VEGETATION RESPONSES TO SEVEN SILVICULTURAL TREATMENTS IN THE SOUTHERN APPALACHIANS ONE-YEAR AFTER HARVESTING

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(ABSTRACT)

The vegetation responses to seven silvicultural treatments one growing season after harvesting were examined on seven sites in the southern Appalachian mountains of Virginia and West Virginia. Treatments included: 1) control, 2) understory control by herbicide, 3) group selection, 4) high-leave shelterwood, 5) low-leave shelterwood, 6) leave tree, and 7) clearcut. The effects of harvesting were compared between treatments and between pre-harvest and post-harvest samplings. Species richness, percent cover, and local species extinctions were calculated for sample plots ranging in size from $1m^2$ to 2 ha. Vegetation richness and cover increased with increasing harvest intensity. Local species extinctions were similar in the control and disturbed treatments. Additional analyses were performed using the control, high-leave shelterwood, and clearcut on five of the seven sites to determine the relationships between soil, litter, and other environmental characteristics and vegetation in the herbaceous layer (<1 m in height). Multivariate analysis techniques were used to analyze average differences in species abundance between pre-harvest and post-harvest and to relate post-harvest vegetation to microsite characteristics. Regional-scale differences in site location were more important in explaining the presence of a species than were environmental characteristics. Within a region, species primarily were distributed along a light/litter weight gradient and secondarily along a soil properties and nutrient gradient.

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I. INTRODUCTION

JUSTIFICATION

There has been much concern over loss in biodiversity recently (Ricklefs 1987, Boyd et al. 1995, Halpern and Spies 1995, De Grandpré and Bergeron 1997, Elliott et al. 1997). Many people believe that forest management practices, especially harvesting old growth and short logging rotations, may reduce diversity in forest ecosystems (Duffy and Meier 1992, Meier et al. 1995).

Rising concern has led to policy changes in forest management. The USDA Forest Service is mandated by the National Forest Management Act of 1976 (16 U.S.C. § 1600) to provide for diversity of plant and animal communities (Roberts and Gilliam 1995). The Forest Service has attempted to achieve this goal by adopting an "ecosystem management" approach and moving away from the emphasis on timber (Gilliam et al. 1995).

However, maintaining diversity on federal lands only is not enough to solve the problem of species decline (Hansen et al. 1991, Boyd et al. 1995, Roberts and Gilliam 1995). Protected areas cover less than three percent of the earth's land surface (Reader and Bricker 1992a). Private forested land must be managed for both commodity production and conservation of diversity if diversity is to be maintained across the landscape (Hansen et al. 1991). The Society of American Foresters stated in 1991 that "Professional foresters should manage forestlands to conserve, maintain, or enhance the biological diversity of the region in which they work and, collectively, of the nation and the earth" (Roberts and Gilliam 1995).

Maintaining diversity is further complicated by the confusion and ambiguity associated with the word (Noss 1990, Angermeier and Karr 1994). For example, diversity can mean the number of species present (species richness), the different types of wildlife habitats across a landscape, or genetic variation in a population (Noss 1990). Diversity changes with scale (local versus regional) and level (ecosystem versus species versus genes). Diversity also implies maintenance of ecosystem functions, such as nutrient cycling and interspecific interactions and the stability, resilience, and productivity of the ecosystem (Noss 1990, Lawton 1994, Schwartz et al 2000). Several recent studies have attempted to determine if land management practices also

lead to a decline in ecosystem stability and function (Halpern 1988, Tilman 1996, DeGranpré and Bergeron 1997, Bengtsson 2000). This is much harder to quantify than species richness.

Most forestry related diversity studies have focused on commercially important timber species and wildlife. Few studies have examined the impacts of silvicultural activities on the forest herbaceous community (Davison and Forman 1982, Reader 1987, Reader and Bricker 1992a, Reader and Bricker 1992b, Halpern and Spies 1995). Little is known about many of the herbaceous species' life history traits or the effects of forestry practices on the species. Most of the studies compare silvicultural treatments against a control or use chronosequencing to study long-term changes in the forest community. These methods are based on the assumption that predisturbance vegetation is the same across sites. Therefore, results from such studies may be confounded by historical or stochastic events (Halpern 1989). Without long-term community studies, it will be impossible to know if current forest management practices are leading to the decline or local extinction of some species.

The southern Appalachian Mountains region is one of the great centers of forest diversity in the United States. It has been estimated that 2,200 native vascular plant species exist in this region (Miller and Wiegert 1989). Of the few studies on forest management impacts on herbaceous plants, only a handful have focused on diversity in the southern Appalachians. Most of these studies have only examined clearcutting (Duffy and Meier 1992, Gilliam and Turrill 1993, Gilliam et al. 1995, Meier et al. 1995, Elliott et al. 1997). I am aware of only one long-term study in the region that has pre-harvest baseline data (Elliott et al. 1997).

Due to the need for more data on forest management impacts on the forest community, a long-term, collaborative research study entitled "The Impacts of Silviculture on Biodiversity in the Southern Appalachians" (hereafter referred to as the Diversity Study) was begun in May 1993. The study is sponsored by Virginia Polytechnic Institute and State University College of Natural Resources, the USDA Forest Service Southern Research Station, the Jefferson National Forest, and Westvaco Corporation. The study includes seven silvicultural treatments: 1) undisturbed control, 2) understory removal with herbicide, 3) group selection, 4) high-leave shelterwood, 5) low-leave shelterwood, 6) leave-tree, and 7) clearcut replicated on seven sites in Virginia and West Virginia. The study examines the impacts of these treatments on the plant and salamander community using pretreatment data and is designed to last approximately 50 years. The short-term effects on the salamander community are discussed in Harpole and Haas (1999)

and Knapp (1999). The woody, shrub, and herbaceous components on five of the sites are reported in Wender (2000). In this thesis, I will report changes in relative richness and cover for the seven treatments on all sites. I will also include a more detailed examination of the short-term impacts on the plant community using the control, high-leave shelterwood, and clearcut treatments.

These three treatments were chosen because they represent a gradient of decreasing forest canopy cover and disturbance. The control is a mature forest, relatively undisturbed for at least 50 years. The high-leave shelterwood is intermediate in cover and disturbance. The group selection treatment is also intermediate but the cover and disturbance are not as homogeneous across the treatment area as in the shelterwood treatment. The clearcut, with complete canopy removal, is the most disturbed treatment of the three. In my opinion this range of treatments should provide a good comparison of the initial impacts of harvesting disturbance on herbaceous plants.

OBJECTIVES

The purpose of this thesis is to evaluate and report the initial (one full growing season post-harvest) effects of seven levels of silvicultural disturbance on the plant communities in the southern Appalachian region. The specific objectives of the thesis are:

I) To quantify changes in woody and herbaceous plant species composition and abundance one full growing season after harvesting on seven sites with seven levels of harvest disturbance (control, understory herbicide, low-leave shelterwood, high-leave shelterwood, group selection, leave-tree, and clearcut).

II) To quantify the effects of selected environmental conditions on species richness and abundance for the control, high-leave shelterwood, and clearcut treatments on five of the sites one full growing season after harvesting in order to:

(i) Determine which species and/or species groups are most vulnerable to harvesting and

(ii) Whether harvesting increases the abundance of exotic species.

II. LITERATURE REVIEW

BIOLOGICAL DIVERSITY

CONCEPTS AND DEFINITIONS OF BIODIVERSITY

Biodiversity in the broadest definition is defined as the diversity of life in all its forms and all its levels of organization, including the ecological structures, functions, and processes at all of these levels (Roberts and Gilliam 1995). Three broad groups of biodiversity have been identified: compositional, structural, and functional. Composition looks at elements in an area, such as the number of species in a forest stand. Structure characterizes the vertical or horizontal distribution of plant mass or age distributions. Function examines ecological processes such as nutrient cycling and energy flow (Noss 1990, Roberts and Gilliam 1995).

The production and maintenance of species diversity over ecological time has been largely attributed to disturbance (Petraitis et al.1989). White and Pickett (1985) define disturbance as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." Forest harvesting, therefore, is a disturbance that may influence species diversity.

STUDIES OF HERBACEOUS DIVERSITY

Most forest diversity studies have focused either on wildlife or commercial timber species. However, there are several studies that have been conducted on herbaceous plant diversity and succession. These studies either examine forest stands of different ages (chronosequencing) or study the same stands through time. Chronosequencing allows successional changes to be analyzed over a short time period, but can incorporate errors into the study. Variations in historical factors (disturbance and land use), site factors (climate, slope, aspect, and soil), and seed sources can confound the data (Elliott et al. 1997). The static approach of repeatedly measuring plot changes in stands over time is the most desired method of acquiring successional data. However, few studies use the static approach due to the long time frame (Elliott et al. 1997) and high cost associated with maintaining a long-term study (data management, personnel, plot locations, etc.).

CHRONOSEQUENCE STUDIES

Goebel et al. (1999) compared second-growth and old-growth stands in southeastern Ohio that had similar site characteristics and land-use histories. While there were no significant differences in species richness, there were compositional differences. The old-growth stands supported higher perennial forb cover and less woody vine cover. While some of the results could be due to stand differences, the authors felt that gap dynamics was the leading cause of the greater forb cover in the old-growth stands (Goebel et al. 1999).

A similar study was conducted using stands in the southern Appalachian forests to determine if the 40-150 year harvesting cycles used by the USDA Forest Service allowed full retention of herbaceous plants (Duffy and Meier 1992). Second-growth stands of 45-87 years were compared with stands that had never been harvested. The study showed a decrease in species richness and total herb cover in the secondary stands, 50 and 33 percent respectively. This study has received criticism because sampling procedures were not random and only conducted early in the growing season (Elliott and Loftis 1993 and Steinbeck 1993; but see Duffy 1993a and 1993b).

Gilliam et al. (1995) compared the herbaceous layer (woody and herb species) of 20-year-old clearcut stands with stands greater than 70-years in West Virginia. There were no significant differences in cover, biomass, or richness between the stand ages. However, the herb species density was significantly greater in the younger stands, while the density of woody species was greater in the older stands.

ONE-SITE LONG TERM STUDIES

Halpern has studied herbaceous plant diversity and successional pathways in managed and unmanaged forested stands of the Pacific Northwest (Halpern 1988, Halpern 1989, Halpern and Spies 1995, and Halpern et al. 1997). These studies are based on pre-harvest data and post-harvest data for up to 20 years. He found in forests that were clearcut and burned, species richness declined one growing season after harvest, increased sharply within two years, then increased at a slower, but continuous, rate over time. Populations of most understory species had recovered to pre-harvest levels prior to canopy closure. Species contributing to the spike in diversity were ruderal, non-forest species. Exotic plant cover peaked in year two and then dropped to near pre-harvest levels. Species occupying the site before disturbance exhibited a

gradual reestablishment over time. The species that did not recover (5 of 57) were either sensitive to fire, had slow rates of reestablishment and growth, or were uncommon in the preexisting forest. They concluded that a system of frequent short-term harvests might reduce and/or cause the local extinction of some species (Halpern and Spies 1995).

Jules (1998) examined the effects of clearcutting and forest fragmentation on *Trillium ovatum* in the Siskiyou Mountains of Oregon. He surveyed *T. ovatum* in stands of different ages that had been clearcut and planted. Using a plant community inventory of the area conducted prior to logging, he compared changes in abundance, growth, and recruitment since harvest. Results showed a high mortality and almost no recruitment of trillium (Jules 1998).

Reader and Bricker (1992a) and Reader (1987) compared species richness in stands with partial canopy removal two years after harvest with 40-year old forests in southern Ontario, Canada. They found that when 33 percent and 66 percent of the canopy was selectively harvested, herbaceous species were lost at about the same rate as in the uncut stands (Reader and Bricker 1992a). When the abundance of five of the most common herbs was examined, the smaller patches increased in herb abundance, while the larger patches decreased. They attributed this to competition from woody species (Reader and Bricker 1992b).

In a 30-year study of a mature oak forest in New Jersey, herb cover increased, while species diversity decreased (Davison and Forman 1982). The increase in cover was largely attributed to mayapple (*Podophyllum peltatum)* and two vines: the non-native Japanese honeysuckle (*Lonicera japonica*) and Virginia creeper (*Parthenocissus quinquefolia*). Thirteen species disappeared from the forest; most of these were rare when the forest was first studied. Seven new herb species appeared in the forest. Most of the new species were shade-intolerant pioneer species. Changes in the herb component were attributed to a natural increase in light as gaps were created in the overstory. The authors suggest that the concepts of climax or steady state forest herbaceous communities are of limited use and that these communities are naturally very dynamic (Davison and Forman 1982).

In a long-term watershed study on clearcutting in North Carolina, species richness declined 17 years after clearcutting. Herbaceous biomass peaked 7 years after harvest, and then declined as canopy closure began. With canopy closure, early successional, shade intolerant species also declined. These results cannot be attributed to clearcutting alone because grazing and fire suppression occurred on the site after initial herb inventories in 1952. The authors

concluded that the forest was in a transition state between early and late succession and that the late succession species had not yet become established (Elliott et al. 1997).

ECOLOGICAL DIVERSITY AND SUCCESSION HYPOTHESES

Several models have been developed to explain how succession changes species diversity over time. Petraitis et al. (1989) stated that "most hypotheses fall into two general classes: those involving selective mortality and those that invoke events that are sometimes catastrophic, causing random, localized, mass mortality." The first category is usually caused by predation. For example, herbivory from a dense deer population may cause the decline of favored plant species and an increase in unfavored ones. The second category is caused by disturbance and is what I will further examine in this thesis.

The competitive exclusion principle hypothesis is guided by the theory that diversity is regulated by competition between species (Petraitis et al. 1989). Lotka (1925) and Volterra (1926) independently developed this idea (from Morin 1999). The Russian ecologist, Gause reinforced this idea through experimental studies. He showed that in a simple system, two species do not coexist for the same limiting resource. This became known as the competitive exclusion principle (Petraitis et al. 1989). Most diversity models designed to explain the variation in species richness over a time period are based on something that dampens the effects of competitive exclusion. In these models competitive exclusion of species is delayed or never occurs because the ecosystem is continuously set back by disturbances. The resulting diversity is a balance between the frequency of disturbance that allow species to recolonize and the rate of competitive exclusion, which sets the pace of local extinction (Petraitis et al. 1989).

The intermediate disturbance hypothesis is a widely accepted idea about how disturbance maintains diversity. It predicts that the highest diversity will be at the intermediate levels of disturbance (Petraitis et al. 1989). The hypothesis is based on the assumption that there is a tradeoff between the ability of a species to tolerate disturbance and its ability to compete. Superior competitors are assumed to be the most susceptible to disturbance, while weak competitors can tolerate disturbance but cannot exist in environments where disturbance is infrequent. This interaction should result in species richness being highest at an intermediate frequency of disturbance, where conditions favor both groups. A second prediction of the hypothesis is that species richness will be highest at intermediate time spans during secondary

succession. This prediction assumes that in the absence of a disturbance, late successional species will competitively exclude early successional species, thus lowering species richness in late successional stages (Collins et al. 1995).

The initial floristic hypothesis was developed by Egler and predicts that species richness is highest during the early stages of succession and decreases with age. The initial floristic model predicts that both early and late successional species are present at the beginning of succession. Under this hypothesis, succession is a function of different growth rates and survivorship among the different species groups (Collins et al. 1995).

The equal chance hypothesis assumes species have similar colonizing abilities and individuals are only killed by a disturbance. After a disturbance there is scramble for resources in which all individuals have an equal chance. The resulting species composition is based on predisturbance abundance and on each species' ability to reproduce and invade (Petraitis et al. 1989).

The gradual change hypothesis is very similar to the equal chance hypothesis. It assumes that gradual changes rather than catastrophic disturbances prevent competitive exclusion (Petraitis et al. 1989).

FACTORS INFLUENCING SPECIES DIVERSITY

The sample size used to inventory herbaceous species will influence the estimated species diversity. Infrequent or rare species have a lower probability of falling within a smaller plot. Reader and Bricker (1992a) found that species number increased significantly with plot size. However, most studies use 1 m^2 plots to sample the herbaceous layer (Duffy and Meier 1992, Gilliam et al. 1995, De Grandpré and Bergeron 1997, and Elliott et al. 1997). This sample size is a tradeoff between total species on the site and the time and resources available to conduct sampling.

Margurran (1988) revealed the problem of veil lines due to sampling that can affect the results of the study. Plants with low abundance are often missed in the sampling. This creates a "veil" that only shows part of the entire community. The larger the area sampled the further back the veil is drawn, until a large enough area is sampled to show the complete community.

ENVIRONMENTAL CONDITIONS

Topographic factors affecting herbaceous species are aspect, elevation, and slope position. These factors influence light availability and soil development (fertility and moisture). Several studies have documented how site characteristics influence herbaceous composition.

LIGHT

Early and late successional environments differ primarily in light conditions. The amount of light reaching the forest floor affects seed germination rates, temperature, and growth. Early and late successional species often have different light saturation points and rates of photosynthesis and respiration. Therefore, light plays a large role in forest succession (Bazzaz 1979).

Estimating light levels in forests can be very challenging due to the spatial variation associated with multiple canopy layers and gaps, changes in cloud cover, and seasonal variation of the sun's angle. Direct measures that measure light over a long time period are most accurate, but are often prohibitive due to the expense of simultaneous and long-term multiple point sampling. Indirect methods therefore are commonly used to estimate light. The most common estimation methods are hemispherical photograph analysis and optical methods using light sensors at one or several points in time (Machado and Reich 1999).

Easter and Spies (1994) support hemispherical photography as potentially the least expensive and time-consuming technique to measure canopy openness and indirectly estimate yearly light levels. Since first introduced to ecology 30 years ago, analysis of hemispherical photography has been proven to be an accurate method of computing relative and absolute measures of solar radiation reaching the sample point (Mitchell and Whitmore 1993). By taking a photograph, a permanent record of the canopy structure is obtained. One of the major advantages of hemispherical photographs is the ability to analyze spatial and temporal light patterns. This is especially applicable to long-term studies with permanent plot locations (Stadt et al. 1997). An additional benefit of hemispherical photography is that a permanent picture of the canopy at a given time is produced. These photographs allow for future comparisons of canopy changes over time.

Optical methods can also be very accurate in estimating light. Working in a mature coniferous forest, Machado and Reich (1999) found a one-time measurement of the canopy using

quantum sensors was the most accurate method of estimating average light levels. However, this method may not be as accurate in open areas that receive large amounts of direct sunlight (Stadt et al. 1997).

SOIL AND LITTER FACTORS

Herbaceous plants respond to environmental gradients that change the moisture, temperature, and nutrient availability in the soil. Greller (1988) stated that herb cover increases with soil fertility across a geographical region, but within a stand, topography and moisture are the most influential factors.

Gilliam and Turrill (1993) studied the relationships between herbaceous cover and species richness and soil fertility on two forests of different ages in West Virginia. The herb layer responded positively to an increase in soil fertility in the young stand (~20 years). In the older stand (>80 years) no response was found. This led the authors to conclude that early in succession, when light availability is uniform and high, herb layer development is nutrient limited. As the canopy closes with stand age, light becomes the more limiting factor to herb development. They did not measure soil moisture, but were of the opinion that water was not a major limiting factor because of a poor correlation of herb cover and clay content. Their logic was that the measured clay content should be positively correlated with water availability (Gilliam and Turrill 1993).

This appears to support Tilman's resource-ratio hypothesis. The theory "assumes each plant species is a superior competitor for a particular proportion of the limiting resources and predicts that community composition should change whenever the relative availability of two or more limiting resources changes" (Tilman 1985).

Beatty (1984) studied the relationship of fine-scale microtopography and herbaceous plants in mature forests in New York. She found that the most significant differences between pit, mounds, and undisturbed microsites were soil moisture, pH, temperature, litter depth, and A horizon depth. Species richness was highest on the mounds. Total density and cover were highest on the undisturbed sites. It is a widely accepted theory that the pit and mound topography associated with older forests allow for higher species richness by creating a more variable habitat (Duffy and Meier 1992, Beatty 1984, and Goebel et al. 1999).

Sydes and Grime (1981a) found a negative correlation between total shoot biomass of herbaceous vegetation and the amount of leaf litter in a deciduous English woodland. They

suggested that topography, the differential ability of species to emerge through litter, and possibly the species growth form play a large role in determining plant distribution across the forest floor. A second study on the effects of litter on herbaceous plants was conducted in experimental plots with different levels of litter in England (Sydes and Grime 1981b). The results showed that the physical properties of the litter depth had a large negative impact on seedling emergence. The deleterious impact varied by species, with grasses having the lowest ability to grow through the litter.

PLANT FUNCTIONAL GROUPS

Grouping species by similar traits regarding function may help in predicting the dynamics of ecological systems (McIntyre et al. 1995). The Global Change and Terrestrial Ecosystems (GCTE) project of the International Geosphere-Biosphere Programme concluded, "that the essential dynamics of ecosystems can be captured by grouping species into a limited number of FTs [functional types]." However, functional groups have been defined in several different ways in the past, creating some confusion over the term. Gitay and Noble (1997) suggest that functional group classifications be "based on whether species respond in a similar way to a specified perturbation."

Gitay and Noble (1997) identified three basic approaches to identifying plant functional types: deductive, subjective, and data-defined. The deductive approach classifies plants based on a model of responses to important ecosystem processes. While this is the most direct way to classify plants, it may lead to an unwieldy number of groups. Paine's (1980) keystone species concept and the vital attributes described by Noble and Slatyer (1980) are examples of the deductive approach. The subjective approach is based on basic observational differences. A common grouping would be trees, shrubs, and herbs. The data-defined approach uses multivariate analysis to determine clusters of plants that respond similarly. Both the subjective and the deductive approaches can be used from local to global scales. The data-defined approach is for use at the local to regional scale (Gitay and Noble 1997).

THE DEDUCTIVE APPROACH

LIFE HISTORY

An increase in the abundance of a species largely depends on its life history (seed production, dispersal, and growth rate) (Halpern et al. 1997). Knowing species life history traits therefore helps to explain changes in abundance.

Bazzaz (1979) has described the physiological characteristics of plants. These characteristics are hard to measure in the field, but are related to many of the morphological features of a plant. He classified species as early or late successional based on a number of attributes. He also described differences between winter and summer annuals. Summer annuals usually have relatively large seeds with a heavy seed coat. These seeds may remain dormant until conditions are favorable for germination. Winter annuals have small seeds that are easily wind dispersed. Seeds germinate soon after they reach the ground and overwinter as basal rosettes. These rosettes are capable of photosynthesizing at low light levels (Bazzaz 1979).

SUCCESSION STAGE

The duration and timing of the growth flush and allocation of energy are also correlated to the seral stage most commonly occupied by tree and shrub species. Early successional species often have long shoot growing periods and an indeterminate growth pattern. Late successional species have short shoot growing season (4-5 weeks) and are determinate. Early successional species typically allocate energy primarily to stems, while late successional species allocate most energy to leaves and roots. The opportunistic patterns of the early successional species allow for high growth rates under favorable conditions. The late successional species' features are more adapted to intense competition and stress (Hicks and Chabot 1985). Late successional perennial herbaceous species may require 10 years from seed to first flowering. At maturity, these species often produce little seed and have slow growth rates. As little as 1 cm/yr of growth is common in late successional forest herbs. Many forest herbs reproduce primarily through vegetative propagation. This method limits dispersal area and rates of colonization (Meier et al. 1995).

Early successional species are often called r-strategists. R-strategists are short-lived species that usually produce copious amounts of seeds. Late successional species are K-strategists. K-strategists are long lived and use little of their energy towards reproduction. It is generally accepted that most species fall along this r-K continuum (Grime 1979).

COMPETITIVE STRATEGIES

While some aspects of a species' life history may contribute to its increase in abundance, a decline in abundance is often attributed to competition (Halpern et al. 1997). Grime (1979) developed the C-S-R model to group plants based on competitive strategies. He proposes that there are four types of strategies: competitive ruderals (C-R), stress-tolerant ruderals (S-R), stress-tolerant competitors (C-S), and C-S-R strategists. C-R plants are adapted to circumstances where there is a low impact of stress and competition is restricted to moderate intensity by disturbance. S-R plants are adapted to lightly disturbed, unproductive habitats. C-S plants are adapted to relatively undisturbed conditions experiencing moderate intensities of stress. C-S-R strategists are adapted to habitats in which the level of competition is restricted by moderate intensities of both stress and disturbance. Both the intensity of the disturbance and stress determine what type of general plant strategy is best suited to the specific environment.

THE SUBJECTIVE APPROACH

PLANT LIFE FORMS

A common method of grouping species by life forms is into annual or perennial grasses and forbs, biennials, and woody plants. In a study of old-field succession, Monk (1983) found that annual grasses initially dominated. By the second year, annual forbs had achieved dominance, followed by perennial forbs in year three. By age four, perennial forbs and grasses were of equal dominance. The woody species continued to increase with time.

McIntyre et al. (1995) studied whether a community's response to a disturbance could be interpreted through a set of biological attributes. He grouped species by Raunkiaer's life form, seed dispersal method, and the capacity for vegetative reproduction. Of the three groupings, life form was the most effective method of explaining the changes in a biologically meaningful way.

Raunkiaer's classification is based mainly on adaptation to overwintering. It is founded on two principles 1) the role played by a particular species in vegetation and 2) its life-history under the conditions prevailing in its habitat, with special reference to duration, protection, and propagation (Clements 1928). In this classification plants are grouped into five major life-forms (Table 2.1).

McIntyre et al. (1995) found that phanerophytes, chamaephytes, and geophytes were most sensitive to grazing disturbance. Therophytes increased in abundance and

hemicryptophytes with versatile rosettes were tolerant of disturbance. The results of the study correlated with many of the aspects of Grime's model. Therophytes and wind-dispersed species (R-strategists) were abundant in the soil-disturbed areas. The undisturbed sites had greater numbers of geophytes, chamaephytes, and phanerophytes and more species with vegetative reproduction.

Herbaceous plants in deciduous forests are dominated by species that overwinter as rosettes or underground perennating organs (Hicks and Chabot 1985). In a floristic study of eight forests (Cain 1950, from Hicks and Chabot 1985) hemicryptophytes were the most abundant (58 percent of the species), followed by geophytes (27 percent). Chamaephytes and therophytes were both low in abundance, 8 and 6 percent, respectively.

Herbs can also be classified by the length and timing of their growth periods relative to the phenology of the canopy and stand microclimate as spring ephemerals, shade tolerants, and evergreens (Hicks and Chabot 1985). Spring ephemerals complete most or all of their annual growth cycle in the few weeks between snow melt and canopy leaf out. This group avoids stress by only being active during periods of high light, water, and nutrient availability. They usually have sun plant characteristics with relatively high light compensation points and high absolute photosynthesis rates. Shade tolerants, also called summer greens, begin to grow at or before canopy leaf out, and continue growth under a closed canopy. Evergreens retain most or all of their aboveground biomass year round, usually having a dormant season during winter. Both shade tolerants and evergreens are stress tolerators (Hicks and Chabot 1985). Moore and Vankat (1986) used an additional grouping of spring-summer species. These plants develop before leaf-out, with completion of their life cycle after canopy closure. The spring-summer species and summer species (summer greens *sensu* Hicks and Chabot 1985) were found to increase in created light gaps (Moore and Vankat 1986).

Table 2.1. Raunkiaer's classification of life-forms (Clements 1928, McIntyre et al. 1995).

Major Life-Forms

Therophyte – Annual plants

Geophyte – Persistent buds buried to a depth of 2-3 cm

Chamaephyte – Persistent buds ≥ 1 cm and < 20-30 cm above ground surface

Phanerophyte – Persistent buds > 20-30 cm on stems above the ground, includes twiners and vines

Hemicryptophyte – Persistent buds in the immediate vicinity of the soil surface only, maximum height 1 cm

Within hemicryptophytes:

Flat or versatile rosette – All leaves radical; leaves flat or erect, depending on growing conditions

Erect rosette – All leaves radical; leaves always erect

Partial rosette – Radical and cauline leaves present; largest leaves on lower portion of stem

Proto-hemicryptophyte – All leaves cauline; largest leaves towards middle of stem

NATIVE V. EXOTIC SPECIES

Disturbance can cause an increase in exotic species. Scougall (from Hobbs 1997) found that the proportion of non-native species was significantly higher on grazed sites. The introduction of exotic species can create changes in the forest structure and composition even without disturbance. *Lonicera japonica*, an exotic, was largely responsible for an increase in herb cover over 30 years in a mature oak forest (Davison and Forman 1982). Exotic species often have rapid growth rates and no natural biological controls. Separating species as native and non-native may prove useful when trying to identify underlying mechanisms to disturbance responses (McIntyre et al. 1995).

THE DATA-DEFINED APPROACH

Halpern (1989) grouped species by seral origin, phase of peak abundance, magnitude of peak abundance, and duration of elevated abundance to study species dynamics after a disturbance. He classified seral origin of species as either invaders or residuals. Invaders were species that were not found on the site prior to disturbance. Residuals were species that located above ground prior to disturbance, regardless of abundance. This method does not include species present in the form of dormant viable seeds. He organized these traits into 11 groupings based on these characteristics to develop population patterns. Many of the patterns could be explained by the species life history traits (Halpern 1989).

There have been several studies that have used a multivariate analysis approach when analyzing species responses to a disturbance. Detrended correspondence analysis, principle components analysis, and canonical correspondence analysis are the most commonly used methods to group plants that respond similarly to disturbance and changes in site conditions and that have similar recovery patterns (Halpern 1988, Gilliam et al. 1995, Goebel 1999, Carvalho et al. 2000, Figueroa-Rangel and Olvera-Vargas 2000, McLachlan and Bazely 2001).

SUMMARY

By collecting data about species and their associated habitats, functional groups can be developed. As discussed above, there are several methods for classifying plants depending on the goal of the study. Tracking species over time after a disturbance allows responses to be monitored and to be correlated with the associated environmental changes. These findings can

then be compared to existing succession and diversity hypotheses for a better understanding of ecosystem changes following a disturbance.

III. METHODS

BROAD SCOPE OF RESEARCH

The floral diversity study was established as a long-term research project to examine the effects of seven different levels of harvest disturbance on the tree, shrub, and herbaceous strata in southern Appalachian forests. Treatments include a clearcut, leave-tree harvest, low-leave shelterwood, high-leave shelterwood, group selection, understory herbicide, and an unmanipulated control. The study was implemented on seven sites in Virginia and West Virginia. Sites included in the study were Blacksburg 1, Blacksburg 2, Clinch 1, Clinch 2, West Virginia 1, West Virginia 2, and Newcastle (hereafter referred to as BB1, BB2, CL1, CL2, WV1, WV2, and NC respectively). Permanent plots were established and sampled before harvesting to establish baseline data. Wender (2000) extensively reviewed the history of the sites and treatment installation.

To examine the effects of harvesting on herbaceous plants more intensely, the number of replicates was reduced to five sites and three treatments: control, high-leave shelterwood, and clearcut. Sites included in this study were CL1, CL2, WV1, WV2, and NC. Soil and various environmental variables were measured for these sites.

SITE SELECTION

Sites were selected that were representative of a large percentage of forested sites in the southern Appalachians (Figure 3.1). Each was selected for uniformity in stand composition, age, structure and geophysical characteristics. Sites also had to be at least 14 hectares in size to accommodate seven, 2-hectare treatments. Mid elevation (600-1200 m) stands were selected that were dominated by red and white oaks (*Quercus* spp.), hickories (*Carya* spp.), and maples (*Acer* spp.). Stands had to have relatively uniform structure with minimal silvicultural disturbance in the last 15 years and a mature overstory of at least 50-150 years. Additional site requirements were moderate slopes (10-40 percent), average site index between 18-21 m (base age 50 for upland oaks), and predominantly southern aspects.

SITE DESCRIPTION

Three sites, BB1, BB2, and NC are located in the Ridge and Valley physiographic region and two sites, CL1 and CL2 are located in the in the Cumberland Plateau physiographic region of the Jefferson National Forest in southwestern Virginia. BB1, BB2, are in the Blacksburg Ranger District of Montgomery County, Virginia. NC is in the Newcastle Ranger District in Craig County, Virginia. CL1 and CL2 are located in the Clinch Ranger District, in Wise and Scott counties respectively. The remaining two sites, WV1 and WV2, are located in the Allegheny Plateau physiographic region in Randolph County, West Virginia. Both of these sites are located on Westvaco's Wildlife and Ecosystem Research Forest, which is owned by Westvaco Corporation.

PLOT ESTABLISHMENT

The experimental design is a randomized complete block design with subsampling. Herb plots and shrub plots are subplot in tree plots, and tree plots are subplots in treatment plots (Figure 3.2). Permanent treatment plots of 2 hectares each were established in a grid pattern, such that all treatments fell within the site boundaries. There were no buffers between the treatments. Once the treatment plots were established, one treatment was randomly assigned to each plot.

Within each treatment plot, three permanent tree plots were established. Each tree plot is 576 m^2. Tree plots have a 23-m buffer between their boundaries and the edge of the treatment plot. A random number generator was used to obtain the distance and angle away from the center of the treatment plot to determine the center of the first tree plot. Once the center of the first tree plot was established, the random number generator was used only to determine the distance away from the treatment plots for the two remaining tree plots. To avoid overlap, the second and third tree plots were established by adding 120^o and 240^o, respectively to the bearing of the first tree plot. After the tree plot centers were located, the plot boundaries were arranged along the four cardinal directions. The shrub and herb plots were established by placing PVC pipe at the 5, 6, 12, 18, and 19-meter mark along each side of the tree plot's perimeter.

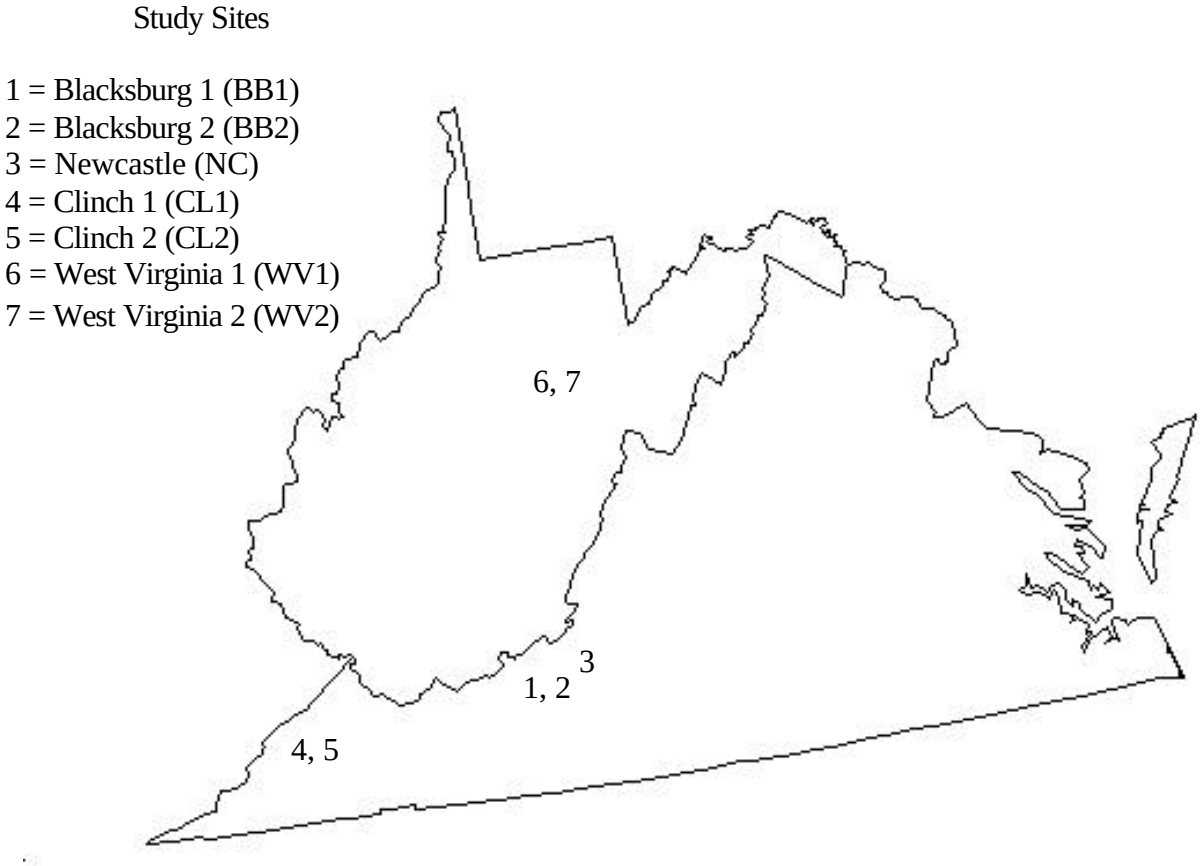


FIGURE 3.1. Location of study sites in Diversity Study. BB1, BB2, and NC are located in the Ridge and Valley near Blacksburg, VA. CL1 and CL2 are located in the Cumberland Plateau near Norton, VA. WV1 and WV2 are located in the Allegheny Plateau near Elkins, WV.

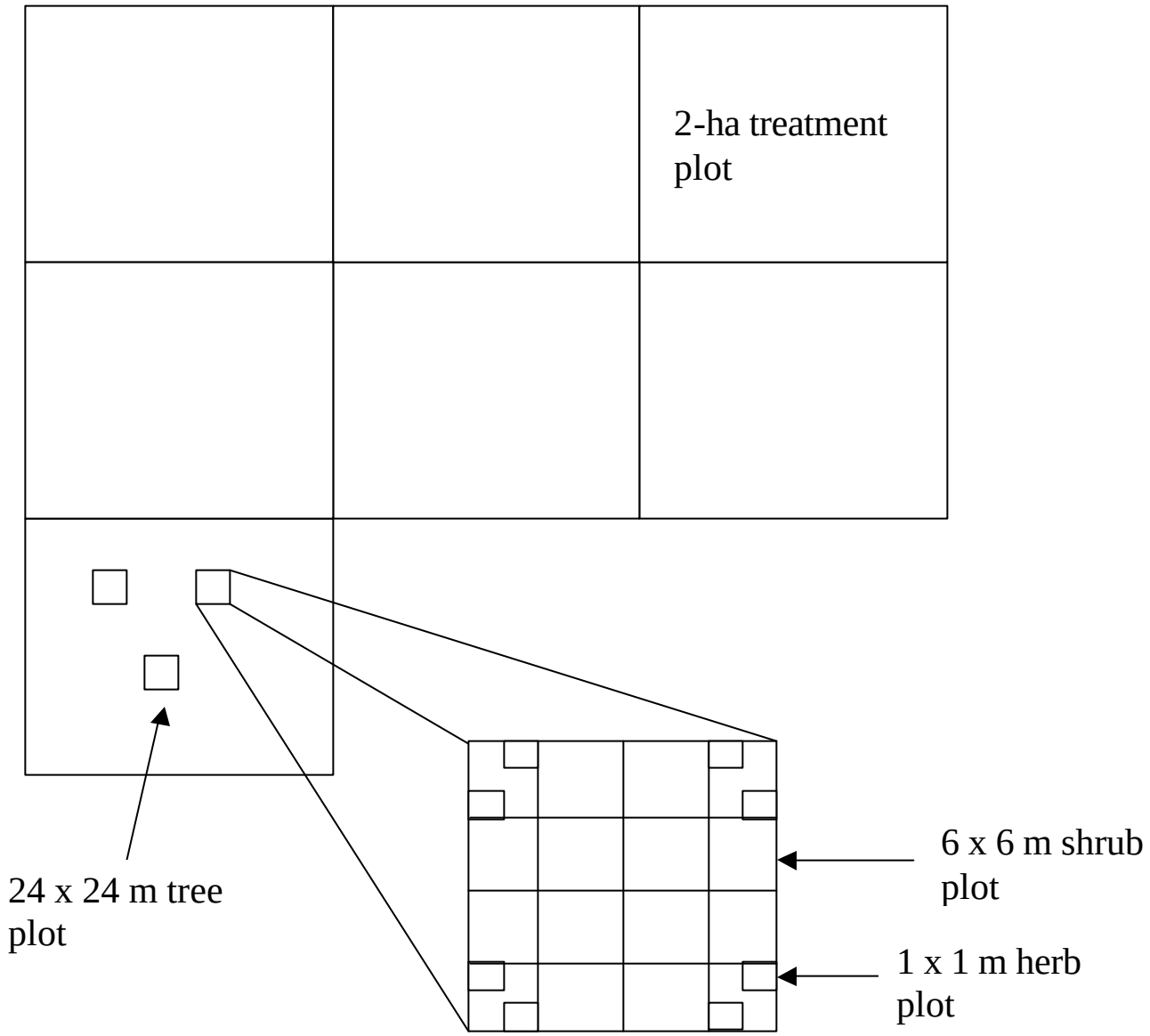


FIGURE 3.2. Example of the nested plot design used for vegetation sampling in the Diversity Study.

TREATMENT DESCRIPTIONS

All harvests were implemented with no buffers between treatments. An on-site project forester designed skid trail placement in accordance with applicable BMPs. Conventional harvesting methods using chainsaws and cable skidders were employed. Tree tops and branches were left on site. In the clearcut treatment, all stems greater than 5 cm d.b.h. were felled. Trees that were not merchantable were felled and left on the site. Mast, snag, or cull trees could be left for wildlife purposes, but could not exceed 10 stems/ha. In the leave-tree harvest, trees in the dominant or codominant crown classes were retained such that the residual stand consisted of no more than 50 trees per hectare or 5 m^2/ha of basal area. The high-leave shelterwood and the low-leave shelterwood treatments were designed to leave 12-15 m^2/ha and 5-7 m^2/ha of basal area respectively, evenly distributed over the treatment area. Residual trees in the high-leave shelterwood were to be dominant or codominant stems. Once adequate advanced regeneration is present, these trees will be removed. This should occur 5-10 years following the initial harvest. Smaller diameter trees, 5-25 cm d.b.h., were to compose the residual canopy in the low-leave shelterwood. Tree form received less consideration than in other treatments. Upon attaining a sufficient establishment and growth of regeneration, a release harvest may be desirable or the residual shelter may be retained as a component of the regenerating stand. The group selection treatment typically had 3 small group cuts with timber stand improvement between the groups. Each group's diameter was not to exceed the two times average height of the codominant and dominant adjacent trees. It is designed to be a five-age class uneven-aged stand cut every 20 years, with 100 percent of the treatment area cut after 100 years. In the understory herbicide, woody competition between 1-5 m was treated by streamline basal herbicide application of triclopyr (61.6% a.i. Garlon4®) and imazapyr (27.6% a.i. Stalker®). No silvicultural activity occurred in the control treatment. Due to the study layout and the normal logistics associated with harvesting operations, some skid trails are present in the corners of the control treatments.

DATA COLLECTION

SAMPLING PROCEDURE

All treatments were sampled before harvesting and were sampled again approximately one complete growing season after harvest. Treatments plots, tree plots, and herb plots were

sampled twice during the growing season, first in May and a second time in August. This aided in the identification of herbaceous plants to the species level by sampling both early and late flowering species. Sites were sampled over a multi-year time frame (Table 3.1). This may introduce some variation in results due to different weather conditions, but could not be avoided due to the staggered harvest schedule and because sampling more than three sites in one summer was not possible due to time and personnel constraints.

TREATMENT PLOTS

Treatment plots were used to obtain presence/absence lists of all species found in the 2 ha plots regardless of height. To obtain woody and herbaceous species richness, each treatment plot was traversed several times so that the entire area within the 2-hectare plot was covered.

TABLE 3.1. Current and projected status of treatment application and vegetation sampling of seven Diversity Study sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia.

Site	Pre-treatment Inventory	1st Post-treatment Inventory (1-year)	2nd Post-treatment Inventory (4-year)	Harvest Start	Harvest Completion
BB1	1993	1996	1999	November 1994	March 1995
BB2	1995	1998	2001	November 1995	June 1996
CL1	1993	2000	2003	April 1994	October 1998
CL2	1995	1999	2002	August 1997	March 1998
NC	1995	1998	2001	November 1995	June 1996
WV1	1996	1999	2002	May 1997	September 1997
WV2	1997	2000	2003	April 1998	August 1998

TREE PLOTS

Tree plots were used to obtain presence/absence lists of all species found in the 24 x 24 m tree plots regardless of height and to measure all vegetation in the tree strata (> 5 m in height). When sampling the tree plots for tree strata data, fiberglass meter tapes were stretched across the tree plot and attached to the 6, 12, and 18-m PVC pipes to form 16-6 x 6 m plots. The location of each tree was then recorded to the nearest 0.1 m using X, Y coordinates from the metric tapes. Tree species and d.b.h. were recorded to estimate basal area.

To obtain woody and herbaceous species richness, each tree plot was traversed several times so that the area within each of the three 24 x 24 m plots was covered. Additional tree data from the tree plots were sampled once, after the first sampling of species richness.

HERB PLOTS

Six of the eight herb plots were randomly selected for sampling in each tree plot. A 1-m^2 frame was used to sample each plot. All vegetation in the herb layer (<1 m in height) was sampled for percent cover and frequency by species. Classes were used for visually estimating percent cover. Classes were 1-7%, 8-25%, 26-50%, 51-75%, 76-93%, and 94-100%. In addition, several more variables were sampled post treatment at the CL1, CL2, WV1, WV2, and NC sites. Bare soil, rock, and coarse woody debris were estimated visually and grouped into the same percent cover classes. Topographic features of aspect, slope position, and slope percent were recorded for each plot. The microtopography was recorded as convex, concave, or linear. Herb plots that were located in primary and secondary skid trails or in intermittent streams were noted. Additional environmental condition methodology and analyses are described in Chapter V.

CHANGES IN SPECIES COMPOSITION AND ABUNDANCE (OBJECTIVE I)

To determine if harvesting changed the woody and herbaceous species composition and/or abundance, the pre-harvest presence/absence and percent cover data were compared with the year one post-harvest data. Average species richness was calculated from the treatment plots, tree plots, and herb plots for each strata. Species abundance was calculated from the herb plots. The null hypothesis for this evaluation was:

H_O: There is no difference in woody and herbaceous species composition or abundance among treatments or sites after harvesting.

EFFECTS OF SELECTED ENVIRONMENTAL CONDITIONS (OBJECTIVE II)

To determine if harvesting had any effect on environmental conditions the control treatment herb plots were compared to the clearcut and shelterwood herb plots. The null hypothesis for this evaluation was:

H_O: Clearcut and shelterwood harvests do not significantly change environmental conditions.

(i) ***Species Vulnerability to Harvesting***

(ii) ***Native v. Exotic Species Responses***

To determine associations between vegetation and environmental conditions the structure of the plant community and environmental conditions were examined using multivariate techniques. Non-metric multidimensional scaling was used to determine average changes in species percent cover between pre-harvest and post-harvest by site. Canonical correspondence analysis was used to identify and group species with similar responses and to determine the strength of the relationships between post-harvest vegetation and environmental conditions. The null hypothesis was:

H_o: All species groups respond similarly to disturbance by clearcut and shelterwood harvests.

These analyses were used to determine if some species groups were more vulnerable to harvesting impacts than others and as such were more likely to become locally extinct. It would also show if there were differences in response to harvests between native and exotic species and the different sites. The resulting species groups will also be compared with other functional groups (i.e. Grime's C-S-R triangle (Grime 1979), spring ephemerals v. summer greens (Hicks and Chabot 1985, etc.).

The floral response to disturbance is presented in two parts. Chapter IV includes a general description of species composition and abundance using an average of the seven sites and seven treatments one-year after harvesting to satisfy objective 1. This is the completion of the year 1 sampling phase of the Diversity Study for all seven sites. More extensive analyses of the data have been completed using five sites (BB1, BB2, NC, CL2, and WV1) in Wender (2000). Chapter V includes the analyses of the herb strata data and the environmental conditions for the clearcut, high-leave shelterwood, and control treatments from the CL1, CL2, NC, WV1,

and WV2 sites to satisfy objective 2. Chapter V is written in a complete manuscript format for submission into an ecological journal.

STATISTICAL ANALYSES

The objectives of the statistical analyses of the general response to disturbance were to detect differences among treatments within years and between years within a treatment. All data were tested for normality using a Shapiro-Wiles test in PROC UNIVARIATE, option NORMAL (SAS Institute v.8 1999) and were found to be normal. To determine differences between pre-harvest and 1-year post-harvest within a treatment, Student's paired t-tests were used. To determine differences between treatments with years, a one-way analysis of variance was used for the pre-harvest data. A one-way analysis of covariance using the pre-harvest richness and percent cover data as the covariates were used for the year-1 post-harvest data. The analyses of variance and analysis of covariance using the pre-harvest data as the covariate were performed using PROC GLM and a randomized incomplete block design model with the treatments being fixed effects. The model is incomplete due to size limitations on the WV1 site, which was only large enough for five treatments. Therefore, the low-leave shelterwood and understory herbicide treatments were not implemented on only six of the seven sites. The LSMEANS statement, with the option PDIFF SINGULAR=0.30 was the method used for means separation. Differences were considered significant at a p-value less than 0.05.

Species richness was analyzed in two ways 1) by separating each season and 2) by grouping both sampling seasons for each plot size. Woody and herbaceous species richness were always analyzed separately. All species found before and after harvest are listed in Appendix A.

IV. OVERALL RESULTS AND DISSCUSION

RESULTS

ONE-YEAR CHANGE IN VEGETATION, ALL TREATMENTS COMBINED

Harvesting caused a noticeable increase in plant species richness (Table 4.1). The pre-harvest community consisted of 339 species in 80 families. The year 1 post-harvest community increased to 571 species in 90 families. This was primarily due to a large increase in herbaceous species. Exotic species increased from 20 species to 80 species. Ten families were found in the post-harvest community that were not present before, while four families in the pre-harvest community were not found post-harvest (Table 4.2). Asteraceace, Cyperaceace, and Poaceae were the most dominant families in both communities. Each increased in relative frequency and number of species within the family in the post-harvest community. Thirty-seven species (11 percent) in the pre-harvest community treatment plots were not present in the treatment plots following harvesting (Table 4.3). Of these, most occurred in very low frequency in the pre-harvest community. Thirteen of the 37 species occurred only in the control treatment and disappeared without the influence of harvesting. We found no federally or state listed threatened or endangered species in either the pre-harvest or post-harvest samplings.

TABLE 4.1. Comparison of pre-harvest vs. 1-year post-harvest vascular plant communities based on compiled species lists from seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia.

Attribute	Pre-harvest	Year 1 Post-harvest
No. of families	80	90
No. of genera	194	279
No. of species	338	571
Native	318 (94%)	491 (86%)
Exotic	20 (6%)	80 (14%)
Woody	78 (23%)	95 (17%)
Herbaceous	260 (77%)	476 (83%)

*Numbers in parentheses are percent of total

TABLE 4.2. Pre- vs. post-treatment distribution of species by family, compiled from species presence lists on seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau, of Virginia and West Virginia. Species are sorted in descending order of frequency in the pre-harvest sampling.

Family	---------Pre-harvest---------			--------Year 1 Post-harvest---------		
	No. species	Relative Frequency %	Rank	No. species	Relative Frequency %	Rank
Asteraceae	30	8.8	1	86	15.1	1
Cyperaceae	30	8.8	1	51	8.9	3
Poaceae	26	7.6	3	53	9.3	2
Liliaceae	24	7.0	4	20	3.5	6
Ericaceae	15	4.4	5	13	2.3	9
Rosaceae	15	4.4	5	26	4.6	5
Violaceae	13	3.8	7	14	2.5	7
Aspleniaceae	9	2.6	8	8	1.4	17
Orchidacae	9	2.6	8	10	1.8	13
Fabaceae	8	2.3	10	32	5.6	4
Fagaceae	8	2.3	10	9	1.6	16
Ranunculaceae	8	2.3	10	13	2.3	9
Rubiaceae	8	2.3	10	10	1.8	13
Lamiaceae	7	2.1	14	12	2.1	11
Pinaceae	6	1.8	15	7	1.2	22
Saxifragaceae	6	1.8	15	8	1.4	17
Apiaceae	5	1.5	17	11	1.9	12
Aquifoliaceae	5	1.5	17	2	0.4	41
Betulaceae	5	1.5	17	5	0.9	25
Polypodiaceae	5	1.5	17	5	0.9	25
Asclepiadaceae	4	1.2	21	5	0.9	25
Juncaceae	4	1.2	21	8	1.4	17
Aceraceae	3	0.9	23	3	0.5	35
Brassicaceae	3	0.9	23	10	1.8	13
Caprifoliaceae	3	0.9	23	4	0.7	30
Caryophyllaceae	3	0.9	23	8	1.4	17
Magnoliaceae	3	0.9	23	3	0.5	35
Oxalidaceae	3	0.9	23	5	0.9	25
Scrophulariaceae	3	0.9	23	14	2.5	7
Araliaceae	2	0.6	30	2	0.4	41
Aristolochiaceae	2	0.6	30	1	0.2	59
Berberidaceae	2	0.6	30	3	0.5	35
Campanulaceae	2	0.6	30	6	1.1	23
Clusiaceae	2	0.6	30	6	1.1	23

TABLE 4.2 continued. Pre- vs. post-treatment distribution of species by family, compiled from species presence lists on seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau, of Virginia and West Virginia. Species are sorted in descending order of frequency in the pre-harvest sampling.

Family	----------Pre-harvest---------			--------Year 1 Post-harvest--------		
	No. species	Relative Frequency	Rank	No. species	Relative Frequency	Rank
		%			%	
Dioscoreaceae	2	0.6	30	1	0.2	59
Gentianaceae	2	0.6	30	1	0.2	59
Hydrangeaceae	2	0.6	30	1	0.2	59
Hydrophyllaceae	2	0.6	30	1	0.2	59
Juglandaceae	2	0.6	30	3	0.5	35
Lauraceae	2	0.6	30	2	0.4	41
Monotropaceae	2	0.6	30	2	0.4	41
Oleaceae	2	0.6	30	2	0.4	41
Ophioglossaceae	2	0.6	30	2	0.4	41
Orobanchaceae	2	0.6	30	2	0.4	41
Osmundaceae	2	0.6	30	2	0.4	41
Pteridiaceae	2	0.6	30	2	0.4	41
Salicaceae	2	0.6	30	4	0.7	30
Vitaceae	2	0.6	30	2	0.4	41
Amaryllidaceae	1	0.3	43	1	0.2	59
Anacardiaceae	1	0.3	43	4	0.7	30
Apocynaceae	1	0.3	43	3	0.5	35
Araceae	1	0.3	43	2	0.4	41
Balsaminaceae	1	0.3	43	1	0.2	59
Bignoniaceae	1	0.3	43	-	-	-
Commelinaceae	1	0.3	43	-	-	-
Convulvulaceae	1	0.3	43	3	0.5	35
Cornaceae	1	0.3	43	1	0.2	59
Cupressaceae	1	0.3	43	1	0.2	59
Diapensiaceae	1	0.3	43	1	0.2	59
Elaeagnaceae	1	0.3	43	1	0.2	59
Equisetaceae	1	0.3	43	1	0.2	59
Euphorbiaceae	1	0.3	43	2	0.4	41
Fumariaceae	1	0.3	43	1	0.2	59
Geraniaceae	1	0.3	43	2	0.4	41
Hamamelidaceae	1	0.3	43	1	0.2	59
Iridaceae	1	0.3	43	2	0.4	41
Lycopodiaceae	1	0.3	43	1	0.2	59
Moraceae	1	0.3	43	-	-	-
Nyssaceae	1	0.3	43	1	0.2	59
Onagraceae	1	0.3	43	4	0.7	30

TABLE 4.2 continued Pre- vs. post-treatment distribution of species by family, compiled from species presence lists on seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau, of Virginia and West Virginia. Species are sorted in descending order of frequency in the pre-harvest sampling.

Family	---------Pre-Treatment---------			--------Year 1 Post-Treatment--------		
	No. species	Relative Frequency %	Rank	No. species	Relative Frequency %	Rank
Oleaceae	1	0.3	43	1	0.2	59
Platanaceae	1	0.3	43	1	0.2	59
Polygalaceae	1	0.3	43	1	0.2	59
Polygonaceae	1	0.3	43	8	1.4	17
Portulacaceae	1	0.3	43	-	-	-
Primulaceae	1	0.3	43	2	0.4	41
Pyrolaceae	1	0.3	43	2	0.4	41
Tiliaceae	1	0.3	43	1	0.2	59
Ulmaceae	1	0.3	43	1	0.2	59
Urticaceae	1	0.3	43	1	0.2	59
Plantaginaceae	-	-	-	4	0.7	30
Linaceae	-	-	-	2	0.4	41
Solanaceae	-	-	-	2	0.4	41
Boraginaceae	-	-	-	1	0.2	59
Cannabinaceae	-	-	-	1	0.2	59
Cistaceae	-	-	-	1	0.2	59
Clethraceae	-	-	-	1	0.2	59
Ebenaceae	-	-	-	1	0.2	59
Melastomaceae	-	-	-	1	0.2	59
Passofloraceae	-	-	-	1	0.2	59
Phytolaccaceae	-	-	-	1	0.2	59
Rhamnaceae	-	-	-	1	0.2	59
Simaroubaceae	-	-	-	1	0.2	59
Verbenaceae	-	-	-	1	0.2	59

TABLE 4.3. Species not found in the post-harvest community that were present in the pre-harvest community, compiled from species presence lists on seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau, of Virginia and West Virginia. X's indicate the treatment where the species occurred pre-harvest.

Species	U.S. Nativity	Growth Form	Family	Clear-cut	Control	Group Selection	Herbicide	Leave Tree	Low-leave SW	High-leave SW
Asarum canadense	n	h	Aristolochiaceae				X			
Asclepias amplexicaulis	n	h	Asclepiadaceae				X			
Aureolaria flava	n	h	Scrophulariaceae	X	X	X	X	X	X	X
Caltha palustris	n	h	Ranunculaceae							X
Carex gracillima	n	h	Cyperaceae					X		
Carpinus caroliniana	n	w	Betulaceae		X					
Claytonia caroliniana	n	h	Portulacaceae				X			
Corallorhiza maculata	n	h	Orchidaceae		X	X				
Cystopteris fragilis	n	h	Polypodiaceae	X						
Dicentra cucullaria	n	h	Fumariaceae				X	X		
Dioscorea quaternata	n	h	Dioscoreaceae	X	X	X	X	X	X	
Epilobium leptophyllum	n	h	Onagraceae			X				
Erythronium sp.	n	h	Liliaceae			X	X	X		
Geum laciniatum	n	h	Rosaceae	X					X	
Ilex decidua	n	w	Aquifoliaceae	X	X	X	X	X	X	
Ilex verticillata	n	w	Aquifoliaceae				X		X	X
Ipomoea purpurea	e	h	Convulvulaceae				X			
Lilium philadelphicum	n	h	Liliaceae		X	X	X			
Luzula multiflora	n	h	Juncaceae			X		X	X	
Meehania cordata	n	h	Lamiaceae				X			
Morus rubra	n	h	Moraceae					X		
Oxalis montana	n	h	Oxalidaceae				X			
Panicum longifolium	n	h	Poaceae			X				
Panicum trifolium	n	h	Poaceae		X		X	X	X	
Parnassia glauca	n	h	Saxifragaceae					X		
Polygala senega	n	h	Polygalaceae			X				X
Potentilla tridentata	n	h	Rosaceae						X	
Pyrola americana	n	h	Ericaceae		X	X	X			
Smilacina trifolia	n	h	Liliaceae			X				
Thalictrum thalictroides	n	h	Ranunculaceae		X					
Thelypteris asplenioides	n	h	Aspleniaceae							X
Ulmus rubra	n	w	Ulmaceae	X	X			X		
Uvularia sessilifolia	n	h	Liliaceae		X	X	X	X	X	X
Veratrum viride	n	h	Liliaceae			X				
Viola affinis	n	h	Violaceae				X			
Viola triloba	n	h	Violaceae	X	X	X	X	X	X	
Zizia aptera	n	h	Apiaceae			X				

[1] n=native species e=exotic species

[2] w=woody species h=herbaceous species

TREATMENT EFFECTS

STAND STRUCTURE

Pre-harvest basal areas and mean tree d.b.h. did not differ significantly between treatments (Table 4.4). Pre-harvest basal areas were approximately 30 m^2/ha for all treatments. Post-harvest, the treatment basal areas ranged from a high of 30.4 m^2/ha in the understory herbicide to a low of 1.4 m^2/ha in the clearcut and were near the targeted levels of residual basal areas designed for each silvicultural prescription. Using residual basal area as an index of disturbance intensity, the post-harvest treatments ranked in order from highest to lowest were understory herbicide, control, group selection, high-leave shelterwood, leave-tree, low-leave shelterwood, and the clearcut. Average pre-harvest tree d.b.h. for each treatment was approximately 14.5 cm. Average d.b.h. increased in the understory herbicide, group selection, high-leave shelterwood, and leave-tree treatments after harvest, while average d.b.h. decreased in the clearcut and remained unchanged in the control and low-leave shelterwood.

TABLE 4.4. Pre- vs. post-treatment d.b.h. and basal area, measured from 576-m^2 tree plots and expanded to a per-ha basis for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	n	Mean DBH		Basal area	
		Pre-harvest[1]	Post-harvest	Pre-harvest[1]	Post-harvest
		----------(cm)----------		----------(m^2/ha)----------	
Control	7	14.9	14.8 ab	29.5	29.7 a
Understory herbicide	6	14.0	16.3 abc*	30.6	30.46 a
Group selection**	7	14.6	17.2 bc	30.5	15.2 b*
Shelterwood (11-14 m^2/ha)	7	14.1	20.6 bc*	30.6	13.2 b*
Shelterwood (4-7 m^2/ha)	6	14.3	14.5 ab	32.9	5.7 cd*
Leave tree	7	14.1	23.5 c*	29.5	7.5 bc*
Clearcut	7	14.6	9.1 a	32.5	1.4 d*

[1] No significant treatment effect within columns ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).
** Group selection treatment had timber stand improvement between groups.

SPECIES RICHNESS

Treatment Plot Richness

Woody species richness increased in all treatments except the control after harvesting (Table 4.5). This difference was more pronounced in the late season sampling. Pre-harvest woody species richness was approximately 30 species per 2 ha, while the post-harvest richness increased to near 40 species per 2 ha in the more intensive harvest treatments. By the late season sampling the control and understory herbicide had significantly lower woody species richness than the harvested treatments.

Herbaceous species richness increased in all treatments, with the harvested treatments experiencing the largest increases (Table 4.6). Richness was higher in the late season sampling for both the pre- and post-harvests. The pre-harvest treatments had approximately 35 herbaceous species per 2 ha. The post-harvest cut treatments almost doubled in species richness. By the late season sampling the control and understory herbicide had significantly lower herbaceous species richness than the harvested treatments.

When sampling seasons were combined using the maximum cover class per species between the seasons, the results were similar to the late season sampling season, with significant differences between treatments and years remaining the same (Tables 4.7 and 4.8). Pre-harvest richness was ~30 woody spp/2 ha and 45 herbaceous spp/2 ha for all treatments. The post-harvest richness increased with increasing harvest intensity to a high of 40.5 woody spp/2 ha in the leave tree treatment and 114.5 herbaceous spp/2 ha in the low-leave shelterwood.

Harvesting caused an increase in both exotic woody and herbaceous species in all treatments (Tables 4.7 and 4.8). Approximately 3.5 more woody exotic species were found post-harvest than pre-harvest in the harvested treatments. Post-harvest exotic herbaceous species richness increased with the intensity of the harvesting to approximately 20 spp/2 ha in the low-leave shelterwood, leave tree, and clearcut treatments compared to 4.8 in the control treatment.

TABLE 4.5. Pre- vs. post-treatment total woody species richness by sampling season per 2 ha treatment plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

		EARLY SEASON		LATE SEASON	
Treatment	n	Pre-harvest[1]	Post-harvest	Pre-harvest	Post-harvest
		(spp/2 ha)		(spp/2 ha)	
Control	7	31.1	30.3 a	32.3 ab	32.7 a
Understory herbicide	6	29.3	31.7 ac	29.8 ab	32.6 a*
Group selection	7	31.6	34.5 bc	32.9 a	37.2 b*
Shelterwood (11-14 m^2/ha)	7	28.9	37.2 b*	30.1 ab	37.0 b*
Shelterwood (4-7 m^2/ha)	6	30.1	36.8 b*	30.7 ab	38.8 b*
Leave tree	7	29.4	36.6 b*	29.6 b	39.1 b*
Clearcut	7	30.6	34.9 b	31.3 ab	37.6 b*

[1] No significant treatment effect within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.6. Pre- vs. post-treatment total herbaceous species richness by sampling season per 2 ha treatment plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

		EARLY SEASON		LATE SEASON	
Treatment	n	Pre-harvest[1]	Post-harvest	Pre-harvest	Post-harvest
		(spp/2 ha)		(spp/2 ha)	
Control	7	32.0	45.6 a	36.9 ab	50.9 a*
Understory herbicide	6	39.3	39.1 a	43.1 a	49.2 a*
Group selection	7	34.4	64.0 b*	38.4 ab	77.5 b*
Shelterwood (11-14 m^2/ha)	7	30.7	64.4 b*	33.7 b	74.2 b*
Shelterwood (4-7 m^2/ha)	6	34.1	72.6 b*	38.3 ab	92.2 b*
Leave tree	7	31.0	77.3 b*	35.3 ab	88.1 b*
Clearcut	7	30.0	73.6 b*	32.7 b	85.7 b*

[1] No significant treatment effect within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.7. Pre- vs. post-treatment exotic and total woody species richness (seasons combined) from all vegetation strata per 2 ha treatment plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	N	Exotic Species		Total Species	
		Pre-harvest	Post-harvest	Pre-harvest[1]	Post-harvest
		(spp/2 ha)		(spp/2 ha)	
Control	7	0.3 a	3.0 ab*	33.0	34.1 a
Understory herbicide	6	0.1 b	4.0 b*	30.5	34.2 a*
Group selection	7	0.8 a	2.4 a*	33.0	38.6 b*
Shelterwood (11-14 m^2/ha)	7	0.1 b	2.5 a*	30.1	39.6 b*
Shelterwood (4-7 m^2/ha)	6	0.4 ab	3.4 bc*	31.3	40.1 b*
Leave tree	7	0.6 ab	3.6 bc*	30.1	40.5 b*
Clearcut	7	0.4 ab	4.1 c*	31.6	38.5 b*

[1] No significant treatment effects within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.8. Pre- vs. post-treatment exotic and total herbaceous species richness (seasons combined) from all vegetation strata per 2 ha treatment plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	N	Exotic Species		Total Species	
		Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
		(spp/2 ha)		(spp/2 ha)	
Control	7	1.0 a	4.8 a*	44.9 ab	65.4 a*
Understory herbicide	6	0.6 ab	4.3 a*	53.0 a	61.0 a*
Group selection	7	0.8 ab	15.1 b*	47.6 ab	94.8 b*
Shelterwood (11-14 m^2/ha)	7	0 b	15.6 b*	42.9 ab	90.9 b*
Shelterwood (4-7 m^2/ha)	6	1.1 a	20.6 c*	46.9 ab	114.5 b*
Leave tree	7	0.6 ab	22.1 c*	43.9 ab	110.8 b*
Clearcut	7	1.3 a	20.9 c*	40.1 b	109.1 b*

[1] No significant treatment effects within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

Tree Plot Richness

Woody species richness increased in the tree plots in all treatments except the control and understory herbicide after harvesting (Table 4.9). Pre-harvest woody species richness was approximately 20 species per 576 m^2, while the post-harvest richness increased only slightly in the harvested treatments to near 25 species per 576 m^2. In general, the harvested treatments had significantly more species than the control and understory herbicide in the late season sampling.

Herbaceous species richness increased in all treatments after harvesting, with the harvested treatments experiencing the largest increases (Table 4.10). Richness was nearly equal for each sampling season for both the pre-harvest and post-harvest. The pre-harvest treatments had about 15 species per 576 m^2. The post-harvest cut treatments almost doubled in species richness, with the exception of the high-leave shelterwood. By the late season sampling the control and understory herbicide treatments had significantly lower herbaceous species richness than all harvested treatments except the high-leave shelterwood.

When sampling seasons were combined, the results were similar to the late season sampling season, with significant differences between treatments and years generally the remaining the same (Tables 4.11 and 4.12). Woody pre-harvest richness was ~20 spp/576m^2 for all treatments. This increased to 26.5 spp/576m^2 in the high-intensity treatments post-harvest. Herbaceous species doubled in richness after harvest to approximately 40 spp/576m^2 in the high-intensity treatments.

Exotic woody species richness only increased significantly in the high-leave shelterwood from pre- to post-harvest (Table 4.11). This increase was very slight, with less that one exotic species introduced on average on the treatment sites. Herbaceous exotic species richness increased in the harvested treatments (Table 4.12). However, increases were only significant in the most intensive harvest treatments, the low-leave shelterwood, leave tree, and clearcut, with about three exotic species gained per treatment.

TABLE 4.9. Pre- vs. post-treatment total woody species richness by sampling season per 576-m^2 tree plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

		EARLY SEASON		LATE SEASON	
Treatment	N	Pre-harvest[1]	Post-harvest	Pre-harvest	Post-harvest
		(spp/576 m^2)		(spp/576 m^2)	
Control	7	19.7	20.2 a	20.1 ab	20.9 ab
Understory herbicide	6	19.0	19.8 a	19.1 ab	19.1 a
Group selection	7	20.2	23.7 b*	21.0 a	24.3 c
Shelterwood (11-14 m^2/ha)	7	18.5	22.1 ab*	18.5 b	22.7 bc*
Shelterwood (4-7 m^2/ha)	6	18.9	23.6 b*	19.9 ab	23.9 c*
Leave tree	7	18.7	23.8 b*	18.7 b	24.1 c*
Clearcut	7	19.5	23.9 b*	20.4 ab	25.0 c*

[1] No significant treatment effect within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.10. Pre- vs. post-treatment total herbaceous species richness by sampling season per 576-m^2 tree plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

		EARLY SEASON		LATE SEASON	
Treatment	n	Pre-harvest[1]	Post-harvest	Pre-harvest[1]	Post-harvest
		(spp/576 m^2)		(spp/576 m^2)	
Control	7	15.7	18.0 a	16.5	17.5 a
Understory herbicide	6	17.1	19.0 ab*	16.7	18.0 a
Group selection	7	17.3	27.2 cd*	17.6	28.0 bc*
Shelterwood (11-14 m^2/ha)	7	13.9	19.7 abc*	15.0	21.4 ab*
Shelterwood (4-7 m^2/ha)	6	17.6	29.3 d*	17.5	32.1 c*
Leave tree	7	15.5	26.9 bcd*	15.6	28.3 c*
Clearcut	7	15.5	28.1 d*	15.6	29.5 c*

[1] No significant treatment effect within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.11. Pre- vs. post-treatment exotic and total woody species richness (seasons combined) from all vegetation strata per 576-m^2 tree plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	N	Exotic Species		Total Species	
		Pre-harvest[1]	Post-harvest	Pre-harvest	Post-harvest
		(spp/576 m^2)		(spp/576 m^2)	
Control	7	0.1	0.1 a	21.0 ab	22.6 ab
Understory herbicide	6	0.2	0 a	20.4 ab	21.7 a
Group selection	7	0.5	0.4 ab	22.0 a	26.3 c*
Shelterwood (11-14 m^2/ha)	7	0.1	0.7 abc*	19.5 b	24.8 bc*
Shelterwood (4-7 m^2/ha)	6	0.3	1.4 c	20.7 ab	26.5 c*
Leave tree	7	0.5	1.1 bc	19.8 b	26.5 c*
Clearcut	7	0.2	0.8 abc	21.4 ab	26.6 c*

[1] No significant treatment effects within columns between treatments ($p < 0.05$).

* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.12. Pre- vs. post-treatment exotic and total herbaceous species richness (seasons combined) from all vegetation strata per 576-m^2 tree plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	N	Exotic Species		Total Species	
		Pre-harvest[1]	Post-harvest[1]	Pre-harvest[1]	Post-harvest
		(spp/576 m^2)		(spp/576 m^2)	
Control	7	0.7	0.7 a	21.9	24.1 a
Understory herbicide	6	0.6	0.1 a	22.5	24.0 a
Group selection	7	0.5	2.1 ab	23.5	36.9 bc*
Shelterwood (11-14 m^2/ha)	7	0	1.3 ab	19.4	27.5 ab*
Shelterwood (4-7 m^2/ha)	6	0.8	4.4 b*	23.1	43.0 c*
Leave tree	7	0.4	3.7 b*	20.9	38.1 c*
Clearcut	7	0.7	4.1 b*	20.6	40.3 c*

[1] No significant treatment effects within columns between treatments ($p < 0.05$).

* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

Herb Plot Richness

Woody species richness increased only slightly in the herb plots for all treatments except the understory herbicide treatment for the early season sampling and the control in the late season sampling after harvesting (Table 4.13). Pre-harvest woody species richness was approximately three species per 1 m^2, while the post-harvest richness increased by about one species in the harvested treatments to near four species per 1 m^2. Generally, the harvested treatments were significantly different in both seasons from the control and understory herbicide treatments.

Herbaceous species richness increased slightly in all treatments (Table 4.14). Richness was nearly equal for each sampling season for both the pre- and post-harvests. The pre-harvest treatments had about two species per 1 m^2. The post-harvest cut treatments increased by less than one species. The low-leave shelterwood, leave-tree, and clearcut were the only harvested treatments that had significantly higher species richness in the post-harvest sampling.

When sampling seasons were combined, the results were similar to the individual sampling seasons, with significant differences between treatments and years generally the remaining the same (Tables 4.15 and 4.16). Pre-harvest woody species richness was approximately 6 spp/m^2 and increased to a high of 8.3 spp/m^2 in the low-leave shelterwood post-harvest. Herbaceous species richness went from ~3 spp/m^2 pre-harvest to a high of 5.2 spp/m^2 in the post-harvest low-leave shelterwood.

No exotic woody species were found in either sampling period (Table 4.15). Herbaceous exotic species richness increased only slightly after harvesting, with no significant differences between pre- and post-harvesting (Table 4.16). The exotic herbaceous richness was highest in the low-leave shelterwood, with only 0.2 exotic spp/m^2.

TABLE 4.13. Pre- vs. post-treatment total woody species richness by sampling season per 1-m^2 herb plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

		EARLY SEASON		LATE SEASON	
Treatment	n	Pre-harvest[1]	Post-harvest	Pre-harvest[1]	Post-harvest
		(spp/1 m^2)		(spp/1 m^2)	
Control	7	3.4	3.6 ab*	3.6 a	3.6 ab
Understory herbicide	6	3.1	3.1 a	3.0 ab	3.2 a
Group selection	7	3.3	3.9 b*	3.5 ab	4.0 bc
Shelterwood (11-14 m^2/ha)	7	3.3	3.9 b	3.4 ab	4.0 bc
Shelterwood (4-7 m^2/ha)	6	3.1	4.1 b*	3.2 ab	4.1 c
Leave tree	7	2.8	3.9 b*	2.9 b	3.9 bc
Clearcut	7	3.3	4.0 b*	3.3 ab	3.9 bc

[1] No significant treatment effect within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.14. Pre- vs. post-treatment total herbaceous species richness by sampling season per 1-m^2 herb plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

		EARLY SEASON		LATE SEASON	
Treatment	n	Pre-harvest[1]	Post-harvest	Pre-harvest[1]	Post-harvest
		(spp/1 m^2)		(spp/1 m^2)	
Control	7	1.8	2.0 ab	1.6	1.6 a
Understory herbicide	6	1.7	1.9 ab	1.5	1.6 a
Group selection	7	2.1	2.2 ab	1.7	2.0 ab
Shelterwood (11-14 m^2/ha)	7	1.2	1.8 a	1.3	1.6 a
Shelterwood (4-7 m^2/ha)	6	2.0	2.3 b*	1.7	2.5 b*
Leave tree	7	2.0	2.6 b*	1.5	2.1 ab
Clearcut	7	1.7	2.6 b*	1.4	2.2 ab*

[1] No significant treatment effect within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.15. Pre- vs. post-treatment exotic and total woody species richness (seasons combined) from herb strata per 1-m^2 herb plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	N	Exotic Species		Total Species	
		Pre-harvest[1]	Post-harvest[1]	Pre-harvest	Post-harvest[1]
		(spp/1 m^2)		(spp/1 m^2)	
Control	7	0	0	7.0 a	7.2 ab
Understory herbicide	6	0	0	6.1 ab	6.3 b
Group selection	7	0	0	6.7 ab	7.9 a*
Shelterwood (11-14 m^2/ha)	7	0	0	6.6 ab	7.9 a
Shelterwood (4-7 m^2/ha)	6	0	0	6.3 ab	8.3 a*
Leave tree	7	0	0	5.8 b	7.8 a*
Clearcut	7	0	0	6.6 ab	7.9 a

[1] No significant treatment effects within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

TABLE 4.16. Pre- vs. post-treatment exotic and total herbaceous species richness (seasons combined) from herb strata per 1-m^2 herb plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	N	Exotic Species		Total Species	
		Pre-harvest	Post-harvest	Pre-harvest[1]	Post-harvest
		(spp/1 m^2)		(spp/1 m^2)	
Control	7	0	0	3.5	3.6 a
Understory herbicide	6	0.1	0	3.2	3.5 a
Group selection	7	0	0	3.8	4.1 ab
Shelterwood (11-14 m^2/ha)	7	0	0	2.5	3.5 a
Shelterwood (4-7 m^2/ha)	6	0	0.2	3.8	5.2 b*
Leave tree	7	0	0.1	3.6	4.7 ab
Clearcut	7	0.1	0.1	3.1	4.9 ab*

[1] No significant treatment effects within columns between treatments ($p < 0.05$).

* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

SPECIES COVER

Average woody plant cover increased in all treatments following harvesting (Table 4.17). The control, understory herbicide, and group selection had significantly less cover than the more intensively harvested treatments in the pre-harvest sampling. Percent cover increased with the intensity of the harvest treatment. In the leave-tree and clearcut treatments cover tripled from pre- to post-harvest.

Average herbaceous cover increased in all treatments except the control and understory herbicide following harvesting (Table 4.17). Herbaceous cover followed the general trend of the woody cover. However, the analysis of the means did not show as clear a separation between treatments in the post-harvest sampling period.

TABLE 4.17. Pre- vs. post-treatment woody and herbaceous percent cover from herb strata per 1-m^2 herb plot for seven silvicultural treatments. Mean of seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Values followed by different letters are significantly different within columns ($p < 0.05$).

Treatment	N	Woody Species Percent Cover		Herbaceous Species Percent Cover	
		Pre[1]	Post	Pre[1]	Post
Control	7	18.8	23.9 a*	12.2	10.9 a
Understory herbicide	6	15.7	26.1 a*	14.1	12.0 a
Group selection	7	16.9	35.0 ab*	11.2	22.3 ab*
Shelterwood (11-14 m^2/ha)	7	20.2	49.7 bc*	7.6	16.8 a*
Shelterwood (4-7 m^2/ha)	6	14.7	52.5 c*	10.5	36.1 c*
Leave tree	7	15.2	59.7 c*	11.3	30.6 bc*
Clearcut	7	15.4	64.5 c*	9.2	38.7 c*

[1] No significant treatment effects within columns between treatments ($p < 0.05$).
* Post-treatment value is significantly different from pre-treatment value across row ($p < 0.05$).

DISCUSSION

GENERAL COMMUNITY RESPONSE

The large initial increase in species richness in the community after disturbance is similar to results in other studies (Collins and Pickett 1988, Halpern and Spies 1995, Beese and Bryant 1999). It also supports several disturbance models that predict increases in richness during the initial period following a disturbance (Petraitis et al. 1989, Roberts and Gilliam 1995). These studies and models support a continued increase in richness for at least several years, some even through canopy closure (Halpern and Spies 1995). Studies show conflicting patterns in the later stages of community reestablishment with some sites having higher species richness in mature and old-growth stands than in younger stands (Duffy and Meier 1992, Elliot et al. 1997, Goebel et al. 1999) and others showing very similar values between stands of various ages (Moore and Vankat 1986, Gilliam et al. 1995, Reader and Bricker 1992a). The planned additional sampling of the sites in this study as the stands age will provide valuable information about changes in the community and recovery of all species over the rotation length.

Species losses after harvesting were similar to those found by Reader and Bricker (1992a). They found similar rates of species losses in uncut and cut forest plots. The most likely cause of these local species extinctions is the initial low abundance of many species prior to harvesting. Also, we only sampled above-ground vegetation. There is the possibility that species in the pre-harvest not found in the post-harvest were not found due to slightly different sampling times and still exist below-ground on the plots either as viable seeds or tubers. There were no federally or state listed threatened or endangered species found on any of the sites either pre-harvest or post-harvest.

TREATMENT COMPARISONS

LOW-DISTURBANCE TREATMENTS

Control

The control was intended to be an undisturbed reference stand. There were changes however, in the control treatments between pre-harvest and post-harvest. These changes can be attributed to natural changes in plant dynamics over time and edge effect and skid trails created when adjacent treatments blocks were harvested. Davison and Forman (1982) found large changes in herb abundance and species composition in an uncut mature forest from year to year.

They attributed the changes to gap dynamics that caused increase growth in areas where mature trees had fallen and created light openings in the forest. The increase in woody cover on the control sites in our study could also be caused by gap dynamics, as there were trees that had fallen between sampling years in the treatment area. This natural mortality may have allowed additional light to reach the forest floor, thus encouraging growth in woody advanced regeneration and *Rubus* sp. Reader and Bricker (1992a) reported a loss in species of 9-13 percent in uncut plots between sampling years. This is slightly lower than the 16 percent we found in the control treatment. The losses may be a result of actual losses between years and losses attributed to missing a species during the inventory.

Although the majority of the control treatments remained undisturbed, two sites (BB1 and CL2) were impacted by primary skid trails. Skid trail design and placement were the discretion of the project forester. Each skid trail in the control treatment only occurred in a small, corner portion of the blocks. Therefore, the tree plots and herb plots were not affected by the skid trails. The presence of the skid trails is reflected in the higher post-harvest control treatment plot herbaceous species richness values. A commercial seed mix was often used to revegetate the skid trails. The mix included many exotics and graminoids. Because buffers were not established between blocks, the control treatment experienced an edge effect that also accounted for an increase in species richness.

Understory Herbicide

While the understory herbicide treatment was intended to increase advanced oak regeneration by removing the midstory, the results were very similar to the control treatment. Species richness increased from pre-harvest to post-harvest in the treatment plots, but it did not in the tree and herb plots. Increases in species richness and exotic species in the treatment plots are likely due to the edge effect described above for the control treatment. Because the herbicide was only targeted at trees and shrubs between 1-5 m, canopy openness was not greatly impacted. However, while species richness did not increase in the tree and herb plots, woody abundance increased significantly after the herbicide treatment. The basal area was slightly reduced from the pre-harvest measurement, although not significantly. This may have increased light levels enough to account for the increase in woody cover from species such as *Acer rubrum, Rubus* sp., *Smilax rotundifolia,* and *Vaccinium stamineum*, but not allow for invasion of additional species or foster additional germination of the shade-intolerant to intermediate tolerant oak species. It is likely that the woody species already present were able to quickly take advantage of the additional light resources, resulting in an increase in growth.

There is no evidence that the herbicide application caused a decrease in species diversity. While herbaceous cover decreased slightly in the post-harvest sampling, it was not significant and species richness did not decline in any of the plot sizes. These results are similar to a study of the effects of herbicide applications on species diversity in Georgia (Boyd et al. 1995, Miller et al. 1999). The authors found no differences in species richness between the treated and control plots either seven years or eleven years following treatment.

INTERMEDIATE DISTURBANCE TREATMENTS

Group Selection

The group selection had the highest residual basal area of the five harvested treatments. The treatment and tree plots behaved similar to the other harvested treatments. After harvest woody and herbaceous species richness were significantly higher for both the control and understory herbicide treatments. In the herb plots, the group selection was only significantly different from the understory control and the low-leave shelterwood. This is probably a relic of the random placement of the herb plots. Many fell on borders of the group cuts, causing half to respond similarly to the high disturbance treatments and half to low disturbance treatments. While abundance was not significantly different than the low disturbance treatments, it doubled from pretreatment levels after harvesting. The group selection treatment responded similarly to the study by Collins and Pickett (1988) of the response of the herb layer to gaps ranging in size from a single tree to 151 m^2. The larger opening in that study is similar to one of the group selection cut areas. The authors found an increase in number of herbs and species richness after creating the gaps regardless of gap size.

High-Leave Shelterwood

The high-leave shelterwood was similar to the group selection in residual basal area. Treatment plot richness was significantly greater than in the control and understory herbicide treatments, but was no different than in the other harvested treatments. Similar trends occurred in the tree plots and herb plots— the high-leave shelterwood woody species richness values were different only from the understory herbicide for both plot sizes and the high-leave shelterwood herbaceous herb plots. Percent cover was more similar to the low disturbance treatments than to the high disturbance treatments. Overall, the high-leave shelterwood fell in the middle between the low and high disturbance treatments, and was therefore often statistically the same as both disturbance intensities.

This is opposite of what Beese and Bryant (1999) found in comparing silvicultural systems in coastal western hemlock forests of British Columbia, Canada. Richness and cover in the study were greatest in the shelterwood, followed by the old-growth, patch clearcut (similar to clearcut treatment), and green tree (similar to leave-tree treatment) treatments. Another study, comparing shelterwood harvests to uncut forests in deciduous forests dominated by maple, oak, and ash in Ontario, Canada removed 33% and 66% of the basal area without negatively affecting the herb layer community (Reader and Bricker 1992a).

HIGH DISTURBANCE TREATMENTS

Low-Leave Shelterwood

The low-leave shelterwood had the second to lowest residual basal area. It had the highest richness values across all plots and the highest herb abundance, although not significantly higher than most of the other harvested treatments. The difference between the two shelterwood treatments reflects the changes in canopy. While both treatments were uniformly disturbed across the treatment plots, unlike the group selection, there is still a large difference in the residual canopy. The high-leave shelterwood has over seven more square meters of basal area. The residual trees in the low-leave shelterwood are also much smaller in diameter. The low-leave shelterwood exhibited the same trends as the shelterwood studies in Canada described above (Beese and Bryant 1999; Reader and Bricker 1992a).

Differences between the high disturbance treatments are small and not statistically significant. They are most likely attributed to differences in available microhabitats, such as streams, seeps, and rock outcrops, which allow a broad range of species to colonize and exist within a given area. The high disturbance treatments generally had more exotic species in the post-harvest sampling. This supports the common view that non-native species are "weedy" and tend to colonize disturbed areas with high light levels.

Leave Tree

The leave tree harvest was intermediate in residual basal area between the low-leave shelterwood and the clearcut. The post-harvest richness values were similar to other high disturbance treatments, although herb abundance was about 10 percent lower. The large increases seen in richness across all plot levels was not found in the green tree treatment in British Columbia (Besse and Bryant 1999). On that site neither richness nor abundance changed after harvesting. Differences in response could be due the different climates, species native in each region, and/or the overall greater number of species in the Appalachians.

Clearcut

The clearcut had almost no residual basal area but responded to disturbance much as the low-leave shelterwood did. The clearcut results are similar to Halpern's and Spies's (1995) finding that richness was higher within two years after cutting and steadily increased over time in forests of the Pacific Northwest. They also found exotic species abundance to peak in year two. Clearcuts and patch clearcuts in British Columbia, Canada did not experience an increase in richness and abundance after harvesting (Beese and Bryant 1999). In a study in the Appalachians, Elliot et al. (1997) found lower species richness after clearcutting in the same forest than 25 years previous before the clearcut was implemented. Grazing and differences in sampling methods however confounded these results.

V. INITIAL IMPACTS OF HARVESTING ON DIVERSITY IN THE SOUTHERN APPALACHIAN MOUNTAINS

INTRODUCTION

There has been much concern over recent loss in biodiversity (Ricklefs 1987, Boyd et al. 1995, Halpern and Spies 1995, De Grandpré and Bergeron 1997, Elliott et al. 1997). Many people believe that forest management practices, especially harvesting old growth and short logging rotations, may reduce diversity in forest ecosystems (Duffy and Meier 1992, Meier et al. 1995). This rising concern has led to policy changes in forest management. The National Forest Management Act of 1976 (16 U.S.C. § 1600) mandates the USDA Forest Service to provide for diversity of plant and animal communities (Roberts and Gilliam 1995). The Forest Service has attempted to achieve this goal by adopting an "ecosystem management" approach and by moving away from an emphasis on timber (Gilliam et al. 1995).

Maintaining diversity on federal lands only is not enough to solve the problem of species decline however (Hansen et al. 1991, Boyd et al. 1995, Roberts and Gilliam 1995). Protected areas cover less than three percent of the earth's land surface (Reader and Bricker 1992a). Private forested land must be managed for both commodity production and conservation of diversity if diversity is to be maintained across the landscape (Hansen et al. 1991). The Society of American Foresters stated in 1991 that "Professional foresters should manage forestlands to conserve, maintain, or enhance the biological diversity of the region in which they work and, collectively, of the nation and the earth" (Roberts and Gilliam 1995).

Diversity is also of interest as it pertains to maintenance of ecosystem functions and the stability, resilience, and productivity of the ecosystem (Lawton 1994, Schwartz et al 2000). Resistance is defined as how far a system deviates from normal behavior following a disturbance (Van Voris 1980). How resistant and resilient an ecosystem is to disturbance determines its stability. Resistance and resilience can be examined for population stability or ecosystem stability.

The rising concern over loss of species diversity due to deforestation, grazing, and urban sprawl has sparked a long-standing debate over the diversity-stability hypothesis. Several recent

studies have attempted to determine if land management practices also lead to a decline in ecosystem stability and function (Halpern 1988, Tilman 1996, DeGranpré and Bergeron 1997, Bengtsson 2000). Since MacArthur (1955) and Elton (1958) (from Morin 1999) first suggested that more complex communities might be more stable than simple ones using models, there have been numerous experiments and models yielding conflicting results. May (1973) and later, King and Pimm in 1983 (from Morin 1999) tested the diversity-stability hypothesis using more complex models. Basing his models on the Lotka-Volterra equation, May found that increasing complexity resulted in decreased stability. King and Pimm came to the same conclusions as May in regard to individual populations within a food web. However, their model predicted increased stability for aggregate properties of the entire community, through compensatory growth and mortality of competing species. These findings revealed important differences between individual populations and ecosystem behavior (from Morin 1999).

Van Voris et al. (1980) studied the relationship between functional complexity and stability in simulated ecosystems. The results of the study showed a significant positive relationship between functional complexity and stability, but no relationship with stability and the community parameters. The authors concluded that their study supported the diversity-stability theory at the ecosystem level, but not at the community level (Van Voris et al. 1980).

The many variables used to measure diversity and stability make studies difficult to compare and are most likely a major cause of the conflicting results. The terms themselves are rarely defined in a similar way. Other potential problems include scale (discussed in Connell and Sousa 1983), natural communities versus simulated communities (Lawton 1994), population versus ecosystem stability (Tilman 1996), and the state of the ecosystem (time since disturbance). Many models and studies assume that the community is stable at the beginning of the experiment. Different types and intensities of disturbances also affect the rate a community returns to stable conditions.

In one of the most recent studies supporting the diversity-stability hypothesis, Tilman (1996) examined the effect of drought on native grasslands and abandoned fields of different ages under different amounts of nitrogen additions and concluded that the richer plots had both greater resistance and resilience to perturbations. However, when the species were examined on an individual basis, biomasses of individuals tended to have greater variability in species-rich plots. Tilman attributed this to compensatory growth of drought-resistant species when the drought-susceptible species declined. He hypothesized that the disturbance resistant species act

to stabilize community biomass. Because there is a higher probability that drought-resistant species will occur in the species rich plots, the species rich plots are more stable.

There are a variety of possible relationships between ecosystem function and diversity (Vitousek and Hooper 1993, Lawton 1994, Schwartz et al. 2000). Schwartz et al. (2000) reviewed both observational and experimental studies of the relationships between ecosystem function and biodiversity modeled two major relationships. The Type A hypothesis states that the stability of ecosystem function increases as diversity increases. The Type B hypothesis predicts a positive correlation between function and species richness, but after relatively few species are added the curve flattens. Evidence seems to be accumulating that the relationship between species richness and ecosystem function is usually a Type 2 or B response. Differences in the response type found in the studies could be due to the different variables used to measure ecosystem function, such as biomass, respiration, CO_2 flux, nutrient retention, and cover.

Hooper (1998) examined the productivity of different levels of functional group diversity in a grassland in California. He found that the functional attributes and interactions between groups, rather than richness, accounted for changes in productivity. Each group had an impact on productivity in different directions. Symstad et al. (1998) found similar responses working in grassland communities. They found that "the magnitude and direction of change in ecosystem functioning with declining diversity" depended on the species deleted and the community it was removed from. Wardle et al. (2000) used constructed microcosms with multiple trophic levels to test for functional group richness and composition on ecosystems. They concluded that the identity of the functional group, not group richness determined the stability of ecosystem properties. Tilman (1996) also alluded to the fact that responses are species specific with his theory of compensatory mortality.

In all likelihood both hypotheses are probably correct to some degree. Species richness increases stability and ecosystem function to a point, and then tapers off. The leveling reflects species functional redundancy in an ecosystem. Functional composition, and therefore species composition, is what then becomes important, not merely richness.

From a land management perspective, ecosystem processes may be of greater interest than species diversity. Angermeier and Karr (1994) argue for biological integrity, rather than diversity, as a primary management objective. The authors contend that altered communities may lack biological integrity without necessarily being less diverse than natural communities. Karr and Dudley (1981) defined biological integrity "as the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity,

and functional organization comparable to that of natural habitat of the region" (Karr 1991). Karr (1991) also points out the importance of ecological health, where a healthy ecosystem is one capable of maintaining a stable condition and able to recover from disturbance. All species do not exhibit the same functional value (Tilman et al. 1997). Consequently, change in species composition—such as the exchange of an exotic species for a native—may prove more disruptive to ecosystem processes than loss of species diversity. Goldstein (1999), however, cautions that management strategies aiming to protect ecosystem processes without consideration for species and their respective life-history requirements are of little merit. Johnson and Mayeux (1992) assert that species can be "added or removed from ecosystems without greatly affecting ecosystem function.

Most forestry related diversity studies have focused on commercially important timber species and wildlife. Few studies have examined the impacts of silvicultural activities on the forest herbaceous community (Davison and Forman 1982, Reader 1987, Reader and Bricker 1992b, Halpern and Spies 1995). Responses to forestry practices are better understood for woody species than for herbaceous species. Most of the studies compare silvicultural treatments against a control, or use chronosequencing to study long-term changes in the forest community. These methods are based on the assumption that predisturbance vegetation is the same across sites. Therefore, results from such studies may be confounded by historical or stochastic events (Halpern 1989) and could lead to erroneous conclusions (Foster and Tilman 2000, Yanai et al. 2000). Without long-term community studies, it will be impossible to know if current forest management practices are leading to the decline or local extinction of some species and the general impact of harvesting on diversity.

The Southern Appalachian Mountains is one of the greatest centers of forest diversity in the United States. It has been estimated that 2,200 native vascular plant species exist in this region (Miller and Wiegert 1989). With the advent of the Shay locomotive, incline logging, and the band saw, extensive logging began in the late 1800s and extended through the 1930s on the majority of primeval Appalachian forest in Virginia and West Virginia (Clarkson 1964, Sarvis 1995). Consequently, today most of the region's forestland is second-growth, except for scattered acreage that was non-merchantable, inaccessible, or overlooked. In addition to logging, the loss of the American chestnut, intermittent wildfires, periodic ice storms, and introduced pests such as the gypsy moth (*Lymantria dispar*) and hemlock wooly adelgid (*Adelges tsugae* Annand) are the most influential disturbance events currently shaping southern Appalachian forests. Of the few studies on forest management impacts on herbaceous plants, only a handful

have focused on diversity in the Southern Appalachians. Most of these studies have only examined clearcutting (Duffy and Meier 1992, Gilliam and Turrill 1993, Gilliam et al. 1995, Meier et al. 1995, Elliott et al. 1997). Of these, only one is a long-term study with pre-harvest baseline data (Elliott et al. 1997).

Due to the need for more data on forest management impacts on the forest community, we implemented a long-term, collaborative research project to study the impacts of silviculture on biodiversity in the southern Appalachian Mountains. Other aspects of the study have been reported elsewhere. The short-term effect on the salamander component is discussed in Harpole and Haas (1999) and the woody, shrub, and herbaceous components of seven silvicultural treatments in Wender (2000). A more detailed examination of the short-term impacts of harvesting on the herbaceous layer community using three treatments, an undisturbed control, a high-leave shelterwood, and a clearcut are reported here. Our specific objectives are to quantify the initial changes in woody and herbaceous plant species composition across a gradient of harvest intensities and to examine the relationships of selected environmental and topographic characteristics on species richness and abundance in order to determine what, if any, species and/or species groups are most vulnerable to harvesting and whether harvesting increases the abundance of exotic species. We also compare differences in harvesting intensities and the general response of the plant communities to examine the changes in species diversity on both a site specific and a regional scale.

METHODS

SITE SELECTION AND DESCRIPTION

Sites were selected to represent common upland hardwood forest types in the southern Appalachians. Each was chosen for uniformity in stand composition, age, structure and geophysical characteristics. Mid elevation (600-1200 m) stands were selected that were dominated by red and white oaks (*Quercus* spp.), hickories (*Carya* spp.), and maples (*Acer* spp.). Stands had to have relatively uniform structure with minimal silvicultural disturbance in the last 15 years and a mature overstory of at least 50-150 years. Additional site requirements were moderate slopes (10-40 percent), average site index between 18-21 m (base age 50 for upland oaks), and predominantly south-facing aspects.

Five sites were selected in Virginia and West Virginia that met the site requirements. Three of the sites are located in the Jefferson National Forest in southwestern Virginia. The Newcastle site (NC) is located in the Newcastle Ranger District in Craig County, Virginia in the

Ridge and Valley physiographic region. Clinch 1 (CL1) and Clinch 2 (CL2) are both located in the Clinch Ranger District, in Wise and Scott countries respectively in the Cumberland Plateau physiographic region. The remaining two sites, West Virginia 1 (WV1) and West Virginia 2 (WV2), are located in the Allegheny Plateau physiographic region in Randolph County, West Virginia. Both of these sites are located on Westvaco Corporation's Wildlife and Ecosystem Research Forest, a private research forest owned by Westvaco Corporation.

The soils of all sites are derived from sandstone and shale residuum and colluvium. Soils tend to overlie the parent sandstone or shale bedrock at depths of 50-125 cm. As is typical of most Appalachian forests, the soils are rocky, well drained, and acidic, and are without exceptional moisture-holding capacity. The representative soil series on all five sites are predisposed only to slight or moderate erosion. All study sites fall within the mesic soil temperature class, meaning the winter to summer range of soil temperature at 50 cm is 8-15 ^{o}C (Daniels et al. 1973). A soil survey of Craig County, Virginia has not been completed as part of the National Cooperative Soil Survey; therefore, published soil data are not available for the NC site. Examination of soils at NC, however, suggests a predominance of shale- and sandstone-derived Weikert and Berks soils. The Berks-Weikert complex is characterized as a loamy-skeletal, mixed, mesic Typic Dystrochrepts in the Berks series and a loamy-skeletal, mixed, mesic Lithic Dytrochrepts in the Weikert series (Creggar et al. 1985). Soils at CL1 and CL2 belong almost entirely to the stony, fine, sandy-loam phase of the Muskingum series (Perry et al. 1954). The Muskingum series is classified as a fine loamy, mixed mesic, Typic Dystrochrepts. Of all the sites, soils at CL1 and CL2 may be the deepest, with a profile of up to 150 cm. Soils at WV1and WV2 belong to the Gilpin-Dekalb stony complex, and are classified as (1) loamy-skeletal, mixed, mesic Typic Dystrochrepts and (2) fine-loamy, mixed, mesic Typic Hapludults (Pyle et al. 1982).

The Ridge and Valley and Allegheny Plateau physiographic provinces are characterized by a moderately moist, temperate, mesothermal climate. Precipitation is distributed throughout the year, without a distinct dry season, although the spring is consistently the wettest season. Temperature and precipitation for both regions can exhibit considerable local variation because of differences in relief, aspect, and vegetation patterns. Mean annual precipitation for NC is approximately 105 cm (NOAA 1995). Annual precipitation is slightly higher at WV1 and WV2 (107 cm), due in part to higher winter snowfall (Pyle et al. 1982). The annual precipitation is highest at CL1 and CL2 (124 cm) (NOAA 1995), typical of the annual average for the Cumberland Plateau. The annual, mean daily temperature is also highest at CL1 and CL2 (12.5

^{o}C), ranging from a January average of 0 ^{o}C to a July average of 21.5 ^{o}C (NOAA 1995). Mean daily temperature for NC is approximately 10.8 ^{o}C, with annual January and July temperatures of –1.0 ^{o}C and 20.5 ^{o}C, respectively (NOAA 1995). WV1 and WV2 exhibit the coldest average January temperature (-1.6 ^{o}C), but are similar to NC in July (20.5 ^{o}C). The WV1 and WV2 annual, mean daily temperature (9.7 ^{o}C) is the lowest of all sites (Pyle et al. 1982).

The study sites are contained within Braun's (1950) Oak-Chestnut Forest region of the eastern deciduous forest, although CL1, CL2, WV1, and WV2 are strongly influenced by the Mixed Mesophytic Forest region. Hammond (1998) characterized the pre-treatment vascular plant community of the sites. *Quercus* species were the dominant overstory component of all sites. *Quercus rubra, Q. prinus, Q. alba,* and *Acer rubrum* were the major components of CL1, CL2, and WV1. *Quercus coccinea, Q. prinus,* and *Q. alba* dominated the NC canopy. WV2 was dominated by *A. rubrum, Magnolia fraseri, Liriodendron tulipifera, A. saccharum,* and *Q. rubra.*

SAMPLING

Permanent plots were established and sampled before harvesting to establish baseline data. The study layout is a randomized complete block design with nested subplots. Permanent treatment plots of 2 hectares each were established in a contiguous block. There were no buffers between the treatments. Once the treatment plots were established, one treatment was randomly assigned to each plot. Within each treatment plot, three permanent 24 m x 24 m tree plots were established. Tree plots have a 23-m buffer between their boundaries and the edge of the treatment plot. A random number generator was used to obtain the distance and angle away from the center of the treatment plot to determine the center of the first tree plot. To avoid overlap, the second and third tree plots were established by adding 120^{o} and 240^{o}, respectively to the bearing of the first tree plot. Distance from the treatment plot center in the two additional plots was determined using a random number generator. After the tree plot centers were located, the plot boundaries were arranged along the four cardinal directions. Eight 1m^{2} herb plots were established inside each tree plot. Plots were located by placing PVC pipe long the tree plot boundary 5 m from each tree plot corner. Of the eight herb plots, six were randomly chosen for sampling. The same six plots were sampled in each year.

Prior to harvest, an on-site project forester designed skid trail placement in accordance with applicable Best Management Practices. Conventional harvesting methods using chainsaws and cable skidders were employed. In the clearcut treatment, all stems greater than 5 cm d.b.h. were felled. Trees that were not merchantable were felled and left on the site. Mast, snag, or

cull trees could be left for wildlife purposes, but could not exceed 10 stems/ha. The shelterwood treatment was designed to leave 12-15 m^2/ha of dominant or codominant stems evenly distributed over the treatment area. Once adequate advanced regeneration is present, these trees will be removed. This should occur 5-10 years following the initial harvest. No silvicultural activity occurred in the control treatment. Due to the study layout, skid trails are present in a small section of the outer perimeter of the CL2 control treatment.

The control, shelterwood, and clearcut treatments were chosen because they represent a gradient of decreasing forest canopy cover and disturbance. The control is a mature forest, relatively undisturbed for at least 50 years. The shelterwood is intermediate in cover and disturbance with relatively homogeneous disturbance across the treatment area. The clearcut, with complete canopy removal, is the most disturbed treatment of the three. This range of treatments should provide a good comparison of the initial impacts of harvesting disturbance on the herbaceous layer.

Sites were sampled over a multi-year time frame (Table 5.1). This may introduce some variation in results due to different weather conditions, but could not be avoided due to the staggered harvest schedule and because sampling more than three sites in one summer was not possible due to time and personnel constraints. In all cases sampling occurred during the second full growing season after harvest.

All treatment plot types (2 ha treatment plots, 576 m^2 tree plots, and 1m^2 herb plots) were sampled before harvesting and were sampled again approximately one complete growing season after harvest. Treatments were sampled twice during the growing season, first in May and secondly in August. This aided in the identification of herbaceous plants to the species level to sample both early and late flowering species. Treatment and tree plots were used to obtain presence/absence lists of all species found in each 2 ha and 24 x 24 m quadrats. Taxonomy primarily follows Strausbaugh and Core's Flora of West Virginia (1978). Due to problems with identifying some herbaceous plants to the species level in the pre-harvest inventory, some species were combined to the genus level. Genera that reflect more that one species include *Aster, Carex, Eupatorium, Panicum, Prenanthes, Prunus, Rhododendron, Rubus, Solidago, Trillium* and *Viola.* To obtain woody and herbaceous species richness, each treatment plot and tree plot was traversed several times so that the entire area within the 2-ha plot and three-24 x 24 m plots was covered.

A 1-m^2 frame was used to sample the herb plots. All vegetation in the herb layer (<1 m) was sampled for percent cover by species. Classes were used for visually estimating percent

cover. Classes were 1-7%, 8-25%, 26-50%, 51-75%, 76-93%, and 94-100%. In addition, several more variables were sampled post treatment for each herb plot. Bare soil, rock, and coarse woody debris were estimated visually and grouped into the same cover classes. Topographic features of aspect, slope position, and slope percent were noted. The microtopography was recorded as convex, concave, or linear. Herb plots that were located in primary and secondary skid trails or in intermittent streams were noted.

Soil samples were collected to a depth of 10-cm using a push tube. Based on observations, we were of the opinion that the majority of the herbaceous plants' root utilization would be in the upper 10 cm of the pedon. Other plant studies have used this depth (Grime and Curtis 1976, Beatty 1984, Gilliam and Turrill 1993) or have used 5 cm (Meier et al. 1995). Several samples were collected across each plot and composited for lab analysis. A 2-dm^2 piece of plywood was placed outside and along the herb plot boundary on top of the litter to account for any moisture differences when measuring litter depth. Litter depth under the plywood was recorded in June to the nearest 0.5 cm using a metal ruler. The litter under the plywood was then collected for weighing.

Soil samples were analyzed for total percent carbon, total percent nitrogen, percent organic matter, pH, and texture. Before analysis, soils were air-dried and ground through a 2-mm sieve. Total soil carbon, nitrogen, and carbon nitrogen ratio was obtained using a Vario-MAX CNS Macro Elemental Analyzer (Elementar Americas, Inc.). Percent organic matter was obtained using the loss on ignition technique, which burns off organic matter by placing samples in a muffle furnace at 430^{o}C for 48 hours (Lim and Jackson 1982). Soil samples were corrected for moisture. Soil acidity was measured using a pH meter and a 1:2 ratio of soil to distilled water (McLean 1982). Soil texture was determined by particle size analysis using a hydrometer (Gee and Bauder 1986). This method separates the percent of sand, silt, and clay for each sample. Litter samples were placed in paper bags, oven dried at 60^{o}C for 48 hours, and weighed.

To estimate light availability hemispherical photographs were taken one meter above the center of each herb plot for light availability analysis using a Nikon 35 mm camera with an attached 180-degree fisheye lens (8 mm). Kodak TRI-X 400 TX 135 black and white film was used to create the highest level of contrast between vegetation and sky. A level and compass were attached to the camera so that all pictures could be level and oriented due north. Photographs were taken just before sunrise or after sunset, or on cloudy days.

Film negatives were scanned into a computer using Adobe PhotoShop. Each photograph was analyzed using the image analysis program Hemiview (Delta-T, UK). This program was used to estimate the gap light index (GLI) for each herb plot (Equation 5.1)

GLI % = [(ISF * Pdiff) + (DSF * Pdir)] 100. (Equation 5.1)

The GLI is a measurement of both the diffuse and direct light reaching the plot. Hemiview calculated the diffuse light as the indirect site factor (ISF) and the direct light as the direct site factor (DSF) using the percentage of each photograph covered by leaves and stems. ISF is calculated using the amount of photograph covered by foliage regardless of the sun's direction. DSF is calculated based on the location of the foliage along the sun's path. The value of 0.5 was used for both Pdiff (proportion of photosynthetic active radiation (PAR) received as diffuse radiation) and Pdir (proportion of PAR received as direct-beam radiation) (Canham et al. 1990). A GLI of 0 indicates that there is no gap in the canopy. A GLI of 100 indicates a fully open site.

DATA ANALYSIS

Species richness values were calculated by treatment and year for each plot type (herb plot, tree plot, and treatment plot). We report richness for the three plot types for several reasons. First, commercial seed mixes were often used to revegetate the skid trails. We were concerned that this may have artificially increased richness in the harvested areas and promoted the spread of exotic species. By analyzing richness at all plot levels, we were able to ascertain if the seed mix greatly affected the spread of exotics and general increase in species richness because few of the tree plots and almost none of the herb plots fell into the skid trails. These analyses also depicted whether the sampling sizes were adequate for accurately estimating species richness. Sampling seasons were combined to form a unique presence/absence list by treatment and plot size.

Analysis of variance of the pre-harvest data and analysis of covariance of the post-harvest data using the pre-harvest data as the covariate were performed using PROC GLM in SAS version 8 with the three treatments as fixed effects (SAS Institute 1998). Treatment plot analysis used a randomized complete block design (RCBD) model with the five sites as blocks, while tree plot and herb plot analyses used a RCBD with subsampling model. Separation of means was tested using LSMEANS for all analysis. Paired t-tests were conducted to test for differences between pre and post harvest by treatment using PROC UNIVARIATE in SAS. Three multivariate analysis techniques were used to analyze the response of the herb layer to harvesting and environmental conditions. Only data collected from the herb plots were used in the analyses.

All multivariate analyses were performed using PC-Ord version 4.17 (MjM Software 1999). Plots with missing variables were deleted from the analysis. All variables measured by cover classes were converted to percent abundance by using the midpoint of the class's range. The maximum abundance of the two sampling seasons for each species was used for analyses. Slope position and topography shape were transformed into a numeric scale from driest to wettest (i.e. skid trail=1, ridge=2, shoulder=3, back slope=4, toe slope=5, floodplain=6, stream=7; and convex=1, linear=2, concave=3). Azimuths were transformed into a scale of 0-180, using 45^{o} as 0 to account for greater dryness in southwest-facing versus southeast-facing slopes. All environmental variables were tested for normality using PROC UNIVARIATE option NORMAL in SAS. The percent coarse woody debris (CWD), bare soil, and rock values exhibited a strong Poisson distribution and were square root transformed. Transforming rock, bare soil, and CWD did not create normal distributions and seemed to be very erratic. In our opinion, our sampling method did not sufficiently capture the patterns associated with these variables and the treatments. After initial ordinations, inclusions of these variables seemed to reduce the accuracy of the results; consequently they were deleted. Carbon and nitrogen were also deleted due to strong correlations between the variables and organic matter to avoid collinearity problems. In addition, we believe that C:N ratio provides a better indicator of organic matter quality. An outlier analysis was performed on the environmental data and the 13 of 215 plots outside two standard deviations of the mean were removed from the dataset. Detrended Correspondence Analysis (DCA) was used to examine the differences among plots using measured environmental conditions (Hill and Gauch 1980). The slope percent variable greatly reduced the eigenvalues and therefore, was deleted from the DCA analysis. No microsite variables were downweighted.

For vegetation analyses, non-metric multidimensional scaling (NMS) and canonical correspondence analysis (CCA) were used. Species not occurring in at least five percent of the herb plots were deleted. NMS was used to examine difference among sites in vegetation structure, and 1-year changes in vegetation structure associated with harvesting. NMS was used because it best preserves distances among samples in low-dimensional space (Clarke 1993). The default "slow and through" NMS option in PC-Ord was used for initial testing. Separate analyses were used for woody species, herbaceous species, and all species combined. The woody and all species analyses resulted in two-dimensional solutions. The herbaceous species analysis resulted in a four-dimensional solution. Because of graphical limitations with a 4-D

solution, a NMS was performed again on the herbaceous only dataset by changing the default number of axes to two. All other default options were kept the same.

CCA was used to explore the relationships between the microsite variables and herb plot species abundance data. CCA allows interpretation of the relationship of environmental variables to species and sites (Ter Braak 1986). Percent sand was excluded from CCA analyses because of high correlations with percent clay and silt. CCA was first analyzed using all sites. The CCA revealed three general groupings of the sites. Therefore, we separated the sites into three groups for separate analysis, again deleting any species not occurring in at least 5 percent of the herb plots. The groups were 1) CL1 and CL2, 2) NC, and 3) WV1 and WV2. We ran an individual CCA for each site grouping by woody species, herbaceous species, and all species combined. The default options in PC-Ord were used for all CCA.

TABLE 5.1. Current status of treatment application and vegetation sampling of five sites in the Cumberland Plateau, Ridge and Valley, and Allegheny Plateau of Virginia and West Virginia.

Site	Pre-treatment Inventory	1st Post-treatment Inventory (1-year)	Harvest Start	Harvest Completion
CL1	1993	2000	April 1994	October 1998
CL2	1995	1999	August 1997	March 1998
NC	1995	1998	November 1995	June 1996
WV1	1996	1999	May 1997	September 1997
WV2	1997	2000	April 1998	August 1998

RESULTS

HARVEST EFFECTS ON ENVIRONMENTAL CONDITIONS

Harvesting caused significant changes in litter depth and weight and percent gap light index (Table 5.2). Litter depth and weight were less in the shelterwood and clearcut treatments. Percent light was lowest in the control, followed by the shelterwood, and highest in the clearcut. All other microsite variables measured were statistically similar across treatments. The detrended correspondence analysis (DCA) depicts a clear difference between the clearcut and control microtopography conditions (Figure 5.1). The shelterwood falls in the middle of the other treatments. Plots fall primarily along a light/litter weight gradient, but are also separated along a second soil gradient of soil texture and organic matter. The clearcut is associated with high light conditions, while the control is associated with more litter. This first axis explains 56.5% of the variance in the microsite data. The second and third axes explain 17.3% and 13.0% respectively. The treatment plots are approximately equally spaced within the plane defined by axes 1 and 2.

TABLE 5.2. Post-treatment environmental variables for mean of five sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Treatment means followed by different letters are significantly different ($p < 0.05$). Standard deviations are in parentheses.

Variable	Treatment Mean		
	Control	Shelterwood	Clearcut
Slope (%)	29 (0.09)	28 (0.09)	27 (0.11)
Slope Position	Backslope (0.14)	Backslope (0.25)	Backslope (0.37)
CWD (%)	0.2 (0.04)	0.4 (0.08)	0.5 (0.07)
Rock (%)	0.0 (0.03)	0.0 (0.06)	0.0 (0.04)
Bare Soil (%)	0.0 (0.03)	0.2 (0.06)	0.1 (0.06)
Litter (cm)	2.8^{a} (0.28)	1.9^{b} (0.54)	1.8^{b} (0.29)
Topo Shape	Linear (0.40)	Linear (0.11)	Linear (0.28)
Aspect (azimuth)	159 (40.8)	160 (24.27)	144 (23.26)
Litter Weight (g)	32.63^{a} (4.77)	25.74^{b} (6.38)	21.38^{b} (4.32)
pH	4.57 (0.32)	4.49 (0.52)	4.36 (0.45)
Sand (%)	57.6 (0.13)	61.2 (0.06)	53.4 (0.12)
Clay (%)	14.6 (0.06)	15.8 (0.08)	17.0 (0.12)
Silt (%)	27.8 (0.09)	23.0 (0.09)	29.6 (0.04)
OM (%)	20.2 (0.06)	19.3 (0.06)	19.9 (0.05)
N (%/mg/l)	0.19 (0.00)	0.19 (0.00)	0.20 (0.00)
C (%/mg/l)	3.90 (0.02)	3.88 (0.02)	4.04 (0.02)
C:N	21.72 (4.39)	21.89 (4.75)	21.78 (5.86)
GLI (%)	8.3^{a} (0.02)	31.7^{b} (0.14)	61.1^{c} (0.23)

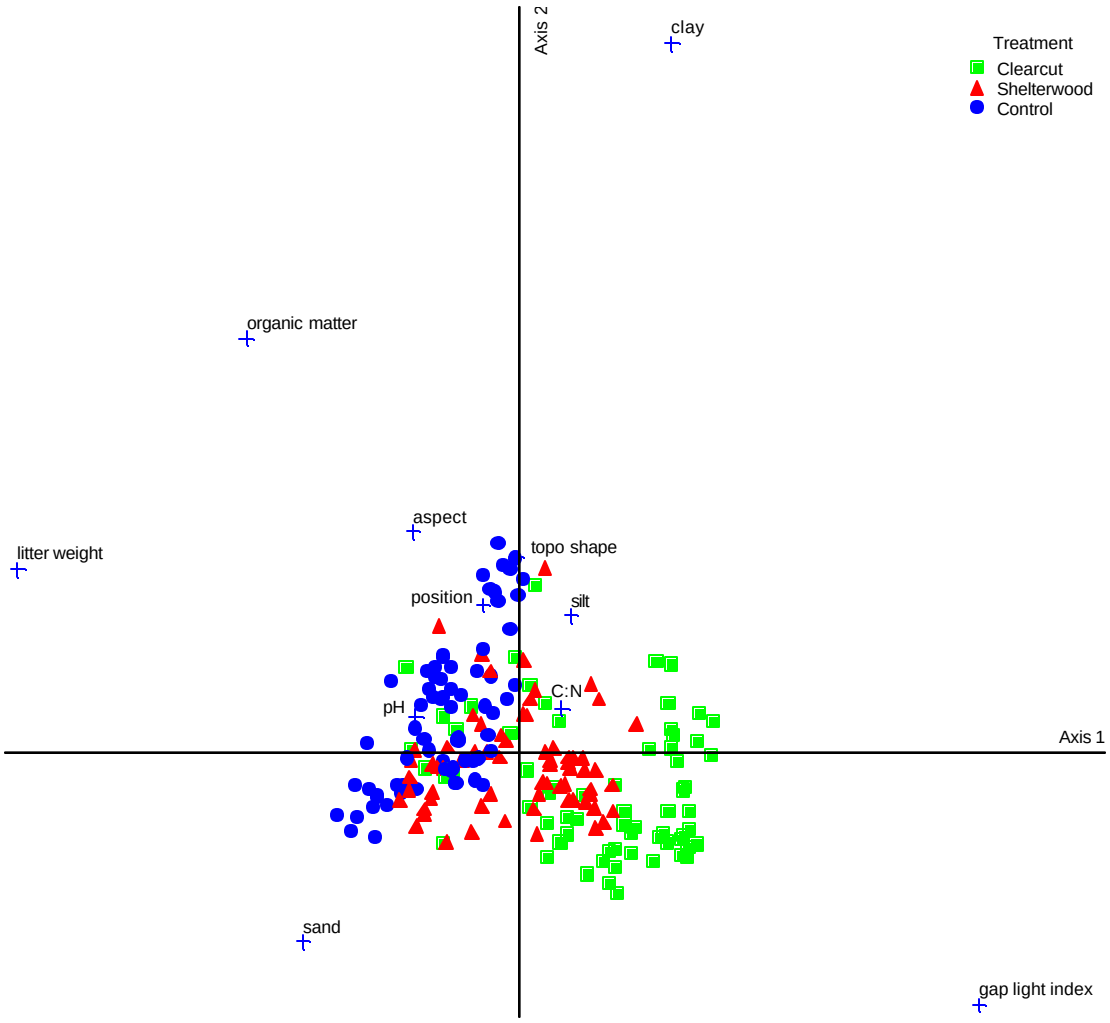


FIGURE 5.1. Detrended correspondence analysis (DCA) biplot (first two axes) of environmental variables in herb plots for five sites in the southern Appalachian Mountains of Virginia and West Virginia one year after harvesting. Total variance = 0.23; axis 1 eigenvalue = 0.13, axis 2 eigenvalue = 0.04, axis 3 eigenvalue = 0.03.

HARVEST EFFECTS ON LOCAL SPECIES RICHNESS, COVER, AND EXTINCTION

There were no significant differences in pre-harvest species richness values between treatments within each plot size (Figure 5.2). Average richness increased with increasing area sampled. In the post-harvest sampling the clearcut and shelterwood species richness values were significantly greater than in the control for all plot sizes. Richness in the clearcut and shelterwood treatments increased significantly from pre-harvest to post-harvest. The pre-harvest tree plot and herb plot samples captured approximately 81% and 48% of the plant community found in the two-hectare treatment plot, respectively. The post-harvest tree plot and herb plots samplings captured even less of the plant community inventoried in the treatment plots, approximately 61% and 35% respectively. The percentages of species in the treatment plot community not found in the tree and herb plots were generally the same regardless of treatment. Harvesting caused an increase primarily in graminoids and perennial forbs (Figure 5.3). There was also an increase in annual and biennial forbs.

Within treatments, there were no significant differences between pre- and post-harvest exotic species richness values (Figure 5.2). However, differences among treatments were significant after harvest. In the 2-ha plots, the clearcut and shelterwood treatments had more exotic species than the control treatment after harvest. This was also seen at the tree plot level for the clearcut treatment. At the herb plot level, virtually no exotic species were inventoried for either sampling year.

Average total herb cover before harvest was 29.5% in the control, 28.7% in the shelterwood, and 24% in the clearcut. There were no significant differences in pre-harvest abundance between treatments. Harvesting caused a significant increase in cover. The control increased to 35.5 %, although this was not significantly different than the pre-harvest sampling. The shelterwood had significantly greater cover than the control, increasing to 62.9%. Clearcut abundance was significantly greater than the control and shelterwood treatments with an abundance of 94.0%.

The percentage of species sampled pre-harvest that were not found in the treatment was approximately the same across all plot sizes and treatments, ranging from 13-25%. The control treatment lost about 19% of the species on all plot sizes. Local extinctions tended to increase with the smaller plot sizes in the shelterwood and clearcut treatments. Species were considered locally extinct that were not found in the above-ground vegetation during the sampling periods.

There is the possibility that locally extinct species were not found due to slightly different sampling times and still exist below-ground on the plots either as viable seeds or tubers. Species not occurring in the post-harvest sampling represented several plant lifeform groups (Figure 5.3). Local extinct species were largely from the perennial forb-lifeform group, which was the largest group in the pre-harvest sampling. Both harvested treatments had roughly the same proportions of lifeform extinctions as the control within the plot sizes. All species that were locally extinct in the post-harvest sampling were uncommon in the pre-harvest sampling. The complete list of species present in the pre-harvest and not in the post-harvest is in Appendix B.

The clearcut gained the most species after harvesting, with 116 species found during the post-harvest sampling that were not seen during the pre-harvest sampling. The shelterwood gained 98 new species, followed by the control with 55 new species. Perennial forbs accounted for the majority of the new species in all the treatments. Biennial and annual forbs increased in the harvested treatments. A large increase in the number of graminoid species was seen in all treatments. The complete list of species gained in the post-harvest is in Appendix C.

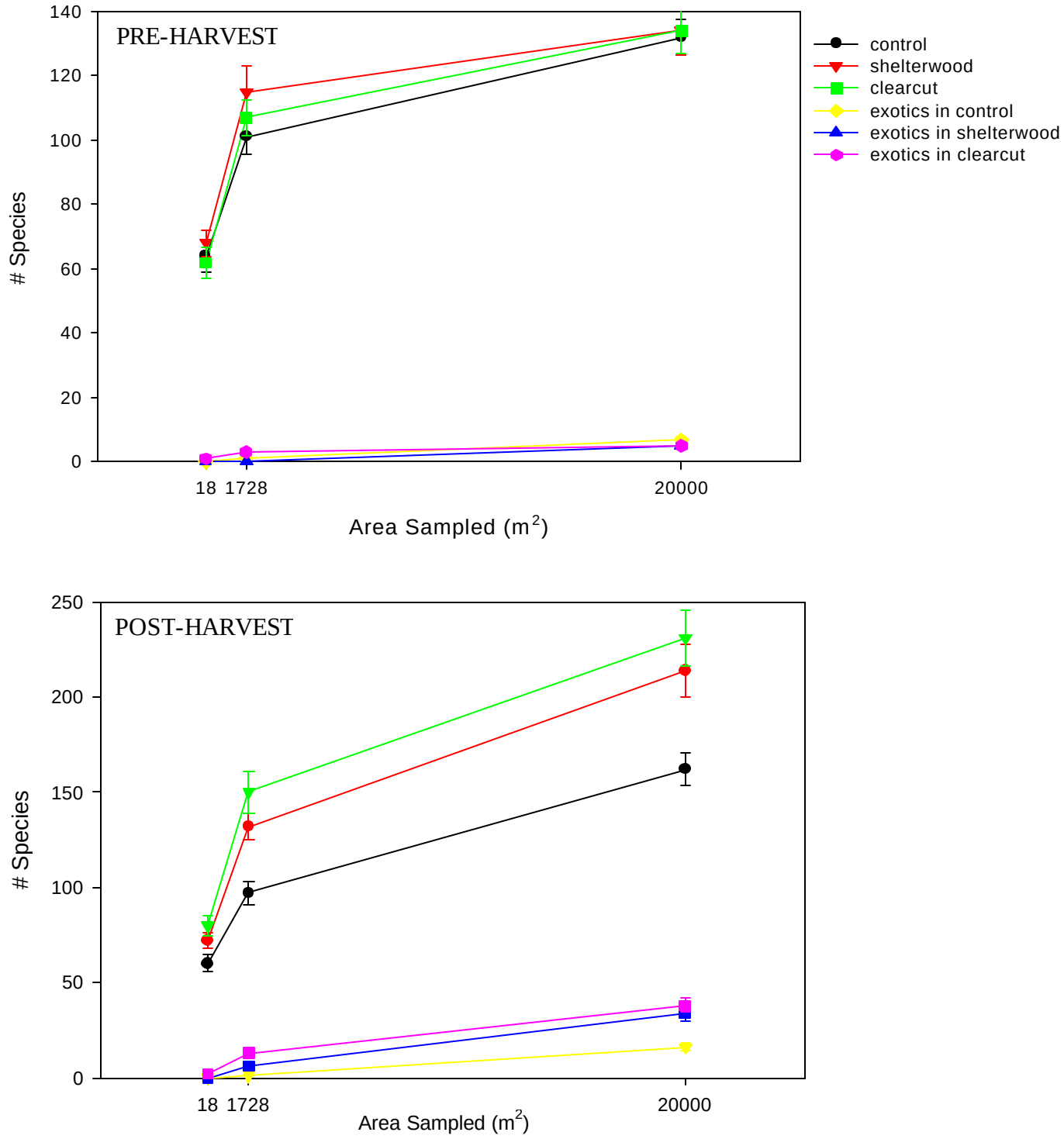
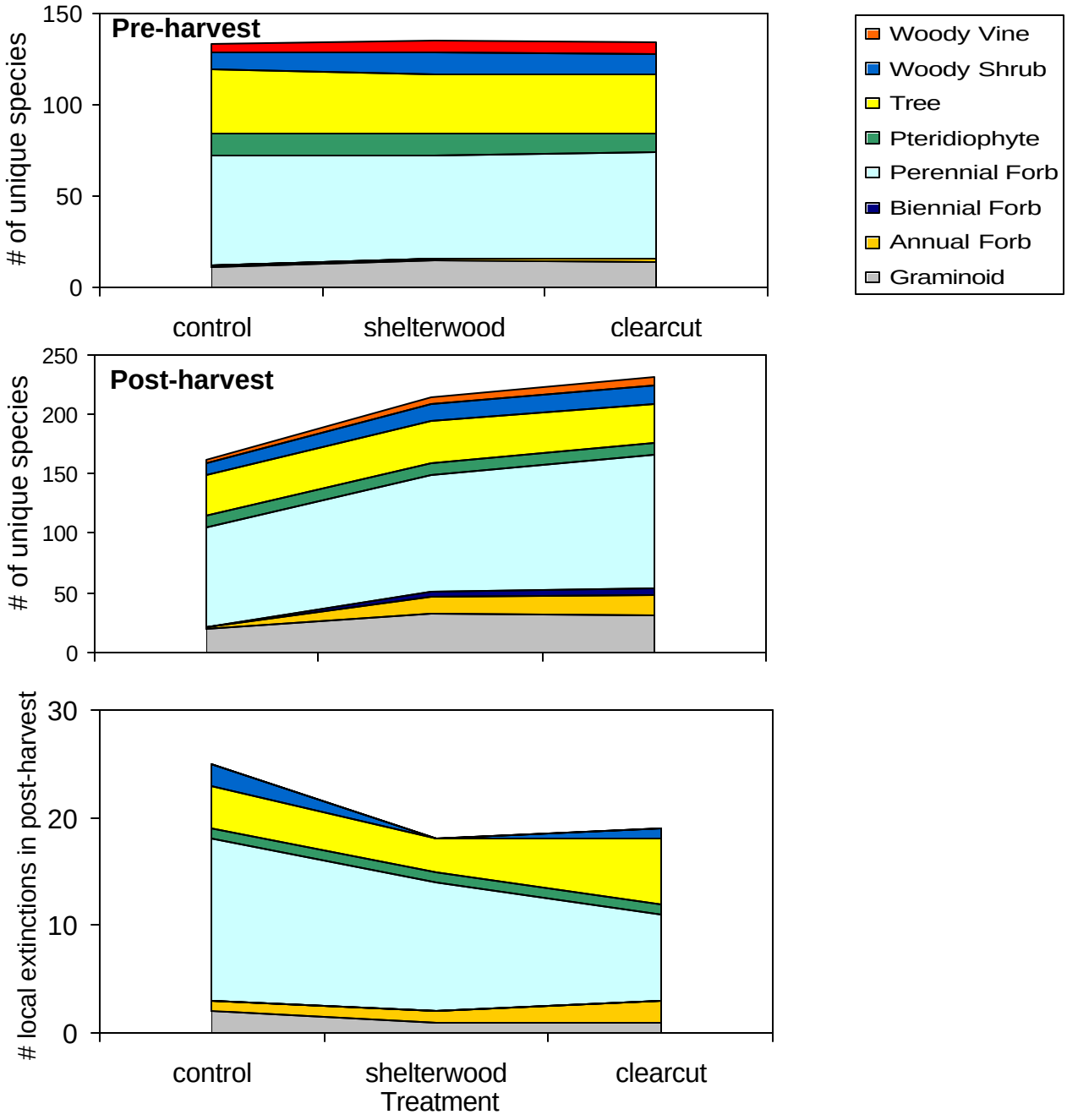


FIGURE 5.2. Pre-harvest and post-harvest species area curves of all species and exotic species by treatment for mean of five sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia. Bars indicate standard error of the mean.


Pre-harvest
# of unique species
150
100
50
0
control
shelterwood
clearcut
Post-harvest
# of unique species
250
200
150
100
50
0
local extinctions in post-harvest
30
20
10
0
control
shelterwood
clearcut
Treatment
Woody Vine
Woody Shrub
Tree
Pteridiophyte
Perennial Forb
Biennial Forb
Annual Forb
Graminoid

F
sa
gr

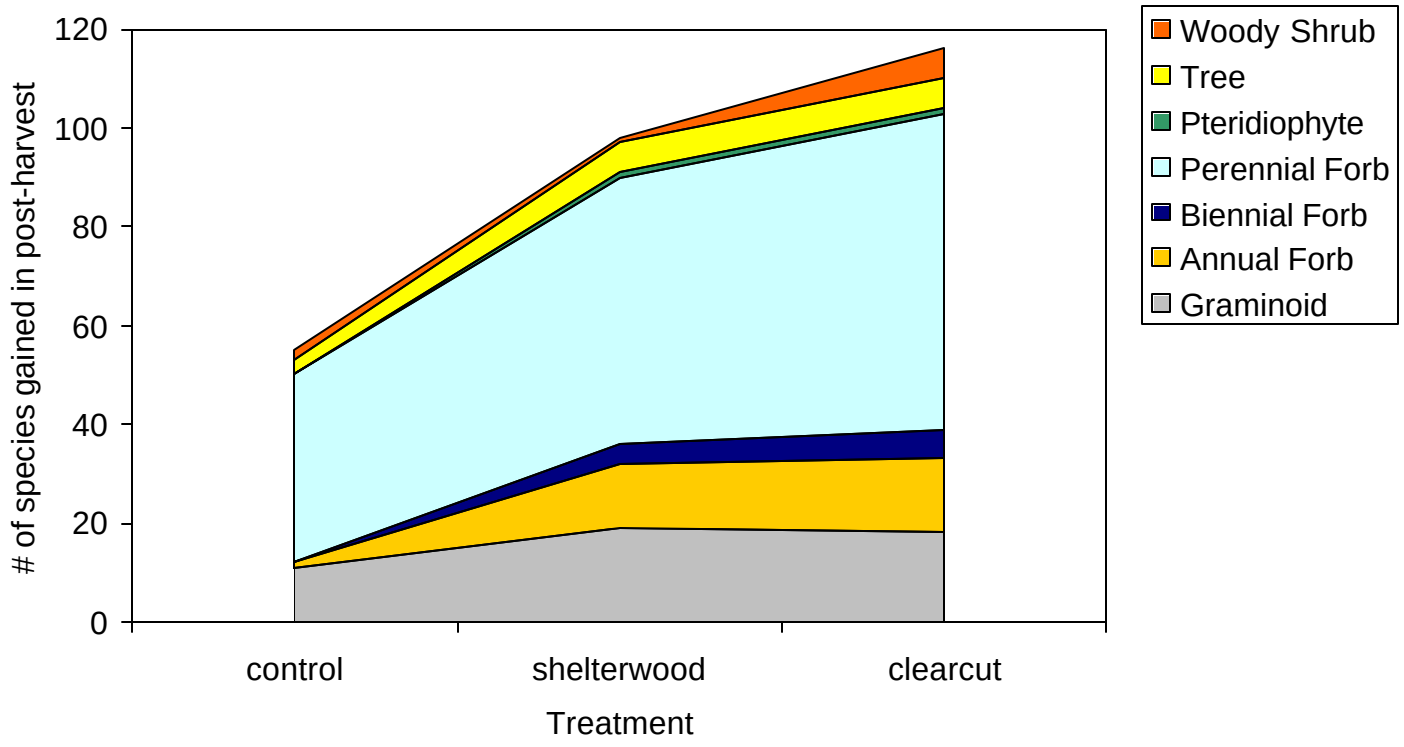


FIGURE 5.4. Lifeforms of species present in post-harvest treatment plot sampling that were not present in pre-harvest sampling.

HARVEST EFFECTS ON COMMUNITY STRUCTURE AT REGIONAL SCALE

Changes in community structure were largely site specific. Geographically close sites responded similarly to disturbance. Non-metric multidimensional scaling (NMS) grouped WV1 and WV2 together, CL1 and CL2 together, and NC alone (Figure 5.5). The three groups seem to be based on differences in species. *Fagus grandifolia, Betula lenta, Rubus sp*., and *Mitchella repens* dominate the West Virginia sites (WV1 and WV2). Ericaceous species such as *Gaultheria procumbens* and *Gaylussacia baccata* dominate the Newcastle site. The Clinch sites (CL1 and CL2) fall in between the two and share many of the same species as either or both of the West Virginia and Newcastle groups. Although the sites are grouped by differences in species, all harvested treatments responded similarly. The clearcut and shelterwood treatments in the post-harvest sampling were associated with increases in the presence of light dependent, early successional species such as *Rubus sp., Carex sp., Panicum sp., Liriodendron tulipifera, Dennstaedtia punctilobula,* and *Erechtites hieracifolia*, but are still dominated by pre-harvest species.

Analysis of woody vegetation alone shows the same trends as the woody and herbaceous species analysis (Figure 5.6). Analysis of the herbaceous vegetation grouped the sites the same as the total vegetation analysis, but the harvested sites often did not respond in the same manner (Figure 5.7). However, the post-harvest treatments are still closely associated with early successional species. The difference in the patterns between woody and herbaceous vegetation suggests that woody species' responses to disturbance are more predictable than herbaceous ones.

In general, community structure changed the most after clearcutting and least in the control sites (Figures 5.5-5.7). The West Virginia sites changed more following harvest than did sites in the other two geographic areas. The richest sites, CL1 and CL2, appear to be the most resistant to disturbance, supporting the diversity-stability hypothesis. WV2, the least rich of the five sites, changed the most after harvesting, and also supports the hypothesis. However, NC has less species than WV1 and it changed approximately the same as the Clinch site, whereas WV1 changed much more. These latter two results contradict the diversity-stability hypothesis.

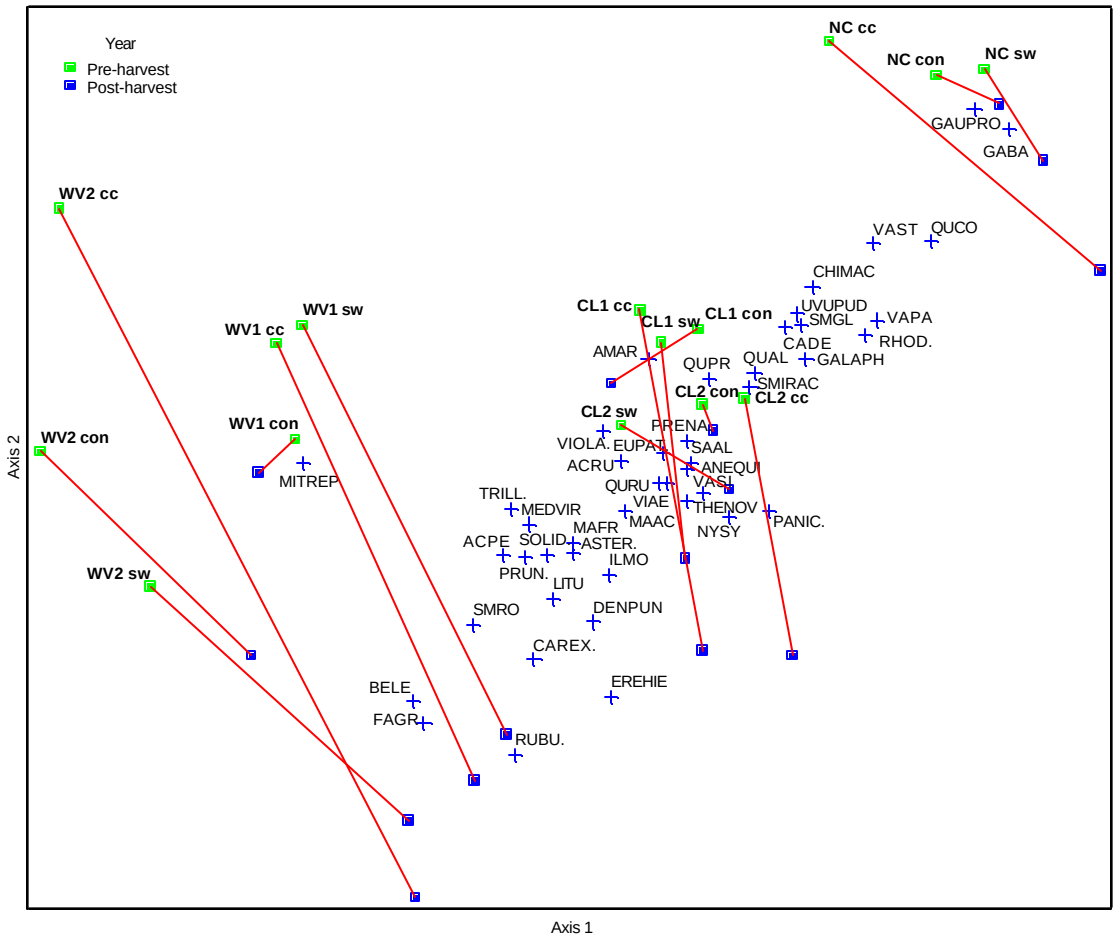


FIGURE 5.5. Non-metric multidimensional scaling (NMS) of average species abundances pre-harvest and post-harvest for each site and treatment. Species included occurred in at least five percent of plots. Stress = 0.08, 2 dimensions. Species codes are as follows: ACPE-*Acer pensylvanicum*; ACRU-*Acer rubrum*; AMAR-*Amelanchier arborea*; ANEQUI-*Anemone quinquefolia*; ASTER-*Aster sp.*; BELE-*Betula lenta*; CADE-*Castanea dentata*; CAREX.-*Carex sp.*; CHIMAC-*Chimaphila maculata*; DENPUN-*Dennstaedtia punctilobula*; EREHIE-*Erechtites hieracifolia*; EUPAT.-*Eupatorium sp.*; FAGR-*Fagus grandifolia*; GABA-*Gaylussacia baccata*; GALAPH-*Galax aphylla*; GAUPRO-*Gaultheria procumbens*; ILMO-*Ilex Montana*; LITU-*Liriodendron tulipifera*; MAAC-*Magnolia acuminata*; MAFR-*Magnolia fraseri*; MEDVIR-*Medeola virginiana*; MITREP-*Mitchella repens*; NYSY-*Nyssa sylvatica*; PANIC.-*Panicum sp.*; PRENA.-*Prenanthes sp.*; PRUN.-*Prunus sp.*; QUAL-*Quercus alba*; QUCO-*Quercus coccinea*; QUPR-*Quercus prinus*; QURU-*Quercus rubra*; RHOD.-*Rhododendron sp.*; RUBU.-*Rubus sp.*; SAAL-*Sassafras albidum*; SMGL-*Smilax glauca*; SMIRAC-*Smilacina racemosa*; SMRO-*Smilax rotundifolia*; SOLID.-*Solidago sp.*; THENOV-*Thelypteris noveboracensis*; TRILL.-*Trillium sp.*; UVUPUD-*Uvularia pudica*; VAPA-*Vaccinium pallidum*; VASI-*Vaccinium simulatum*; VAST-*Vaccinium stamineum*; VIAE-*Vitis aestivalis*; VIOLA.-*Viola sp.*

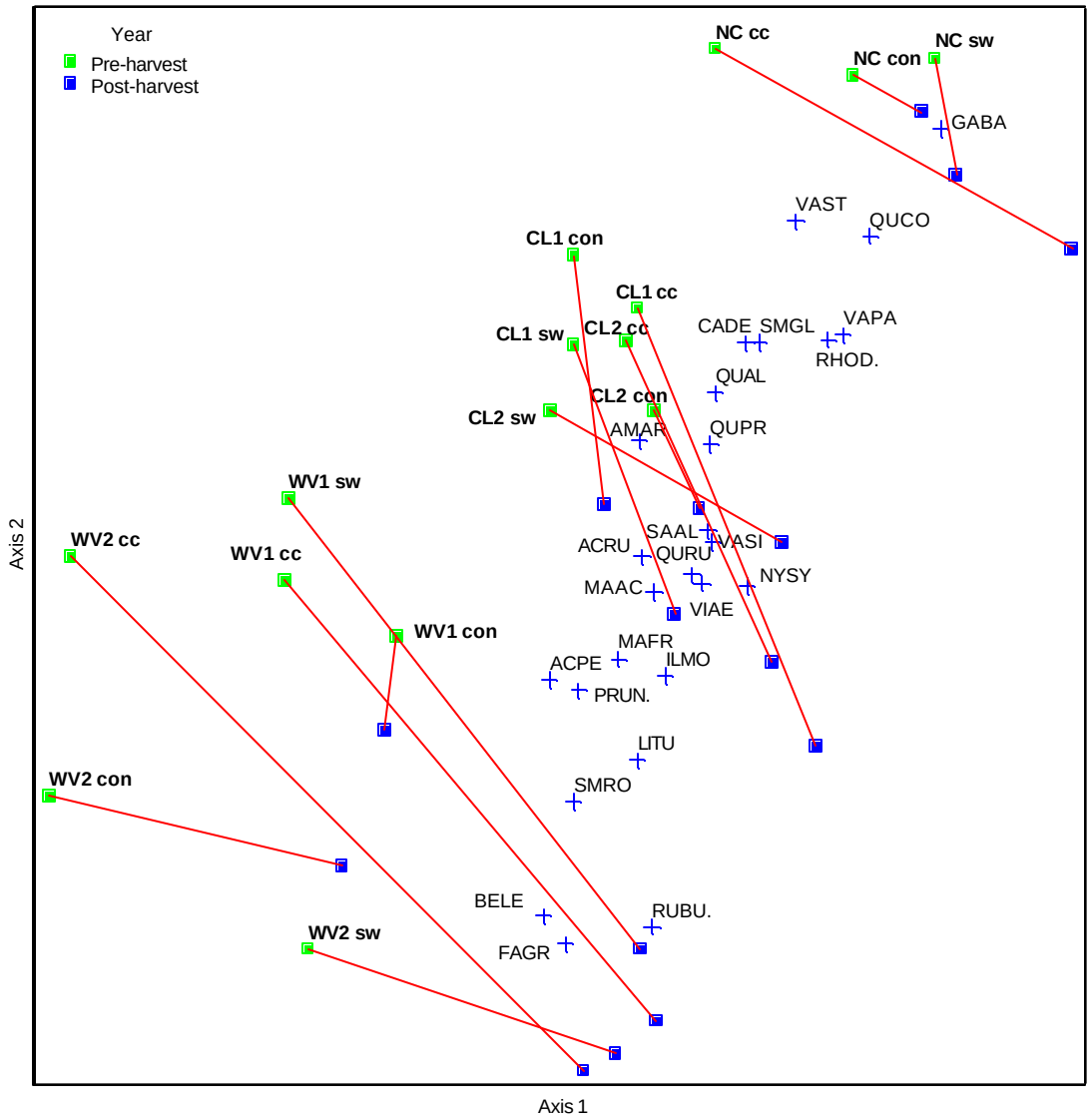


FIGURE 5.6. Non-metric multidimensional scaling (NMS) of average woody species abundances pre-harvest and post-harvest for each site and treatment. Species included occurred in at least five percent of plots. Stress = 0.10, 2 dimensions. Species codes are as follows: ACPE-*Acer pensylvanicum*; ACRU-*Acer rubrum*; AMAR-*Amelanchier arborea*; BELE-*Betula lenta*; CADE-*Castanea dentate;* FAGR-*Fagus grandifolia*; GABA-*Gaylussacia baccata*; ILMO-*Ilex Montana*; LITU-*Liriodendron tulipifera*; MAAC-*Magnolia acuminata*; MAFR-*Magnolia fraseri*; MEDVIR-*Medeola virginiana*; MITREP-*Mitchella repens*; NYSY-*Nyssa sylvatica*; PRUN.-*Prunus sp.*; QUAL-*Quercus alba*; QUCO-*Quercus coccinea*; QUPR-*Quercus prinus*; QURU-*Quercus rubra*; RHOD.-*Rhododendron sp.*; RUBU.-*Rubus sp.*; SAAL-*Sassafras albidum*; SMGL-*Smilax glauca*; SMRO-*Smilax rotundifolia*; VAPA-*Vaccinium pallidum*; VASI-*Vaccinium simulatum*; VAST-*Vaccinium stamineum*; VIAE-*Vitis aestivalis*.

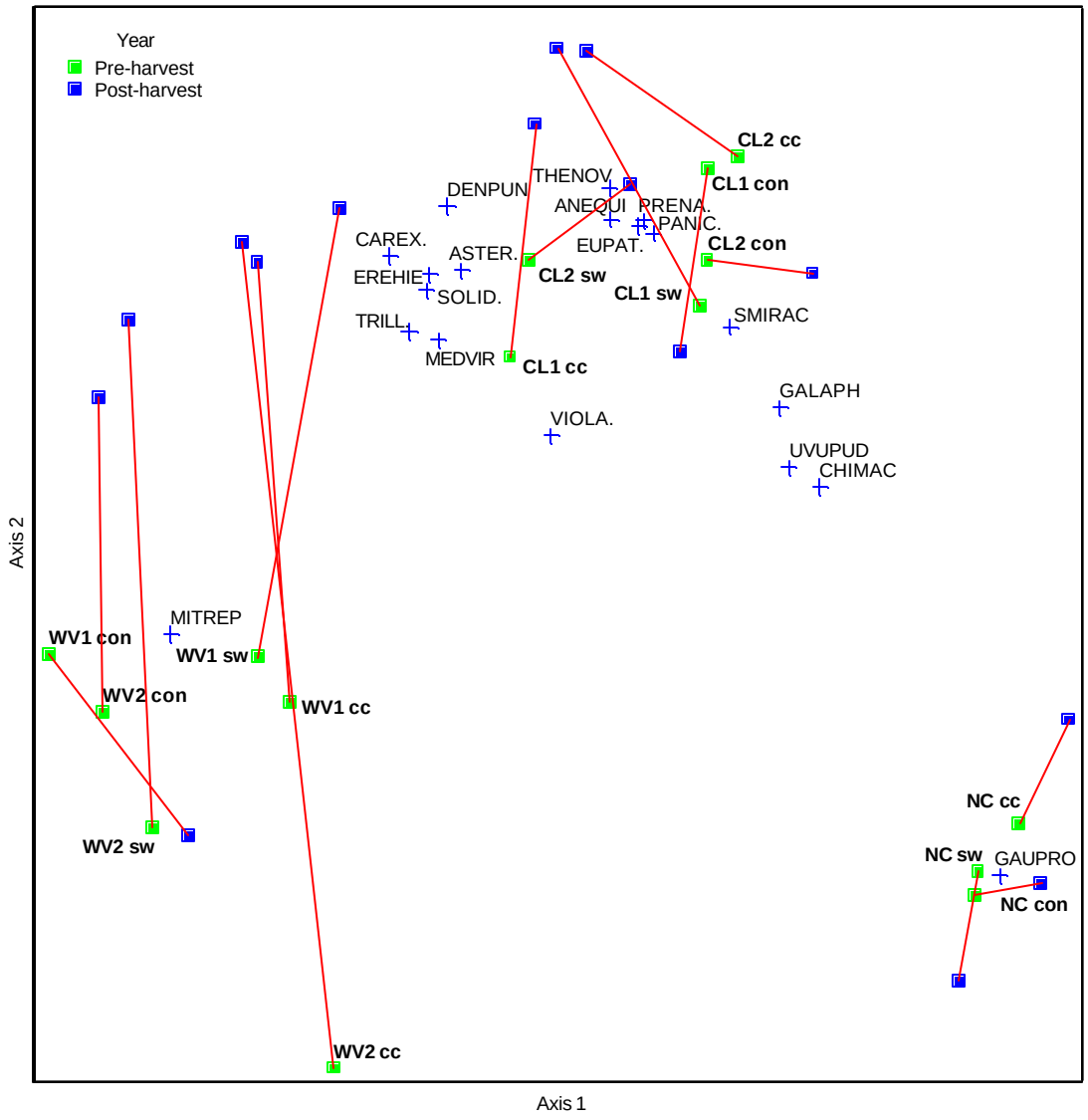


FIGURE 5.7. Non-metric multidimensional scaling (NMS) of average herbaceous species abundances pre-harvest and post-harvest for each site and treatment. Species included occurred in at least five percent of plots. Stress = 0.18, 2 dimensions. Species codes are as follows: ANEQUI-*Anemone quinquefolia*; ASTER-*Aster sp.*; CAREX.-*Carex sp.*; CHIMAC-*Chimaphila maculata*; DENPUN-*Dennstaedtia punctilobula*; EREHIE-*Erechtites hieracifolia*; EUPAT.-*Eupatorium sp.*; GALAPH-*Galax aphylla*; GAUPRO-*Gaultheria procumbens*; MEDVIR-*Medeola virginiana*; MITREP-*Mitchella repens*; PANIC.-*Panicum sp.*; PRENA.-*Prenanthes sp.*; SMIRAC-*Smilacina racemosa*; SOLID.-*Solidago sp.*; THENOV-*Thelypteris noveboracensis*; TRILL.-*Trillium sp.*; UVUPUD-*Uvularia pudica*; VIOLA.-*Viola sp.*

SPECIES-ENVIRONMENT RELATIONSHIPS

In general, the canonical correspondence analyses (CCA) distributed species along the same axes of light/litter weight and soil properties described in the DCA of environmental conditions (Figures 5.8-5.16). Biplots of variables appearing on the CCA graphs had an r-square of 0.2 or greater. All eleven environmental variables used in the CCA were important in at least one of the analyses.

No clear species groups were created in the analyses of environmental conditions and vegetation relationships. Gap light index (GLI) was an important site variable at all sites, both for woody and herbaceous vegetation. Clay and aspect were important variables at all sites for woody vegetation, while organic matter and silt were important for herbaceous vegetation.

The first three canonical axes for the Clinch sites accounted for only 2.1% of the variation in the distance matrix. Organic matter and aspect were most correlated with the first axis, litter weight, aspect, clay, and GLI with the second axis (Figure5.8, Table 5.3). Slightly more variance was explained in the woody only CCA, 4.1%. Woody species litter weight was strongly correlated with the first axis. Aspect, slope percent, and clay were correlated with the second axis (Figure 5.9, Table 5.4). Only 2.1% of the variance was explained by the variables in the CCA of Clinch sites with herbaceous species. Organic matter was strongly correlated with the first axis followed by aspect (Figure 5.10, Table 5.5). GLI and C:N were correlated with the second axis.

Monte Carlo tests of the woody and herbaceous CCA and the woody CCA for the Newcastle site were not significant ($p>0.05$). The first two canonical axes explained 7.2% of the variance in species data for the NC herbaceous CCA. Aspect was highly correlated with the first axis, as was organic matter (Figure 5.13, Table 5.6). GLI, organic matter, and silt were associated with the second axis.

The first two canonical axes explained 7.4% of the variance in species data for the West Virginia sites. GLI was most correlated with the first axis (Figure 5.14, Table 5.7). The second axis was associated with topo shape, GLI, and slope. Monte Carlo tests of the woody species CCA for the West Virginia sites were not significant ($p>0.05$). The CCA of WV1 and WV2 herbaceous species explained 4.9% of the variance (Figure 5.16). The first axis was correlated with silt, organic matter, and slope (Table 5.8). GLI, slope, and topo shape were most correlated with the second axis.

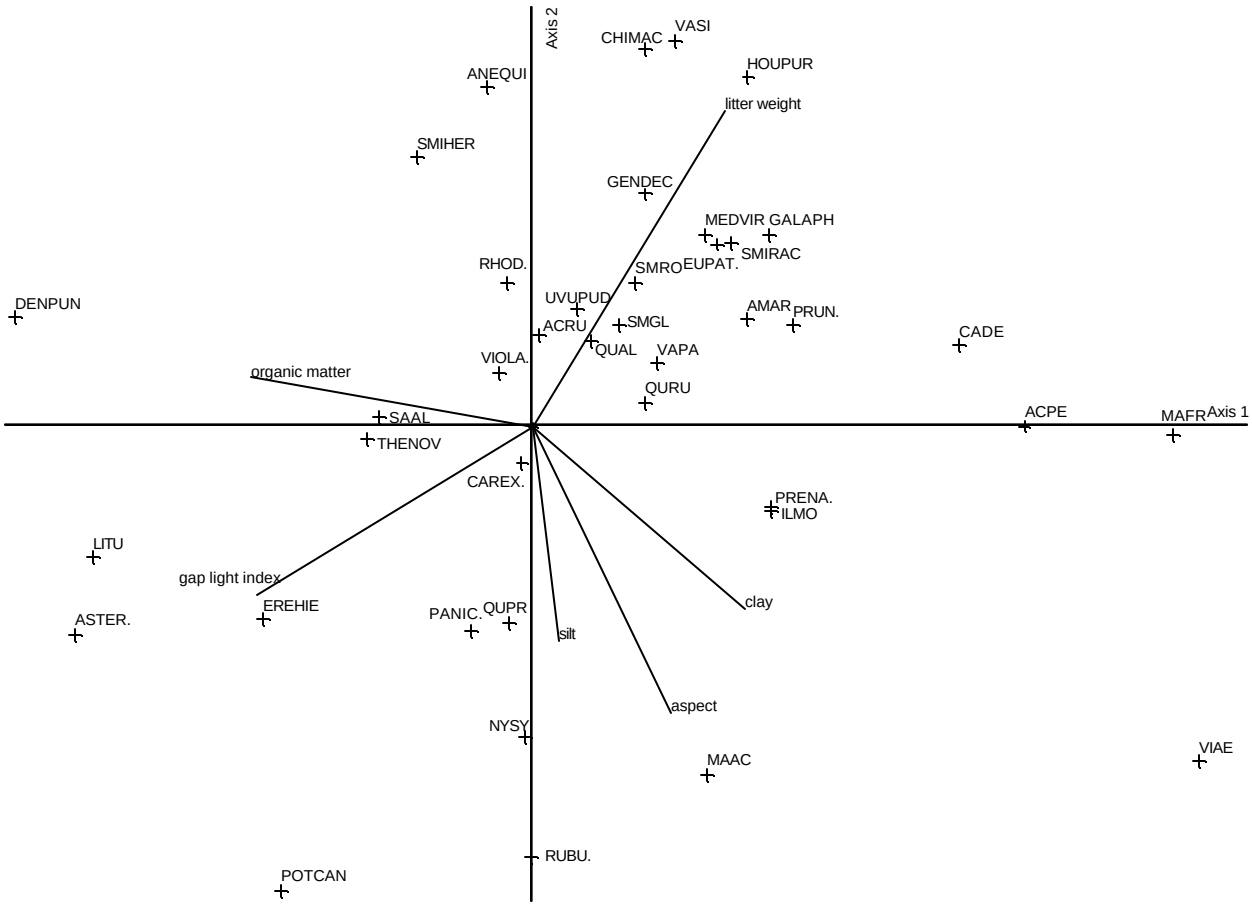


FIGURE 5.8. Canonical correspondence analysis (CCA) of CL1 and CL2 1-year post-harvest vegetation relationships with environmental variables. Species codes are as follows: ACPE-*Acer pensylvanicum*; ACRU-*Acer rubrum*; AMAR-*Amelanchier arborea*; ANEQUI-*Anemone quinquefolia*; ASTER.-*Aster sp.*; CADE-*Castanea dentata*; CAREX.-*Carex sp.*; CHIMAC-*Chimaphila maculata*; DENPUN-*Dennstaedtia punctilobula*; EREHIE-*Erechtites hieracifolia*; EUPAT.-*Eupatorium sp.*; GALAPH-*Galax aphylla*; GENDEC-*Gentiana decora*; HOUPUR-*Houstonia purpurea*; ILMO-*Ilex montana*; LITU-*Liriodendron tulipifera*; MAAC-*Magnolia acuminata*; MAFR-*Magnolia fraseri*; MEDVIR-*Medeola virginiana*; NYSY-*Nyssa sylvatica*; PANIC.-*Panicum sp.*; POTCAN-*Potentilla canadensis*; PRENA.-*Prenanthes sp.*; PRUN.-*Prunus sp.*; QUAL-*Quercus alba*; QUPR-*Quercus prinus*; QURU-*Quercus rubra*; RHOD.-*Rhododendron sp.*; RUBU.-*Rubus sp.*; SAAL-*Sassafras albidum*; SMGL-*Smilax glauca*; SMIHER-*Smilax herbacea*; SMIRAC-*Smilacina racemosa*; SMRO-*Smilax rotundifolia*; THENOV-*Thelypteris noveboracensis*; UVUPUD-*Uvularia pudica*; VAPA-*Vaccinium pallidum*; VASI-*Vaccinium simulatum*; VIAE-*Vitis aestivalis*; VIOLA.-*Viola sp*.

TABLE 5.3. Canonical coefficients of microsite variables on axes 1 and 2 of the CCA for 40 woody and herbaceous species at CL1 and CL2.

	Canonical Coefficients	
	1	2
Eigenvalue	0.243	0.195
Slope %	0.394	-0.091
Slope position	-0.182	-0.168
Topo shape	-0.085	0.056
Aspect	0.408	-0.455
Litter Weight	0.311	0.357
pH	-0.053	0.391
Clay	0.163	-0.379
Silt	-0.128	-0.109
Organic matter	-0.523	-0.015
GLI	-0.117	-0.339
C:N	0.246	0.240

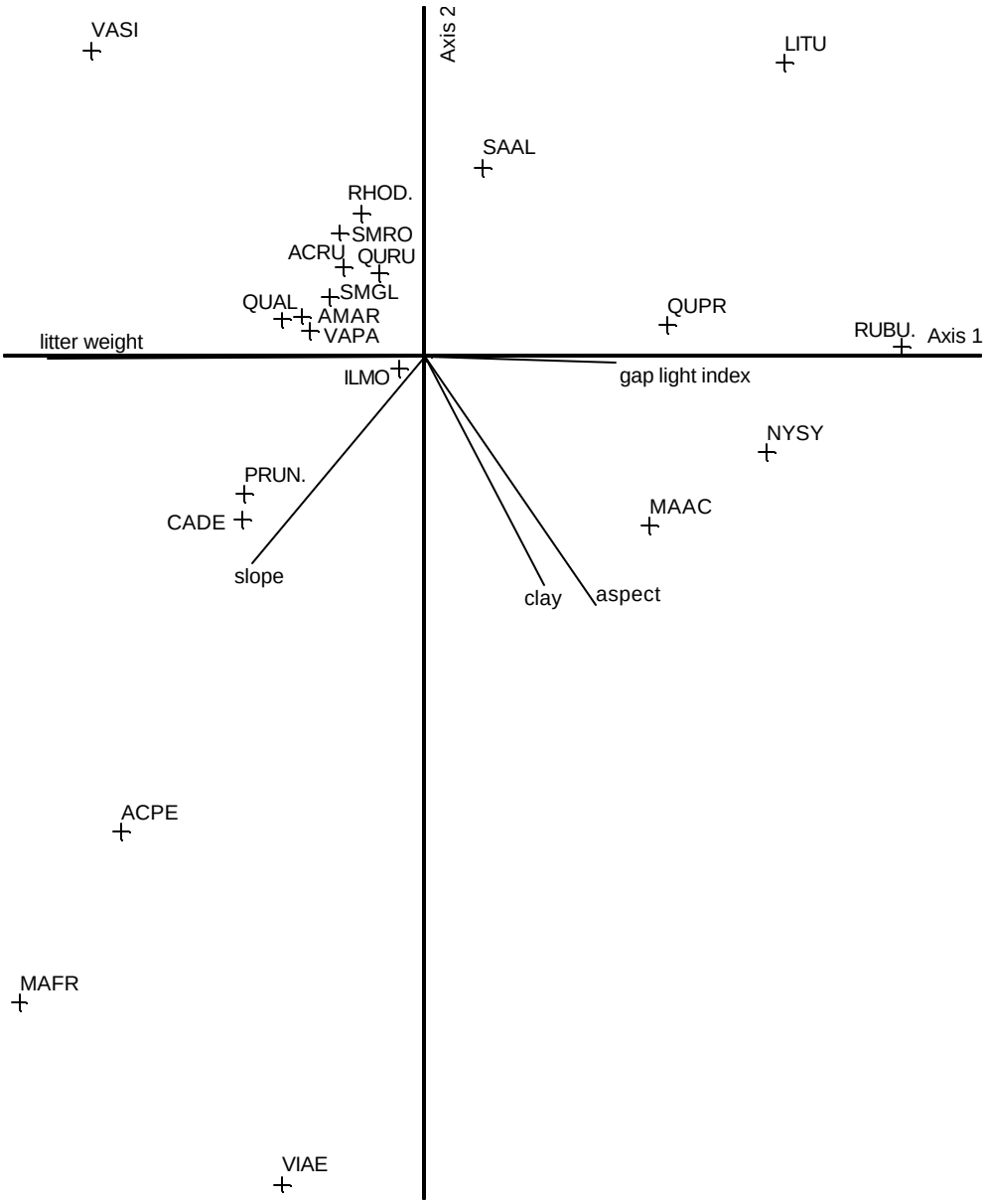


FIGURE 5.9. Canonical correspondence analysis (CCA) of CL1 and CL2 1-year post-harvest woody vegetation relationships with environmental variables. Species codes are as follows: ACPE-*Acer pensylvanicum*; ACRU-*Acer rubrum*; AMAR-*Amelanchier arborea*; CADE-*Castanea dentata*; ILMO-*Ilex montana*; LITU-*Liriodendron tulipifera*; MAAC-*Magnolia acuminata*; MAFR-*Magnolia fraseri*; NYSY-*Nyssa sylvatica*; PRUN.-*Prunus sp.*; QUAL-*Quercus alba*; QUPR-*Quercus prinus*; QURU-*Quercus rubra*; RHOD.-*Rhododendron sp.*; RUBU.-*Rubus sp.*; SAAL-*Sassafras albidum*; SMGL-*Smilax glauca*; SMRO-*Smilax rotundifolia*; VAPA-*Vaccinium pallidum*; VASI-*Vaccinium simulatum*; VIAE-*Vitis aestivalis*.

TABLE 5.4. Canonical coefficients of microsite variables on axes 1 and 2 of the CCA for 21 woody species at CL1 and CL2.

	Canonical Coefficients	
	1	2
Eigenvalue	0.252	0.215
Slope %	-0.313	-0.634
Slope position	0.387	0.151
Topo shape	0.016	0.136
Aspect	0.165	-0.569
Litter Weight	-0.587	-0.187
pH	-0.179	0.341
Clay	0.251	-0.592
Silt	0.219	0.411
Organic matter	0.182	-0.038
GLI	0.092	-0.350
C:N	-0.061	0.315

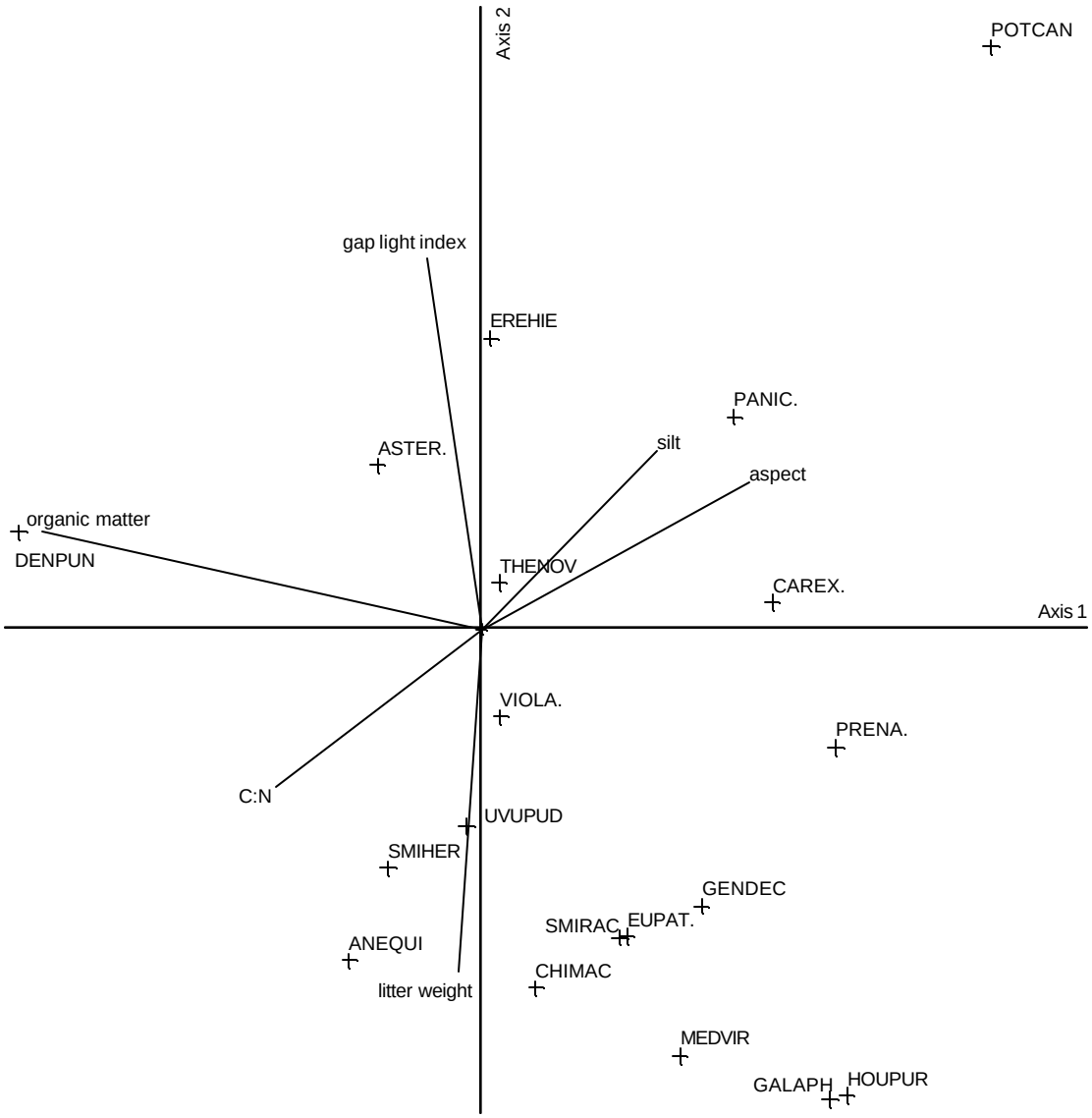


FIGURE 5.10. Canonical correspondence analysis (CCA) of CL1 and CL2 1-year post-harvest herbaceous vegetation relationships with environmental variables. Species codes are as follows: ANEQUI-*Anemone quinquefolia*; ASTER.-*Aster sp*.; CAREX.-*Carex sp*.; CHIMAC-*Chimaphila maculata*; DENPUN-*Dennstaedtia punctilobula*; EREHIE-*Erechtites hieracifolia*; EUPAT.-*Eupatorium sp*.; GALAPH-*Galax aphylla*; GENDEC-*Gentiana decora*; HOUPUR-*Houstonia purpurea*; MEDVIR-*Medeola virginiana*; PANIC.-*Panicum sp*.; POTCAN-*Potentilla canadensis*; PRENA.-*Prenanthes sp*.; SMIHER-*Smilax herbacea*; SMIRAC-*Smilacina racemosa*; THENOV-*Thelypteris noveboracensis*; UVUPUD-*Uvularia pudica*; VIOLA.-*Viola sp*.

TABLE 5.5. Canonical coefficients of microsite variables on axes 1 and 2 of the CCA for 19 herbaceous species at CL1 and CL2.

	Canonical Coefficients	
	1	2
Eigenvalue	0.253	0.175
Slope %	0.114	-0.069
Slope position	0.007	-0.009
Topo shape	-0.175	-0.106
Aspect	0.417	0.094
Litter Weight	0.002	-0.227
pH	-0.009	-0.361
Clay	-0.082	0.069
Silt	0.118	0.131
Organic matter	-0.821	0.342
GLI	0.126	0.643
C:N	0.139	-0.596

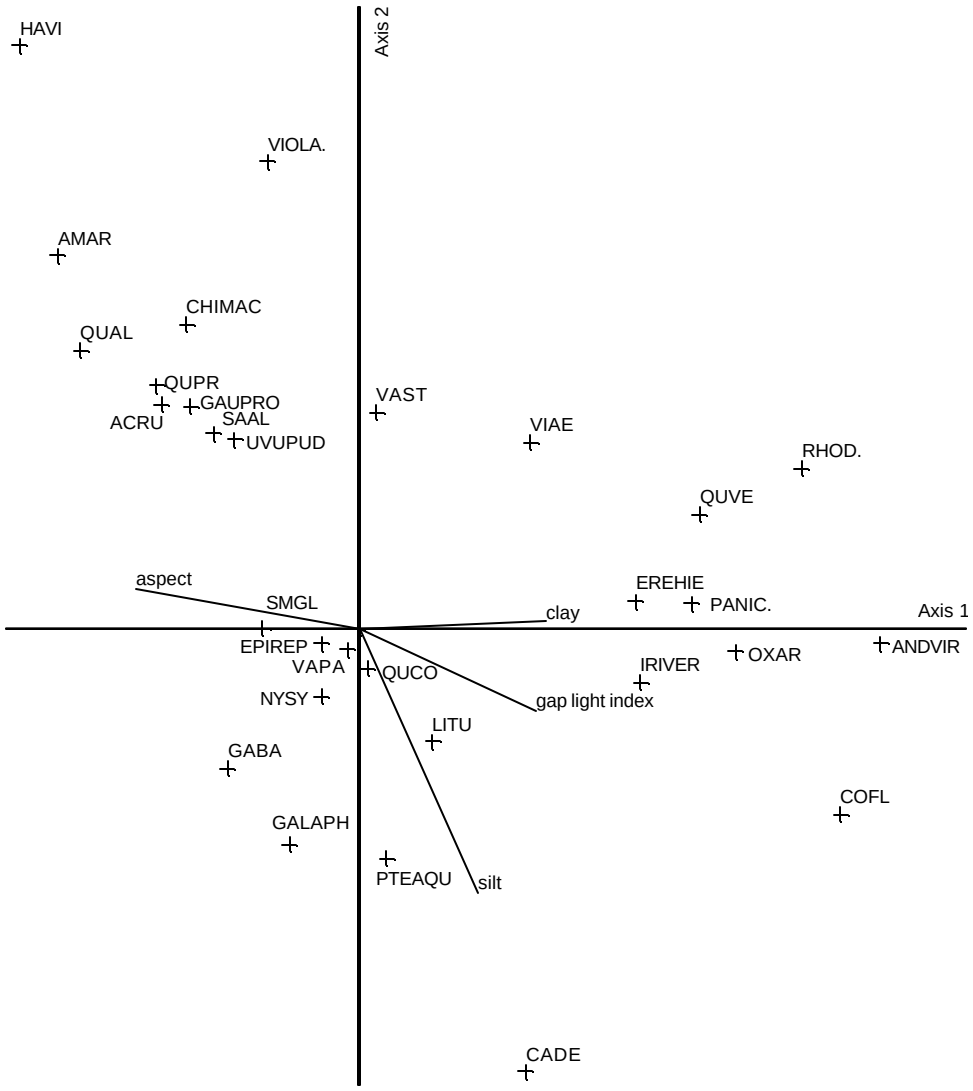


FIGURE 5.11. Canonical correspondence analysis (CCA) of NC 1-year post-harvest vegetation relationships with environmental variables. Species codes are as follows: ACRU-*Acer rubrum*; AMAR-*Amelanchier arborea*; ANDVIR-*Andropogon virginicus*; CADE-*Castanea dentata*; CHIMAC-*Chimaphila maculata*; COFL-*Cornus florida*; EPIREP-*Epigaea repens*; EREHIE-*Erechtites hieracifolia*; GABA-*Gaylussacia baccata*; GALAPH-*Galax aphylla*; GAUPRO-*Gaultheria procumbens*; HAVI-*Hamamelis virginiana*; IRIVER-*Iris verna*; LITU-*Liriodendron tulipifera*; NYSY-*Nyssa sylvatica*; OXAR-*Oxydendrum arboreum*; PANIC.-*Panicum sp.*; PTEAQU-*Pteridium aquilinum*; QUAL-*Quercus alba*; QUCO-*Quercus coccinea*; QUPR-*Quercus prinus*; QUVE-*Quercus velutina*; RHOD.-*Rhododendron sp.*; SAAL-*Sassafras albidum*; SMGL-*Smilax glauca*; UVUPUD-*Uvularia pudica*; VAPA-*Vaccinium pallidum*; VAST-*Vaccinium stamineum*; VIAE-*Vitis aestivalis*; VIOLA.-*Viola sp.*

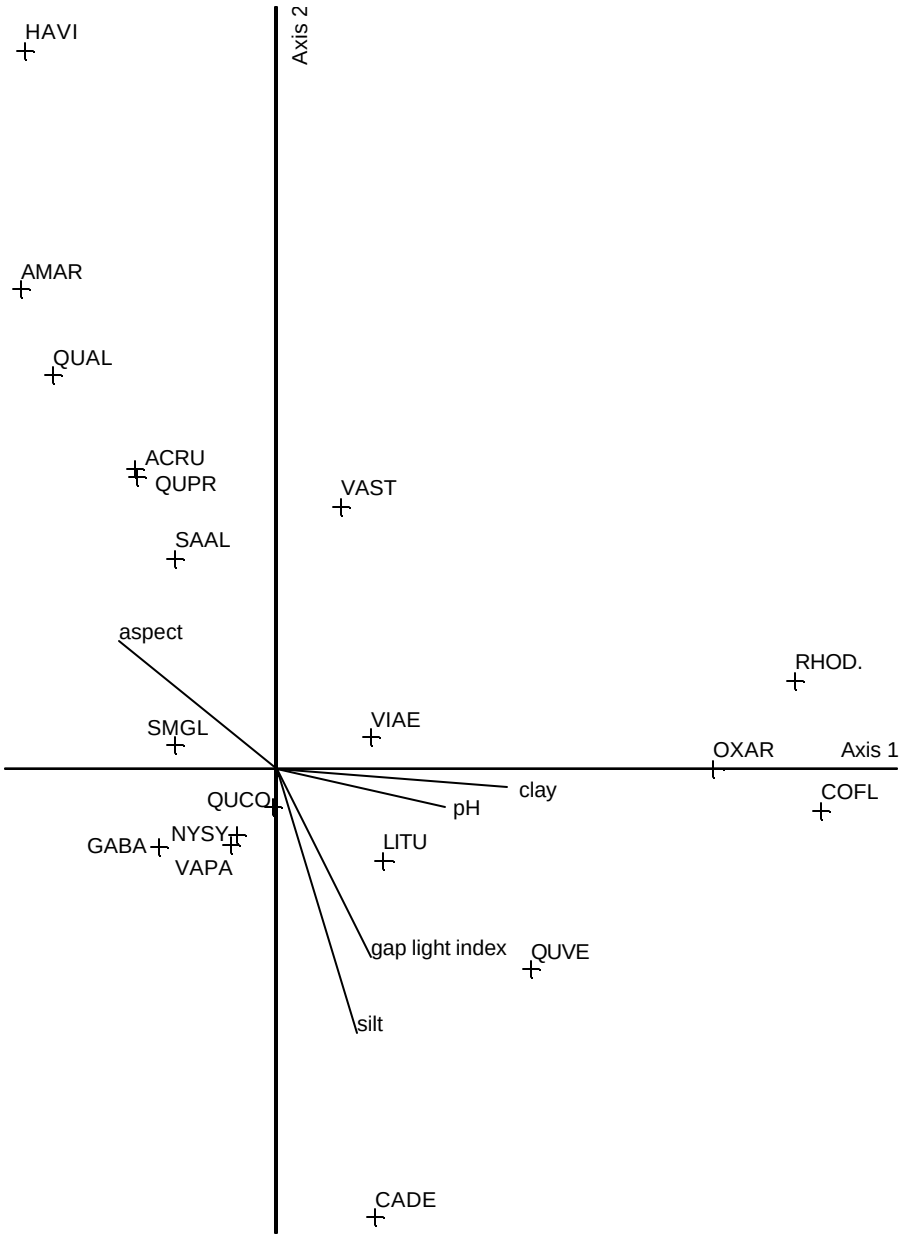


FIGURE 5.12. Canonical correspondence analysis (CCA) of NC 1-year post-harvest woody vegetation relationships with environmental variables. Species codes are as follows: ACRU-*Acer rubrum*; AMAR-*Amelanchier arborea*; CADE-*Castanea dentata*; COFL-*Cornus florida*; GABA-*Gaylussacia baccata*; HAVI-*Hamamelis virginiana*; LITU-*Liriodendron tulipifera*; NYSY-*Nyssa sylvatica*; OXAR-*Oxydendrum arboreum*; QUAL-*Quercus alba*; QUCO-*Quercus coccinea*; QUPR-*Quercus prinus*; QUVE-*Quercus velutina*; RHOD.-*Rhododendron sp.*; SAAL-*Sassafras albidum*; SMGL-*Smilax glauca*; VAPA-*Vaccinium pallidum*; VAST-*Vaccinium stamineum*; VIAE-*Vitis aestivalis*.

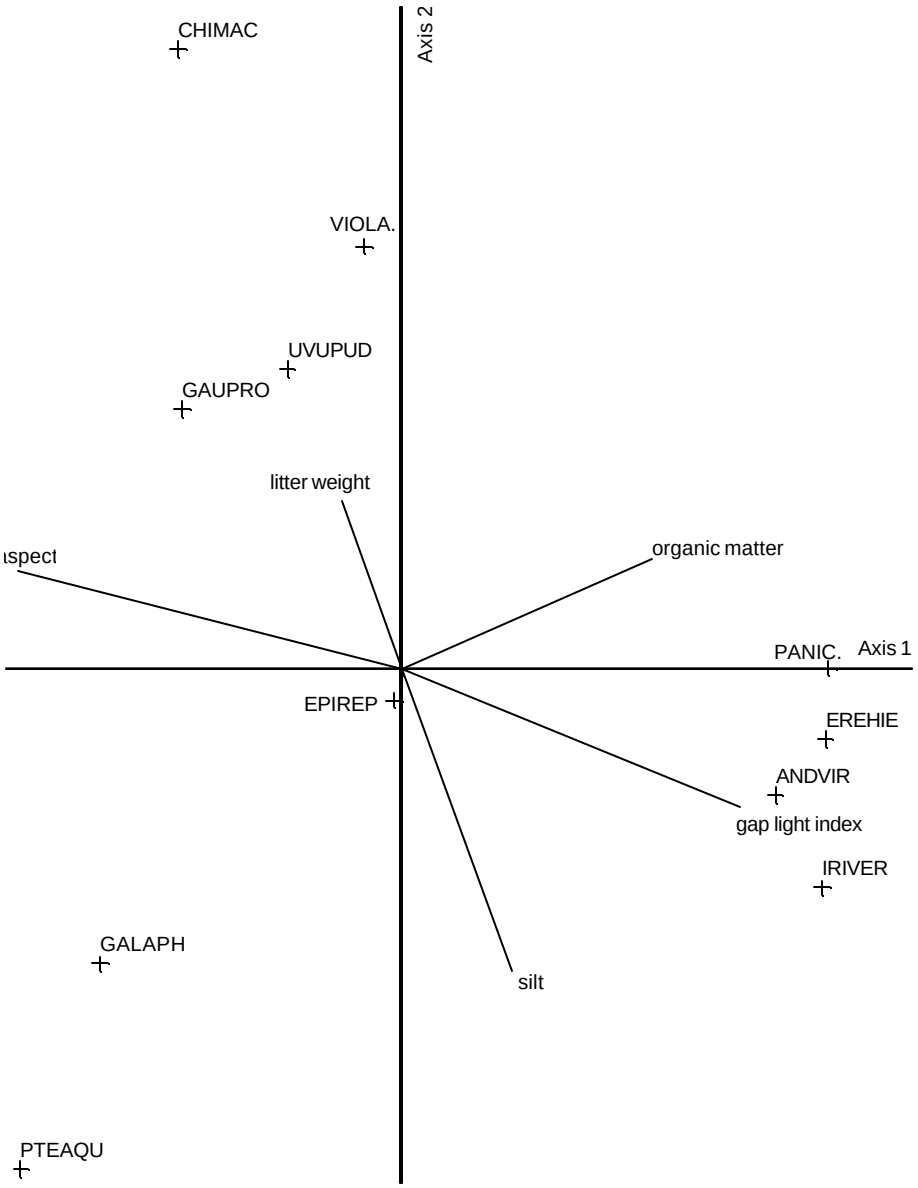


FIGURE 5.13. Canonical correspondence analysis (CCA) of NC 1-year post-harvest herbaceous vegetation relationships with environmental variables. Species codes are as follows: ANDVIR-*Andropogon virginicus*; CHIMAC-*Chimaphila maculata*; EPIREP-*Epigaea repens*; EREHIE-*Erechtites hieracifolia*; GALAPH-*Galax aphylla*; GAUPRO-*Gaultheria procumbens*; IRIVER-*Iris verna*; PANIC.-*Panicum sp*.; PTEAQU-*Pteridium aquilinum*; UVUPUD-*Uvularia pudica*; VIOLA.-*Viola sp*.

TABLE 5.6. Canonical coefficients of microsite variables on axes 1 and 2 of the CCA for 11 herbaceous species at NC.

	Canonical Coefficients	
	1	2
Eigenvalue	0.535	0.402
Slope %	-0.141	-0.194
Slope position	0.000	0.000
Topo shape	-0.102	0.338
Aspect	-0.769	-0.226
Litter Weight	0.007	0.191
pH	0.312	0.377
Clay	0.172	0.143
Silt	-0.110	-0.504
Organic matter	0.482	0.849
GLI	-0.012	-0.909
C:N	-0.029	0.133

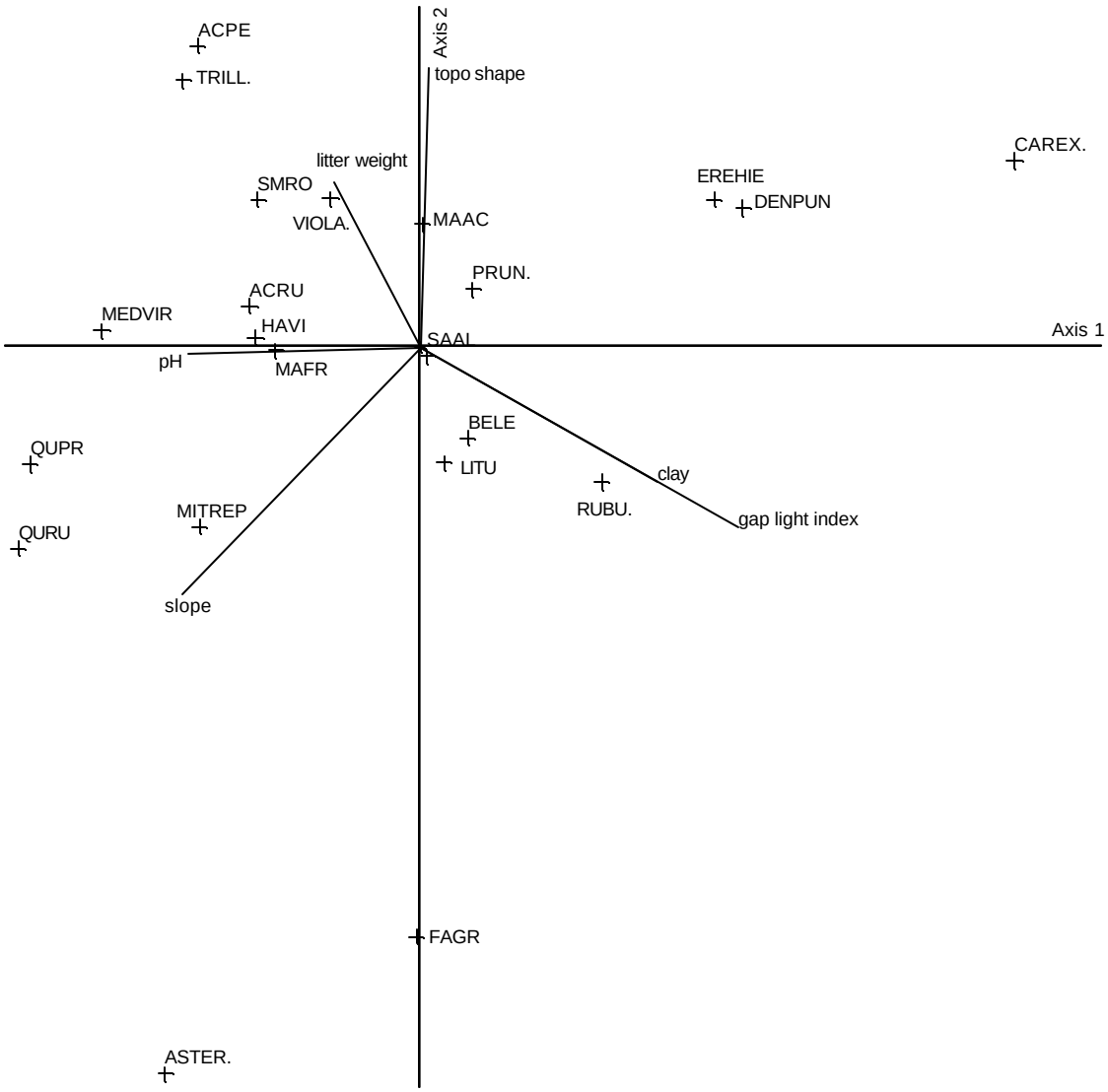


FIGURE 5.14. Canonical correspondence analysis (CCA) of WV1 and WV2 1-year post-harvest vegetation relationships with environmental variables. Species codes are as follows: ACPE-*Acer pensylvanicum;* ACRU-*Acer rubrum;* ASTER.-*Aster sp.;* BELE-*Betula lenta;* CAREX.-*Carex sp.;* DENPUN-*Dennstaedtia punctilobula;* EREHIE-*Erechtites hieracifolia;* FAGR-*Fagus grandifolia;* HAVI-*Hamamelis virginiana;* LITU-*Liriodendron tulipifera;* MAAC-*Magnolia acuminata;* MAFR-*Magnolia fraseri;* MEDVIR-*Medeola virginiana;* MITREP-*Mitchella repens;* PRUN.-*Prunus sp.;* QUPR-*Quercus prinus;* QURU-*Quercus rubra;* RUBU.-*Rubus sp.;* SAAL-*Sassafras albidum;* SMRO-*Smilax rotundifolia;* TRILL.-*Trillium sp.;* VIOLA.-*Viola sp.*

TABLE 5.7. Canonical coefficients of microsite variables on axes 1 and 2 of the CCA for 22 woody and herbaceous species at WV1 and WV2.

	Canonical Coefficients	
	1	2
Eigenvalue	0.322	0.220
Slope %	-0.470	-0.529
Slope position	0.101	0.113
Topo shape	-0.142	0.618
Aspect	0.125	0.067
Litter Weight	0.061	-0.150
pH	-0.165	-0.405
Clay	0.006	-0.226
Silt	0.326	0.155
Organic matter	0.108	-0.164
GLI	0.715	-0.547
C:N	0.032	0.094

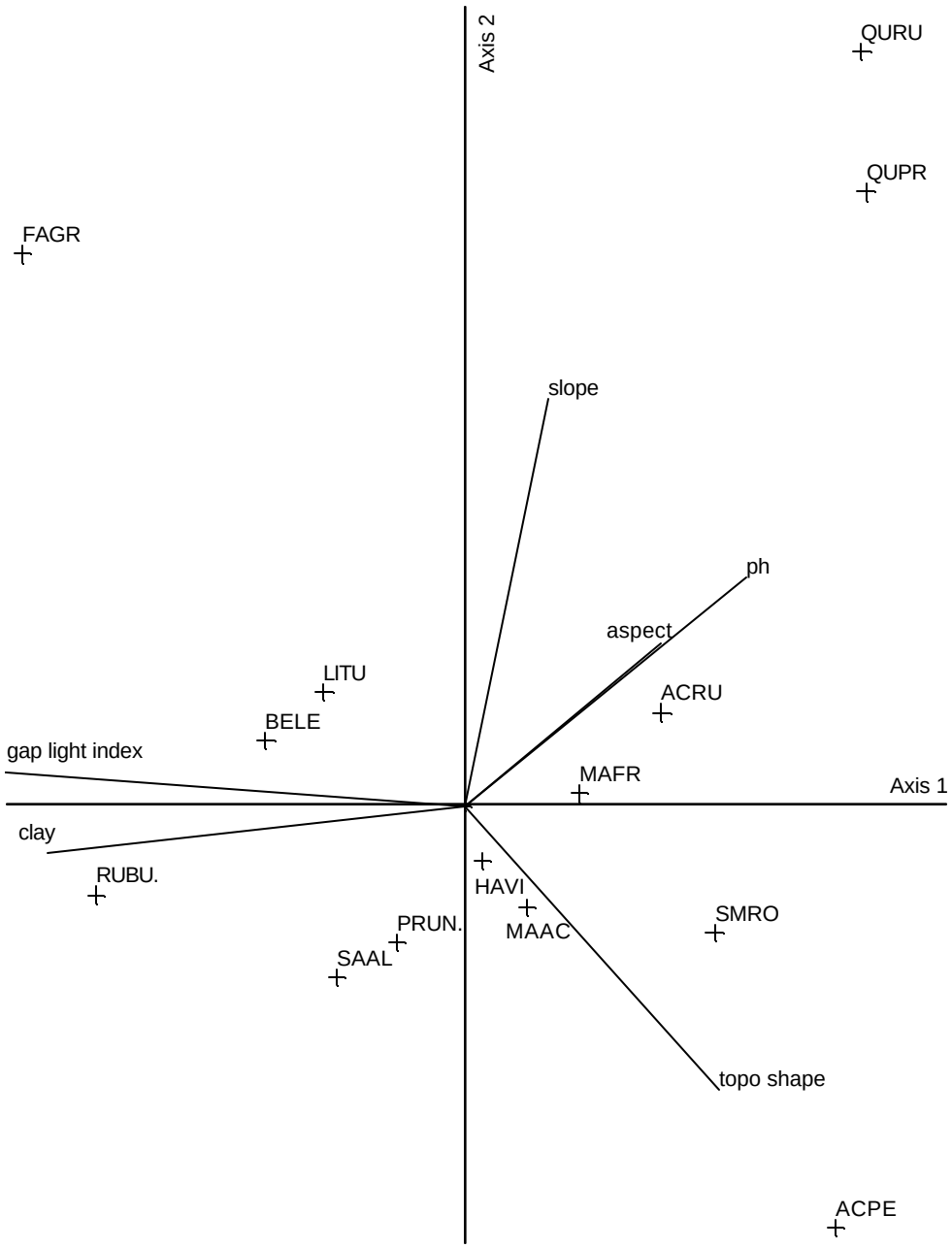


FIGURE 5.15. Canonical correspondence analysis (CCA) of WV1 and WV2 1-year post-harvest woody vegetation relationships with environmental variables. Species codes are as follows: ACPE-*Acer pensylvanicum;* ACRU-*Acer rubrum;* BELE-*Betula lenta;* FAGR-*Fagus grandifolia;* HAVI-*Hamamelis virginiana;* LITU-*Liriodendron tulipifera;* MAAC-*Magnolia acuminata;* MAFR-*Magnolia fraseri;* PRUN.-*Prunus sp.;* QUPR-*Quercus prinus;* QURU-*Quercus rubra;* RUBU.-*Rubus sp.;* SAAL-*Sassafras albidum;* SMRO-*Smilax rotundifolia.*

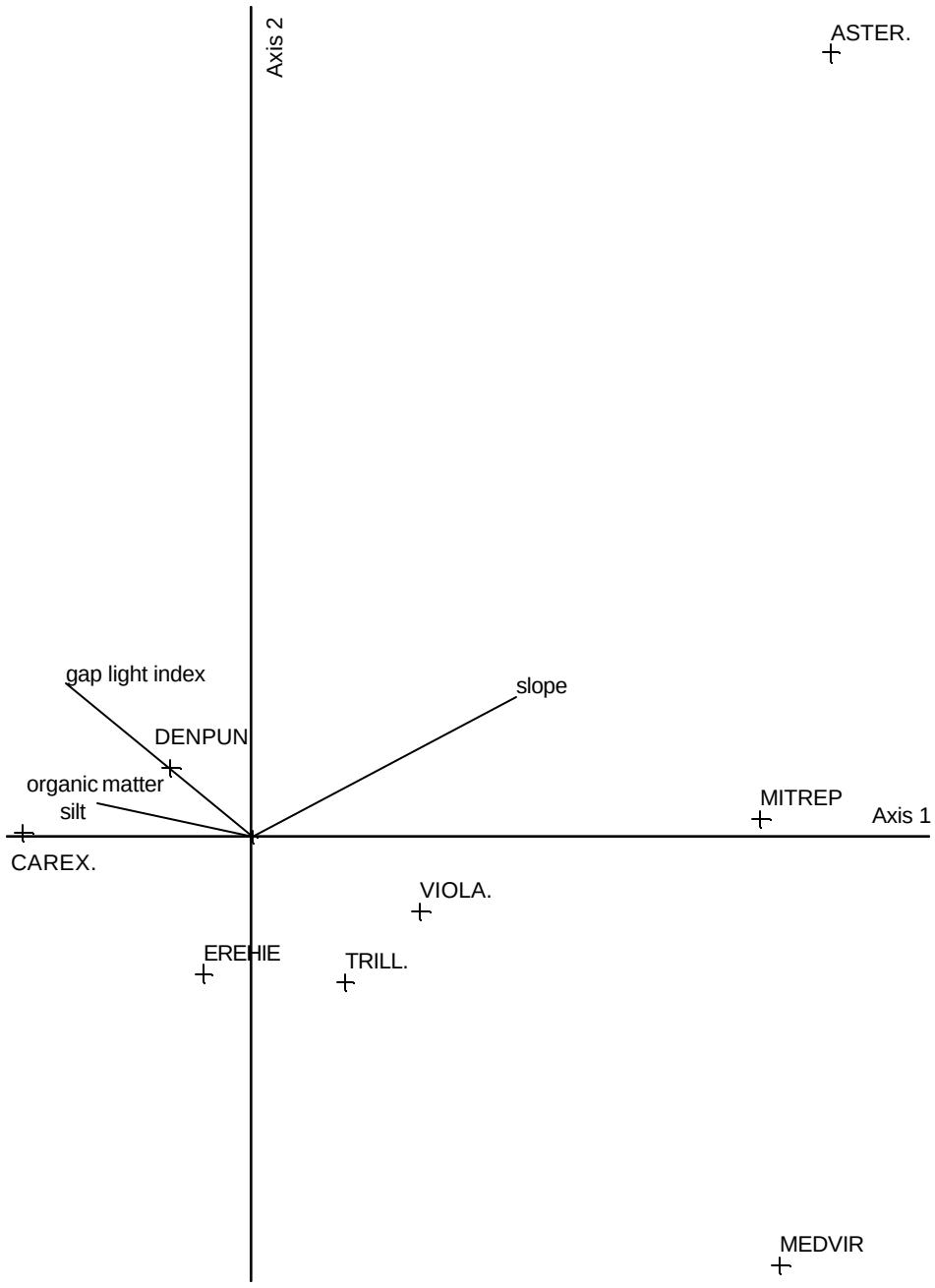


FIGURE 5.16. Canonical correspondence analysis (CCA) of WV1 and WV2 1-year post-harvest herbaceous vegetation relationships with environmental variables. Species codes are as follows: ASTER.-*Aster sp.;* CAREX.-*Carex sp.;* DENPUN-*Dennstaedtia punctilobula;* EREHIE-*Erechtites hieracifolia;* MEDVIR-*Medeola virginiana;* MITREP-*Mitchella repens;* TRILL.-*Trillium sp.;* VIOLA.-*Viola sp.*

TABLE 5.8. Canonical coefficients of microsite variables on axes 1 and 2 of the CCA for 8 herbaceous species at WV1 and WV2.

	Canonical Coefficients	
	1	2
Eigenvalue	0.628	0.392
Slope %	0.409	0.788
Slope position	0.235	-0.289
Topo shape	0.131	-0.635
Aspect	0.068	-0.266
Litter Weight	-0.153	0.353
pH	0.293	0.312
Clay	0.094	-0.426
Silt	-0.676	0.389
Organic matter	-0.406	0.726
GLI	-0.182	1.084
C:N	-0.126	-0.256

DISCUSSION

INITIAL CHANGES IN VEGETATION

The large initial increases in species richness seen in the clearcut and shelterwood treatments are similar to other studies (Collins and Pickett 1988, Halpern and Spies 1995, Beese and Bryant 1999). These increases are consistent with several disturbance models that predict increases in richness during the initial period following a disturbance (Petraitis et al. 1989, Roberts and Gilliam 1995). These studies and models support a continued increase in richness for at least several years, some even through canopy closure (Halpern and Spies 1995). Studies show conflicting patterns in the later stages of community reestablishment with some sites having higher species richness in mature and old-growth stands than in younger stands (Duffy and Meier 1992, Elliot et al. 1997, Goebel et al. 1999) and others showing very similar values between stands of various ages (Moore and Vankat 1986, Reader and Bricker 1992a, Gilliam et al. 1995). Additional sampling of the sites as the stands age will provide valuable information about changes in the community and recovery of all species over time on these southern Appalachian sites.

The increasing richness values associated with increasing plot sizes were expected. However, it is interesting that the percent of species in the treatment plot that were not included in the herb and tree plot was approximately the same across the treatments within sampling years, but post-harvest smaller plots missed many more species. This suggests that more intensive sampling or larger plot sizes are required in younger forests than in mature forest when estimating community richness. The number of species not included in the smaller size plots is most likely a result of an uneven distribution of plant species due to increases in microsite variability created by harvesting. This is reflected in the larger standard deviations for post-harvest richness. The DCA shows the control plots fairly clustered along a soil properties gradient. The shelterwood plots are slightly more scattered along the light/litter gradient and along the soil properties gradient. The clearcut is even more scattered. The increase in microsite variability would theoretically allow a broader range of species to co-exist. As the sites age, the plant species may become more evenly distributed across the treatments, meaning the herb plots will capture more of the treatment community than in the 1-year post-harvest sampling.

There were changes in richness and abundance in the control treatments between pre-harvest and post-harvest. These changes can be attributed to natural changes in plant dynamics over time and edge effect and skid trails created when adjacent treatments blocks were harvested.

Davison and Forman (1982) found large changes in herb abundance and species composition in an uncut mature forest from year to year. Reader and Bricker (1992a) reported a loss in species of 9-13 percent in uncut plots between sampling years. We found slightly higher species losses after harvesting than those found by Reader and Bricker (1992a).

Richness and abundance increased significantly in the shelterwood treatment after harvesting. As expected, the shelterwood fell in between the control and clearcut. This is opposite of what Beese and Bryant (1999) found in comparing silvicultural systems in British Columbia, Canada. Richness and cover in this study were greatest in the shelterwood, followed by the old-growth, patch clearcut, and green tree treatments. The clearcut did not increase significantly in abundance or richness in that study. Another study comparing shelterwood harvests to uncut forests in Ontario, Canada removed 33% and 66% of the basal area without negatively affecting the herb layer community (Reader and Bricker 1992a).

The clearcut experienced the greatest response to harvesting. These results are similar to Halpern's and Spies's (1995) finding that richness was higher within two years after cutting and steadily increased over time in forests of the Pacific Northwest. Other studies do not support our findings. Clearcuts and patch clearcuts in British Columbia, Canada did not experience an increase in richness and abundance after harvesting (Beese and Bryant 1999). In a study in the Appalachians, Elliot et al. (1997) found lower species richness after clearcutting. Grazing, 25 years between sampling, and differences in sampling methods however confounded comparison between this study and ours.

Increases in exotic species were greater in the shelterwood and clearcut treatment post-harvest. Harvesting appears to have caused an increase in exotic species even in the control through edge effect and skid trails. Although the majority of the control treatments remained undisturbed, CL2 was impacted slightly by a primary skid trail in one corner of the treatment. The tree plots and herb plots were not affected by the skid trails. The presence of the skid trails is reflected in the higher post-harvest control treatment plot species richness values. Because buffers were not established between blocks, the control treatment experienced an edge effect that also accounted for an increase in species richness. More exotic species were found in the larger size plots. This reflects the patchiness of the exotic species, which were primarily found in skid trails. Few herb plots fell in the skid trails explaining why virtually no exotic species were sampled in the plots. Halpern and Spies (1995) also found an initial spike in exotic species richness after harvesting in the Pacific Northwest. Exotic plant cover peaked in year two and then dropped to near pre-harvest levels.

The local species extinctions found on our sites are similar to those in other studies. Halpern and Spies (1995) reported an initial 10-30% loss in species after harvesting and burning. Reader and Bricker (1992a) found similar rates of species losses in uncut and partially cut forest plots. After 25 years most of the species had reappeared on the site. Seventeen years after clearcutting a watershed in the southern Appalachians Elliott et al. (1997) found that most species had recovered from harvesting, although late successional species had not returned to pre-harvest levels. Species extinctions in our study were from all life-forms and did not change dramatically between the control and harvested treatments. Because our first sampling began in the middle of May, our sampling does not include many spring-ephemeral species. There is much concern over the loss of these vernal herbs due to harvesting (Duffy and Meier 1992, Meier et al. 1995); unfortunately, our study was not able to capture this segment of the plant community. Although the majority of species recover to predisturbance levels in most studies, managing forest on short rotations may cause a decline in some sensitive species (Duffy and Meier 1992, Halpern and Spies 1995). Long-term experimental sites must continue to be sampled after disturbance in order to assess this possibility.

DIVERSITY-STABILITY HYPOTHESIS

By comparing hardwood sites across a region, we have demonstrated the site specific nature of plant community responses to disturbance. The degree of change was not correlated with pre-disturbance species richness, a result that adds to the growing consensus that the complexity of a system cannot be fully evaluated merely by species richness. The five sites responded differently by location and available species pools, supporting the theory that changes in functional types, individual species, and environmental gradients determines a community's resistance to disturbance. The correlation between species and local environmental conditions appeared to be weak. The CCA analyses showed that vegetation was not strongly controlled by the environment, which suggests that the harvest impact on the community structure was low. Further sampling of the sites over the rotation will reveal the communities' resilience to disturbance. Smith (1980) pointed out that each ecosystem is dependent on environmental gradients that affect species composition. Therefore, results studying diversity and stability in different ecosystems may yield varying results. The conflicting results in these studies and across our study sites underscores the importance of caution when extrapolating assumptions about diversity and stability to other ecosystems.

VI. SYNOPSIS AND MANAGEMENT IMPLICATIONS

Harvesting caused a significant increase in both woody and herbaceous plant species richness in each treatment plot and tree plot and in the majority of the herb plots one-year after disturbance. Reducing the plot size dramatically reduced the number of species sampled. Exotic species increased significantly after harvesting in the treatment and tree plots, but not in the herb plots. Increases in exotic species richness were largely a result of seeding the skid trails with commercial seed mixes that included exotic species. Forest managers could easily remedy this by only using seed mixes composed of native species. In general, there were no major differences in local species extinctions between treatments.

Harvesting created different forest floor environments in the high-leave shelterwood and clearcut. The major gradient ranged from high light and less litter biomass in the clearcuts to less light and more litter biomass in the control. Soil properties acted as the second gradient. Sites fell into three groups based on geographic proximity, most likely due to different species pools in each area. Site location appears to be more influential on species presence than relationships with the microsite variables measured. Average changes between pre-harvest and post-harvest species composition and abundance were largest in the clearcut, followed by the shelterwood. The control did change between years, reflecting the dynamic nature of plant species. The richest sites, CL1 and CL2, appear to be the most resistant to disturbance, supporting the Diversity-Stability Hypothesis. However, the less rich NC site changed approximately the same as the Clinch site. This contradicts the Diversity-Stability Hypothesis and suggests that relationships between diversity and site resistance to disturbance is site specific.

The results presented here only reflect the initial changes in forest vegetation following disturbance. It is difficult to draw conclusions about local species extinctions or management of individual species at this stage. Results will become more useful as the sites age and patterns of recovery can be examined. The varying impacts of the five harvested treatments should also become more apparent as the stands age. The high-leave shelterwood will likely be entered again to remove residual trees and the group selection is scheduled to have 1/5 of the treatment removed every 20 years. These additional stand entries may cause an increase in exotic species richness and promote a larger component of early successional species in the treatments. The low-leave shelterwood, leave tree, and clearcut treatments will most likely not undergo additional manipulation. Theoretically, the spike in early successional species such as

graminoids and *Rubus sp*. will decline after canopy closure and conditions begin to favor mid to late successional species. Future vegetation sampling of the treatments will provide much information to the theory of recovery patterns following disturbance and the rate of succession in the southern Appalachian mountains.

VII. LITERATURE CITED

Angermeier, P. L. and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives. *BioScience* 44: 690-697.

Bazzaz, F. A. 1979. The physiological ecology of plant succession. *Annual Review of Ecology and Systematics* 10: 351-371.

Beatty, S. W. 1984. Influence of microtopography and canopy species on spatial patterns of forest understory plants. *Ecology* 65: 1406-1419.

Beese, W. J. and A. A. Bryant. 1999. Effect of alternative silvicultural systems on vegetation and bird communities in coastal montane forest of British Columbia, Canada. *Forest Ecology and Management* 115:231-242.

Bengtsson, J. S., G Nilsson, A. Franc, and P. Menozzi. 2000. Biodiversity, disturbances, ecosystem function and management of European forests. *Forest Ecology and Management* 132: 39-50.

Boyd, R. S., J. D. Freeman, J. H. Miller, and M. B. Edwards. 1995. Forest herbicide influences on floristic diversity seven years after broadcast pine release treatments in central Georgia, USA. *New Forests* 10: 17-37.

Braun, E. L. 1950. Deciduous Forests of Eastern North America. Philadelphia: Blakiston Co. 596 p.

Cain, S. A. 1950. Life forms and phytoclimate. *Botanical Reviews.* 16: 1-32.

Canham, C.D., J.S. Denslow, W.J. Platt, J.R. Runkle, T.A. Spies, P.S. White. 1990. Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. *Canadian Journal of Forest Resources* 20 (5): 620-631.

Carvalho, L. M., M. A. Fontes, and A. T. Oliveira-Filho. 2000. Tree species distribution in canopy gaps and mature forest in an area of cloud forest of the Ibitipoca Range, south-eastern Brazil. *Plant Ecology* 149:9-22.

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18:117-143.

Clarkson, R. B. 1964. Tumult on the Mountains. Parsons, WV: McClain Printing Co. 410 p.

Clements, F. E. *Plant Succession and Indicators*. 1928. Carnegie Institute of Washington. The H. W. Wilson Co., New York, New York.

Collins, B. S. and S. T. A. Pickett. 1988. Demographic responses of herb layer species to experimental canopy gaps in a northern hardwoods forest. *Journal of Ecology* 76:437-450.

Collins, S. L., S. M. Glenn, and D. J. Gibson. 1995. Experimental analysis of intermediate disturbance and initial floristic composition: decoupling cause and effect. *Ecology* 76: 486-492.

Connell, J. H. and W. P. Sousa. 1983. On the evidence needed to judge ecological stability or persistence. *American Naturalist* 121:789-824.

Creggar, W. H., H. C. Hudson, and H. C. Porter. 1985. Soil Survey of Montgomery County, Virginia. USDA Soil Conservation Service. 158 p.

Daniels, R. B., B. L. Allen, H. H. Bailey, and F. H. Beinroth. 1973. Physiography. In S. W. Bull (ed.), Soils of the southern states and Puerto Rico, pp. 3-16. USDA Southern Cooperative Series, Bulletin 174.

Davison, S. E. and R. T. Forman. 1982. Herb and shrub dynamics in a mature oak forest: a thirty year study. *Bulletin of the Torrey Botanical Club* 109: 64-73.

De Grandpré, L. and Y. Bergeron. 1997. Diversity and stability of understorey communities following disturbance in the southern boreal forest. *Journal of Ecology* 85: 777-784.

Duffy, D. C. and A. J. Meier. 1992. Do Appalachian herbaceous understories ever recover from clearcutting? *Conservation Biology* 6: 196-201.

Duffy, D. C. 1993a. Seeing the forest for the trees: a response to Johnson et al. *Conservation Biology* 7: 436-439.

Duffy, D. C. 1993b. Letters. Herbs and clearcutting: Reply to Elliot and Loftis and Steinbeck. *Conservation Biology* 7: 221-223.

Easter, M. J. and T. A. Spies. 1994. Using hemispherical photography for estimating photosynthetic photon flux density under canopies and in gaps in Douglas-fir forests of the Pacific Northwest. *Canadian Journal of Forest Research* 24: 2050-2058.

Elliott, K. J. and D. L. Loftis. 1993. Letters. Vegetation diversity after logging in the southern Appalachians. *Conservation Biology* 7:7: 220-221.

Elliott, K. J., L. R. Boring, W. T. Swank, and B. R. Haines. 1997. Successional changes in plant species diversity and composition after clearcutting a southern Appalachian watershed. *Forest Ecology and Management* 92: 67-85.

Elton, C. S. 1958. The Ecology of Invasions by Animals and Plants. Chapman & Hall, London.

Figueroa-Rangel, B. L. and M. Olvera-Vargas. 2000. Regeneration patterns in relation to canopy species composition and site variables in mixed oak forests in the Sierra de Manantlán Biosphere Reserve, Mexico. *Ecological Research* 15:249-261.

Foster, B. L, and D. Tilman. 2000. Dynamic and static views of succession: Testing the descriptive power of the chronosequence approach. *Plant Ecology* 146:1-10.

Gee, G. W. and J. W. Bauder. 1986. Particle-size analysis, pp. 383-411. *In* Arnold Klute [ed.], Methods of Soil Analysis Part 1: Physical and Mineralogical Methods. Soil Science Society of America, Inc. Madison, Wisconsin, USA. 1188 pp.

Gilliam, F. S. and N. L. Turrill. 1993. Herbaceous layer cover and biomass in a young versus a mature stand of a central Appalachian hardwood forest. *Bulletin of the Torrey Botanical Club* 120: 445-450.

Gilliam, F. S., N. L Turrill, and M. B. Adams. 1995. Herbaceous-layer and overstory species in clear-cut and mature central Appalachian hardwood forests. *Ecological Applications* 5: 947-955.

Gitay, H. and I. R. Noble. 1997. What are functional types and how should we seek them? *In*: Plant functional types. Eds: T.M. Smith, H. H. Shugart, and F. I. Woodward. Cambridge.

Goebel, P C., D. M. Hix, and A. M. Olivero. 1999. Seasonal ground-flora patterns and site factor relationships of second-growth and old-growth south-facing forest ecosystems, Southeastern Ohio, USA. *Natural Areas Journal* 19: 12-29.

Goldstein, P. Z. 1999. Functional ecosystems and biodiversity buzzwords. *Conservation Biology* 13: 247-255.

Greller, A. M. 1988. Deciduous forest, pp. 287-316. *In* M. Barbour and W. D. Billings [eds.], The terrestrial vegetation of North America, Cambridge Univ. Press, London.

Grime, J. P. 1979. *Plant Strategies and Vegetation Processes.* Chichester: John Wiley & Sons.

Grime, J. P. and A. V. Curtis. 1976. The interaction of drought and mineral nutrient stress in calcareous grassland. *Journal of Ecology*. 64: 975-988.

Halpern, C. B. 1988. Early successional pathways and the resistance and resilience of forest communities. *Ecology* 69:1703-1715.

Halpern, C. B. 1989. Early successional patterns of forest species: interactions of life history traits and disturbance. *Ecology* 70: 704-720.

Halpern, C. B. and T. A. Spies. 1995. Plant species diversity in natural and managed forests of the pacific northwest. *Ecological Applications* 5: 913-934.

Halpern, C. B., J. A. Antos, M. A. Geyer, and A. M. Olson. 1997. Species replacement during early secondary succession: the abrupt decline of a winter annual. *Ecology* 78: 621-631.

Hammond, D. N. 1998. Characterization of vascular plant species composition and relative abundance in southern Appalachian mixed-oak forests. M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA. 112 p.

Hansen, A. J., T. A. Spies, F. J. Swanson, and J. L. Ohmann. 1991. Conserving biodiversity in managed forests. *BioScience* 41: 382-391.

Harpole, D. N. and C. A. Haas. 1999. Effects of seven silvicultural treatments on terrestrial salamander species richness and relative abundance. *Forest Ecology and Management* 114: 349-356.

Hicks, D. J. and B. F. Chabot. 1985. Deciduous forest. *In*: Physiological Ecology of North American Plant Communities. Eds. B. F. Chabot and H. A. Mooney. Chapman & Hall, Cambridge. Pp. 258-277.

Hill, M. O. and H. G. Gauch. 1980. Detrended correspondence analysis, an improved ordination technique. *Vegetatio* 42:47-58.

Hobbs, R. J. 1997. Can we use plant functional types to describe and predict responses to environmental change? *In*: Plant functional types. Eds: T.M. Smith, H. H. Shugart, and F. I. Woodward. Cambridge.

Hooper, D. U. 1998. The role of complementarily and competition in ecosystem responses to variation in plant diversity. *Ecology* 79: 704 – 719.

Johnson, H. B. and H. S. Mayeux. 1992. Viewpoint: A view on species additions and deletions and the balance of nature. *Journal of Range Management* 45:322-333.

Jules, E. S. 1998. Habitat fragmentation and demographic change for a common plant: trillium in old-growth forest. *Ecology* 79: 1645-1656.

Karr, J. R. 1991. Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications* 1:66-84.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. *Environmental Management* 5:55-68.

King, A. and S. Pimm. 1983. Complexity, diversity, and stability: reconciliation of theoretical and empirical results. *American Naturalist*. 122:229-239.

Knapp, S. M. 1999. Effects of Timber Harvesting on Terrestrial Salamander Abundance and Behavior. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA. 122 p.

Lawton, J. H. 1994. What do species do in ecosystems? *Oikos* 71:367-374.

Lim, C H. and M. L. Jackson. 1982. Dissolution for total elemental analysis, pp. 1-12. *In* A. L. Page, R. H. Miller, and D.R. Keeney [eds.], Methods of Soil Analysis Part 2: Chemical and Microbiological Properties. Soil Science Society of America, Inc. Madison, Wisconsin, USA. 1159 pp.

Lotka, A. J. 1925. *Elements of Physical Biology*. Williams & Wilkins, Baltimore.

MacArthur, R. H. 1955. Fluctuations of animal populations, and a measure of community stability. *Ecology* 36:533-536.

Machado, J. L. and P. B. Reich. 1999. Evaluation of several measures of canopy openness as predictors of photosynthetic photon flux density in deeply shaded conifer-dominated forest understory. *Canadian Journal of Forest Research* 29:1438-1444.

Magurran, A. 1988. Ecological Diversity and Its Measurement. Princeton University. 179 pp.

May, R. M. 1973. Stability and complexity in model ecosystems. Princeton, NJ. 235 pages.

McIntyre, S., S. Lavorel, R. M. Tremont. 1995. Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. *Journal of Ecology* 83: 31-44.

McLachlan, S. M. and D. R. Bazely. 2001. Recovery patterns of understory herb and their use as indicators of deciduous forest regeneration. *Conservation Biology* 15:98-110.

McLean, E. O. 1982. Soil pH and lime requirement, pp. 199-224. *In* A. L. Page, R. H. Miller, and D.R. Keeney [eds.], Methods of Soil Analysis Part 2: Chemical and Microbiological Properties. Soil Science Society of America, Inc. Madison, Wisconsin, USA. 1159 pp.

Meier, A. J., S. P. Bratton, and D. C. Duffy. 1995. Possible ecological mechanisms for loss of vernal-herb diversity in logged eastern deciduous forests. *Ecological Application* 5: 935-946.

Miller, J. H., R. S. Boyd, and M. B. Edwards. 1999. Floristic diversity, stand structure, and composition 11 years after herbicide site preparation. *Canadian Journal of Forest Resources* 29:1073-1083.

Miller, R. I. and R. G. Wiegert. 1989. Documenting completeness, species-area relations, and the species-abundance distribution of a regional flora. *Ecology* 70: 16-22.

Mitchell P. L. and T. C. Whitmore. 1993. Use of hemispherical photographs in forest ecology. *Oxford Forestry Institute Occasional Papers* No. 44.

Monk, C. D. 1983. Relationship of life forms and diversity in old-field succession. *Bulletin of the Torrey Botanical Club* 110:449-453.

Moore, M. R. and J. L. Vankat. 1986. Responses of the herb layer to the gap dynamics of a mature beech-maple forest. *The American Midland Naturalist* 115:336-347.

Morin, P. J. 1999. Community ecology. Blackwell Science, Massachusetts. 424 pages.

NOAA. 1995. Climatological data. Annual summary: Virginia 105 (13). Department of Commerce, National Oceanic and Atmospheric Administration.

Noble, I. R. and R. O. Slatyer. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vetetatio* 43:5-21.

Noss. R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* 4: 355-364.

Paine, R. T. 1980. Food webs: linkage, interaction strength and community infrastructure. *Journal of Animal Ecology* 49:667-685.

Perry, H. H., P. C. Conner, A. M. Baisden, C. S. Coleman, E. F. Henry, and A. W. Sinclair. 1954. Soil Survey of Wise County, Virginia. USDA Soil Conservation Service. 114 p.

Petraitis, P. S., R. E. Latham, and R. A. Niesenbaum. 1989. The maintenance of species diversity by disturbance. *The Quarterly Review of Biology* 64: 393-418.

Pyle, R. E., W. W. Beverage, T. Yoakum, D. P. Amick, W. F. Hatfield, and D. E. McKinney. 1982. Soil Survey of Randolph County Area, Main Part, West Virginia. USDA Soil Conservation Service and Forest Service. 167 p.

Reader, R. J. 1987. Loss of species from deciduous forest understorey immediately following selective tree harvesting. *Biological Conservation* 42: 231-244.

Reader, R. J. and B. D. Bricker. 1992a. Value of selectively cut deciduous forest for understory herb conservation: an experimental assessment. *Forest Ecology and Management* 51: 317-327.

Reader, R. J. and B. D. Bricker. 1992b. Response of five deciduous forest herbs to partial canopy removal and patch size. *American Midland Naturalist* 127: 149-157.

Ricklefs, R. E. 1987. Community diversity: relative roles of local and regional processes. *Science* 235: 167-171.

Roberts, M. R. and F. S. Gilliam. 1995. Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. *Ecological Applications* 5: 969-977.

Sarvis, W. 1995. The Potts Valley Branch Railroad and Tri-State incline lumber operation in West Virginia and Virginia, 1892-1932. West Virginia History 54: 42-58.

Schwartz, M.W., C.A. Brigham, J.D. Hoeksema, K.G. Lyons, M.H. Mills, P.J. van Mantgem. 2000. Linking biodiversity to ecosystem function: implications for conservation ecology. *Oecologia* 122: 297- 305.

Smith, O. L. 1980. The influence of environmental gradients on ecosystem stability. *American Naturalist* 116:1-24.

Stadt, K. J., S M. Landhauser, and J. D. Stewart. 1997. Comment-The effects of direct-beam light on overcast-day estimates of light availability. *Canadian Journal of Forest Resources* 27:272-275.

Steinbeck, K. 1993. Letters. *Conservation Biology* 7: 221.

Strausbaugh, P. D. and E. L. Core. 1978. Flora of West Virginia. 2nd ed. Seneca Books, Inc, Morgantown, WV. 1079 p.

Sydes, C. and J. P. Grime. (1981a). Effects of tree leaf litter on herbaceous vegetation in deciduous woodland. I. Field investigations. *Journal of Ecology*. 69: 237–248.

Sydes, C. and J. P. Grime. (1981b). Effects of tree leaf litter on herbaceous vegetation in deciduous woodland. II. An experimental investigation. *J. of Ecology*. 69: 249–262.

Symstad, A. J., D. Tilman, J. Wilson, J.M.H. Knops. 1998. Species loss and ecosystem functioning: effects of species identity and community composition. *Oikos* 81: 389 – 397.

Ter Braak, C. J. 1986. Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67:1167-1179.

Tilman, D. 1985. The resource-ratio hypothesis of plant succession. *The American Naturalist* 125:827-852.

Tilman, D. 1996. Biodiversity: population versus ecosystem stability. *Ecology* 77:350-363.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, and E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. *Science* 277: 1300-1302.

Van Voris, P., R. V. O'Neill, W. R. Emanuel, and H. H. Shugart, Jr. 1980. Functional complexity and ecosystem stability. *Ecology* 61:1352-1360.

Vitousek, P. M. and D. U. Hooper. 1993. Biological diversity and terrestrial ecosystem biogeochemistry. In: E. D. Schulze and H. A. Mooney. Eds. Biodiversity and ecosystem function. Springer-Verlag, Berlin, Germany.

Volterra, V. 1926. Variations and fluctuations in the numbers of individuals in animal species living together. (Reprinted in 1931. In Chapman, R. N., *Animal Ecology*, McGraw-Hill, New York.

Wardle, D. A., K. I. Bonner, G. M. Barker. 2000. Stability of ecosystem properties in response to aboveground functional group richness and composition. *Oikos* 89: 11-23.

Wender, B. W. 2000. Impacts of seven silvicultural alternatives on vascular plant community, composition, structure, and diversity in the southern Appalachians. M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA. 168 p.

White, P. S. and S. T. A. Pickett. 1985. Natural disturbance and patch dynamics: an introduction. *In* S. T. A. Pickett and P. S. White (eds.), *The Ecology of Natural Disturbance and Patch Dynamics*, p. 3-13. Academic Press, Orlando.

Yanai, R. D., M. A. Arthur, T. G. Siccama, and C. A. Federer. 2000. Challenges of measuring forest floor organic matter dynamics Repeated measures from a chronosequence. *Forest Ecology and Management* 5171:1-11.

APPENDIX A: SPECIES LIST

Pre-harvest and post-harvest unique species list of 2 ha treatment plot walkthroughs in seven sites in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West Virginia.

Species	U.S. Nativity	Growth form	Family	Pre-harvest	Year 1 Post-harvest
Acalypha rhomboidea	n	h	Euphorbiaceae		**X**
Acer pensylvanicum	n	w	Aceraceae	**X**	**X**
Acer rubrum	n	w	Aceraceae	**X**	**X**
Acer saccharum	n	w	Aceraceae	**X**	**X**
Achillea millefolium	e	h	Asteraceae	**X**	**X**
Adiantum pedatum	n	h	Polypodiaceae		**X**
Agalinis tenuifolia	n	h	Scrophulariaceae		**X**
Agrimonia gryposepala	n	h	Rosaceae		**X**
Agrimonia parviflora	n	h	Rosaceae		**X**
Agrimonia pubescens	n	h	Rosaceae		**X**
Agrimonia rostellata	n	h	Rosaceae		**X**
Agrostis alba	e	h	Poaceae	**X**	**X**
Agrostis gigantea	n	h	Poaceae		**X**
Agrostis perennans	n	h	Poaceae	**X**	**X**
Agrostis tenuis	n	h	Poaceae		**X**
Ailanthus altissima	e	w	Simaroubaceae		**X**
Allium tricoccum	n	h	Liliaceae	**X**	**X**
Allium vineale	e	h	Liliaceae		**X**
Ambrosia artemisiifolia	n	h	Asteraceae		**X**
Amelanchier arborea	n	w	Rosaceae	**X**	**X**
Amelanchier laevis	n	w	Rosaceae		**X**
Amphicarpa bracteata	n	h	Fabaceae		**X**
Andropogon virginicus	n	h	Poaceae	**X**	**X**
Anemone lancifolia	n	h	Ranunculaceae		**X**
Anemone quinquefolia	n	h	Ranunculaceae	**X**	**X**
Anemone virginiana	n	h	Ranunculaceae		**X**
Angelica venenosa	n	h	Apiaceae	**X**	**X**
Antennaria parlinii	n	h	Asteraceae		**X**
Antennaria plantaginifolia	n	h	Asteraceae	**X**	**X**
Anthoxanthum odoratum	n	h	Poaceae	**X**	**X**
Apocynum androsaemifolium	n	h	Apocynaceae	**X**	**X**
Apocynum cannabinum	n	h	Apocynaceae		**X**
Arabidopsis thaliana	e	h	Brassicaceae		**X**
Arabis canadensis	n	h	Brassicaceae	**X**	**X**
Arabis laevigata	n	h	Brassicaceae		**X**
Aralia nudicaulis	n	h	Araliaceae	**X**	**X**
Aralia spinosa	n	w	Araliaceae	**X**	**X**
Arctium minus	e	h	Asteraceae		**X**
Arenaria serpyllifolia	n	h	Caryophyllaceae		**X**
Arisaema triphyllum	n	h	Araceae	**X**	**X**
Arisiolochia serpentaria	n	h	Araceae		**X**

Aristolochia macrophylla	n	h	Aristolochiaceae	**X**	**X**
Arrhenatherum elatius	e	h	Poaceae		**X**
Asarum canadense	n	h	Aristolochiaceae	**X**	
Asclepias amplexicaulis	n	h	Asclepiadaceae	**X**	
Asclepias exaltata	n	h	Asclepiadaceae		**X**
Asclepias incarnata	n	h	Asclepiadaceae		**X**
Asclepias quadrifolia	n	h	Asclepiadaceae	**X**	**X**
Asclepias syriaca	n	h	Asclepiadaceae		**X**
Asclepias variegata	n	h	Asclepiadaceae	**X**	**X**
Asplenium montanum	n	h	Aspleniaceae	**X**	
Asplenium platyneuron	n	h	Aspleniaceae	**X**	**X**
Aster acuminatus	n	h	Asteraceae	**X**	**X**
Aster argutus	n	h	Asteraceae		**X**
Aster cordifolius	n	h	Asteraceae		**X**
Aster divaricatus	n	h	Asteraceae	**X**	**X**
Aster dumosus	n	h	Asteraceae		**X**
Aster infirmus	n	h	Asteraceae	**X**	**X**
Aster lateriflorus	n	h	Asteraceae	**X**	**X**
Aster linariifolius	n	h	Asteraceae		**X**
Aster macrophyllus	n	h	Asteraceae	**X**	**X**
Aster paternus	n	h	Asteraceae		**X**
Aster pilosus	n	h	Asteraceae		**X**
Aster prenanthoides	n	h	Asteraceae	**X**	**X**
Aster simplex	n	h	Asteraceae		**X**
Aster umbellatus	n	h	Asteraceae		**X**
Aster undulatus	n	h	Asteraceae	**X**	**X**
Athyrium filix-femina	n	h	Aspleniaceae	**X**	**X**
Aureolaria flava	n	h	Scrophulariaceae	**X**	
Aureolaria laevigata	n	h	Scrophulariaceae	**X**	**X**
Aureolaria pedicularia	n	h	Scrophulariaceae		**X**
Aureolaria virginica	n	h	Scrophulariaceae		**X**
Baptisia tinctoria	n	h	Fabaceae	**X**	**X**
Barbarea verna	e	h	Brassicaceae		**X**
Barbarea vulgaris	e	h	Brassicaceae		**X**
Berberis thunbergii	e	h	Berberidaceae		**X**
Betula alleghaniensis	n	w	Betulaceae	**X**	**X**
Betula lenta	n	w	Betulaceae	**X**	**X**
Bidens frondosa	n	h	Asteraceae		**X**
Botrychium dissectum	n	h	Ophioglossaceae	**X**	**X**
Botrychium virginianum	n	h	Ophioglossaceae	**X**	**X**
Boykinia aconitifolia	n	h	Saxifragaceae		**X**
Brachyelytrum erectum	n	h	Poaceae	**X**	**X**
Brassica sp.	e	h	Brassicaceae		**X**
Bromus japonicus	e	h	Poaceae		**X**
Bromus pubescens	n	h	Poaceae		**X**
Cacalia atriplicifolia	n	h	Asteraceae		**X**
Caltha palustris	n	h	Ranunculaceae	**X**	
Campanula americana	n	h	Campanulaceae		**X**
Campanula divaricata	n	h	Campanulaceae	**X**	**X**

Cardamine hirsulta	n	h	Brassicaceae		**X**
Cardamine parviflora	n	h	Brassicaceae		**X**
Carduus acanthoides	e	h	Asteraceae		**X**
Carduus nutans	e	h	Asteraceae		**X**
Carex aestivalis	n	h	Cyperaceae	**X**	**X**
Carex appalachica	n	h	Cyperaceae	**X**	**X**
Carex artitecta	n	h	Cyperaceae		**X**
Carex atlantica	n	h	Cyperaceae		**X**
Carex baileyi	n	h	Cyperaceae	**X**	**X**
Carex blanda	n	h	Cyperaceae	**X**	**X**
Carex brevior	n	h	Cyperaceae		**X**
Carex brunnescens	n	h	Cyperaceae	**X**	**X**
Carex cephalophora	n	h	Cyperaceae		**X**
Carex communis	n	h	Cyperaceae	**X**	**X**
Carex complanata	n	h	Cyperaceae		**X**
Carex crinita	n	h	Cyperaceae	**X**	**X**
Carex debilis	n	h	Cyperaceae	**X**	**X**
Carex digitalis	n	h	Cyperaceae	**X**	**X**
Carex flaccosperma	n	h	Cyperaceae		**X**
Carex gracillima	n	h	Cyperaceae	**X**	
Carex intumescens	n	h	Cyperaceae	**X**	**X**
Carex laxiflora	n	h	Cyperaceae	**X**	**X**
Carex leptonervia	n	h	Cyperaceae	**X**	**X**
Carex lurida	n	h	Cyperaceae	**X**	**X**
Carex muhlenbergii	n	h	Cyperaceae		**X**
Carex nigromarginata	n	h	Cyperaceae		**X**
Carex normalis	n	h	Cyperaceae		**X**
Carex ormostachya	n	h	Cyperaceae	**X**	**X**
Carex pensylvanica	n	h	Cyperaceae	**X**	**X**
Carex prasina	n	h	Cyperaceae	**X**	**X**
Carex radiata	n	h	Cyperaceae		**X**
Carex roanensis	n	h	Cyperaceae		**X**
Carex rosea	n	h	Cyperaceae	**X**	**X**
Carex scabrata	n	h	Cyperaceae	**X**	**X**
Carex scoparia	n	h	Cyperaceae		**X**
Carex stipata	n	h	Cyperaceae	**X**	**X**
Carex styloflexa	n	h	Cyperaceae		**X**
Carex swanii	n	h	Cyperaceae	**X**	**X**
Carex tribuloides	n	h	Cyperaceae		**X**
Carex umbellata	n	h	Cyperaceae	**X**	**X**
Carex virescens	n	h	Cyperaceae	**X**	**X**
Carex vulpinoidea	n	h	Cyperaceae	**X**	**X**
Carex willdenowii	n	h	Cyperaceae		**X**
Carpinus caroliniana	n	w	Betulaceae	**X**	
Carya glabra	n	w	Juglandaceae	**X**	**X**
Carya ovalis	n	h	Juglandaceae		**X**
Carya tomentosa	n	w	Juglandaceae	**X**	**X**
Castanea dentata	n	w	Fagaceae	**X**	**X**
Castanea pumila	n	w	Fagaceae	**X**	**X**

Caulophyllum thalictroides	n	h	Berberidaceae	**X**	**X**
Ceanothus americanus	n	w	Rhamnaceae		**X**
Cerastium glomeratum	e	h	Caryophyllaceae		**X**
Cerastium viscosum	e	h	Caryophyllaceae		**X**
Cerastium vulgatum	e	h	Caryophyllaceae		**X**
Cercis canadensis	n	w	Fabaceae	**X**	**X**
Chamaelirium luteum	n	h	Liliaceae	**X**	**X**
Chelone glabra	n	h	Scrophulariaceae	**X**	**X**
Chimaphila maculata	n	h	Pyrolaceae	**X**	**X**
Chimaphila umbellata	n	h	Pyrolaceae		**X**
Chrysanthemum leucanthemum	e	h	Asteraceae	**X**	**X**
Chrysopsis mariana	n	h	Asteraceae		**X**
Chrysosplenium americanum	n	h	Saxifragaceae	**X**	**X**
Cimicifuga racemosa	n	h	Ranunculaceae	**X**	**X**
Circaea lutetiana	n	h	Onagraceae		**X**
Cirsium arvense	e	h	Asteraceae		**X**
Cirsium discolor	n	h	Asteraceae		**X**
Cirsium vulgare	e	h	Asteraceae		**X**
Claytonia caroliniana	n	h	Portulacaceae	**X**	
Clematis virginiana	n	h	Ranunculaceae		**X**
Clethra acuminata	n	w	Clethraceae		**X**
Clintonia umbellulata	n	h	Liliaceae	**X**	**X**
Collinsonia canadensis	n	h	Lamiaceae	**X**	**X**
Conopholis americana	n	h	Orobanchaceae	**X**	**X**
Convallaria montana	n	h	Liliaceae	**X**	**X**
Corallorhiza maculata	n	h	Orchidaceae	**X**	
Coreopsis major	n	h	Asteraceae	**X**	**X**
Cornus florida	n	w	Cornaceae	**X**	**X**
Coronilla varia	e	h	Fabaceae		**X**
Corydalis sempervirens	n	h	Fumariaceae		**X**
Corylus americana	n	w	Betulaceae		**X**
Corylus cornuta	n	w	Betulaceae	**X**	**X**
Crataegus sp.	n	w	Rosaceae	**X**	**X**
Crepis capillaris	e	h	Asteraceae		**X**
Cynoglossum virginianum	n	h	Boraginaceae		**X**
Cyperus filiculmis	n	h	Cyperaceae		**X**
Cyperus lancastriensis	n	h	Cyperaceae		**X**
Cyperus strigosus	n	h	Cyperaceae		**X**
Cypripedium acaule	n	h	Orchidaceae	**X**	**X**
Cypripedium calceolus	n	h	Orchidaceae		**X**
Cystopteris fragilis	n	h	Polypodiaceae	**X**	
Dactylis glomerata	e	h	Poaceae	**X**	**X**
Danthonia compressa	n	h	Poaceae	**X**	**X**
Danthonia spicata	n	h	Poaceae	**X**	**X**
Daucus carota	e	h	Apiaceae		**X**
Dennstaedtia punctilobula	n	h	Pteridiaceae	**X**	**X**
Dentaria diphylla	n	h	Brassicaceae	**X**	**X**
Deparia acrostichoides	n	h	Polypodiaceae	**X**	**X**
Desmodium acuminatum	n	h	Fabaceae		**X**

Desmodium canescens	n	h	Fabaceae		**X**
Desmodium glabellum	n	h	Fabaceae		**X**
Desmodium laevigatum	n	h	Fabaceae		**X**
Desmodium nudiflorum	n	h	Fabaceae	**X**	**X**
Desmodium paniculatum	n	h	Fabaceae	**X**	**X**
Desmodium rotundifolium	n	h	Fabaceae		**X**
Dicentra cucullaria	n	h	Fumariaceae	**X**	
Digitaria ischaemum	e	h	Poaceae		**X**
Digitaria sanguinalis	n	h	Poaceae		**X**
Dioscorea quaternata	n	h	Dioscoreaceae	**X**	
Dioscorea villosa	n	h	Dioscoreaceae	**X**	**X**
Diospyros virginiana	n	w	Ebenaceae		**X**
Disporum lanuginosum	n	h	Liliaceae	**X**	**X**
Dryopteris intermedia	n	h	Aspleniaceae	**X**	**X**
Elaeagnus umbellata	e	w	Elaeagnaceae	**X**	**X**
Eleocharis obtusa	n	h	Cyperaceae		**X**
Eleocharis tenuis	n	h	Cyperaceae	**X**	**X**
Epifagus virginiana	n	h	Orobanchaceae	**X**	**X**
Epigaea repens	n	h	Ericaceae	**X**	**X**
Epilobium coloratum	n	h	Onagraceae		**X**
Epilobium leptophyllum	n	h	Onagraceae	**X**	
Equisetum arvense	n	h	Equisetaceae	**X**	**X**
Eragrostis sp.		h	Poaceae		**X**
Erechtites hieracifolia	n	h	Asteraceae	**X**	**X**
Erigeron annuus	n	h	Asteraceae	**X**	**X**
Erigeron canadensis	n	h	Asteraceae		**X**
Erigeron philadelphicus	n	h	Asteraceae		**X**
Erigeron strigosus	n	h	Asteraceae		**X**
Erythronium sp.	n	h	Liliaceae	**X**	
Eupatorium fistulosum	n	h	Asteraceae		**X**
Eupatorium maculatum	n	h	Asteraceae		**X**
Eupatorium perfoliatum	n	h	Asteraceae		**X**
Eupatorium purpureum	n	h	Asteraceae	**X**	**X**
Eupatorium rotundifolium	n	h	Asteraceae		**X**
Eupatorium rugosum	n	h	Asteraceae	**X**	**X**
Eupatorium serotinum	n	h	Asteraceae		**X**
Eupatorium sessilifolium	n	h	Asteraceae		**X**
Eupatorium steelei	n	h	Asteraceae	**X**	**X**
Euphorbia corollata	n	h	Euphorbiaceae	**X**	**X**
Fagus grandifolia	n	w	Fagaceae	**X**	**X**
Festuca elatior	e	h	Poaceae	**X**	**X**
Festuca obtusa	n	h	Poaceae		**X**
Festuca ovina	n	h	Poaceae		**X**
Festuca rubra	n	h	Poaceae	**X**	**X**
Fragaria virginiana	n	h	Rosaceae		**X**
Fraxinus americana	n	w	Oleaceae	**X**	**X**
Fraxinus pennsylvanica	n	w	Oleaceae	**X**	**X**
Galax aphylla	n	h	Diapensiaceae	**X**	**X**
Galium aparine	n	h	Rubiaceae	**X**	**X**

Galium circaezans	n	h	Rubiaceae	**X**	**X**
Galium lanceolatum	n	h	Rubiaceae		**X**
Galium latifolium	n	h	Rubiaceae	**X**	**X**
Galium pilosum	n	h	Rubiaceae		**X**
Galium tinctorium	n	h	Rubiaceae		**X**
Galium triflorum	n	h	Rubiaceae	**X**	**X**
Gaultheria procumbens	n	h	Ericaceae	**X**	**X**
Gaylussacia baccata	n	w	Ericaceae	**X**	**X**
Gentiana decora	n	h	Gentianaceae	**X**	**X**
Geranium caroliniana	n	h	Geraniaceae		**X**
Geranium maculatum	n	h	Geraniaceae	**X**	**X**
Geum laciniatum	n	h	Rosaceae	**X**	
Geum virginianum	n	h	Rosaceae		**X**
Gillenia trifoliata	n	h	Rosaceae	**X**	**X**
Glechoma hederacea	e	h	Lamiaceae	**X**	**X**
Glyceria melicaria	n	h	Poaceae	**X**	**X**
Glyceria striata	n	h	Poaceae	**X**	**X**
Gnaphalium obtusifolium	n	h	Asteraceae	**X**	**X**
Gnaphalium purpureum	n	h	Asteraceae		**X**
Goodyera pubescens	n	h	Orchidaceae	**X**	**X**
Gratiola neglecta	n	h	Scrophulariaceae		**X**
Habenaria clavellata	n	h	Orchidaceae	**X**	**X**
Habenaria orbiculata	n	h	Orchidaceae	**X**	**X**
Hamamelis virginiana	n	w	Hamamelidaceae	**X**	**X**
Hedeoma pulegioides	n	h	Lamiaceae		**X**
Helianthus divaricatus	n	h	Asteraceae		**X**
Helianthus microcephalus	n	h	Asteraceae		**X**
Heuchera alba	n	h	Saxifragaceae		**X**
Heuchera americana	n	h	Saxifragaceae	**X**	**X**
Hieracium gronovii	n	h	Asteraceae		**X**
Hieracium paniculatum	n	h	Asteraceae	**X**	**X**
Hieracium pilosella	e	h	Asteraceae	**X**	**X**
Hieracium pratense	e	h	Asteraceae	**X**	**X**
Hieracium scabrum	n	h	Asteraceae		**X**
Hieracium venosum	n	h	Asteraceae	**X**	**X**
Holcus lanatus	e	h	Poaceae	**X**	**X**
Houstonia longifolia	n	h	Rubiaceae	**X**	**X**
Houstonia purpurea	n	h	Rubiaceae	**X**	**X**
Humulus lupulus	n	h	Cannabinaceae		**X**
Hydrangea arborescens	n	w	Hydrangeaceae	**X**	**X**
Hydrophyllum virginianum	n	h	Hydrophyllaceae	**X**	**X**
Hypericum canadense	n	h	Clusiaceae	**X**	**X**
Hypericum gentianoides	n	h	Clusiaceae		**X**
Hypericum hypericoides	n	h	Clusiaceae		**X**
Hypericum mutilum	n	h	Clusiaceae		**X**
Hypericum prolificum	n	h	Clusiaceae		**X**
Hypericum punctatum	n	h	Clusiaceae	**X**	**X**
Hypochaeris radicata	e	h	Asteraceae		**X**
Hypoxis hirsuta	n	h	Amaryllidaceae	**X**	**X**

Ilex decidua	n	w	Aquifoliaceae	**X**	
Ilex montana	n	w	Aquifoliaceae	**X**	**X**
Ilex verticillata	n	w	Aquifoliaceae	**X**	
Impatiens sp.	n	h	Balsaminaceae	**X**	**X**
Ipomoea pandurata	n	h	Convulvulaceae		**X**
Ipomoea purpurea	e	h	Convulvulaceae	**X**	
Iris verna	n	h	Iridaceae	**X**	**X**
Isotria verticillata	n	h	Orchidaceae	**X**	**X**
Juncus canadensis	n	h	Juncaceae		**X**
Juncus effusus	n	h	Juncaceae	**X**	**X**
Juncus marginatus	n	h	Juncaceae		**X**
Juncus subcaudatus	n	h	Juncaceae	**X**	**X**
Juncus tenuis	n	h	Juncaceae	**X**	**X**
Juniperus virginiana	n	w	Cupressaceae	**X**	**X**
Kalmia latifolia	n	w	Ericaceae	**X**	**X**
Kummerowia stipulacea	e	h	Fabaceae		**X**
Lactuca canadensis	n	h	Asteraceae		**X**
Lactuca scariola	e	h	Asteraceae		**X**
Laportea canadensis	n	h	Urticaceae	**X**	**X**
Lechea racemulosa	n	h	Cistaceae		**X**
Leersia virginica	n	h	Poaceae	**X**	**X**
Lepidium campestre	e	h	Brassicaceae		**X**
Lespedeza bicolor	e	h	Fabaceae		**X**
Lespedeza cuneata	e	h	Fabaceae		**X**
Lespedeza hirta	n	h	Fabaceae	**X**	**X**
Lespedeza intermedia	n	h	Fabaceae		**X**
Lespedeza nuttallii	n	h	Fabaceae		**X**
Lespedeza procumbens	n	h	Fabaceae		**X**
Lespedeza repens	n	h	Fabaceae		**X**
Lespedeza virginica	n	h	Fabaceae		**X**
Ligusticum canadense	n	h	Apiaceae		**X**
Lilium michauxii	n	h	Liliaceae	**X**	**X**
Lilium philadelphicum	n	h	Liliaceae	**X**	
Lindera benzoin	n	w	Lauraceae	**X**	**X**
Linum striatum	n	h	Linaceae		**X**
Linum virginianum	n	h	Linaceae		**X**
Liriodendron tulipifera	n	w	Magnoliaceae	**X**	**X**
Lobelia cardinalis	n	h	Campanulaceae		**X**
Lobelia inflata	n	h	Campanulaceae	**X**	**X**
Lobelia spicata	n	h	Campanulaceae		**X**
Lolium perenne	e	h	Poaceae		**X**
Lotus corniculatus	e	h	Fabaceae		**X**
Ludwigia alternifolia	n	h	Onagraceae		**X**
Luzula bulbosa	n	h	Juncaceae		**X**
Luzula echinata	n	h	Juncaceae		**X**
Luzula multiflora	n	h	Juncaceae	**X**	
Lycopodium obscurum	n	h	Lycopodiaceae	**X**	**X**
Lycopus americanus	n	h	Lamiaceae		**X**
Lycopus uniflorus	n	h	Lamiaceae		**X**

Lycopus virginicus	n	h	Lamiaceae	**X**	**X**
Lysimachia quadrifolia	n	h	Primulaceae	**X**	**X**
Magnolia acuminata	n	w	Magnoliaceae	**X**	**X**
Magnolia fraseri	n	w	Magnoliaceae	**X**	**X**
Maianthemum canadense	n	h	Liliaceae	**X**	**X**
Malaxis unifolia	n	h	Orchidaceae		**X**
Medeola virginiana	n	h	Liliaceae	**X**	**X**
Medicago lupulina	e	h	Fabaceae		**X**
Meehania cordata	n	h	Lamiaceae	**X**	
Melampyrum hybridum	n	h	Liliaceae		**X**
Melilotus officinalis	e	h	Fabaceae		**X**
Mentha sp.	n	h	Lamiaceae		**X**
Microstegium vimineum	e	h	Poaceae		**X**
Mimulus ringens	n	h	Scrophulariaceae		**X**
Mitchella repens	n	h	Rubiaceae	**X**	**X**
Monarda sp.	n	h	Lamiaceae	**X**	
Monotropa hypopithys	n	h	Monotropaceae	**X**	**X**
Monotropa uniflora	n	h	Monotropaceae	**X**	**X**
Morus rubra	n	h	Moraceae	**X**	
Muhlenbergia frondosa	n	h	Poaceae		**X**
Muhlenbergia schreberi	n	h	Poaceae		**X**
Muhlenbergia tenuiflora	n	h	Poaceae		**X**
Nyssa sylvatica	n	w	Nyssaceae	**X**	**X**
Oenothera biennis	n	h	Onagraceae		**X**
Onoclea sensibilis	n	h	Onocleaceae	**X**	**X**
Orchis spectabilis	n	h	Orchidaceae	**X**	**X**
Osmorhiza claytoni	n	h	Apiaceae	**X**	**X**
Osmunda cinnamomea	n	h	Osmundaceae	**X**	**X**
Osmunda regalis	n	h	Osmundaceae	**X**	**X**
Ostrya virginiana	n	w	Betulaceae	**X**	**X**
Oxalis acetosella	n	h	Oxalidaceae	**X**	**X**
Oxalis dellenii	n	h	Oxalidaceae		**X**
Oxalis montana	n	h	Oxalidaceae	**X**	
Oxalis stricta	n	h	Oxalidaceae	**X**	**X**
Oxalis violacea	n	h	Oxalidaceae		**X**
Oxydendrum arboreum	n	w	Ericaceae	**X**	**X**
Oxypolis rigidior	n	h	Apiaceae	**X**	**X**
Panicum acuminatum	n	h	Poaceae	**X**	**X**
Panicum boscii	n	h	Poaceae	**X**	**X**
Panicum capillare	n	h	Poaceae		**X**
Panicum clandestinum	n	h	Poaceae	**X**	**X**
Panicum commutatum	n	h	Poaceae	**X**	**X**
Panicum depauperatum	n	h	Poaceae		**X**
Panicum dichotomum	n	h	Poaceae	**X**	**X**
Panicum latifolium	n	h	Poaceae	**X**	**X**
Panicum linearifolium	n	h	Poaceae		**X**
Panicum longifolium	n	h	Poaceae	**X**	
Panicum sphaerocarpon	n	h	Poaceae	**X**	**X**
Panicum trifolium	n	h	Poaceae	**X**	

Parnassia asarifolia	n	h	Saxifragaceae		**X**
Parnassia glauca	n	h	Saxifragaceae	**X**	
Paronychia canadensis	n	h	Caryophyllaceae		**X**
Parthenocissus quinquefolia	n	w	Vitaceae	**X**	**X**
Paspalum setaceum	n	h	Poaceae		**X**
Passiflora lutea	n	h	Passofloraceae		**X**
Paulownia tomentosa	e	w	Scrophulariaceae		**X**
Phalaris arundinacea	n	h	Poaceae		**X**
Phleum pratense	e	h	Poaceae		**X**
Phytolacca americana	n	h	Phytolaccaceae		**X**
Picea glauca	n	w	Pinaceae		**X**
Pinus echinata	n	w	Pinaceae	**X**	**X**
Pinus pungens	n	w	Pinaceae	**X**	**X**
Pinus rigida	n	w	Pinaceae	**X**	**X**
Pinus strobus	n	w	Pinaceae	**X**	**X**
Pinus virginiana	n	w	Pinaceae	**X**	**X**
Plantago lanceolata	e	h	Plantaginaceae		**X**
Plantago major	e	h	Plantaginaceae		**X**
Plantago rugelii	n	h	Plantaginaceae		**X**
Plantago virginica	n	h	Plantaginaceae		**X**
Platanus occidentalis	n	w	Platanaceae	**X**	**X**
Poa alsodes	n	h	Poaceae	**X**	**X**
Poa compressa	e	h	Poaceae		**X**
Poa cuspidata	n	h	Poaceae	**X**	**X**
Poa pratensis	e	h	Poaceae		**X**
Podophyllum peltatum	n	h	Berberidaceae	**X**	**X**
Polygala polygama	n	h	Polygalaceae		**X**
Polygala senega	n	h	Polygalaceae	**X**	
Polygonatum biflorum	n	h	Liliaceae	**X**	**X**
Polygonatum pubescens	n	h	Polygonaceae		**X**
Polygonum acre	n	h	Polygonaceae		**X**
Polygonum cespitosum	e	h	Polygonaceae		**X**
Polygonum persicaria	e	h	Polygonaceae		**X**
Polygonum scandens	n	h	Polygonaceae		**X**
Polypodium appalachianum	n	h	Polypodiaceae	**X**	**X**
Polypodium polypodioides	n	h	Polypodiaceae		**X**
Polypodium virginianum	n	h	Polypodiaceae	**X**	**X**
Polystichum acrostichoides	n	h	Aspleniaceae	**X**	**X**
Populus grandidentata	n	w	Salicaceae	**X**	**X**
Potentilla canadensis	n	h	Rosaceae	**X**	**X**
Potentilla norvegica	n	h	Rosaceae		**X**
Potentilla recta	e	h	Rosaceae		**X**
Potentilla simplex	n	h	Rosaceae	**X**	**X**
Potentilla tridentata	n	h	Rosaceae	**X**	
Prenanthes sp.	n	h	Asteraceae	**X**	**X**
Prunella vulgaris	e	h	Lamiaceae	**X**	**X**
Prunus pensylvanica	n	w	Rosaceae	**X**	**X**
Prunus serotina	n	w	Rosaceae	**X**	**X**
Pteridium aquilinum	n	h	Pteridiaceae	**X**	**X**

Pycnanthemum incanum	n	h	Lamiaceae		**X**
Pycnanthemum pycnanthemoides	n	h	Lamiaceae		**X**
Pyrola americana	n	h	Ericaceae	**X**	
Pyrola rotundifolia	n	h	Ericaceae	**X**	**X**
Quercus alba	n	w	Fagaceae	**X**	**X**
Quercus coccinea	n	w	Fagaceae	**X**	**X**
Quercus prinus	n	w	Fagaceae	**X**	**X**
Quercus rubra	n	w	Fagaceae	**X**	**X**
Quercus stellata	n	w	Fagaceae		**X**
Quercus velutina	n	w	Fagaceae	**X**	**X**
Ranunculus abortivus	n	h	Ranunculaceae		**X**
Ranunculus allegheniensis	n	h	Ranunculaceae		**X**
Ranunculus hispidus	n	h	Ranunculaceae	**X**	**X**
Ranunculus recurvatus	n	h	Ranunculaceae	**X**	**X**
Rhexia virginica	n	h	Melastomaceae		**X**
Rhododendron calendulaceum	n	w	Ericaceae	**X**	**X**
Rhododendron canescens	n	w	Ericaceae		**X**
Rhododendron maximum	n	w	Ericaceae	**X**	**X**
Rhododendron periclymenoides	n	w	Ericaceae		**X**
Rhus copallina	n	w	Anacardiaceae		**X**
Rhus glabra	n	w	Anacardiaceae		**X**
Rhus typhina	n	w	Anacardiaceae		**X**
Rhynchospora capitellata	n	h	Cyperaceae	**X**	**X**
Robinia pseudo-acacia	n	w	Fabaceae	**X**	**X**
Rosa carolina	n	w	Rosaceae		**X**
Rosa multiflora	e	w	Rosaceae	**X**	**X**
Rubus allegheniensis	n	w	Rosaceae	**X**	**X**
Rubus argutus	n	w	Rosaceae		**X**
Rubus canadensis	n	w	Rosaceae	**X**	**X**
Rubus flagellaris	n	w	Rosaceae	**X**	**X**
Rubus occidentalis	n	w	Rosaceae		**X**
Rubus phoenicolasius	e	w	Rosaceae		**X**
Rubus strigosus	n	w	Rosaceae		**X**
Rudbeckia laciniata	n	h	Asteraceae		**X**
Rumex acetosella	e	h	Polygonaceae		**X**
Rumex obtusifolius	e	h	Polygonaceae	**X**	**X**
Salix caprea	e	w	Salicaceae	**X**	**X**
Salix nigra	n	w	Salicaceae		**X**
Salix purpurea	e	w	Salicaceae		**X**
Sanicula canadensis	n	h	Apiaceae		**X**
Sassafras albidum	n	w	Lauraceae	**X**	**X**
Satureja vulgaris	e	h	Lamiaceae	**X**	**X**
Saxifraga micranthidifolia	n	h	Saxifragaceae	**X**	**X**
Schizachyrium scoparium	n	h	Poaceae		**X**
Scirpus atrovirens	n	h	Cyperaceae	**X**	**X**
Scirpus cyperinus	n	h	Cyperaceae	**X**	**X**
Scirpus polyphyllus	n	h	Cyperaceae	**X**	**X**
Scleria ciliata	n	h	Cyperaceae		**X**
Scutellaria elliptica	n	h	Lamiaceae		**X**

Secale cereale	e	h	Poaceae		**X**
Senecio anonymus	n	h	Asteraceae		**X**
Senecio aureus	n	h	Asteraceae	**X**	**X**
Senecio obovatus	n	h	Asteraceae		**X**
Setaria faberi	e	h	Poaceae		**X**
Setaria viridis	e	h	Poaceae		**X**
Silene stellata	n	h	Caryophyllaceae	**X**	**X**
Silene virginica	n	h	Caryophyllaceae	**X**	**X**
Sisyrinchium angustifolium	n	h	Iridaceae		**X**
Smilacina racemosa	n	h	Liliaceae	**X**	**X**
Smilacina trifolia	n	h	Liliaceae	**X**	
Smilax glauca	n	w	Liliaceae	**X**	**X**
Smilax herbacea	n	h	Liliaceae	**X**	**X**
Smilax rotundifolia	n	w	Liliaceae	**X**	**X**
Solanum carolinense	n	h	Solanaceae		**X**
Solanum ptychanthum	n	h	Solanaceae		**X**
Solidago altissima	n	h	Asteraceae		**X**
Solidago arguta	n	h	Asteraceae		**X**
Solidago bicolor	n	h	Asteraceae		**X**
Solidago caesia	n	h	Asteraceae	**X**	**X**
Solidago canadensis	n	h	Asteraceae		**X**
Solidago curtisii	n	h	Asteraceae	**X**	**X**
Solidago erecta	n	h	Asteraceae		**X**
Solidago flexicaulis	n	h	Asteraceae	**X**	**X**
Solidago gigantea	n	h	Asteraceae		**X**
Solidago graminifolia	n	h	Asteraceae	**X**	**X**
Solidago nemoralis	n	h	Asteraceae		**X**
Solidago puberula	n	h	Asteraceae	**X**	**X**
Solidago roanensis	n	h	Asteraceae		**X**
Solidago rugosa	n	h	Asteraceae	**X**	**X**
Solidago ulmifolia	n	h	Asteraceae		**X**
Sonchus asper	e	h	Asteraceae		**X**
Sonchus oleraceus	e	h	Asteraceae		**X**
Specularia perfoliata	n	h	Campanulaceae		**X**
Sphenopholis nitida	n	h	Poaceae		**X**
Sphenopholis obtusata	n	h	Poaceae		**X**
Spiraea japonica	e	w	Rosaceae	**X**	**X**
Stellaria pubera	n	h	Caryophyllaceae	**X**	**X**
Taenidia integerrima	n	h	Apiaceae		**X**
Taraxacum officinale	e	h	Asteraceae	**X**	**X**
Tephrosia virginiana	n	h	Fabaceae		**X**
Thalictrum dioicum	n	h	Ranunculaceae	**X**	**X**
Thalictrum revolutum	n	h	Ranunculaceae		**X**
Thalictrum thalictroides	n	h	Ranunculaceae	**X**	
Thaspium trifoliatum	n	h	Apiaceae		**X**
Thelypteris asplenioides	n	h	Aspleniaceae	**X**	
Thelypteris hexagonoptera	n	h	Aspleniaceae	**X**	**X**
Thelypteris noveboracensis	n	h	Aspleniaceae	**X**	**X**
Tiarella cordifolia	n	h	Saxifragaceae	**X**	**X**

Tilia americana	n	w	Tiliaceae	**X**	**X**
Tipularia discolor	n	h	Orchidaceae		**X**
Toxicodendron radicans	n	w	Anacardiaceae	**X**	**X**
Trientalis borealis	n	h	Primulaceae		**X**
Trifolium agrarium	e	h	Fabaceae		**X**
Trifolium campestre	e	h	Fabaceae		**X**
Trifolium hybridum	e	h	Fabaceae		**X**
Trifolium pratense	e	h	Fabaceae	**X**	**X**
Trifolium pusillum	n	h	Fabaceae		**X**
Trifolium repens	n	h	Fabaceae	**X**	**X**
Trillium erectum	n	h	Liliaceae	**X**	**X**
Trillium grandiflorum	n	h	Liliaceae	**X**	**X**
Trillium undulatum	n	h	Liliaceae	**X**	**X**
Tsuga canadensis	n	w	Pinaceae	**X**	**X**
Tussilago farfara	e	h	Asteraceae		**X**
Ulmus americana	n	w	Ulmaceae		**X**
Ulmus rubra	n	w	Ulmaceae	**X**	
Uvularia perfoliata	n	h	Liliaceae	**X**	**X**
Uvularia pudica	n	h	Liliaceae	**X**	**X**
Uvularia sessilifolia	n	h	Liliaceae	**X**	
Vaccinium pallidum	n	w	Ericaceae	**X**	**X**
Vaccinium simulatum	n	w	Ericaceae	**X**	**X**
Vaccinium stamineum	n	w	Ericaceae	**X**	**X**
Veratrum viride	n	h	Liliaceae	**X**	
Verbascum blattaria	e	h	Scrophulariaceae		**X**
Verbascum thapsus	e	h	Scrophulariaceae		**X**
Verbascum virgatum	e	h	Scrophulariaceae		**X**
Verbena urticifolia	n	h	Verbenaceae		**X**
Verbesina occidentalis	n	h	Asteraceae		**X**
Vernonia noveboracensis	n	h	Asteraceae		**X**
Veronica arvensis	e	h	Scrophulariaceae		**X**
Veronica officinalis	e	h	Scrophulariaceae		**X**
Viburnum acerifolium	n	w	Caprifoliaceae	**X**	**X**
Viburnum alnifolium	n	w	Caprifoliaceae	**X**	**X**
Viburnum cassinoides	n	w	Caprifoliaceae		**X**
Viburnum prunifolium	n	w	Caprifoliaceae	**X**	**X**
Vicia caroliniana	n	h	Fabaceae		**X**
Viola affinis	n	h	Violaceae	**X**	
Viola blanda	n	h	Violaceae	**X**	**X**
Viola canadensis	n	h	Violaceae	**X**	**X**
Viola cucullata	n	h	Violaceae	**X**	**X**
Viola eriocarpa	n	h	Violaceae	**X**	**X**
Viola fimbriatula	n	h	Violaceae		**X**
Viola hastata	n	h	Violaceae	**X**	**X**
Viola hirsutula	n	h	Violaceae	**X**	**X**
Viola macloskeyi	n	h	Violaceae		**X**
Viola palmata	n	h	Violaceae	**X**	**X**
Viola pedata	n	h	Violaceae	**X**	**X**
Viola primulifolia	n	h	Violaceae		**X**

Viola rotundifolia	n	h	Violaceae	**X**	**X**
Viola sororia	n	h	Violaceae	**X**	**X**
Viola triloba	n	h	Violaceae	**X**	
Vitis aestivalis	n	w	Vitaceae	**X**	**X**
Vulpia myuros	n	h	Poaceae		**X**
Zizia aptera	n	h	Apiaceae	**X**	
Zizia aurea	n	h	Apiaceae		**X**
Zizia trifoliata	n	h	Apiaceae	**X**	**X**

APPENDIX B: LOCAL SPECIES EXTINCTIONS

List of species that were present in pre-harvest treatment plot (2 ha) sampling and not in year 1 post-harvest sampling for five sites (CL1, CL2, NC, WV1, and WV2) in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West.

Species	Clearcut	Control	Shelterwood
Agrostis alba	X	X	
Apocynum androsaemifolium			X
Asplenium montanum		X	
Aureolaria flava	X	X	X
Betula alleghaniensis	X		X
Botrychium virginianum			X
Caltha palustris			X
Cystopteris fragilis	X		
Dioscorea quaternata		X	
Disporum lanuginosum		X	
Epifagus virginiana	X		
Euphorbia corollata		X	
Fraxinus pennsylvanica		X	
Galium aparine	X		
Galium circaezans	X	X	
Galium latifolium	X		X
Geranium maculatum	X		X
Geum laciniatum	X		
Habenaria clavellata		X	X
Habenaria orbiculata			X
Hieracium pratense		X	
Hydrangea arborescens	X		
Ilex decidua	X	X	
Ilex verticillata			X
Impatiens sp.	X	X	X
Juniperus virginiana	X		
Lilium philadelphicum		X	
Monotropa hypopithys			X
Monotropa uniflora	X		
Orchis spectabilis	X		
Osmorhiza claytoni		X	
Ostrya virginiana	X		
Oxypolis rigidior			
Pinus echinata	X		X
Polygala senega			X
Quercus coccinea		X	
Ranunculus recurvatus		X	
Rosa multiflora		X	
Scirpus cyperinus		X	
Scirpus polyphyllus			X

Species	Clearcut	Control	Shelterwood
Senecio aureus			X
Silene stellata		X	
Spiraea japonica		X	
Stellaria pubera		X	
Thalictrum thalictroides		X	
Tilia americana		X	
Tsuga canadensis	X		
Uvularia perfoliata		X	X
Uvularia sessilifolia		X	X

APPENDIX C: SPECIES GAINED IN POST-HARVEST

List of species that were gained in the post-harvest treatment plot (2 ha) sampling for five sites (CL1, CL2, NC, WV1, and WV2) in the Ridge and Valley, Cumberland Plateau, and Allegheny Plateau of Virginia and West.

Species	Control	Shelterwood	Clearcut
Acalypha rhomboidea		X	
Achillea millefolium	X	X	X
Agrostis gigantea	X	X	X
Agrostis tenuis	X	X	X
Ailanthus altissima			X
Ambrosia artemisiifolia		X	X
Amelanchier laevis		X	X
Amphicarpa bracteata			X
Anemone lancifolia	X		X
Anthoxanthum odoratum		X	X
Antennaria parlinii	X		
Antennaria plantaginifolia	X		
Apocynum androsaemifolium			X
Apocynum cannabinum		X	
Aralia spinosa			X
Asclepias exaltata			X
Aureolaria laevigata	X		X
Aureolaria pedicularia		X	X
Baptisia tinctoria	X	X	
Bidens frondosa		X	
Botrychium virginianum			X
Boykinia aconitifolia	X	X	X
Brachyelytrum erectum		X	
Campanula divaricata		X	
Carya ovalis		X	
Cardamine hirsulta		X	X
Carya tomentosa	X	X	
Cerastium viscosum		X	
Cerastium vulgatum	X	X	X
Chamaelirium luteum	X	X	
Chelone glabra	X		X
Chrysanthemum leucanthemum		X	X
Cirsium vulgare		X	X
Clematis virginiana		X	
Collinsonia canadensis	X		

Species	Control	Shelterwood	Clearcut
Coronilla varia		X	X
Crataegus sp.			X
Cypripedium calceolus	X		
Danthonia spicata	X	X	
Daucus carota		X	
Desmodium paniculatum		X	
Digitaria ischaemum		X	X
Diospyros virginiana			X
Elaeagnus umbellata	X		
Epilobium coloratum			X
Eragrostis sp.		X	
Erechtites hieracifolia	X	X	
Erigeron annuus		X	X
Erigeron canadensis		X	X
Erigeron philadelphicus		X	X
Erigeron strigosus			X
Euphorbia corollata		X	
Fragaria virginiana	X	X	X
Galium lanceolatum	X	X	X
Galium pilosum			X
Galium triflorum			X
Gillenia trifoliata			X
Gnaphalium obtusifolium			X
Gnaphalium purpureum		X	X
Hedeoma pulegioides			X
Helianthus microcephalus			X
Hieracium gronovii	X	X	X
Hieracium pratense		X	X
Hieracium scabrum			X
Hieracium venosum		X	
Holcus lanatus	X	X	X
Houstonia longifolia		X	X
Houstonia purpurea	X	X	
Hypericum canadense		X	
Hypericum hypericoides		X	X
Hypericum mutilum	X	X	X
Hypericum punctatum		X	
Hypochaeris radicata		X	X
Ipomoea pandurata	X		
Juncus subcaudatus		X	
Juncus tenuis	X	X	X

Species	Control	Shelterwood	Clearcut
Lactuca canadensis		X	X
Leersia virginica	X	X	X
Lepidium campestre		X	
Lespedeza cuneata	X	X	X
Lespedeza hirta		X	
Lespedeza intermedia		X	X
Lespedeza procumbens		X	
Lespedeza repens		X	X
Lilium michauxii	X	X	
Linum striatum		X	X
Lobelia inflata	X	X	
Lolium perenne	X	X	X
Lotus corniculatus	X	X	X
Luzula bulbosa	X		
Luzula echinata		X	X
Lycopodium obscurum		X	
Lycopus uniflorus	X	X	X
Malaxis unifolia			X
Medicago lupulina		X	
Melampyrum hybridum			X
Melilotus officinalis			X
Microstegium vimineum		X	
Muhlenbergia frondosa			X
Muhlenbergia schreberi	X	X	X
Muhlenbergia tenuiflora			X
Ostrya virginiana		X	
Oxalis dellenii	X	X	X
Oxalis stricta		X	X
Parnassia asarifolia		X	
Paulownia tomentosa			X
Phalaris arundinacea			X
Phleum pratense		X	X
Phytolacca americana	X	X	X
Pinus pungens	X		
Pinus strobus	X		
Pinus virginiana		X	
Plantago lanceolata		X	X
Plantago rugelii		X	X
Plantago virginica			X
Platanus occidentalis		X	
Poa cuspidata	X		

Species	Control	Shelterwood	Clearcut
Podophyllum peltatum			X
Polygonum acre	X		X
Polygonum cespitosum		X	
Polygonum persicaria			X
Polygonatum pubescens	X		
Polygonum scandens			X
Potentilla canadensis	X	X	X
Potentilla norvegica		X	X
Prunella vulgaris		X	X
Ranunculus allegheniensis			X
Ranunculus hispidus	X		X
Ranunculus recurvatus			X
Rhus copallina			X
Rhus glabra			X
Rhus typhina			X
Rosa carolina	X		
Rosa multiflora			X
Rumex acetosella	X	X	X
Sanicula canadensis			X
Sambucus pubens		X	X
Satureja vulgaris			X
Schizachyrium scoparium		X	X
Scleria ciliata			X
Secale cereale	X	X	X
Senecio anonymus			X
Senecio aureus			X
Sisyrinchium angustifolium	X		X
Solanum carolinense			X
Sonchus asper		X	X
Sonchus oleraceus			X
Specularia perfoliata			X
Taraxacum officinale	X		X
Tephrosia virginiana		X	X
Thalictrum revolutum	X		
Thelypteris hexagonoptera		X	
Trifolium agrarium			X
Trientalis borealis	X	X	
Trifolium hybridum	X	X	X
Trifolium pratense	X	X	X
Trifolium repens		X	X
Tussilago farfara		X	X

Species	Control	Shelterwood	Clearcut
Veronica officinalis	X		X
Verbascum thapsus			X
Viburnum cassinoides			X
Vicia caroliniana		X	
Vulpia myuros			X
Zizia trifoliata	X		X

VITA

Sharon Metzger Hood was born October 30, 1974 in Mobile, Alabama to Catherine and William J. Metzger, Jr. She completed her B.S. in Forestry at Mississippi State University in 1997 and worked for Kimberly-Clark Corporation for one year following graduation before pursuing a M.S. in Forestry from Virginia Polytechnic Institute and State University.