (including woody vines and saplings) with a height less than 3.0 m but greater than 0.5 m. Data collected for the designated herb stratum included all herbaceous vegetation with a height less than 3.0 m but greater than 0.5 m at the time of sampling. Shrub and herb data were collected within a 1 x 5 m plot nested within the last five meters of the 2 x 10 m plot and included species name, height, and the diameter of the area that each individual covered. These parameters were used to calculate area of coverage for each individual and subsequent importance values for each species.

Groundcover vegetation included all plants with a height of less than 0.5 m. Data on groundcover vegetation were collected in a 1 x 1 m plot nested at the end of the 20 m² plot and included species name and estimations of percent cover which were converted into abundance-vigor-coverage values for calculation of importance values. The abundance-vigor-coverage scale for each species was classified and recorded as one of the following Domin-Dahl values (Evans and Dahl, 1955):

- 1 One or two individuals with normal vigor; no measurable cover
- 2 Several individuals; no measurable cover
- 3 Numerous individuals, cover less than 4% of total area
- 4 Cover up to 1/10 (4 to 10%) of total area
- 5 Cover about 1/5 (11 to 25%) of total area
- 6 Cover 1/4 to 1/3 (26 to 33%) of total area
- 7 Cover 1/3 to 1/2 (34 to 50%) of total area
- 8 Cover 1/2 to 3/4 (51 to 75%) of total area
- 9 Cover 3/4 to 9/10 (76 to 90%) of total area
- 10 Cover 9/10 to complete (91 to 100%)

Plants not identifiable in the field were assigned a number (UK#), bagged, pressed, dried, and later identified to the lowest possible taxonomic level. Taxonomic determination and nomenclature follow Radford (1968). Raw data and voucher specimens are being stored at Coastal Plains Soil and Water Conservation Research Center USDA-ARS in Florence, SC (Appendix B).

Parameters of Structure and Composition

Importance Values:

Dominance of plant species in canopy, subcanopy, shrub, and herb strata was determined on the basis of importance values. Importance values were calculated using relative values of density, coverage, and frequency (Cox 1991). Density was calculated as the number of individuals per area sampled. Relative density is the density of a species divided by the total density for all species times 100. Coverage was calculated as the basal area for canopy and subcanopy strata or areal coverage values for shrub and herb strata per area sampled. Relative coverage was calculated as the coverage value for a species divided by the total coverage value for all species

times 100. Frequency was calculated as the number of plots in which a species occurred per total number of plots sampled. Relative frequency was calculated as the frequency value for a species divided by the total frequency values for all species times 100.

Importance values for each groundcover species were calculated by summing its relative frequency and relative Domin-Dahl value.

Community Similarity:

Sørensen's Coefficient of Similarity was used to evaluate the degree of similarity of species composition that the two communities possess (Sørensen 1948).

The equation used was:

$$\text{Coefficient of Similarity} = (2w)/(c + e)$$

In this equation, **c** was the total number of species in the control community, **e** was the total number of species in the experimental community, and **w** was the number of species common to both communities. These values are expressed as percentages.

Species Diversity:

Diversity indices were calculated for each stratum of both communities using the Shannon Index (Cox 1991). This index evaluates both species richness and evenness and is calculated using the following equation:

$$H' = - \sum p_i \log p_i$$

In this equation for every strata except groundcover, **p_i** is the decimal fraction of

individuals belonging to the i^{th} species. For the groundcover stratum, p_i is the decimal fraction of cover for each species. Values for this index vary from 0 for communities with very low diversity to higher values with increasing diversity. No statistical test of significance was conducted on the Shannon diversity indices because these values are not numerically proportional to each other.

Species Richness:

Species richness was calculated separately for each stratum as the number of species present within each plot. Mean species richness was calculated for each stratum for the control and experimental communities and statistically analyzed for differences.

Woody Vegetative Biomass:

Estimated biomass for each community was calculated using methods from Smith (1975) for Branch Bottom forests. Biomass, estimated in terms of yield (m^3ha^{-1}), was calculated for each 20 m^2 plot for trees with a DBH $> 12.6 \text{ cm}$ (both canopy and subcanopy strata). This estimation of biomass is restricted because it does not account for a small amount of limb material and calculations are based on averages of tree height and stand age for a prescribed community type which was determined to be most similar to the communities being studied. The calculation of biomass was computed with a BASIC program developed by Jerry Faulkner (UTK).

Density:

Plant density was calculated by adding the total number of individuals per plot, all species combined. Means density was calculated for each stratum and statistically analyzed for differences between the control and experimental communities.

Data Analysis

Species Richness, Density, and Biomass:

Differences in means of species richness, total plant density, and woody vegetative biomass between the experimental and control communities were statistically determined for each stratum using both Analysis of Variance (ANOVA) and Mann-Whitney U tests (Sokal and Rohlf 1981) with the SPSS statistical package. The two treatment effects tested were high (experimental community) and low (control community) levels of nutrient inputs. Transects and plots were aggregated within each treatment (community). Data that showed a normal distribution were analyzed using parametric Analysis of Variance. Data that did conform to ANOVA's assumption of normal distribution were transformed by $\log_{10}$ and reanalyzed with ANOVA and were also analyzed with the ranking nonparametric Mann-Whitney U test.

The irregularity of length and number of plots in each transect may have created enough variation to prevent the detection of significant differences. Therefore, ANOVAs were performed on the four adjacent plots on both sides of the streams for each transect.

Plants directly adjacent to the stream have the potential to receive nutrients directly from stream waters saturating the soil. To evaluate possible differences in vegetation produced by this phenomenon, ANOVA was performed on plots adjacent to the streams.

Extraneous Data

Slope, descriptions of soil, and depth of organic litter, were also measured for each plot. Instantaneous weather data was recorded each day of data collection. This information included measurements of air temperature and estimations of cloud coverage, wind direction and force, and humidity. Percent canopy closure was visually estimated in the center of each 2 x 10 m plot. Downed trees, major disturbances, and abrupt environmental gradients were noted. Permanent aluminum stakes were installed at the stream intersection of each transect.

CHAPTER IV

RESULTS AND DISCUSSION

Canopy

The five most important canopy species in the control community were, from more to less important, *Pinus taeda* L., *Nyssa sylvatica* Marshall, *Liquidambar styraciflua* L., *Acer rubrum* L., and *Liriodendron tulipifera* L. (Table 1)¹. The five most important species of the canopy stratum in the experimental community were *Pinus taeda*, *Liquidambar styraciflua*, *Acer rubrum*, *Nyssa sylvatica*, and *Liriodendron tulipifera*. All canopy dominants, except for *Nyssa sylvatica*, are fast growing, shade intolerant species (Fowells 1965) and are indicative of a relatively young or recently disturbed forest of the southeastern United States (Johnson et al. 1974).

The two communities shared the same dominant species, but *Pinus taeda* strongly dominated both the control and experimental communities with importance values of 90 and 98 respectively. The next most dominant species had importance values of only 59 (control) and 65 (experimental). The canopy strata had 75% community similarity of species composition (Table 7). Overall, species were more evenly distributed within the control community than the experimental.

Due to their elevated position in the community, growth of canopy trees in either community are not limited by light and probably never were. Therefore, it is reasonable to assume that differences in the canopy strata are due to the difference

¹All tables and Figures 4 and 5 may be found in Appendix A.

in availability of nutrients. These differences were expected to manifest themselves within the experimental community as a decrease in biodiversity and an increase in biomass and density.

Species biodiversity of the canopy was lower in the experimental community than in the control community (Figure 4). Previous studies have shown that an increase in soil fertility will decrease biodiversity as a result of an increase in dominance by species which were previously nutrient limited (Thurston 1968, Tilman 1982, Huston 1993). When nutrients are readily available, as in the experimental community, species whose growth and survival is normally limited by the lack of these nutrients, are able to monopolize total resources and increase dominance within the community. In the control community, nutrient limited species may have to compete for available nutrients and are unable to express strong dominance. This may contribute to greater biodiversity.

Mean species richness of the canopy stratum was slightly higher in the experimental community than the control community (Table 6). Data were not normally distributed, and neither data transformation by $\log_{10}$ nor Mann-Whitney U analysis yielded significant differences. The fact that species diversity was lower, but species richness was higher in the experimental community may be due to a more even distribution of species over the whole control community as compared to that of the experimental community.

Because plant growth in natural ecosystems is usually limited by nutrients, light, and many other factors, the addition of nutrients should increase plant biomass

if no other factors are limiting (Tilman 1988). Contrary to this phenomenon, density (insignificant) of the canopy (Figure 5) and combined biomass (significant) of canopy and subcanopy trees in the experimental community were lower than in the control community. Mean biomass (cubic yield) for canopy and subcanopy trees was $605 \text{ m}^3\text{ha}^{-1} \pm 75.4$ in the control community and $260 \text{ m}^3\text{ha}^{-1} \pm 76.9$ in the experimental community. Analysis of variance showed the means to be significantly different ($p=0.01$). Data describing canopy density were not normally distributed so they were transformed by $\log_{10}$. The mean value for the control community was higher, but an ANOVA of the transformed data yielded a nonsignificant probability of 0.08. There were no significant differences between means for analyses of data restricted to the one adjacent and four stream-adjacent plots.

Estimations of percent canopy closure showed the control canopy to average 78% closure while the experimental community averaged 56% closure. Field notes indicate that the difference may be due to more frequent cutting and treefalls in the experimental community. Estimates of canopy height show an average of 24.5 m for the control community canopy and an average of 20.7 m for the experimental community canopy. The height difference between the communities indicates that as a whole, the experimental community may be slightly younger than the control community. These community differences would explain significant differences in biomass and slight differences in plant density of the canopy stratum.

Initially, potential differences in lower strata were hypothesized to be due mainly to differences in nutrient subsidies. However, results strongly indicate that an

increase in disturbance in the experimental community resulted in an increase in light availability to lower strata. Therefore differences between the communities in the lower strata must be explained in terms of species responses to an increase in nutrients *and* light.

Subcanopy

The five most important species in the subcanopy stratum of the control community were *Ilex opaca* Aiton, *Liquidambar styraciflua*, *Symplocos tinctoria* (L.) L'Her., *Quercus nigra* L., and *Acer rubrum* (Table 2). The five most important species in the subcanopy of the experimental community were *Pinus taeda*, *Liquidambar styraciflua*, *Ilex opaca*, *Acer rubrum*, and *Magnolia virginiana* L.. Community similarity was 70% between the two subcanopy strata, indicating a high coefficient of similarity of species composition (Table 7).

Structure and composition of the subcanopy strata should not only be affected by nutrient levels but also by the availability of light, which is influenced by the percent closure of the canopy stratum. Because the canopy of the control community was more closed than that of the experimental community, both light and nutrients may have been limiting. Indirect effects, due to competition for limited light include increased biodiversity (reduced dominance) and reduced biomass of subcanopy stratum. In the more open experimental community, greater availability of nutrients and light should result in relatively low biodiversity (high dominance) and higher biomass.

The most significant result of the study was that the subcanopy of the control community had a higher species diversity (Figure 4) and significantly higher species richness (Table 6) than the experimental community when the entire data set was analyzed with ANOVA ($p=0.03$). Even though there is potential for greater disturbances in the experimental community to increase diversity, the fact that diversity is much higher in the control community strongly supports the suggestion that both light and nutrients may have been limiting and therefore prevented species from expressing strong dominance.

Again, combined canopy and subcanopy biomass was significantly higher in the control community. Density of subcanopy trees in the control community was slightly higher but not statistically different than that of the experimental community (Figure 5). These data were not normally distributed even after $\log_{10}$ transformation so the nonparametric Mann-Whitney U test was applied to yield a nonsignificant probability of 0.07. The lower biomass and density of the experimental subcanopy stratum, similar to canopy, was also probably due to more frequent cutting and treefalls.

Although there is a high coefficient of similarity between the subcanopy strata, there are differences in the dominance of species in the two communities. The most striking difference between subcanopy strata of the experimental and control communities is the strong dominance of *Pinus taeda* in the former and its near absence in the latter. The relatively fast growing, shade intolerant species *Liquidambar styraciflua* also dominates the subcanopy of the experimental community while a relatively slow growing species, *Ilex opaca* dominates the control community.

Quercus nigra was the third most dominant subcanopy species of the control community and many other relatively slow growing oaks were present. The openness of the canopy in the experimental community helps to maintain the presence and dominance of fast growing, opportunistic species in the subcanopy stratum and inhibits dominance of slower growing, shade tolerant trees like oaks.

Greater openness of both canopy and subcanopy strata in the experimental community can be expected to increase light available to lower strata. Upper strata in the control community are more closed and therefore both light and nutrients may be limiting.

Shrubs

The five most important species in the shrub stratum of the control community were *Clethra alnifolia* L., *Symplocos tinctoria*, *Arundinaria gigantea* (Walter) Muhl., *Smilax rotundifolia* L., and *Ilex opaca* (Table 3). The five most important species in the shrub stratum of the experimental community were *Smilax rotundifolia*, *Ilex opaca*, *Arundinaria gigantea*, *Clethra alnifolia*, and *Liquidambar styraciflua*. These communities shared 4 dominant shrub species and had a relatively high coefficient of similarity of species composition (66%) (Table 7).

The lower strata of the experimental community should not be nutrient limited and should be less light limited than the lower strata of the control community. This should increase dominance (decrease biodiversity) and increase density in the experimental community. The limitation of light and nutrients in the control

community should increase competition and suppress dominance and thereby increase biodiversity and decrease density.

Contrary to the preceding expectation, species diversity was slightly higher for shrubs in the experimental community than in the control community (Figure 4) and means of species richness were basically equal in both communities (Table 6). Greater diversity probably exists for this stratum in the experimental community because of the apparent frequency of disturbances.

As expected, mean density of shrubs was significantly higher in the experimental community only for ANOVA performed on data restricted to the four stream-adjacent plots (Figure 5). The higher availability of light and nutrients in this stratum seemed to support higher densities of individuals.

Canopy populations are dependent upon recruitment from smaller and probably younger size classes. The shrub stratum contains saplings which are well established and are a source of recruitment for canopy and subcanopy populations of the same species. Canopy dominants of the control community are present in the shrub stratum but not of great importance. *Liquidambar styraciflua* and *Acer rubrum* have the highest importance values of 6.7 and 9.1, respectively. In the shrub stratum of the experimental community, all canopy dominants except *Nyssa sylvatica* have higher importance values than in the control community. Most striking are the relatively high importance values of *Pinus taeda* (9 versus 1), *Liquidambar styraciflua* (16 versus 9), and *Liriodendron tulipifera* (0.8 versus 0.3). These three species are shade intolerant, opportunistic, fast growing species (Fowells 1965). Their greater

dominance in this lower stratum provides strong evidence that there is greater light availability for the shrub stratum in the experimental community. Significant differences in canopy biomass and percent canopy closure are consistent with this evidence.

Herbs

The five most important species of the herb stratum in the control community were *Woodwardia areolata* (L.) Moore, *Impatiens capensis* Meerb., *Athyrium asplenoides* (Michaux) A. A. Eaton, *Osmunda cinnamomea* L., and an unknown graminoid #1 (Table 4). The five most important species of the herb stratum in the experimental community were *Impatiens capensis*, *Woodwardia areolata*, *Juncus effusus* L., *Osmunda cinnamomea*, and *Eupatorium capillifolium* (Lam.) Small. The communities shared three dominant species and had a low coefficient of similarity of species composition of 31% (Table 7).

The herb stratum of the experimental community should not be nutrient limited and should be less light limited than the lower strata of the control community. This should increase dominance (decrease diversity) and increase density in the experimental community. The limitation of light and nutrients in the control should produce increased diversity and decreased density.

As with the shrub stratum, species diversity was higher for herbs in the experimental community than the control community (Figure 4) and species richness was not significantly different between the two communities (Table 6). The increase

in intermediate disturbances in the experimental community (frequent cuts/more treefalls) may maintain higher diversity of herbs within this community.

Consistent with expectations, density for herbs was significantly higher in the experimental community than the control community (Figure 5). The Mann-Whitney U test showed a significant difference in herb density between the communities ($p=0.05$). This result supports the suggestion that plant growth will increase with an increased availability of light and nutrients. Differences were probably more detectable in this stratum because naturally high growth rates (compared to canopy and subcanopy species) allow for quicker and more dynamic responses to nutrient loading or other environmental changes.

Groundcover

The five most important groundcover species in the control community were *Lonicera japonica* Thunberg, *Woodwardia areolata*, *Arundinaria gigantea*, *Smilax rotundifolia*, and *Parthenocissus quinquefolia* (L.) Planchon (Table 5). The five most important groundcover species in the experimental community were *Clethra alnifolia*, *Smilax rotundifolia*, *Gelsemium sempervirens* (L.) Aiton, *Acer rubrum*, and *Woodwardia areolata*. Both communities were dominated by vines and ferns but also included many juvenile individuals of species found in the higher strata and relatively few mosses and lichens. The coefficient of similarity showed the communities to have a 49% similarity in species composition (Table 7).

Seedlings of the shade intolerant species *Liriodendron tulipifera*, are absent in

both communities. Seedlings of *Pinus taeda* are present only in the experimental community and seedlings of *Acer rubrum* have an importance value 3 times that of the control community. These results, provide additional evidence that light is less limiting in the experimental community. The absence of *Pinus taeda* seedlings from the control community further supports the importance of intermediate disturbance from cutting or treefalls in maintaining high species diversity and replacement of these shade intolerant species.

Diversity of the groundcover stratum was higher in the experimental community than the control community. Again, as in the other lower strata, greater diversity in this stratum of the experimental community may have been due to greater disturbance. Species richness and total percent cover of groundcover vegetation was not significantly different in the two communities.

Predictions of Future Canopy Dominance

Presently, the canopy of both communities are dominated by *Pinus taeda* and other species typical of relatively young, disturbed forests of this region (Johnson et al. 1974). Looking at the presence of potential canopy recruits in lower strata may help in predicting future compositional differences in the communities (Table 8). Subcanopy and shrub dominants indicate that the experimental community will continue to be dominated by *Pinus taeda* and *Liquidambar styraciflua*. The continued domination of shade intolerant species indicates that the experimental community, as a whole, may be at a younger successional stage or be more repressed than the

control. Species present in the subcanopy and shrub strata of the control community indicate that *Pinus taeda* will probably be replaced in the canopy by *Liquidambar styraciflua* and *Quercus nigra*. The dominance of *Acer rubrum* and *Quercus nigra* seedlings in the groundcover stratum of both communities indicates potential convergence of canopy dominance in later successional stages. If differences in nutrient availability continue, diversity should continue to be lower in the upper strata and productivity should increase in the experimental community over time. Of course, all of these predictions are based upon the unlikely contingency that these communities will remain undisturbed. It is almost certain that they will continue to be disturbed (logged) keeping the communities at a relatively early successional stage dominated by the same opportunistic species presently dominating the canopy.

Conclusions

Forest communities are complex holistic systems, seldom governed by a single factor (Maurer 1987). Changes in even one factor may have a variety of secondary impacts which vary among community strata or species populations. However, structural differences between the control and experimental communities were identified and seemed to be associated with significant differences in two factors, nutrients and light.

As a whole, the experimental community is less nutrient limited, less light limited (more open canopy), more disturbed than the control community, and favors faster growing species. The most prominent difference between communities was

higher species diversity in the subcanopy stratum of the control community. The high degree of similarity in the upper strata of the control and experimental communities in terms of species composition and dominance, indicates that differences in diversity may be strongly associated with differences in nutrient levels. These results are consistent with those found in a study of tropical forests where low soil fertility was found to support high species richness of canopy and subcanopy trees (Huston 1980).

The phenomenon of increased diversity with decreased soil nutrient content, is not evident in the lower strata because the availability of light becomes an important differentiating factor, masking any effects produced by differing nutrient levels. Higher species diversity and the species composition of lower strata of the experimental community support the suggestion that disturbance (higher availability of light) plays a strong role in this community's structure. Higher plant density in 2 out of 3 lower experimental strata are consistent with the concept that with increased light there is increased growth.

There was 44% community similarity of total species composition. Although this number indicates that there was not much similarity in species composition between the communities at the level of all taxa - canopy, subcanopy, and shrub strata were very similar in composition. The successive decrease in percent community similarity from canopy to subcanopy, shrubs, groundcover, and to herbs is probably due to the increased differentiation of the microenvironments and microhabitats.

Results of this study provide baselines for subsequent field studies and leave

enough questions unanswered to stimulate rigorous tests of a variety of hypotheses.

Management Options for Riparian Communities

Water quality data gathered by the USDA over the last four years has indicated a need for the reduction of nutrients in the waters of Herrings Marsh Run watershed. For this study, management practices were developed for the watershed to maximize the riparian forest communities' ability to reduce nutrient levels in stream waters, while minimizing destruction of the communities as valuable habitats and providing a sustainable source of income to land owners.

Because much of the United State's riparian ecosystems have been lost and are still being lost at an extremely high rate, ideally the best management practice would be passive management, i.e. leave them alone. However, the riparian systems in Herrings Marsh Run watershed are located on privately owned land and offer multiple values to the land owner. For example, these forests have been cut for timber on approximately 40-50 year cycles. Strategic planning is needed in order to derive an optimal solution for sustaining the multiple values of riparian forest ecosystems. One approach is to prescribe management through regulatory control. A more desirable approach is to prescribe management which provides fiscal incentives to land owners. The most effective approach is often a combination of regulatory control and fiscal incentives.

Water quality of agricultural watersheds is traditionally dependent on nutrient uptake and removal by riparian communities. Both preservation of existing riparian

communities and management of adjacent land must be considered for preservation of habitat and improvement of water quality.

High levels of nutrients in the experimental stream could be decreased by several BMPs (Best Management Practices) which, if implemented, could increase the riparian community's ability to reduce levels of nitrate, phosphate, and ammonium presently able to reach stream waters. One method of forest management is clearcutting. This method is sometimes detrimental to water quality because it destroys above ground woody vegetation that normally absorbs runoff nutrients from row crops and animal production units and temporarily adds nutrients from the degradation of large quantities of organic debris left from cutting. For this reason, and because it also removes habitat for wildlife, extensive clearcutting is not recommended as a management practice for the study area.

Selective logging of mature trees of all species, is one way of increasing nutrient uptake by the community while maintaining a sustainable income for the landowner. Of the five dominant canopy species of the experimental community, *Pinus taeda*, *Acer rubrum*, and *Liriodendron tulipifera* have high commercial value (Handbook 1965). Water quality would be improved because mature trees which have dominated the community and have relatively low rates of nutrient uptake are replaced with young successional vegetation with higher rates of uptake (Lowrance 1984). Although selective cutting of mature trees also allows for less disturbance to the soil as compared to clearcutting, there remains the problem of getting to and removing the selected trees with large equipment.

Mimicking natural treefall gaps by cutting strip shelter belts (Hartshorn 1989) is an alternative method of logging which minimizes impacts to the community as compared to clearcutting, increases nutrient uptake by replacing mature vegetation with new growth, and provides an income for the landowner. In this method, strips similar in size, if not shape, to gaps created by a natural treefalls, are clearcut. Gaps in the canopy, natural or artificial, favor species with higher growth rates and subsequently higher nutrient uptake rates than mature trees that are removed (Doyle 1981). The five dominant canopy species of both communities in the study area are typical opportunistic, fast-growing, shade intolerant species that would quickly regenerate the forest after the canopy was opened. Fast regeneration would be aided by the high availability of seeds from intact vegetation surrounding all sides of the narrow strip shelter belts. Another benefit of implementing this method is that *Acer rubrum*, *Liriodendron tulipifera*, and *Liquidambar styraciflua* are stump sprouters and would contribute to rapid regeneration of the forest. Based upon tree size, strip shelter belts for forests of Costa Rica were recommended by Hartshorn (1989) to have areas with an average width to length ratio of 1 to 8. However, the average height of trees in the study area (21 m) indicates that a lower ratio must be used (blocks instead of strips). Length and total area cut will depend upon the width of the riparian forest. After the initial cut, successive cuts should be at least 100 meters from other previously cut shelter belts. Based upon the growth rates provided by Fowells (1965) and implied for the species present in the forest communities of Herrings Marsh Run, a rotation of 40-50 years should be implemented.

In addition to alternative logging practices, another method of improving stream water quality is to plant strips of vegetation between row crops and/or animal production units and the riparian forest community. These buffer strips should be established on land that was previously cultivated and would serve as sinks to both N and P. Osborne et al. (1993) found that grass buffers (4.6-27m wide) and forested buffers (30-50m wide) reduced N levels in subsurface water flow up to 98% and 84%, respectively. They found that the forested strips were most effective in N reduction but grass strips were more effective in P reduction. The buffer system should provide revenues to land owners as well as serve as nutrient sinks. One possibility is an agroecosystem of domestic grasses or other perennial species which accumulate P and are of high economic value. Interspersed among economic grasses would be fruit or nut trees which would assimilate N and also provide revenues to land owners.

Some areas of the study communities presently have inadequate width of riparian vegetation adjacent to the stream to maintain high water quality. Various widths for riparian buffer strips were reviewed by Howard et al. (1988) and a minimum of 24 meters was suggested for maintenance of acceptable water quality by the South Carolina Forestry Commission (1988). Regulatory control or cooperative agreements with landowners requiring a 24 meter minimum riparian buffer along streams, is another method of preserving valuable habitat while improving water quality.

Based upon recent advances in ecological science and forest management, the preferred management practice would combine various aspects of preceding

alternative practices. For communities in this study, the preferred practice would be a combination of:

1. regulatory controls or cooperative agreements ensuring a riparian forest width of at least 24 m for all stream channels,
2. timber harvests (24 x 21 m) within the riparian forest communities using strip shelter belt procedures on a 40-50 year rotation, and
3. an agroforestry buffer system (30m wide) which assimilates nutrients and produces revenues for landowners.

The use of block shelter belts as part of the management practice is consistent with ecological characteristics of the experimental community. This community is a relatively fast growing forest due to significantly high nutrient resources and relatively high light availability. Dominant canopy species of the experimental community are opportunistic, shade intolerant species which benefit from intermediate disturbances like treefalls and shelter belts which add light to the nutrient rich system and ensure rapid regeneration following timber harvests. The strip shelter belt system provides sustained economic revenues to the landowner, little if any maintenance costs, preservation of habitat, and improved water quality.

An agroforestry buffer at least 30m wide would consist of a mixture of either agricultural or sod grasses and nut or fruit bearing trees to maximize uptake of both P and N, respectively. The buffer provides the same benefits as the strip shelter belts and in addition, provides the landowner with a greater diversity of agricultural products and revenues. The minimal width of riparian forest adds to sustainability of this complex multiple use, multiple value system.

Research Limitations

One significant limitation of this project is that data were collected for only one season. It would be valuable to monitor the study area over time. To better evaluate direct impacts of nutrient loading on riparian communities it may preferable to concentrate efforts to detecting effects produced by nutrient loading or overloading on herbs and woody seedlings. Because of their high growth rates, dynamic short-term reactions to changes in the environment can be more easily detected than by looking for responses from plants with slower growth rates.

Further research should include analysis of environmental factors and their influence upon community composition. Influential factors that were not considered in this brief study include wet and dry atmospheric inputs, biocide inputs, and other anthropogenic disturbances. Also, the present study should be repeated in future years to evaluate the success of mitigation strategies and BMPs.

BIBLIOGRAPHY

- Albrektson, A., A. Aronsson, & C. Tamm. 1977. The effect of forest fertilization on primary production and nutrient cycling in the forest ecosystem. Silva Fenn. 11:233-239.
- Anonymous, North Carolina fertilizer tonnage report. 1983. North Carolina Agricultural Statistics. North Carolina Department of Agriculture, Raleigh, NC. 1945-1983.
- Brown, S., M. Brinson, & A. Lugo. 1978. Structure and Function of Riparian Wetlands. Proceedings of the Symposium on Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Callaway Gardens, GA.
- Cain, S. A. 1959. Manual of Vegetation Analysis. New York: Harper & Brothers.
- Canter, L. W. 1986. Environmental Impacts of Agricultural Production Activities. Chelsea, Michigan: Lewis Publishers.
- Chapman, S.B. 1976. Methods in Plant Ecology. New York: Blackwell Scientific Publications.
- Cox, G. W. 1991. Laboratory Manual of General Ecology. Dubuque, Iowa: Wm. C. Brown Publishers.
- Doyle, T.W. 1980. The role of disturbance in the gap dynamics of a montane rain forest: An application of a tropical forest succession model. In D.C. West, H.H. Shugart & D.B. Botkin, eds., Forest Succession: Concepts and Applications, 56-73. New York: Springer-Verlag.
- Faulkner, J. 1989. BASIC program for calculation of woody vegetative biomass. Botany Department, University of Tennessee, Knoxville.
- Fowells, H. 1965. Silvics of Forest Trees of the United States. Agricultural Handbook # 271. USDA Forest Service.
- Gregory, S.V., F.J. Swanson & W.A. McKee. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. BioScience. 41:540-551.
- Harris, R. 1987. Occurrence of vegetation on geomorphic surfaces in the active floodplain of a California alluvial stream. Amer. Midl. Naturalist. 118:393-405.

- Hartshorn, G. 1989. Sustained yield management of natural forests: The palcazu production forest. In J.O. Browder, ed. Fragile Lands of Latin America: Strategies for Sustainable Development, 130-138. Boulder: Westview Press.
- Huston, M. 1980. Soil nutrients and tree species richness in Costa Rican forests. J. Biogeogr. 7:147-157.
- Huston, M. 1993. Biological diversity, soils, and economics. Science. 262:1676-1679.
- Jacobs, T.C. & J.W. Gilliam. 1985. Riparian losses of nitrate from agricultural drainage waters. J. Environ. Qual. 14(4):472-478.
- Johnson, W.C. & D. Sharpe. 1974. Forest Dynamics in the Northern Georgia Piedmont. Environmental Sciences Division, Oak Ridge National Laboratory.
- Knapp, R. (ed). 1984. Sampling Methods and Taxon Analysis in Vegetation Science. Boston: W. Junk Publishers.
- Knopf, L. Fritz, R. Johnson, R. Roy, & T. Rich. 1988. Conservation of riparian ecosystems in the United States. Wilson Bull. 100:272-84.
- Kuenzler, E. J. 1988. Value of forested wetlands as filters for sediments and nutrients. Proceedings from Forested Wetlands of the Southern United States Symposium.
- Lewis, Jack. 1991. Some other options on the farm (to reduce nonpoint source pollution). EPA Journal. 17:45.
- Lowrance, R., R. Todd & J. Fail. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience. 34:374-377.
- McCormick, J.F. 1979. A summary of the national riparian symposium: A proposal for a national program. Proceedings of the Symposium on Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Callaway Gardens, GA.
- Osborne, L. & D. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restorations and stream management. Freshwater Biol. 29:243-258.
- Osterkamp, W.R. & C.R. Hupp. 1984. Geomorphic and vegetative characteristics along three northern Virginia streams. Bull. Geol. Soc. Amer. 95:1093-1101.
- Radford, A.E., H.E. Ahles & C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. Chapel Hill: The University of North Carolina Press.

- Schmidt, R.H. 1991. Defining and redefining value for riparian systems. Rangelands. 13(2):80-82.
- Sheridan, J.M., P. Yates & L. Asmussen. 1983. Hydrology and nutrient and sediment movement from Southeastern Coastal Plain watersheds. R. Lowrance, R. Todd, L. Asmussen & R. Leonard, eds. In Nutrient Cycling in Agricultural Ecosystems. Univ. of Ga., Coll. Agric. Spec. Publ. No. 23. 281 p.
- Smith, H.D., D.L. Hatley, D.L. Holley & R.C. Kellison. 1975. Yields of mixed hardwood stands occurring naturally on a variety of sites in the southern united states. North Carolina State University, School of Forest Resources. Tech. Rep No. 55.
- Sokal, R. R. & F.J. Rohlf 1981. Biometry, The Principles and Practice of Statistics in Biological Research. New York: W.H. Freeman and Company.
- Sørensen, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish Commons. Biol. Skr. (K. danske vidensk selsk. N.S.) 5:1-34.
- Swift, B.L. 1984. Status of riparian ecosystems in the United States. Water Res. Bull. 20(2):223-227.
- Thurston, J.M. 1968. The effect of liming and fertilizers on the botanical composition of permanent grassland, and on the yield of hay, In I. Rorison, et al., eds., Ecological Aspects of the Mineral Nutrition of Plants. Oxford: Blackwell Scientific Publications.
- Tilman, D. 1982. Resource Competition and Community Structure. Princeton, New Jersey: Princeton University Press.
- Tilman, D. 1988. Plant Strategies and the Dynamics and Structure of Plant Communities. Princeton, NJ: Princeton University Press.
- Todd, R., R. Lowrance, O. Hendrickson, L. Asmussen, R. Leonard, J. Fail & B. Herrick. 1983. Riparian vegetation as filters of nutrients exported from a coastal plain agricultural watershed, In T. Lowrance, L. Asmussen, & R. Leonard, eds. Nutrient Cycling in Agricultural Ecosystems. Univ. of Ga., Coll. Agric. Spec. Publ. No. 23. 485 p.
- United States Department of Agriculture. 1991. FY91 Annual progress report for USDA Water Quality Demonstration Project in Herrings Marsh Run, Duplin County, North Carolina.

- United States Geological Service. 1980. Summerlins Crossroads Quadrangle. Duplin County, North Carolina. DMA 5454 III SW-Series V842.
- United States Soil Conservation Service. 1954. Soil Survey of Duplin County, North Carolina. 1So32F 1954, no. 2.
- Vrba, J. & E. Romijn. 1986. Impact of Agricultural Activities on Ground Water. Hannover: International Association of Hydrogeologists.
- Warren, C.E. 1971. Biology and Water Pollution Control. Philadelphia: W.B. Saunders Company.

APPENDICES

APPENDIX A
TABLES AND FIGURES

Table 1. Importance Values for Canopy Species of Control and Experimental Communities.

Canopy	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
<i>Acer rubrum</i>	24.27	32.61
<i>Carya tomentosa</i>	---	6.52
<i>Liquidambar styraciflua</i>	32.95	65.22
<i>Liriodendron tulipifera</i>	22.54	13.04
<i>Magnolia virginiana</i>	1.73	---
<i>Nyssa sylvatica</i>	58.96	19.57
<i>Pinus strobus</i>	3.47	---
<i>Pinus taeda</i>	90.17	97.83
<i>Quercus alba</i>	19.08	7.38
<i>Quercus falcata</i>	8.67	13.76
<i>Quercus marilandica</i>	3.62	6.00
<i>Quercus nigra</i>	20.45	13.52
<i>Quercus palustris</i>	1.85	---
<i>Quercus stellata</i> var. <i>margaretta</i>	3.12	---
<i>Sassafras albidum</i>	1.61	---

Table 2. Importance Values for Subcanopy Species in Control and Experimental Communities.

Subcanopy	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
Acer rubrum	15.03	13.74
Alnus serrulata	1.61	1.15
Asimina triloba	---	1.28
Carpinus carolinana	---	1.51
Carya tomentosa	2.60	1.65
Castanea pumila	0.39	---
Cornus florida	1.73	9.16
Cyrilla racemiflora	0.29	2.29
Ilex opaca	51.16	44.66
Ligustrum sinense	1.16	---
Liquidambar styraciflua	41.91	70.99
Liriodendron tulipifera	4.62	5.73
Magnolia virginiana	11.85	11.45
Morus rubra	1.22	---
Myrica cerifera	1.10	---
Nyssa sylvatica	12.43	10.31
Oxydendrum arboreum	1.67	8.38
Persea palustris	0.52	---
Pinus taeda	7.80	96.18
Prunus serotina	2.89	---
Quercus alba	8.42	---
Quercus falcata	10.40	1.15
Quercus marilandica	2.60	---
Quercus nigra	18.40	3.44

Subcanopy	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
Quercus palustris	0.21	1.14
Quercus phellos	0.31	---
Quercus stellata	0.24	---
Quercus stellata var. margeretta	6.07	---
Quercus velutina	2.57	---
Rhododendron nudiflorum	0.23	---
Sassafras albidum	6.97	2.27
Symplocos tinctoria	32.66	1.25
Vaccinium arboreum	1.734	1.27
Vaccinium stamineum	5.49	1.09
Viburnum nudum	0.31	---

Table 3. Importance Values for Shrub Species in Control and Experimental Communities.

Shrubs	Importance Values Control	Importance Values Experimental
<i>Acer rubrum</i>	6.67	8.31
<i>Alnus serrulata</i>	1.77	3.32
<i>Amelanchier canadensis</i>	0.86	1.46
<i>Aralia spinosa</i>	---	0.66
<i>Aronia arbutifolia</i>	0.62	---
<i>Arundinaria gigantea</i>	21.94	28.63
<i>Asimina triloba</i>	0.19	1.41
<i>Callicarpa americana</i>	0.18	---
<i>Campsis radicans</i>	0.97	0.74
<i>Carpinus carolinana</i>	0.37	0.55
<i>Carya aquatica</i>	0.31	---
<i>Carya tomentosa</i>	1.31	---
<i>Castanea pumila</i>	0.37	---
<i>Clethra alnifolia</i>	45.50	23.02
<i>Cornus florida</i>	1.20	0.50
<i>Cornus stricta</i>	---	0.43
<i>Crataegus</i> sp.	0.19	---
<i>Cyrilla racemiflora</i>	0.40	---
<i>Decumaria barbara</i>	0.22	0.87
<i>Diospyros virginiana</i>	0.77	---
<i>Euonymus americanus</i>	0.17	---
<i>Gaylussacia frondosa</i>	7.68	2.03
<i>Gelsemium sempervirens</i>	3.73	7.89
<i>Hypericum hypericoides</i>	0.71	1.83

Shrubs	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
<i>Ilex coriacea</i>	1.55	0.63
<i>Ilex glabra</i>	0.43	1.71
<i>Ilex opaca</i>	17.76	33.90
<i>Ilex sp.</i>	9.52	---
<i>Ilex verticillata</i>	0.20	9.00
<i>Itea virginica</i>	7.85	---
<i>Kalmia angustifolia</i>	---	0.55
<i>Leucothoe axillaris</i>	0.56	3.06
<i>Leucothoe racemosa</i>	0.26	---
<i>Ligustrum sinense</i>	3.31	2.25
<i>Liquidambar styraciflua</i>	9.14	16.33
<i>Liriodendron tulipifera</i>	0.28	0.82
<i>Lonicera japonica</i>	2.66	0.91
<i>Magnolia virginiana</i>	6.70	1.78
<i>Malus angustifolia</i>	---	0.72
<i>Myrica cerifera</i>	2.20	---
<i>Nyssa sylvatica</i>	3.59	1.08
<i>Oxydendrum arboreum</i>	1.56	5.38
<i>Parthenocissus quinquefolia</i>	---	0.56
<i>Persea palustris</i>	0.55	0.31
<i>Pinus taeda</i>	1.20	9.07
<i>Prunus serotina</i>	0.68	1.52
<i>Quercus alba</i>	2.94	---
<i>Quercus sp.</i>	---	0.46
<i>Quercus falcata</i>	0.60	---
<i>Quercus lyrata</i>	---	0.35

Table 3. Continued

Shrubs	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
<i>Quercus marilandica</i>	0.17	0.63
<i>Quercus nigra</i>	8.99	1.73
<i>Quercus phellos</i>	0.40	---
<i>Quercus stellata</i> var. <i>margaretta</i>	2.21	---
<i>Rhododendron</i> sp.	2.95	---
<i>Rhus copallina</i>	0.40	---
<i>Rhus radicans</i>	2.79	0.44
<i>Rubus argutus</i>	11.58	14.00
<i>Salix caroliniana</i>	---	0.44
<i>Sambucus canadensis</i>	2.19	1.84
<i>Sassafras albidum</i>	2.44	4.61
<i>Smilax glauca</i>	0.17	---
<i>Smilax laurifolia</i>	1.32	0.86
<i>Smilax rotundifolia</i>	21.17	38.76
<i>Sorbus arbutifolia</i>	0.54	0.34
<i>Symphoricarpos orbiculatus</i>	---	4.62
<i>Symplocos tinctoria</i>	26.17	16.32
<i>Ulmus rubra</i>	1.02	---
<i>Vaccinium arboreum</i>	0.86	0.52
<i>Vaccinium elliotii</i>	1.03	---
<i>Vaccinium stamineum</i>	5.51	13.62
<i>Viburnum</i> sp.	1.24	---
<i>Viburnum nudum</i>	0.73	---
<i>Viburnum prunifolium</i>	0.43	1.29
<i>Vitis rotundifolia</i>	10.83	7.57
<i>Xanthorhiza simplicissima</i>	0.28	---

Table 3. Continued

Shrubs	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
Unknown 1	0.65	---
Unknown 2	---	0.32
Unknown 3	---	5.96
Unknown 4	---	8.42

Table 4. Importance Values for Herb Species in Control and Experimental Communities.

Herbs	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
<i>Ambrosia artemisiifolia</i>	---	2.44
<i>Aneilema keisak</i>	---	0.61
<i>Aster</i> sp.	---	0.73
<i>Asplenium platyneuron</i>	1.71	---
<i>Athyrium asplenioides</i>	48.28	5.51
<i>Boehmeria cylindrica</i>	2.30	---
<i>Carex lurida</i>	---	9.66
<i>Cassia nictitans</i>	---	0.63
<i>Chenopodium ambrosioides</i>	---	2.73
<i>Cladium jamaicense</i>	---	0.72
<i>Dioscorea villosa</i>	0.80	---
<i>Erechtites hieracifolia</i>	---	4.69
<i>Erigeron canadensis</i>	---	4.23
<i>Eupatorium capillifolium</i>	1.74	16.74
<i>Foeniculum vulgare</i>	---	4.20
<i>Gnaphalium obtusifolium</i>	---	0.57
<i>Impatiens capensis</i>	63.98	42.66
<i>Indigofera carolinana</i>	0.77	---
<i>Juncus canadensis</i>	---	1.35
<i>Juncus effusus</i>	---	27.33
<i>Lespedeza virginica</i>	---	0.70
<i>Liatris graminifolia</i>	---	1.95
<i>Lobelia cardinalis</i>	---	0.78
<i>Lycopus virginicus</i>	2.76	---

Table 4. Continued

Herbs	Importance Values Control	Importance Values Experimental
<i>Myriophyllum brasiliense</i>	---	1.28
<i>Osmunda cinnamomea</i>	40.91	18.27
<i>Osmunda regalis</i>	---	0.66
<i>Panicum</i> sp. 1	---	0.58
<i>Panicum</i> sp. 2	---	1.26
<i>Passiflora incarnata</i>	---	0.86
<i>Phytolacca americana</i>	4.66	15.35
<i>Polygonum</i> sp. 1	---	0.64
<i>Polygonum</i> sp. 2	1.45	2.93
<i>Ptilimnium capillaceum</i>	---	4.76
<i>Rumex crispus</i>	---	0.64
<i>Saururus cernuus</i>	7.74	12.42
<i>Scirpus cyperinus</i>	---	0.97
<i>Solidago arguta</i>	1.51	10.76
<i>Solidago altissima</i>	---	2.78
<i>Solidago odora</i>	---	0.69
<i>Typha latifolia</i>	0.86	1.76
<i>Uniola sessiflora</i>	---	1.92
<i>Verbena urticifolia</i>	---	1.57
<i>Vernonia</i> sp. 1	---	0.60
<i>Vernonia</i> sp. 2	---	4.59
<i>Woodwardia areolata</i>	86.20	28.00
Unknown Graminoid 1	19.80	7.21
Unknown Graminoid 2	8.27	9.89
Unknown 5	1.36	---
Unknown 6	2.18	---

Herbs	<u>Importance Values</u> Control	<u>Importance Values</u> Experimental
Unknown 7	1.77	---
Unknown 8	---	0.73
Unknown 9	---	0.74
Unknown 10	---	1.32
Unknown 11	---	1.32
Unknown 12	---	1.62
Unknown 13	---	1.66
Unknown 14	---	1.32
Unknown 15	---	0.94
Unknown 16	---	12.11

Table 5. Importance Values for Groundcover Species in Control and Experimental Communities.

Groundcover	Importance Values Control	Importance Values Experimental
<i>Acer rubrum</i>	3.41	9.81
<i>Amblystegium serpens</i>	---	0.81
<i>Ambrosia artemisiifolia</i>	---	0.92
<i>Amelanchier canadensis</i>	---	1.16
<i>Arundinaria gigantea</i>	9.48	1.62
<i>Asimina triloba</i>	---	0.70
<i>Athyrium asplenoides</i>	6.51	2.65
<i>Calypogeia raddi</i>	---	0.70
<i>Campsis radicans</i>	1.77	0.47
<i>Carex debilis</i>	0.62	---
<i>Carex lurida</i>	---	3.63
<i>Carya</i> sp.	---	1.84
<i>Cladonia</i> sp. 1	7.35	---
<i>Cladonia</i> sp. 2	0.43	---
<i>Cladonia</i> sp. 3	1.95	---
<i>Clethra alnifolia</i>	3.29	15.88
<i>Cornus florida</i>	---	0.47
<i>Decumaria barbara</i>	0.71	2.20
<i>Dicranum condensatum</i>	0.53	---
<i>Ditrichum pallidum</i>	0.80	---
<i>Euonymus americanus</i>	0.87	---
<i>Eupatorium capillifolium</i>	---	1.62
<i>Euphorbia maculata</i>	0.43	---
<i>Gaylussacia frondosa</i>	2.85	4.17

Table 5. Continued

<i>Gelsemium sempervirens</i>	17.19	10.55
<i>Gnaphalium purpureum</i>	---	0.94
<i>Hexastylis arifolia</i>	---	0.58
<i>Hexastylis virginica</i>	1.43	3.72
<i>Hypericum</i> sp.	1.43	1.05
<i>Ilex coriacea</i>	0.81	---
<i>Ilex glabra</i>	---	0.81
<i>Ilex opaca</i>	3.91	3.86
<i>Impatiens capensis</i>	8.22	4.74
<i>Isopterygium tenerum</i>	1.95	0.81
<i>Itea virginica</i>	1.24	3.23
<i>Kalmia angustifolia</i>	---	0.81
<i>Leucobryum albidum</i>	1.71	0.70
<i>Leucothoe axillaris</i>	---	5.17
<i>Leucothoe racemosa</i>	0.71	0.81
<i>Ligustrum sinense</i>	0.62	0.94
<i>Liquidambar styraciflua</i>	1.86	1.88
<i>Lonicera japonica</i>	11.62	4.83
<i>Magnolia virginiana</i>	1.05	---
<i>Malaxis unifolia</i>	---	0.47
<i>Mitchella repens</i>	0.71	2.78
<i>Murdannia keisak</i>	---	0.81
<i>Myriophyllum brasiliense</i>	---	0.92
<i>Myrica cerifera</i>	1.15	0.58
<i>Nyssa sylvatica</i>	0.43	---
<i>Odontoschisma prostratum</i>	---	0.70
<i>Osmunda cinnamomea</i>	---	0.47
<i>Oxalis dillenii</i>	---	0.81

<i>Oxydendrum arboreum</i>	---	1.97
<i>Pallavicinia lyellii</i>	---	0.70
<i>Panicum</i> sp. 1	---	2.20
<i>Panicum</i> sp. 3	1.09	---
<i>Parthenocissus quinquefolia</i>	8.93	6.27
<i>Persea palustris</i>	---	0.47
<i>Phytolacca americana</i>	0.71	0.81
<i>Pinus taeda</i>	---	1.41
<i>Plagiomnium ciliare</i>	1.24	---
<i>Plagiomnium cuspidatum</i>	---	0.81
<i>Polygonum</i> sp.	0.34	0.81
<i>Polytrichum commune</i>	3.13	---
<i>Ptilimnium capillaceum</i>	---	0.81
<i>Quercus alba</i>	0.96	0.47
<i>Quercus falcata</i>	1.95	---
<i>Quercus marilandica</i>	---	0.81
<i>Quercus nigra</i>	6.91	3.62
<i>Quercus</i> sp.	---	0.83
<i>Quercus stellata</i>	2.48	---
<i>Rhus copallina</i>	---	0.81
<i>Rhododendron</i> sp.	2.02	---
<i>Rhus radicans</i>	5.46	1.39
<i>Rubus argutus</i>	4.43	7.63
<i>Sambucus canadensis</i>	0.87	0.70
<i>Sassafras albidum</i>	4.59	2.42
<i>Saururus cernuus</i>	5.27	1.62
<i>Smilax glauca</i>	0.34	3.60
<i>Smilax laurifolia</i>	---	0.58

Table 5. Continued

<i>Smilax rotundifolia</i>	9.38	12.64
<i>Sphagnum lescurii</i>	0.71	---
<i>Steerecleus serrulatus</i>	1.05	---
<i>Stipulicida setacea</i>	1.24	---
<i>Symphoricarpos orbiculatus</i>	---	0.92
<i>Symplocos tinctoria</i>	1.95	3.01
<i>Tephrosia spicata</i>	1.43	---
<i>Thudium allenii</i>	1.24	0.81
<i>Vaccinium stamineum</i>	0.80	2.42
<i>Vaccinium tenellum</i>	---	3.34
<i>Viburnum nudum</i>	---	1.16
<i>Viola primulifolia</i>	0.62	---
<i>Vitis rotundifolia</i>	4.90	8.47
<i>Woodwardia areolata</i>	11.25	9.69
Unknown 17	5.24	---
Unknown 18	3.94	---
Unknown Graminoid 1	6.79	0.81
Unknown 19	0.43	---
Unknown 20	0.43	---
Unknown 21	1.18	---
Unknown 22	0.71	---
Unknown 23	0.43	---
Unknown 24	---	0.81
Unknown 25	---	0.58
Unknown 26	---	0.65
Unknown 27	---	0.81
Unknown 28	---	0.58
Unknown 29	---	0.92

Unknown 30	---	0.47
Unknown 31	---	1.50
Unknown 32	---	0.81
Unknown 33	---	2.41
Unknown 34	---	1.16
Unknown 35	---	0.47
Unknown 36	---	0.70
Unknown 37	---	2.54

Table 6. Mean $\pm$ Standard Error for Species Richness for Each Stratum In Control and Experimental Communities.

Stratum	<u>Mean $\pm$ SE</u> Control	<u>Mean $\pm$ SE</u> Experimental
Canopy	0.573 $\pm$ 0.105	0.601 $\pm$ 0.140
Subcanopy	2.099 $\pm$ 0.348	1.269 $\pm$ 0.171
Shrubs	3.416 $\pm$ 0.172	3.425 $\pm$ 0.260
Herbs	1.457 $\pm$ 0.536	2.237 $\pm$ 0.574
Groundcover	4.343 $\pm$ 0.260	4.514 $\pm$ 0.432

Table 7. Percent Similarity of Species Composition in Control and Experimental Communities Subdivided by Stratum.

Stratum	Percent Similarity
Canopy	75%
Subcanopy	70%
Shrubs	66%
Herbs	31%
Groundcover	49%
Total	44%

Table 8. Importance Values of Canopy Dominants in Various Strata.

Species	Community	Canopy	Subcanopy	Shrub	Groundcover
<i>Pinus taeda</i>	Control	90.17	7.08	1.20	---
	Experimental	97.83	96.18	9.07	1.41
<i>Liquidambar styraciflua</i>	Control	32.95	41.91	9.14	1.86
	Experimental	65.22	70.99	16.33	1.88
<i>Liriodendron tulipifera</i>	Control	22.54	4.62	0.28	---
	Experimental	13.04	5.73	0.82	---
<i>Acer rubrum</i>	Control	24.27	15.03	6.67	3.41
	Experimental	32.61	13.74	8.31	9.81
<i>Quercus nigra</i>	Control	20.45	18.40	8.99	6.91
	Experimental	13.52	3.44	1.73	3.62

DIVERSITY

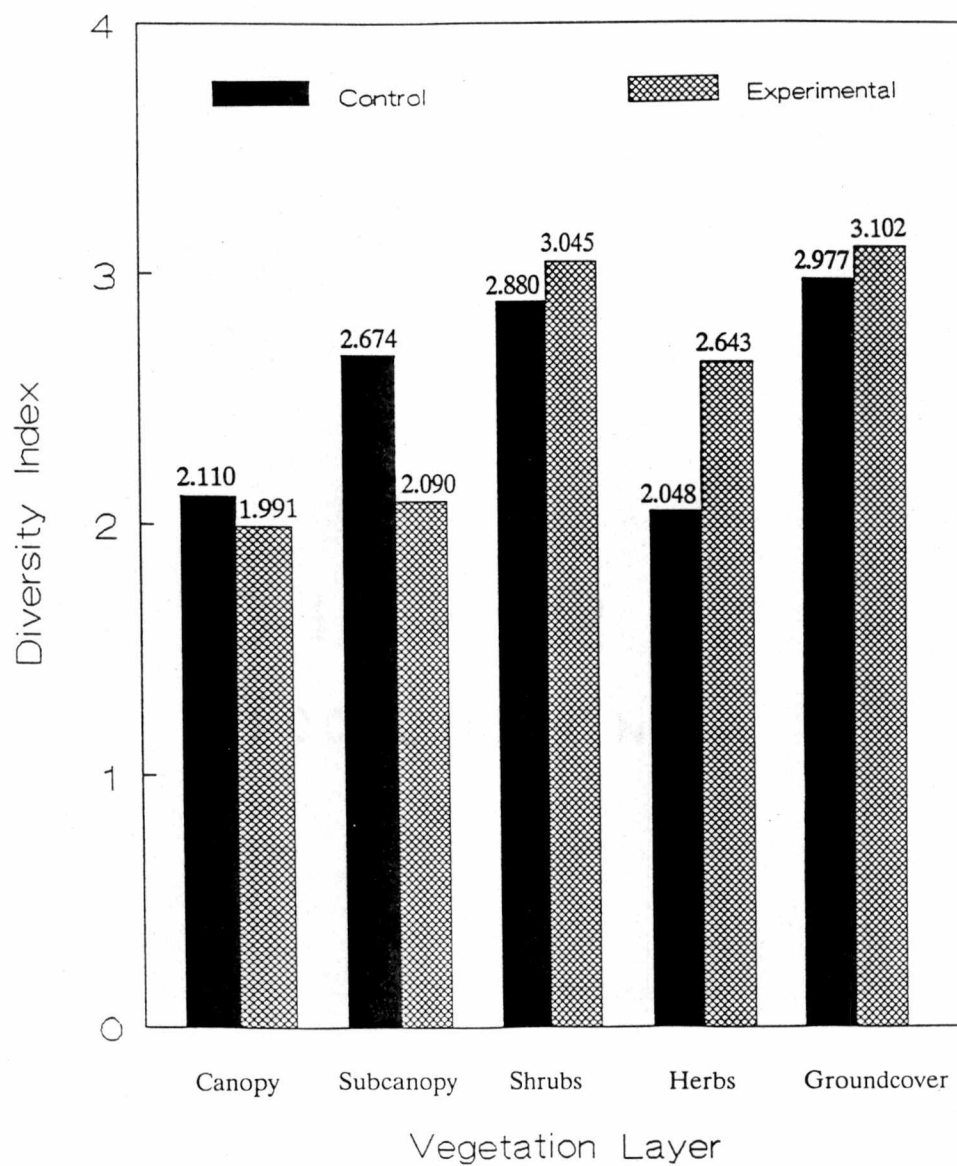


Figure 4. Diversity Index Values for Each Stratum in Control and Experimental Communities.

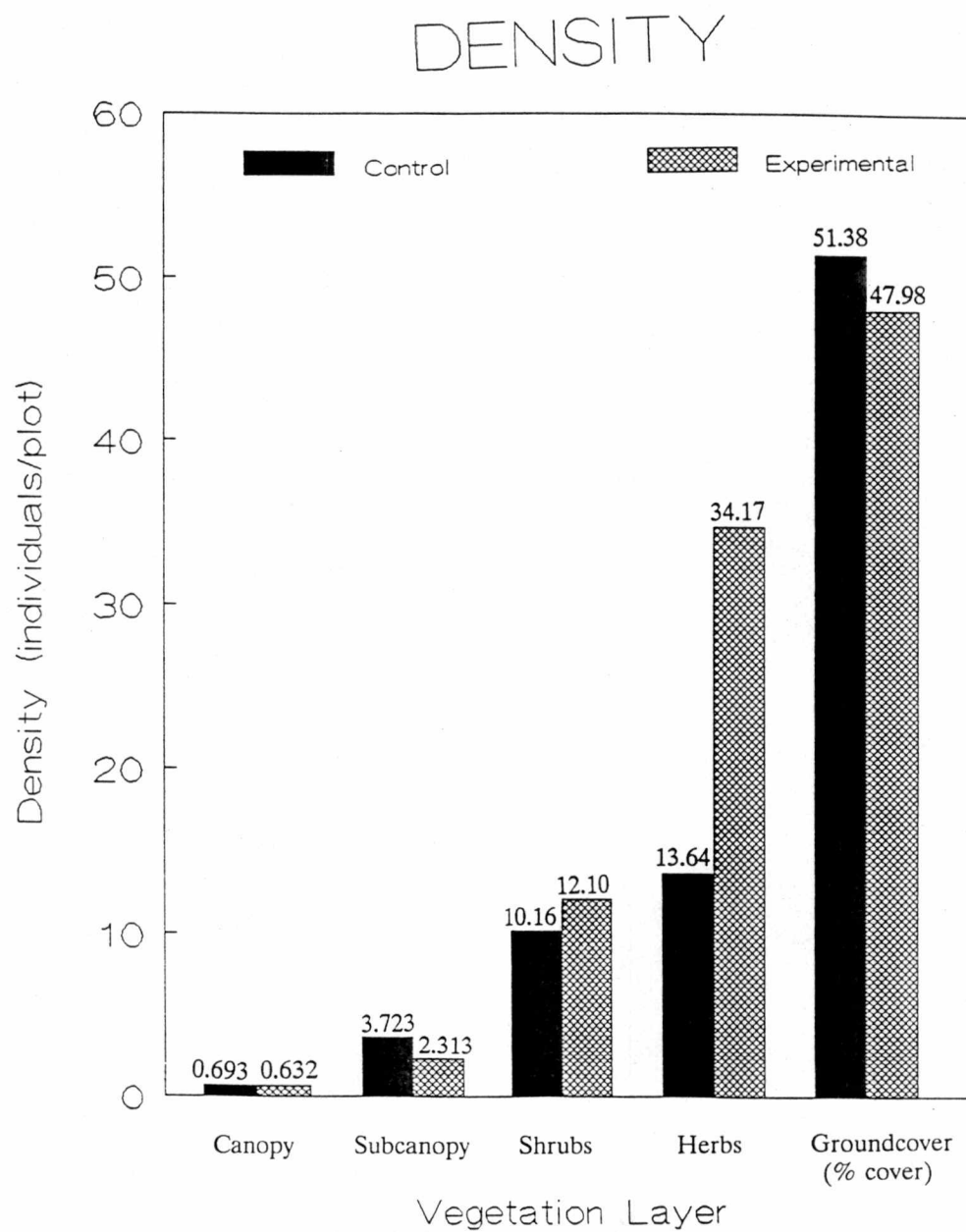


Figure 5. Plant Density for Each Stratum in Control and Experimental Communities.

APPENDIX B
LOCATION OF RAW DATA AND VOUCHERS

Raw data and voucher plant specimens are being kept at Coastal Plains Soil and Water Conservation Research Center USDA-ARS in Florence, SC. Their current telephone number is (803) 669-5203 and their address is:

CPSWCRC USDA-ARS
P.O. Box 3039
Florence, SC 29502

VITA

Jennifer Marie Hart was born in Asheville, North Carolina on April 27, 1969. She and her family moved to Winston Salem, NC and eventually ended up in Florence, SC where she graduated from West Florence High School in June, 1987. The following Fall she entered Francis Marion College where in May of 1991, she earned her Bachelor of Science degree in Biology. During her undergraduate career, she worked for the USDA Agricultural Research Service and upon graduation she worked fulltime in their water quality lab for one year. In August of 1992 she entered the University of Tennessee, Knoxville in May of 1994 she received her Master of Science degree in Botany.