

CHANGES IN OLD-GROWTH AND SECOND-GROWTH EASTERN HEMLOCK (*TSUGA CANADENSIS*)
COMMUNITIES IN THE SOUTHERN APPALACHIANS AFTER THE INTRODUCTION OF THE HEMLOCK
WOOLLY ADELGID, *ADELGES TSUGAE*.

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Abstract

ANDREW DANIEL GERSCHUTZ: Changes in old-growth and second-growth eastern hemlock (*Tsuga canadensis*) communities in the southern Appalachians after the introduction of the hemlock woolly adelgid, *Adelges tsugae*.

(Under the direction of Robert K. Peet)

The hemlock woolly adelgid was discovered in the southern Appalachians as early as 2002. It has caused widespread mortality of eastern hemlocks in the northern Appalachians and researchers have predicted a similar effect in the southern Appalachians. This study characterizes the early-stage impacts of hemlock woolly adelgid on eastern hemlock forests throughout the southern Appalachians.

Twenty-eight permanent plots were reinventoried in 2004 and 2005. They were originally inventoried between 1990 and 1998 before the introduction of the hemlock woolly adelgid. The plots were located in Great Smoky Mountains National Park, Joyce Kilmer Memorial Forest, and Ellicott Rock Wilderness Area in the southern Appalachians. They encompass a wide geographic range, a wide range of environmental variables, and different levels of eastern hemlock dominance. The plots were divided into either old-growth forests or second-growth forests based on visual inspection. Within each 1000 m² plot, vegetation inventory was performed for both herbs and woody species. Changes in eastern hemlock abundance and changes in species richness between the two inventory dates were examined. Environmental variables were correlated with the changes to determine if the changes were consistent with those caused by the hemlock woolly adelgid.

This work found that small < 2.5 cm dbh eastern hemlock trees decreased in density in both old-growth and second-growth plots when reinventoried after arrival of the hemlock woolly adelgid. The percentage change in eastern hemlock density was correlated with the initial eastern hemlock importance value in both categories. Change in eastern hemlock density was not correlated with observed environmental variables, location, or successional stage. Instead, this study found that successional stage was relevant to the change in species richness after the introduction of the hemlock woolly adelgid. Old-growth forests increased in species richness whereas second-growth forests decreased in species richness. Initial eastern hemlock basal area, pH, and elevation were correlated with species richness in old-growth forests and measures of eastern hemlock dominance were correlated with the change in species richness in old-growth forests. In second-growth forests, however, pH was the most important variable in determining species richness and only nitrogen was correlated with the change in species richness.

The contrasting response of species richness in reinventoried old- and second-growth plots may be reconciled by examining the differences in initial eastern hemlock dominance in old-growth and second-growth forests. Eastern hemlock importance value varied based on stage, with old-growth forests having a higher importance value than second-growth forests. The different responses between old growth and second growth may be explained by the initial difference in eastern hemlock importance value.

Eastern hemlock mortality has been swift and widespread. If the hemlock woolly adelgid cannot be controlled, eastern hemlock will likely decline precipitously in importance throughout the southern Appalachians.

Dedication

To Tyler and my family. Without you this would not have been possible. Thank you.

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Preface

Dust of Snow

The way a crow
Shook down on me
The dust of snow
From a hemlock tree

Has given my heart
A change of mood
And saved some part
Of a day I had rued.

Robert Frost

“Dust of Snow” from THE POETRY OF ROBERT FROST edited by Edward Connery Lathem.

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CHAPTER 1

INTRODUCTION

(1) Invasive Species

In 2002, the hemlock woolly adelgid, *Adelges tsugae* Annand, was discovered in Great Smoky Mountains National Park (Lambdin et al., 2006). It is unclear when and where it first spread into the southern Appalachians, defined herein as the Appalachian region of western North Carolina, South Carolina, and Georgia, but by 2004 it was present in all plots reinventoried in this study.

This study, conducted in 2004 and 2005, characterizes the changes that occur after the introduction of the hemlock woolly adelgid. The effect on eastern hemlock (*Tsuga canadensis* (L.) Carr.) communities is expected to be severe. This study addresses three questions:

- (1) How do eastern hemlocks in the southern Appalachians respond to the early stages of hemlock woolly adelgid infestation?
- (2) How does species richness change after the introduction of the hemlock woolly adelgid?
- (3) How does the effect in the southern Appalachians compare to the effect in the northern Appalachians?

Exotic species have a long history of affecting natural communities (Liebhold et al., 1995; Costello and Leopold, 1995). They can alter species diversity (Yurkonis and Meiners, 2004), alter processes (Brooks et al., 2004), and change structural characteristics of the community (Ellison et al., 2005). Ellison et al. (2005) state that there can be wide-ranging impacts on other species and ecosystem processes if an exotic species affects an important species. Other dominant species, such

as the American chestnut (Busing, 1989) and the Fraser fir (Busing et al., 1988), have already declined precipitously because of exotic species. This study is one of the few characterizing the invasion of eastern hemlock communities by the hemlock woolly adelgid in the Southern Appalachian Mountains.

(2) Eastern hemlock

Eastern hemlock, *Tsuga canadensis* (L.) Carr.,¹ is a late successional dominant tree species found from Nova Scotia to northern Georgia and west across the Lake states through Wisconsin, with outliers west of the main range to Alabama and Minnesota (Burns and Honkala, 1990). Ellison et al. (2005) consider eastern hemlock a foundation species throughout its range, meaning that “by virtue of its structural or functional attributes [it] creates and defines an entire ecological community or ecosystem.” Eastern hemlock’s structural characteristics create a cool, damp, acidic understory with a heavy detritus layer under a dense canopy of eastern hemlock (Rogers, 1978). These conditions are created because of eastern hemlock’s shade tolerance (Kessell, 1979), up to 800 year life span (Evans, 2002), ability to withstand suppression for up to 400 years (Rogers, 1978), acidic slowly-decomposing needles (Finzi et al., 1998), dense cover allowing low light (Battles et al., 1999), and evergreen habit.

Eastern hemlock distribution is influenced by its evolutionary history, environmental variables, biotic factors, and disturbance history. Its evolutionary history includes expansion from glacial refugia in the southeastern United States after the most recent glacial maximum of the Pleistocene epoch, 12,000 – 20,000 years ago (Potter et al., 2008). Potter et al. (2008) found that the species has low genetic diversity throughout its range but greater population differentiation than other conifers. They suggest that the glacial refuge area for eastern hemlock was located east

¹ Nomenclature follows Radford et al., 1968.

of the southern Appalachians because of higher genetic diversity in populations on the eastern edge of its range compared to the rest of the range. From the last glacial maximum, eastern hemlock has expanded to include 2.3 million acres of hemlock-dominated stands from Georgia to Nova Scotia (McWilliams and Schmidt, 1999).

The environmental variables that influence eastern hemlock's distribution include moisture availability, aspect, elevation, temperature, pH, nutrient availability, light availability, and forest floor cover. Eastern hemlock's distribution across a landscape is influenced by its preference for mesic conditions and its ability to persist in resource-limited habitats (Benzinger, 1994a; Rogers, 1978). These conditions are found in the southern Appalachians in rich and acidic coves (Oosting and Billings, 1939). Eastern hemlock also survives in ravines where soil conditions maintain sufficient moisture (Oosting and Bordeau, 1954). Aspect is also relevant to eastern hemlock distribution because it relates to moisture availability; hence few eastern hemlock-dominated communities are found on south-facing slopes (Rogers, 1978). Similarly, elevation and temperature are related to moisture-availability. In the Great Smoky Mountains National Park, eastern hemlock is found at elevations from 457 to 1737 m (Johnson et al., 1999). In the northern portion of its range, it grows from sea level to 730 m (Burns and Honkala, 1990). These environmental variables interact with eastern hemlock's functional attributes in a feedback system that causes the environment to be even more shaded and nutrient-poor (Mladenoff, 1987; Catovsky and Bazzaz, 2000). As a result, light penetration to the understory can be <5% (Orwig and Kizlinski, 2002) and the soil pH is often within a range of 3.06 – 3.63 with high soil organic matter in healthy eastern hemlock stands (Oosting and Billings, 1939).

Biotic variables such as competitors and pathogens also limit the distribution of eastern hemlock throughout its range. Woods (2000a) describes eastern hemlock as a late successional species because it is often successful in competition with hardwood tree species but still undergoes

change with disturbance and competition. Others describe eastern-hemlock-dominated forests as climax communities because eastern hemlock maintains dominance without disturbance (Benzinger, 1994a). Few hardwoods are able to persist in the understory of an eastern hemlock canopy (Benzinger, 1994a). In the southern Appalachians, ericaceous plants such as *Rhododendron maximum* and *Kalmia latifolia* can form a dense shrub layer that inhibits hardwood competition even more (Oosting and Bourdeau, 1955). Phillips and Murdy (1985) found that eastern hemlock was the only canopy species capable of reproducing through a dense *R. maximum* layer. Eastern hemlock seedlings in hemlock stands have higher survivorship than more numerous *Acer saccharum*, *Acer rubrum*, and *Betula lenta* seedlings because of hemlocks ability to persist in acidic soils and low light (Rogers 1978). Kincaid (2007) suggested that disturbances such as large-scale clearing and smaller-scale gaps resulted in the co-existence of eastern hemlock with hardwood dominants. Alternatively, Rogers (1978) suggested that inappropriate site conditions can cause incomplete dominance by eastern hemlock and therefore co-existence with hardwoods; he also cited Olson et al. (1959) for the proposition that rich, damp soil may result in fungi limiting eastern hemlock success.

In addition to the hemlock woolly adelgid, the elongate hemlock scale (*Fiorinia externa* Ferris.; Hemiptera: Diaspididae), is a pathogen that is currently influencing the distribution of eastern hemlock. This species was introduced from Asia in the early 1900's and has spread to at least 15 eastern states (Lambdin et al., 2006). It weakens eastern hemlock trees and kills declining trees (McClure, 2002). Preisser et al. (2008) studied the interaction of elongate hemlock scale and the hemlock woolly adelgid on eastern hemlocks. They found that the adelgid caused greater hemlock mortality but that elongate hemlock scale had an increased frequency when the adelgid was at low density. The hemlock woolly adelgid and the elongate hemlock scale are only the most recent pathogens to affect eastern hemlocks. The pollen record indicates that eastern hemlock

decreased in abundance throughout its range in eastern North America approximately 5400 years ago and took two thousand years to recover (Fuller, 1998). By examining the pollen record after the decline, Fuller (1998) concluded that *Quercus* spp., *Ulmus* spp., *Fagus grandifolia*, *Acer saccharum*, and *Betula* spp. replaced eastern hemlock.

Other disturbances that influence eastern hemlock distribution include fires, tree-fall gap formation, intermediate scale wind disturbances, and anthropogenic disturbances. Eastern hemlock is especially susceptible to fires because of its shallow root system, thin bark on smaller individuals, and build-up of humus on the forest floor (Benzinger, 1994a; Rogers, 1978). Some studies have indicated that low-intensity fires result in an even-aged stands of hemlock (Maissarow, 1941; Miles and Smith, 1960). Other studies have shown that fire is very important in limiting eastern hemlock abundance in the northern part of its range (Frelich and Lorimer, 1991; Foster and Zebryk, 1993). The frequency of fires is low in eastern-hemlock dominated communities. For example, Frelich and Lorimer (1991) distinguish fire rotation periods in northern hemlock-hardwood forests in Michigan between a pre-fire-suppression period and a post-fire-suppression period. In the pre-fire-suppression period, they found a rotation period of 566 years for surface fires and 2797 years for canopy-killing fires. During the fire-suppression years, the rotation periods approximately doubled to 1273 years for surface fires and 4545 years for canopy-killing fires. Frelich and Lorimer (1991) suggest that the low frequency of fire in eastern-hemlock dominated communities is due to the moist, thick humus layer. While fire may be a low-frequency disturbance in eastern hemlock communities, the susceptibility of eastern hemlock to even surface fires makes it a controlling factor in the eastern hemlock's distribution.

Disturbances such as tree fall gaps and wind-events are often smaller in scale than fires but occur more frequently. Tree fall gaps in eastern hemlock forests have a rotation frequency and average canopy residence time of 100 years (Runkle, 1982). Kincaid and Parker (2008) found a

similar mean canopy residence time of 105 years for eastern hemlock forests in the southern Appalachians. This high frequency does not limit dominance by eastern hemlock because the gaps are most likely to be filled by smaller suppressed eastern hemlocks (Runkle, 1981; Runkle, 1982; Frelich et al., 1993). Frelich and Lorimer (1991) state that severe wind-disturbance in hemlock-hardwood forests in Michigan has a rotation period of approximately 6000 years, but that lower-intensity storms are much more frequent with a rotation period of between 94 years and 236 years; they state that moderate wind disturbance “can be expected once or twice during the life span of a cohort of trees.” Wind disturbances can create a gap large enough to open up the canopy and allow regeneration of gap species, often hardwoods such as *Liriodendron tulipifera* (Hibbs, 1982).

Anthropogenic disturbances have influenced the distribution of eastern hemlock through various means as well. Early in the 20th century eastern hemlocks were logged to make room for farming and planting of trees considered more productive (Foster and Zebryk, 1993). The history of logging in the eastern U.S. has left small pockets of old-growth eastern hemlock communities and a wider range of hemlock-hardwood communities resulting from secondary succession (Benzinger, 1994a).

The mosaic of eastern hemlock communities varies based on eastern hemlock dominance. This variation in dominance is most apparent when comparing old-growth eastern hemlock communities to more recently disturbed eastern hemlock communities. Woods (2000a) states that unlogged hemlock-hardwoods communities of the Great Lakes region can be thought of as late successional communities rather than old-growth communities because there is no “meaningful community equilibrium or compositional stability.” He does, however, suggest that these communities diverge to dominance by eastern hemlock, sugar maple, or American beech (Woods, 2000a; Woods, 2000b). Other studies have found low rates of turnover in old-growth mesic forests in the southern Appalachians (Runkle, 2000; Busing, 2005). Busing (2005) estimated a mortality rate

for eastern hemlock in southern Appalachian old-growth cove forests of only 0.3% per year but found that mortality was increased for very small and very large eastern hemlocks. In the central Appalachians, old-growth beech forests showed a shift towards eastern hemlock dominance (McEwan and Muller, 2006).

Size class structure in old-growth hemlock-hardwood forests displays a variety of patterns including negative exponential, bell-shaped unimodal, and small-diameter skewed unimodal (Tyrrell and Crow, 1994). These suggest that the complex relationship between stand age and size class structure is influenced by the initial stand formation and disturbance dynamics over time. Negative exponential size classes may be representative of “balanced, equilibrium all-aged forests” (Tyrrell and Crow, 1994). Bell-shaped and skewed distributions may be the result of disturbances such as deer browsing or surface fires. Tyrrell and Crow (1994) conclude that old-growth stands “do not show a tendency to converge on a single distribution with time.”

Eastern hemlock dominance varies with the nature of the disturbance, the re-colonization process, and the interactions between species over time. Larger-scale disturbances open up the canopy and allow colonizers such as *Liriodendron tulipifera* to enter. Clebsch and Busing (1989) studied secondary succession in the southern Appalachians and fit their results to a four-stage model by Shugart and West (1977): (1) stand initiation, (2) stem exclusion, (3) understory reinitiation, and (4) old-growth, mixed-size and mixed-age structure. They recognized eastern hemlock entering the stands in the stem exclusion stage after 30 – 60 years. In a gap-model projection, eastern hemlock did not attain dominance after 250 years because of its slow growth rate (Clebsch and Busing, 1989). Clebsch and Busing (1989) also investigated size-class structure over time in second-growth forests and found a transition from *L. tulipifera* dominance to *Acer saccharum* and *T. canadensis* dominance. Initially, *L. tulipifera*, *Robinia pseudo-acacia*, *Sassafras albidum*, *Halesia carolina*, *Acer rubrum*, and *Betula lenta* were present in the understory, but later,

Aesculus octandra, *Fagus grandifolia*, and *T. canadensis*, came in. At the end point, *T. canadensis* and *Acer saccharum* were dominant in the canopy, but *T. canadensis* was regenerating in the understory and *A. saccharum* was not (Clebsch and Busing, 1989). They concluded that small-scale disturbance and variability in temperature and moisture allowed co-existence of several canopy species during secondary succession.

Eastern hemlock dominance influences the other plant species that co-exist with it. Eastern hemlock trees occur in numerous community types and can co-occur with many other tree species, though *Halesia carolina*, *Betula allegheniensis*, and *Magnolia fraseri* are the most common canopy associates (Whittaker, 1956). Subcanopy species include *B. lenta*, *Ilex opaca*, and *Acer pensylvanicum*, or an ericaceous layer of *Rhododendron maximum* or *R. catawbiense* (Whittaker, 1956). Kincaid (2007) divided eastern hemlock communities in Great Smoky Mountains National Park into four community types: (1) *Tsuga canadensis*/*Betula*/*Acer rubrum*; (2) *Tsuga canadensis*/*Liriodendron tulipifera*; (3) *Tsuga canadensis*/*Betula*; and (4) *Tsuga canadensis*. The first community type, eastern hemlock-birch-maple, was found at the highest elevations and had the greatest woody species richness, although it could also have a high cover of *Rhododendron maximum*. The second community type, eastern hemlock-tulip poplar, also had high species richness and high *R. maximum* cover. This community type may be representative of earlier stage successional communities. The third community type, eastern hemlock-birch, had higher nutrient availability and a higher cover of *Acer saccharum*. Finally, the fourth community, eastern hemlock, was dominated solely by the hemlock. Kincaid found that this community type had lower *R. maximum* cover than the other community types. He also compared his community delineations to numerous prior attempts at characterizing eastern hemlock communities in the southern Appalachians. His community types were consistent with findings from Whittaker (1956), Golden (1981), Callaway et al. (1987), and MacKenzie and White (1998). His findings are also consistent

with community classifications near Highlands, NC (Oosting and Billings, 1939), and in Joyce Kilmer Memorial Forest in western NC (Oosting and Bourdeau, 1955).

The studies near Highlands and Joyce Kilmer Memorial Forest also recognize a distinction between eastern hemlock community types with *R. maximum* in the understory and those without it. Other studies reinforce the importance of *R. maximum* affecting eastern hemlock community structure (Phillips and Murdy, 1985; Monk, McGinty, and Day 1985). Oosting and Bourdeau (1955) found that in wetter eastern hemlock sites, *R. maximum* is dominant in the understory and the herb layer is depauperate. On the drier eastern hemlock sites, *R. maximum* is present at much lower cover value and the herb layer and canopy have higher species richness (Oosting and Bourdeau, 1955). The eastern hemlock-rhododendron community type is characterized by eastern hemlock, beech, and birch in the canopy, rhododendron in the understory, and few herbs. The eastern hemlock-herb community type includes a variety of mixed-mesophytic tree species in the canopy, *Hamamelis virginiana* and *Euonymus sp.* in the shrub layer, and *Aster sp.*, *Parthenocissus sp.*, *Cimicifuga sp.*, *Thalictrum sp.*, and *Polystichum sp.* in the herb layer. A study of the vegetation in the Black Mountains of North Carolina also recognized eastern hemlock community types with distinctive shrub and herb layers, such as a cove climax community with eastern hemlock, *R. maximum*, *K. latifolia*, and *Leucothoe sp.* and a cove hemlock-beech community with *Mitchella repens*, *Houstonia sp.*, *Galax aphylla*, *Viola rotundifolia*, and *Listera smallii* (Davis, 1930).

In contrast to the characteristic herbs in eastern hemlock dominated communities in the southern Appalachians, Rogers (1980) found no characteristic herbs in the northern part of its range. He inventoried 71 stands from Wisconsin to Nova Scotia and found turnover in herbs throughout the range of eastern-hemlock-dominated communities. There were also no important shrubs in this community type (Rogers, 1980). *Maianthemum canadense*, *Dryopteris austriaca*, and *Acer rubrum*

were ubiquitous in Rogers' hemlock plots, but they are also abundantly present in non-eastern hemlock forests.

In the southern Appalachians, eastern hemlock herb communities vary by successional stage. Duffy and Meier (1992) found significantly decreased herb richness, up to a 50% decrease, in secondary mixed mesophytic forests that had at one time been cut compared to primary forests that had not been cut. Elliot et al. (1997) found late successional, shade-tolerant species present at low rates in second-growth cove-hardwood forests after logging. In contrast, Ford et al. (2000) did not find significant differences in species richness based on stand age, although they describe a non-significant trend towards increased species richness as a stand ages.

(3) The Hemlock Woolly Adelgid

The hemlock woolly adelgid, *Adelges tsugae* (Annand), was introduced into the western United States from Japan in the 1920s (Lambdin et al., 2006). It was discovered in Virginia in 1952 and initially spread through the northeastern United States (Souto et al., 1996). In 2002, the hemlock woolly adelgid was discovered in Great Smoky Mountains and other southern Appalachian locations (Lambdin et al., 2006). As a result of its rapid spread, the hemlock woolly adelgid now threatens the majority of eastern hemlock and Carolina hemlock communities in the southern Appalachians.

The hemlock woolly adelgid has few natural predators in the United States (Wallace and Hain, 2000). Instead, it is limited by its susceptibility to very cold temperatures and can have its population reduced dramatically during very cold winters (McClure and Cheah, 2002; Skinner et al., 2003; Parker et al., 1998). The latitudinal gradient in temperature also limits hemlock woolly adelgid populations in the northern part of eastern hemlock's range.

The hemlock woolly adelgid spreads via wind, animal, and human transport (McClure, 1990). Its dispersal rate has been estimated by Ward et al. (2004) at between 20–30 km/yr and by Evans and Gregoire (2006) at 12.5 km/yr in general, with an increased dispersal rate of 15.6 km/yr in the South. Further, in the southern Appalachians the hemlock woolly adelgid may develop earlier because of the milder weather (Grant et al., 2006). Finally, a model based on hemlock woolly adelgid spread in Great Smoky Mountains National Park found that its spread is facilitated by corridors (Koch et al., 2006).

In Japan the hemlock woolly adelgid is a pest but causes limited decline of native *Tsuga* species (Havill et al., 2006). Even *T. canadensis* trees introduced into Japan are only minimally affected by the hemlock woolly adelgid (McClure and Cheah, 1999). McClure (1991) suggests that this is because native predator species limit the hemlock woolly adelgid's population. The beetle *Sasajiscymnus tsugae* (Sasaji and McClure) (Coleoptera: Coccinellidae) is a known native predator of the adelgid that has been studied as an effective biocontrol agent in the U.S. It has been shown to limit the effect of the hemlock woolly adelgid on eastern hemlocks, although it does not prevent eventual hemlock death and it has not yet spread beyond the initial release sites (Graham, 2008; McClure et al., 2000). It has also been released in the Great Smoky Mountains National Park with mixed results; it was relocated at only 30% of the sites where it was released and there was only a small decrease in hemlock woolly adelgid population near the release site (Lambdin et al., 2006).

(4) Impact of the Hemlock Woolly Adelgid on Eastern Hemlock Communities

Researchers have studied the hemlock woolly adelgid in eastern hemlock communities of the northern Appalachians (Mayer et al., 2002; Battles et al., 1999; Small et al., 2005). In addition, a few studies have reported on the effect of the hemlock woolly adelgid on southern Appalachian eastern hemlock communities (Ford and Vose, 2007; Kincaid, 2007; Nuckolls et al., 2009; Graham,

2008). This is the first study comparing the response of both second-growth and old-growth eastern hemlock forests in the southern Appalachians to the hemlock woolly adelgid. This additional research is necessary because of the warmer climate and different species composition in the South. The previous research has indicated that the hemlock woolly adelgid is likely to significantly alter eastern hemlock distribution and community composition.

In the north, the hemlock woolly adelgid has resulted in widespread mortality of eastern hemlock (Evans, 2002). Kizlinkski et al. (2002) compared logging to the hemlock woolly adelgid and concluded that logging caused more abrupt changes, but that the hemlock woolly adelgid will still cause profound changes. Nuckoll et al. (2009) compared girdling to hemlock woolly adelgid infestation and concluded that they were similar in effect. While small individuals die first from the defoliation (Weckel et al., 2006), even canopy hemlocks often die within ten years of infestation (McClure, 1991; Battles et al., 1999). Orwig et al. (2002) found mortality among eastern hemlocks to be spatially autocorrelated in New England, with increased mortality in locations where the hemlock woolly adelgid had been present longer. In one study, 80% of eastern hemlocks were dead fifteen years after infestation (Small et al., 2005).

Few environmental factors limit eastern hemlock mortality. Orwig et al. (2002) found that the most important factor associated with infestation was latitude and suggested that it was a proxy for time since infestation. A larger stand size was also related to increased canopy mortality, possibly because larger stands are larger targets for infection than smaller stands (Orwig et al., 2002). Mayer et al. (2002) found a small increase in hemlock mortality on southwestern slopes, and postulated that the drier environment stressed hemlocks and made them vulnerable to decline.

Eastern hemlock mortality has been causally linked to drastic changes in environmental variables and ecosystem functioning (Stadler et al., 2005). Increased light reaches the understory as the dense canopy in eastern hemlock forests thins (Jenkins et al., 1999). Nuckolls et al. (2009)

reported 80% crown loss after three years of hemlock woolly adelgid infestation in the southern Appalachians. The increased light raises the temperature, decreases the moisture availability, and increases nitrogen cycling. Increased nitrogen availability is a result of increased decomposition, decreased uptake by hemlock trees, and N-enriched throughfall from infested canopies (Orwig et al., 2008; Yorks et al., 1999). The increased nitrogen availability has been shown to change stream chemistry (Lewin and Likens, 2007). Finally, the decline in eastern hemlock can change hydrologic processes because of the reduced uptake of water year-round, resulting in increases in water discharge (Ford and Vose, 2007; Hadley et al., 2008; Daley et al., 2007).

In the northern Appalachians, *Betula lenta* L. is the species most likely to replace eastern hemlock in the canopy because of its prevalence in the understory, its dispersal ability, and its fast growth rate (Kizlinski et al., 2002; Stadler et al., 2005). *Acer rubrum* L. has also increased in density in eastern hemlock stands after the introduction of the hemlock woolly adelgid (Orwig, 2002; Small et al., 2005). Small et al. (2005) found that communities previously dominated by eastern hemlock diverged after the introduction of the hemlock woolly adelgid, with different species replacing the hemlock on dry ledges (primarily *Quercus velutina*) compared to in mesic ravines (mixed canopy dominance). In the southern Appalachians, Graham (2008) suggested that *Acer*, *Quercus*, *Fagus*, or *Betula* species will replace eastern hemlock in the canopy. Alternatively, Nuckolls et al. (2009) put forth two potential trajectories for eastern hemlock replacement: *Rhododendron maximum* may limit the growth of new canopy species when it has a high initial cover value in the subcanopy. Early successional tree species such as *A. rubrum*, *B. lenta*, and *Liriodendron tulipifera* may replace the hemlock when *R. maximum* does not have high cover. Finally, Kincaid (2007) also suggested that many eastern hemlock stands will become monocultures of *R. maximum*, but recognized that *Acer* spp., *Betula* spp., *Fagus grandifolia*, and *Halesia carolina* may establish in the canopy also.

The herb community composition is also expected to change with the introduction of the hemlock woolly adelgid. The increased light availability, increased nitrogen cycling, higher pH, and decreased moisture may alter the species poor communities commonly found under eastern hemlock. Small et al. (2005) found an increase in herb species richness after the introduction of the hemlock woolly adelgid. They found an increase in species richness from 25 to 38 species and an increase in frequency of herb presence from 64% to 89% (Small et al., 2005). Evidence also indicates that invasive species such as *Berberis thunbergii*, *Celastrus orbiculatus*, *Lonicera japonica*, and *Microstegium vimineum* may benefit from the changing environment (Orwig and Foster, 1998; Small et al., 2005).

The decline of eastern hemlock in plant communities may affect more than just vascular plant species (Evans et al., 1996). Bryophytes have increased in species richness after the thinning caused by hemlock woolly adelgid; especially those species that benefit from the increased nitrogen cycling (Cleavitt et al., 2008). Deer, however, may decline because of the loss of evergreen cover and food sources (Lishawa et al., 2007). In the northern Appalachians multiple studies have concluded that bird communities will be profoundly affected by the loss of structural diversity in eastern forests (Benzinger, 1994b; Tingley et al., 2002; Ross et al., 2004). Finally, terrestrial insects associated with eastern hemlock communities may be threatened by the hemlock decline (Dilling et al., 2007).

(5) Predictions for the southern Appalachians

Our current knowledge of the impact of the hemlock woolly adelgid leads to several predictions. First, eastern hemlock will decline quickly, starting with the small diameter hemlocks. The initial dominance values of eastern hemlock should not influence eastern hemlock mortality, similar to the findings by Orwig et al. (2002). Other species will increase in density or importance as the hemlock declines, the most likely candidates being *Betula lenta*, *Acer rubrum*, and

Rhododendron maximum. Dispersal ability and initial forest composition will influence which species replace the hemlock. Those areas with very high eastern hemlock cover will have more openings than mixed hemlock-hardwood forests. The initial presence of a high *R. maximum* cover may also have a significant determinative effect on eastern hemlock replacement because *R. maximum* limits hardwood recruitment.

Second, eastern hemlock mortality is not expected to be affected by old-growth compared to second-growth forest stage. However, the species richness response is expected to differ between old-growth and second-growth forests. Old-growth eastern hemlock forests often have initially low species richness because of their dense shade and low nutrient availability. As the canopy opens up, the species richness in old growth should increase because of the increased light and the somewhat more transient increase in nitrogen availability. Second-growth eastern hemlock forests may not show as large a response to the hemlock woolly adelgid. Second-growth forests often have a mixed canopy composition and the decline of eastern hemlock will not cause as significant a change in light availability at the forest floor. Instead, second-growth hemlock forests may respond less dramatically to gap-phase dynamics as the individual hemlocks die and open up smaller gaps in the canopy. As these gaps are continually occurring and filling up in second-growth forests, the species richness may not increase over larger scales as a result of the hemlock woolly adelgid.

CHAPTER 2

METHODS

(1) Field Sites

During 2004 and 2005, twenty eight eastern hemlock plots were reinventoried in the southern Appalachians. The reinventory was conducted in Ellicott Rock Wilderness, Joyce Kilmer Memorial Forest, and Cataloochee Valley. Ellicott Rock Wilderness and Joyce Kilmer Memorial Forest are in the Nantahala National Forest in western North Carolina. Cataloochee Valley is located in the eastern side of Great Smoky Mountains National Park, also in western North Carolina. These locations cover a wide geographic range in the southern Appalachians. Tables 1 and 2 provide the elevation, slope, and aspect for all of the inventoried plots, and a map of the reinventoried plots is presented in Figure 3.

The reinventoried plots were originally inventoried between 1990 and 1998 by other investigators. The Ellicott Rock Wilderness plots were inventoried by Karen Patterson (Patterson, 1994), the Joyce Kilmer Memorial Forest plots by Claire Newell (Newell, 1997), and the Cataloochee Valley plots by Dan Pittillo, Aaron Cooper, and Larissa Knebel (Cooper, 1999; Knebel, 1999). These researchers included their data in the Carolina Vegetation Survey ("CVS") database, a database of vegetation plots collected throughout North and South Carolina. Plots were selected from the CVS

for reinventory based on multiple criteria. Initially, the criteria included a 1000 m² plot size in the mountains of North Carolina and a cover value of greater than 25% for eastern hemlock. When relocating a sufficient number of plots under these restrictions proved difficult, the criteria were broadened to include plots with a cover value of greater than 5% for eastern hemlock.

The Carolina Vegetation Survey protocol (Peet et al., 1998) was used for both the original inventory and reinventory. Plot corners were relocated using a metal detector to locate the permanent metal stakes marking the boundaries. If a metal stake could not be located, that corner was not used for intensively inventoried modules. This was done because exact location was necessary for accurate comparisons of small scale species richness. The reinventory date was selected to be close to the original sampling so that phenology would be similar.

Plots are 20 m by 50 m, separated into ten 10 m by 10 m modules. Peet et al. (1998) describe the general plot layout (Figure 1).

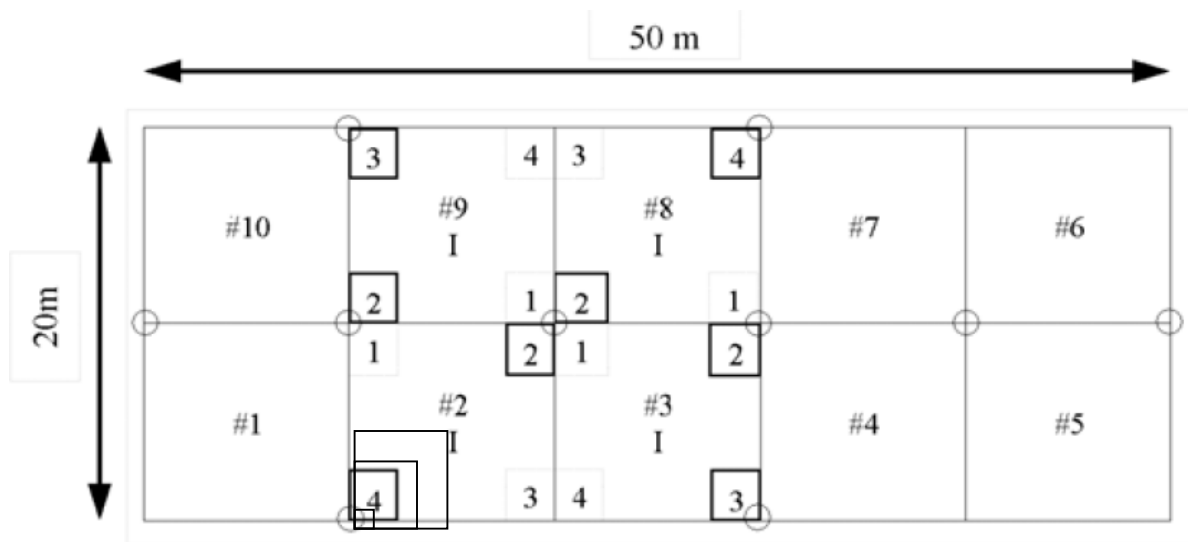


Figure 1: Carolina Vegetation Survey plot layout from Peet et al. (1998).

Modules 2, 3, 8, and 9 are intensively inventoried modules for which species richness and cover values for every species in the module are calculated in nested, log-linearly increasing grain sizes. Figure 1 illustrates the nested grain sizes from corner 4 in intensively inventoried module 2 above. The smallest grain size is 10 cm by 10 cm, or 0.01 m²; the grain sizes increase exponentially. The increasing grain sizes are 0.01 m², 0.1 m², 1 m², 10 m², and 100 m². The entire plot is 1000 m².

Plants are identified to species starting with the smallest grain size and continuing to the entire module. Once a species is present in a smaller grain size it will also be considered present for a larger encompassing grain size. Cover is evaluated for each species based on its cover in the entire module. Plants are also identified in the non-intensive, or residual, modules and a cover value for the species in the entire plot is recorded. To ensure accurate comparisons of species richness and composition between sample periods, all species nomenclature was standardized to conform to Radford et al. (1968).

Cover was visually estimated for each species in every plot based on the 10-point CVS scale (1 = trace, 2 = 0 – 1%, 3 = 1 – 2%, 4 = 2 – 5%, 5 = 5 – 10%, 6 = 10 – 25%, 7 = 25 – 50%, 8 = 50 – 75%, 9 = 75 – 95%, 10 or * = 95 – 100%). Each point in the scale includes a range of cover, which is an estimate of the plot surface area covered by a species. Overlapping cover values are allowed because species overlap in a plot and the total cover in the plot can sum to more than 100%. The geometric mean of the cover values was calculated to determine a single cover value for any species present in an intensively inventoried module. Species present in only the residual modules only received a single cover value estimate for the entire plot and no calculation was necessary.

Woody species diameter for all species was estimated at breast height (1.37 m) using a biltmore stick for individuals less than 40 cm diameter at breast height (“dbh”) and a diameter tape for individuals greater than 40 cm dbh. Individuals below 40 cm dbh were placed into one of ten size classes (0 – 1 cm, 1 – 2.5 cm, 2.5 – 5 cm, 5 – 10 cm, 10 – 15 cm, 15 – 20 cm, 20 – 25 cm, 25 – 30

cm, 30 – 35 cm, and 35 – 40 cm) whereas dbh for all individuals greater than 40 cm dbh was rounded downward to the nearest centimeter.

The plot-level data were collected by the original investigator. Latitude and longitude were confirmed using a handheld GPS during reinventory. All of the original investigators had their soil samples analyzed by Brookside Laboratories, New Knoxville, Ohio. The resulting soil measurements and other original measurements including elevation, slope, Landform Index, and Terrain Shape Index were applied to analyses for both the original data and the reinventoried data. Landform Index (LFI) is a metric that quantifies the relationship of a plot to the surrounding landscape (McNab, 1992). It relates to slope position and is associated with a simple landform classification: ridge, slope, and cove (McNab, 1992). Terrain Shape Index (TSI) is a metric that quantifies topographic position of a plot compared to its local surroundings (McNab, 1989). The metric usually varies from -1 to +1 within forest sites, corresponding to a shift from convex to concave topographic shape (McNab, 1989). Local topographic shape can be a proxy measurement for moisture availability as concave sites may be wetter than convex sites. TSI is a finer scale measure of topographic position than LFI and has proven effective in predicting the occurrence of species requiring mesic conditions (Abella, 2003).

The field sites were also categorized as old growth or second growth based on field site inspections. Factors that influenced the classification as one stage or another included the presence of cut logs or stumps in the plot, canopy tree size, and location near roads. The distinction between old growth and second growth has been questioned in the literature. Woods (2000a) preferred late successional because of continuing disturbance regimes and lack of stability in structural characteristics of non-logged forests. Nevertheless, old growth was used as a category to describe plots because of its common use in conservation practices. The plots included fifteen old-growth plots and thirteen second-growth plots.

The reinventoried plots were also compared to two subsets of CVS plots selected to represent a wide range of eastern hemlock communities. The CVS plots were originally inventoried before the introduction of the hemlock woolly adelgid. The selection criteria were the same as for the reinventoried plots: 1000 m² plot size, in the mountains of North Carolina, with an eastern hemlock cover value of at least 5%. Originally the selection criteria required a hemlock cover value of at least 25%. When it proved difficult to locate sufficient number of plots, the selection criteria were changed to greater than 5% eastern hemlock cover. The two CVS subsets used for comparison correspond to these two sets of selection criteria. CVS plots with a cover class for eastern hemlock ≥ 5 include a CVS subset of 114 plots with greater than 5% eastern hemlock cover. CVS plots with a cover class for eastern hemlock ≥ 7 include a CVS subset of 77 plots with greater than 25% eastern hemlock cover.

The CVS subsets chosen for reinventory came from three different research studies, but the goal of each was similar: to characterize local vegetation composition. The Cataloochee Valley plots were inventoried “to learn more about the role of *Tsuga canadensis* in hemlock forests of the Great Smoky Mountains National Park” (Knebel, 1999). The purpose of the Patterson research was to classify vegetation in Ellicott Rock Wilderness of the southeastern Blue Ridge Escarpment (Patterson, 1994). The eastern hemlock plots inventoried by Newell (1997) in Joyce Kilmer Memorial Forest were part of a larger effort “to develop a regional synthesis of variation in forest composition.” As the plots were originally selected to be representative of the range of eastern hemlock communities, they come from a wide range of elevation and topographic positions, and have a wide range of eastern hemlock dominance. While these three locations do not cover the entire geographic and environmental range of eastern hemlock in the Southern Appalachians, they do provide a starting part for analyzing the effect of the hemlock woolly adelgid in the region.

(2) Data Analysis

Dominance values were calculated for selected species in the plots. These were absolute density (stems/ha) and absolute basal area (m²/ha). Relative density and relative basal area were also calculated by summing the absolute density and absolute basal area of every woody species in a plot and calculating the value for each species as a percent of all species in the entire plot. Finally importance value was calculated as an average of the relative density and relative basal area.

Diversity indices were calculated in PC-Ord 5.0. The Shannon diversity index was calculated based on the formula:

$$H' = - \sum_{i=1}^s p_i \log p_i$$

The Simpson diversity index was calculated based on the formula:

$$D = 1 - \sum_{i=1}^s p_i^2$$

Change in dominance values from pre-adelgid to post-adelgid were tested for significance with paired t-tests. In paired t-tests, results are matched in pairs and the outcomes are compared within each matched pair (Moore and McCabe, 1993; Reilly et al., 2006). Comparisons between paired values at different sampling dates are presented as bar graphs with standard error bars. Tests for significance compare the change from time A to time B. Paired t-tests were calculated in Excel 2007 and significance is reported at the 95% confidence level.

Non-metric multidimensional scaling ordinations (NMS) were conducted in autopilot mode in PC-ORD 5 to array plots in ordination space (McCune and Mefford, 1999). Cover values were used as a measure of species abundance in all ordinations. Sorenson distance was used as a measure of plot similarity and species occurring less than three times in the dataset were excluded from the ordination so that they would not distort the results. NMS ordination can be used to “detect

differences in species composition among treatments and among time periods” (Vidra et al., 2007). Here, the treatments being compared included by project and old growth compared to second growth. The time periods being compared were pre-adelgid compared to post-adelgid.

Figure 2 is an NMS ordination of the reinventoried plots grouped by location. It is presented here as an example of NMS ordinations and to show that grouping of plots occurred by field site. Two dimensions were appropriate, the cumulative R^2 for both axes was 0.84, and the orthogonality was 98.4%.

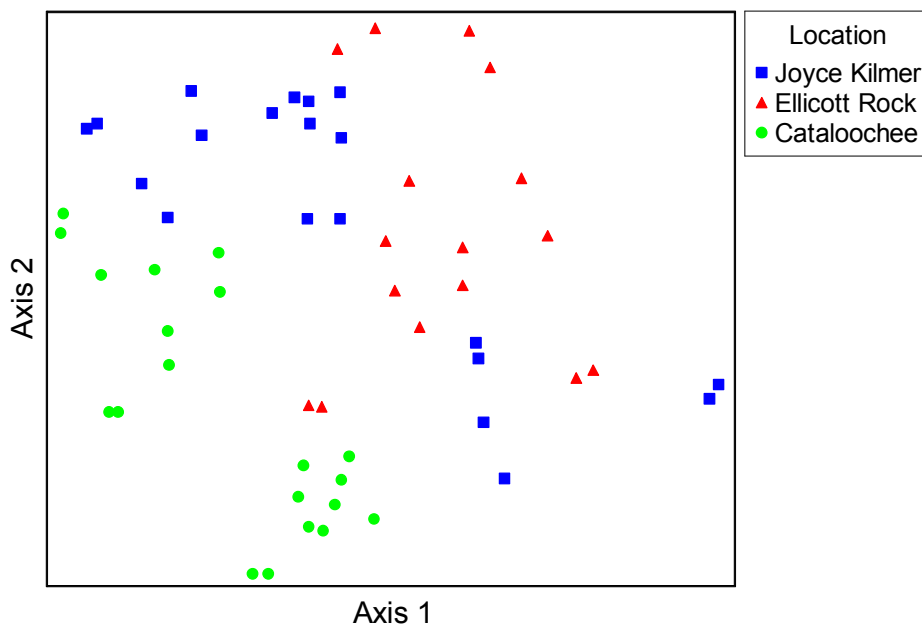


Figure 2: NMS ordination of reinventoried plots showing Joy Kilmer, Ellicott Rock, and Cataloochee Valley plots.

Grouping by field site can limit the effectiveness of analyses that combine field sites inappropriately. Analysis of covariance (ANCOVA) in SPLUS 8.0 was used to determine if a single regression could be used to analyze data across multiple field sites. Analysis of Covariance tests whether the regressions for multiple sites were coincident (had the same slope and y-intercept). If

the regressions are coincident, the sites can be combined into a single regression (Riggs et al., 2008; Kleinbaum et al., 1998). If the regressions are not coincident, sites need to be separated into their own regression analyses. The ANCOVA analysis is performed using the following regression model:

[Dependent variable ~ site + independent variable + site*independent variable]

The significance of the interaction term (site*independent variable) determines whether the regressions have equal slopes. If the slopes of the regressions are equal, a second model is necessary to determine if the regressions also have the same y-intercept. This model is:

[Dependent variable ~ site + independent variable]

If the results of this model indicate that both the site and the independent variable are non-significant then the regressions are coincident and can be combined into a single regression. If the results of this model indicate that the site is significant and the independent variable is non-significant, then the model is only based on site and the independent variable is not significantly correlated with the dependent variable. Finally, if the site is not significant but the independent variable is significant, then the lines have equal slopes but a different y-intercept.

Linear regressions were performed in SPLUS 8.0 to determine whether environmental variables were correlated with changes in eastern hemlock dominance, species richness, and changes in species richness.

CHAPTER 3

RESULTS

(1) Are the reinventoried plots representative of southern Appalachian eastern hemlock plots?

A. Location of the reinventoried plots

Table I displays the plot number, the initial sampling date, the reinventory date, general location, elevation, slope, aspect, LFI, and TSI for the fifteen old-growth plots. Table II indicates the same information for the thirteen second-growth plots. Note that old-growth forests were only inventoried in Joyce Kilmer and Cataloochee Valley. Second-growth forests were present in all three sampling locations.

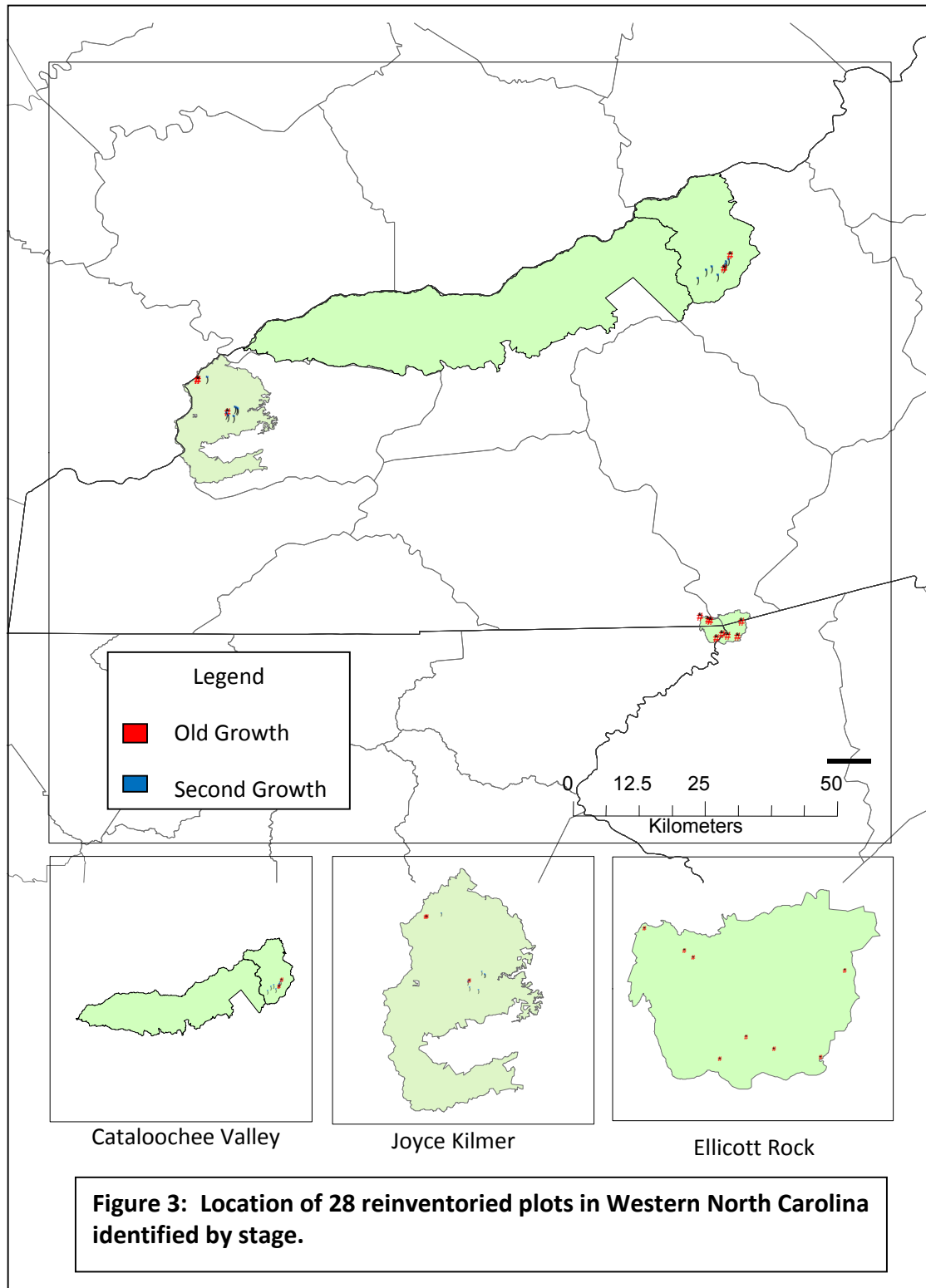
Initial Plot ID	General Location	Initial Sampling Date	Reinventory Date	Elev (m)	Slope	Aspect	LFI	TSI
012-0C-501	Joyce Kilmer	5/22/1994	6/2/2004	864	15	212	0.32	0.01
012-0C-507	Joyce Kilmer	5/26/1994	6/18/2004	940	26	238	0.20	0.00
012-0C-513	Joyce Kilmer	6/3/1994	6/3/2004	715	13	188	0.36	0.00
012-0C-514	Joyce Kilmer	6/3/1994	6/4/2004	761	8	105	0.42	-0.03
012-0C-525	Joyce Kilmer	6/13/1994	6/7/2004	800	13	354	0.29	-0.08
012-0C-629	Joyce Kilmer	8/19/1994	8/21/2004	785	32	38	0.30	-0.03
012-0C-684	Joyce Kilmer	8/9/1997	8/20/2004	764	15	47	0.29	0.04
071-01-0008	Cataloochee	6/17/1998	7/12/2005	1196	22	300	-0.01	0.06
071-01-0016	Cataloochee	7/7/1998	7/14/2005	893	30	215	0.00	0.10
071-01-0017	Cataloochee	7/8/1998	7/15/2005	1031	14	260	0.13	0.17
071-01-0018	Cataloochee	7/9/1998	7/19/2005	869	22	100	0.06	0.17
071-01-0025	Cataloochee	7/29/1998	8/2/2005	930	20	315	0.00	0.10
071-01-0028	Cataloochee	8/4/1998	8/3/2005	954	6	316	-0.04	0.01
071-01-0029	Cataloochee	8/5/1998	8/3/2005	893	6	282	0.12	0.18
071-01-0036	Cataloochee	8/22/1998	8/19/2005	872	23	310	0.03	0.13

Table I: Plot characteristics for fifteen old-growth plots in the Southern Appalachian Mountains inventoried before and after the introduction of the hemlock woolly adelgid.

Initial Plot ID	General Location	Initial Sampling Date	Resampling Date	Elev (m)	Slope	Aspect	LFI	TSI
012-0C-519	Joyce Kilmer	6/8/1994	6/19/2004	612	1	30	0.36	0.00
012-0C-520	Joyce Kilmer	6/8/1994	6/20/2004	630	29	291	0.45	0.05
012-0C-522	Joyce Kilmer	6/9/1994	6/8/2004	754	26	239	0.36	0.01
013-0K-0001	Ellicott Rock	7/10/1990	5/28/2004	899	21	70	0.08	-0.05
013-0K-0002	Ellicott Rock	7/11/1990	5/17/2004	701	28	224	0.26	-0.03
013-0K-0004	Ellicott Rock	7/17/1990	5/22/2004	634	1	300	0.23	0.03
013-0K-0010	Ellicott Rock	7/28/1990	5/25/2004	866	30	120	0.20	0.05
013-0K-0011	Ellicott Rock	7/30/1990	5/21/2004	638	1	272	0.27	0.10
013-0K-0016	Ellicott Rock	8/8/1990	5/20/2004	860	19	316	0.22	0.07
013-0K-0022	Ellicott Rock	6/24/1991	5/27/2004	808	3	330	0.24	0.11
013-0K-0033	Ellicott Rock	7/9/1991	5/24/2004	872	11	31	0.10	0.02
071-01-0033	Cataloochee	8/17/1998	8/18/2005	841	21	53	0.04	0.14
071-01-0041	Cataloochee	9/24/1998	10/16/2005	818	1	60	0.00	0.03

Table II: Plot characteristics for thirteen second-growth plots in the Southern Appalachian Mountains inventoried before and after the introduction of the hemlock woolly adelgid.

Figure 3 is a map showing the location of all plots in the southern Appalachians. The hemlock woolly adelgid would have first dispersed to the northeastern most corner, Cataloochee Valley, if it gradually dispersed southward from Virginia. Joyce Kilmer Memorial Forest is approximately 50 miles west-southwest of Cataloochee Valley. Ellicott Rock is approximately 45 miles south of Cataloochee. Joyce Kilmer and Ellicott Rock are approximately 55 miles apart.



B. Environmental variables comparison between the reinventoried plots and the CVS plots.

The old-growth plots range in elevation from 715 – 1196 m, range in slope from 6 – 32 degrees, and have a wide range of aspects. The second-growth plots range in elevation from 612 – 899 m, range in slope from 1 – 30 degrees, and also have a wide range of aspects. These ranges are similar to those of the eastern hemlock plots in the CVS survey data, which range in elevation from 335 – 1603 m, range in slope from 0 – 45 degrees, and have a wide range of aspects. The soil variable values were also within the range of the CVS survey data. Soil variables relevant to later analyses include pH and nitrogen. In old-growth plots, pH ranged from 3.425 – 5.05 and nitrogen ranged from 60.25 – 123.25 ppm. In second-growth plots, pH ranged from 4.1 – 6.125 and nitrogen ranged from 25.75 – 124.5 ppm. In the CVS plots, pH ranged from 3.275 – 6 and nitrogen ranged from 27.25 – 103 ppm. See Appendix A for all of the soil nutrient data for the reinventoried plots.

Old-growth and second-growth plots differ in elevation. The old growth average elevation is 884 meters compared to 764 meters for second growth. This is the result of two outliers in Cataloochee Valley: plot 071-01-0017 at 1031 meters and plot 071-01-0008 at 1196 meters. Both have low species richness and are dominated by very large eastern hemlocks. They are representative of old-growth eastern hemlock stands in the southern Appalachians and will be included in the old-growth analyses.

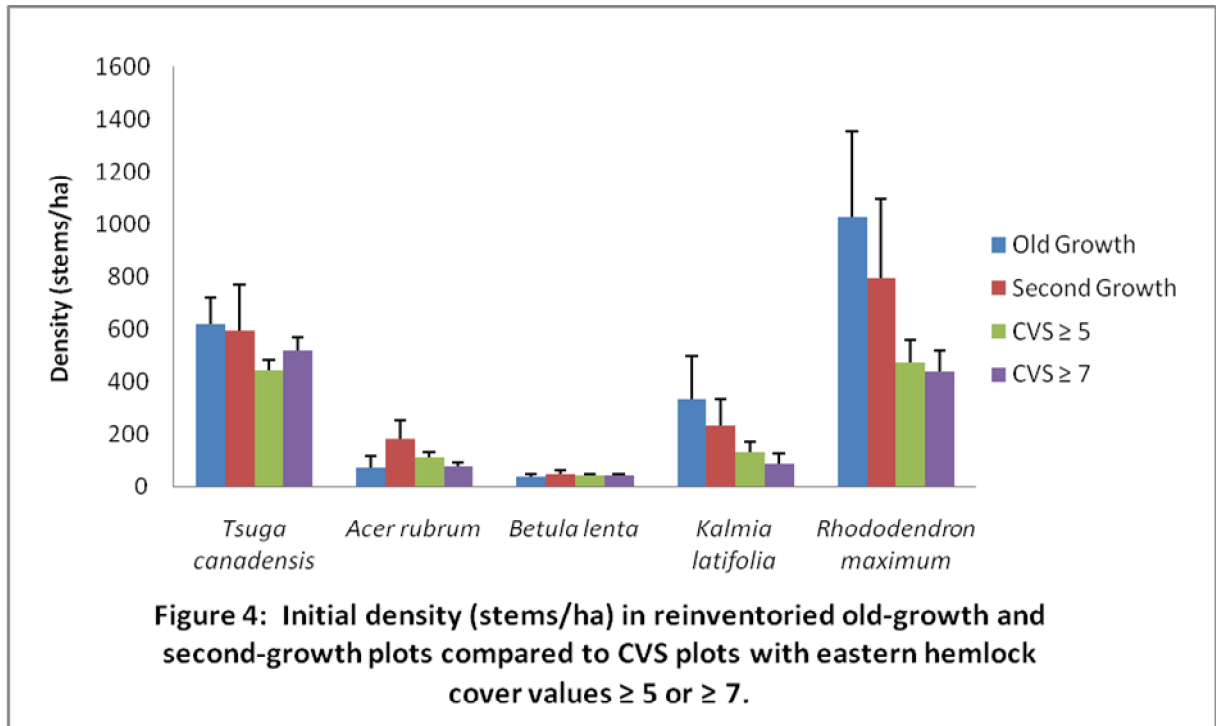
C. Dominant species comparison between the reinventoried plots and the CVS plots.

Dominance values for important species provide another basis for determining whether or not the reinventoried plots are representative of southern Appalachian eastern hemlock forests. These dominance values include absolute density (stems/ha), relative density (%), absolute basal area (m^2/ha), relative basal area (%), importance value (%), and density of stems < 2.5 cm dbh

(stems/ha). The dominant species characterized in these plots are *Tsuga canadensis*, *Acer rubrum*, *Betula lenta*, *Kalmia latifolia*, and *Rhododendron maximum*. These species were chosen because they have been shown to have important effects on community composition (*T. canadensis*, *K. latifolia*, *R. maximum*) or they have been proposed as canopy replacements for *T. canadensis* after the introduction of the hemlock woolly adelgid (*A. rubrum* and *B. lenta*). The reinventoried plot data are compared to species data from two CVS data subsets.

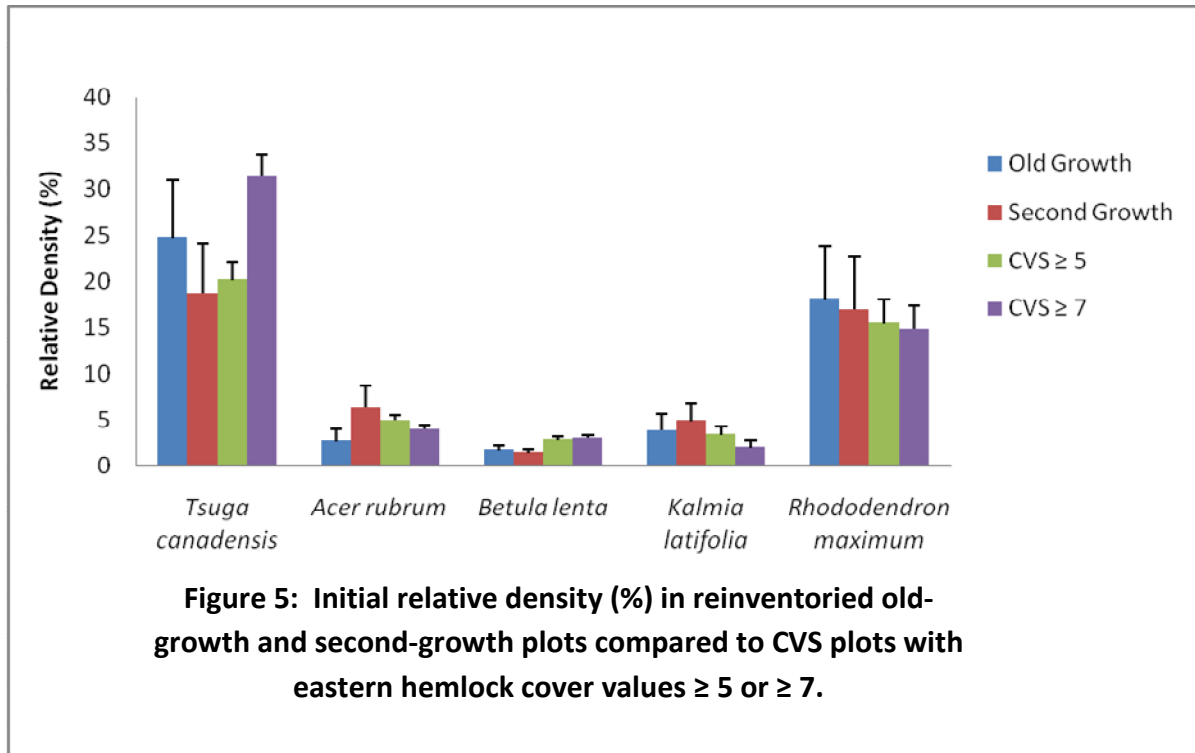
i. Density

The absolute density values for the selected species are presented in Figure 4. The reinventoried old-growth and second-growth plots have a similar density for *T. canadensis*, *A. rubrum*, *B. lenta*, and *K. latifolia*. Only *R. maximum* shows large differences between the reinventoried plots and the CVS plots. These differences are not statistically significant. *Tsuga canadensis* has a higher density than *A. rubrum* and *B. lenta*, as expected based on the selection criteria. *Betula lenta* is present at very low densities in the southern Appalachians compared to the ericaceous shrubs.



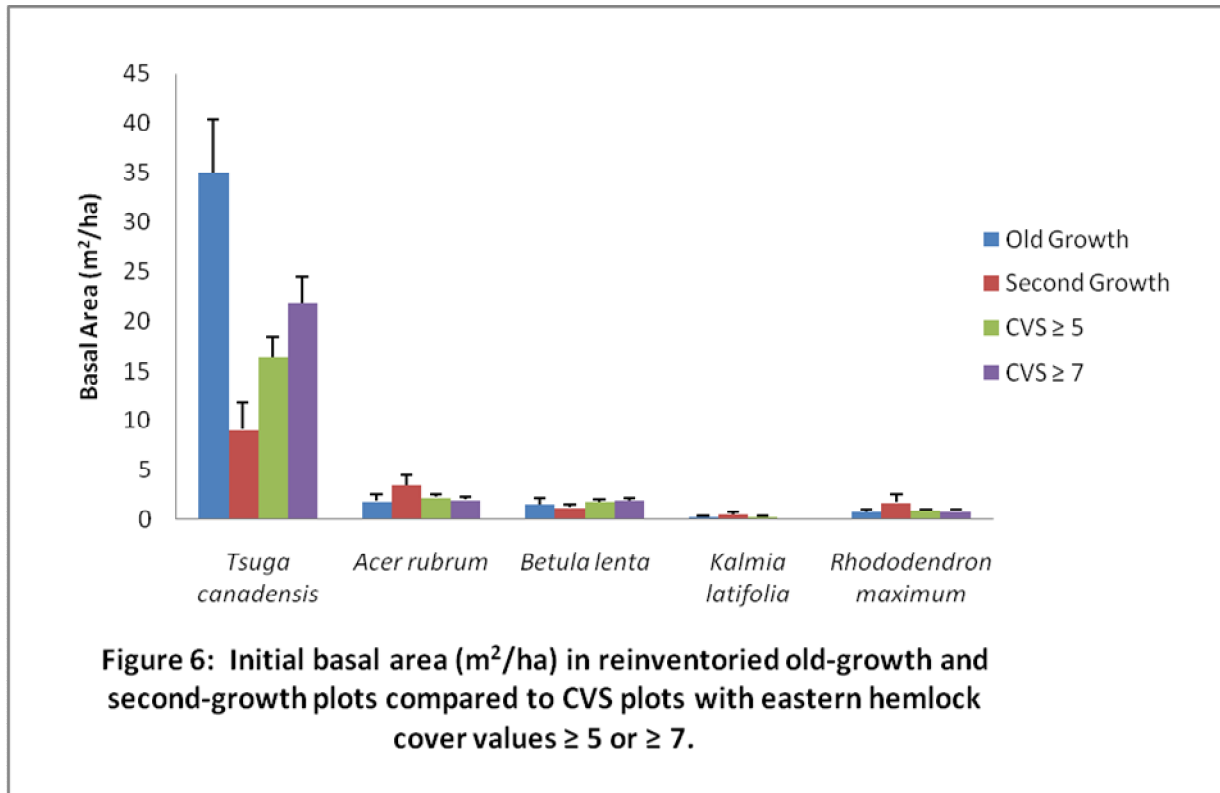
ii. Relative Density

The relative density values of the selected species for old growth and second growth are presented in Figure 5. Again, the reinventoried plots have very similar relative density for all selected species when compared to one another and to both subsets of CVS plots. *Tsuga canadensis* varies in relative density from 19% in reinventoried second-growth forests to 31% in CVS plots with ≥ 7 cover of eastern hemlock. *Acer rubrum* and *B. lenta* have very low relative densities in comparison to *T. canadensis*. Finally, *R. maximum* has very similar relative densities among the reinventoried plots and the CVS plots.



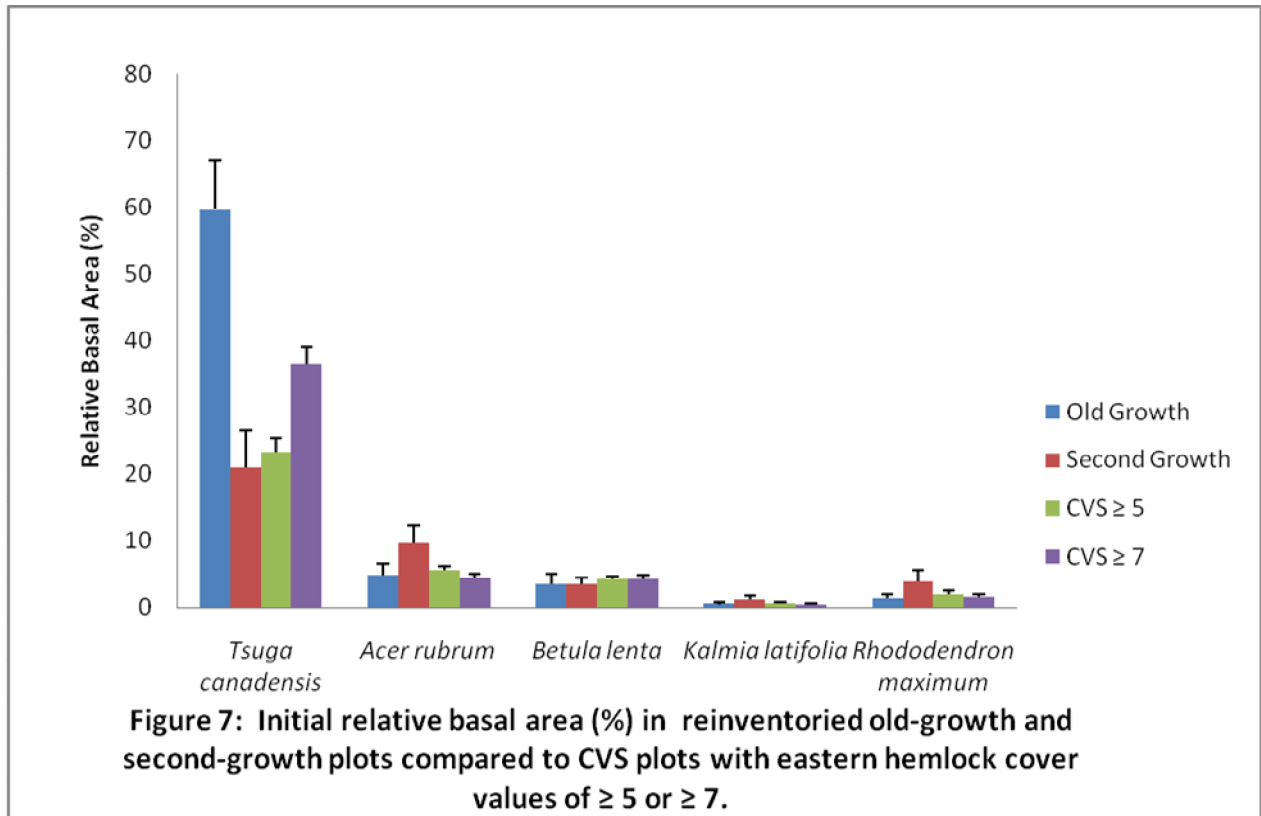
iii. Absolute Basal Area

Figure 6 presents the absolute basal area of the reinventoried plots and the CVS subsets. There is a wide range of basal area, especially for *Tsuga canadensis*. Reinventoried old-growth plots have the highest *T. canadensis* basal area at 35 m²/ha and reinventoried second growth plots have the lowest basal area at 9 m²/ha. This large difference in *T. canadensis* basal area illustrates the significant differences in the reinventoried plot categories. The old-growth plots were dominated by large eastern hemlocks with few other large trees. The second-growth plots often had a mixed canopy of hemlock and hardwoods and had fewer trees > 40 cm in diameter. In both old-growth and second-growth plots, and in the CVS subsets, species other than hemlock had very small basal area compared to the hemlock. This is largely because of the selection criteria for plots. The ericaceous shrubs have small absolute basal areas because they do not grow to large diameters compared to the canopy species in the plots.



iv. Relative Basal Area

The relative basal areas of the selected species are presented in Figure 7. A pattern similar to that of absolute basal area values is apparent. Reinventoried old-growth plots are thoroughly dominated by eastern hemlock, with a relative basal area value of 60%. Reinventoried second-growth plots only had a relative basal area value of 20%. This large difference is another example of the dominance differences between the old-growth and second-growth plots. Even the reinventoried second-growth plots, however, have eastern hemlock as the highest relative basal area of any of the selected species. *Acer rubrum* and *B. lenta* are less than 5% of the basal area in any of the categories. The ericaceous shrubs, while present in large numbers in the plots (see Figure 4 and Figure 5), are not a large percentage of the basal area covered by plants in the plots.



v. *Importance Value*

The importance values for the selected species are presented in Figure 8. As the importance value is an average of the relative density and relative basal area, many of the similar patterns seen previously will also be represented here. The reinventoried old-growth plots have a similar eastern hemlock importance value to the CVS plots with ≥ 7 hemlock cover. The high values are largely because of the greater relative basal area for eastern hemlock in old-growth and high cover plots. The other selected species have very similar importance values for both reinventoried sets and the CVS subsets.

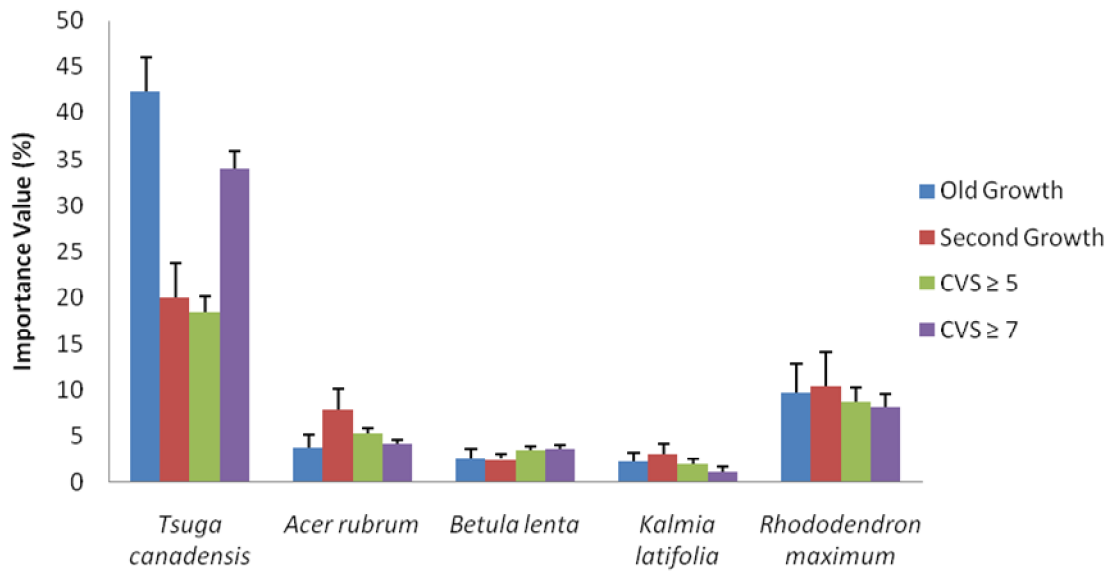
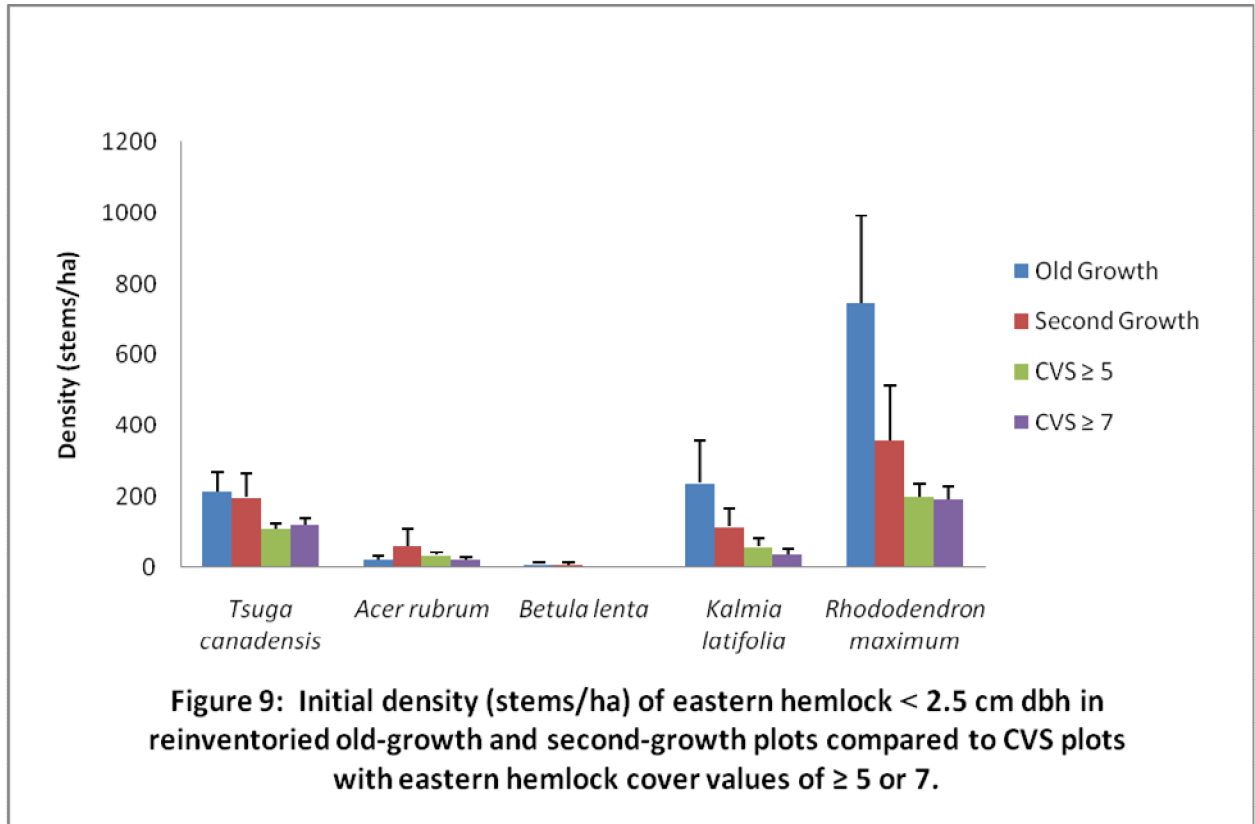


Figure 8: Initial importance value (%) in reinventoried old-growth and second-growth plots compared to CVS plots with eastern hemlock cover values of ≥ 5 or ≥ 7 .

vi. *Absolute density of 0 - 2.5 cm dbh individuals*

Density, basal area, and importance values are influenced by individuals in all size classes. As indicated by previous research in the Northeast, the impact will likely be seen in the small size classes first. Small et al. (2005) reinventoried plots in the Northeast five years after the appearance of the hemlock wooly adelgid and found low mortality. Fifteen years after infestation, however, there were few hemlocks of any size still living. Figure 9 presents the absolute density of 0 – 2.5 cm dbh stems (stems/ha) for the selected species in the reinventoried old-growth and second-growth plots and in the CVS subsets. The reinventoried plots have a higher density of small hemlocks than the CVS subsets, but the standard error makes the difference non-significant. The reinventoried old-growth plots stand out as having a high density of both *K. latifolia* and *R. maximum*. There are very few small *B. lenta* individuals in any of the categories. Small *A. rubrum* individuals are present at

higher density than the *B. lenta* saplings, especially in second-growth plots. Based on these results, it is possible that *R. maximum* and *A. rubrum* will be more likely to replace eastern hemlock than *B. lenta*.



vii. Change in dominance values after the introduction of the hemlock woolly adelgid.

The dominance values shown in Figures 4 – 9 were calculated before the introduction of the hemlock woolly adelgid. Table III shows these average values and standard errors as well as the post-adelgid dominance values for the reinventoried old-growth and second-growth plots. The abbreviations “pre” and “post” for the selected species indicate whether the dominance values are from before the introduction of the hemlock woolly adelgid or after its introduction. The only significant changes are the decreased density of < 2.5 cm dbh eastern hemlocks in both old-growth and second-growth plots.

Dominance Value	<i>T. canadensis</i> , pre	<i>T. canadensis</i> , post	<i>A. rubrum</i> , pre	<i>Acer rubrum</i> , post	<i>B. lenta</i> , pre	<i>B. lenta</i> , post	<i>K. latifolia</i> , pre	<i>K. latifolia</i> , post	<i>R. maximum</i> , pre	<i>R. maximum</i> , post
Density (stems/ha), old growth	618 ± 105	541 ± 76	75 ± 42	54 ± 35	39 ± 12	33 ± 10	331 ± 169	315 ± 147	1031 ± 323	1125 ± 328
Density (stems/ha), second growth	596 ± 176	552 ± 162	186 ± 69	145 ± 54	51 ± 14	47 ± 12	234 ± 98	223 ± 93	796 ± 302	602 ± 212
Relative Density (%), old growth	24.74 ± 6.15	22.58 ± 5.48	2.61 ± 1.39	1.43 ± 0.74	1.62 ± 0.52	1.24 ± 0.45	3.81 ± 1.87	4.47 ± 2.25	18.05 ± 5.83	21.07 ± 6.08
Relative Density (%), second growth	18.72 ± 5.41	20.39 ± 5.73	6.26 ± 2.48	4.56 ± 1.61	1.35 ± 0.39	1.44 ± 0.40	4.86 ± 1.92	4.72 ± 1.93	16.90 ± 5.91	17.62 ± 6.37
Basal area (m ² /ha), old growth	34.95 ± 5.40	36.81 ± 5.50	1.83 ± 0.73	1.44 ± 0.54	1.50 ± 0.64	1.62 ± 0.64	0.25 ± 0.12	0.28 ± 0.13	0.77 ± 0.24	0.72 ± 0.21
Basal area (m ² /ha), second growth	9.08 ± 2.73	11.60 ± 2.40	3.47 ± 0.96	9.55 ± 5.27	1.22 ± 0.32	2.00 ± 0.52	0.48 ± 0.23	0.49 ± 0.18	1.72 ± 0.83	1.91 ± 0.71
Relative Basal Area (%), old growth	59.69 ± 7.32	61.50 ± 7.24	4.80 ± 1.81	3.71 ± 1.51	3.47 ± 1.55	3.51 ± 1.44	0.50 ± 0.25	0.51 ± 0.23	1.44 ± 0.54	1.15 ± 0.35
Relative Basal Area (%), second growth	21.05 ± 5.46	24.45 ± 5.11	9.60 ± 2.66	10.18 ± 3.14	3.49 ± 1.05	4.50 ± 1.70	1.22 ± 0.53	1.06 ± 0.42	3.79 ± 1.77	2.93 ± 1.06
Importance Value (%), old growth	42.22 ± 3.76	42.04 ± 3.74	3.70 ± 1.46	2.57 ± 1.09	2.54 ± 0.99	2.38 ± 0.93	2.16 ± 1.04	2.49 ± 1.23	9.75 ± 3.10	11.11 ± 3.20
Importance Value (%), second growth	19.88 ± 3.85	22.42 ± 3.74	7.93 ± 2.12	7.37 ± 2.24	2.42 ± 0.66	2.97 ± 0.98	3.04 ± 1.13	2.89 ± 1.07	10.34 ± 3.80	10.28 ± 3.62
Density <2.5cm dbh (stems/ha), old growth	213 ± 53	112 ± 41	21 ± 12	10 ± 6	9 ± 6	11 ± 6	237 ± 121	198 ± 94	745 ± 248	819 ± 260
Density <2.5cm dbh (stems/ha) second growth	197 ± 67	100 ± 42	62 ± 45	31 ± 20	7 ± 5	5 ± 4	113 ± 53	88 ± 40	358 ± 155	307 ± 135
Table III: Dominance values and standard error for <i>Tsuga canadensis</i>, <i>Acer rubrum</i>, <i>Betula lenta</i>, <i>Kalmia latifolia</i>, and <i>Rhododendron maximum</i> before and after the introduction of the hemlock woolly adelgid. The dominance values are density (stems/ha), relative density (%), basal area (m²/ha), relative basal area (%), importance value (%), and density of stems < 2.5 cm dbh (stems/ha).										

D. Species richness comparison between the reinventoried plots and the CVS plots.

Table IV includes a comparison of the average species richness, evenness, Shannon's Diversity Index, Simpson Diversity Index, and number of species present in more than three plots, for the reinventoried plots before and after the adelgid and for the CVS plot subset that has ≥ 5 cover class for eastern hemlock. These values were calculated in PC-ORD 5 using species lists that excluded species not present in more than three plots.

The average species richness is similar for all plots. Only second-growth plots have a significant decline from before the adelgid, average species richness = 52.8, to after the adelgid, average species richness = 43.7. The evenness and diversity indices for all plots are similar and support the proposition that the reinventoried plots are representative of the CVS plot subset.

The reinventoried plots before and after the adelgid have similar numbers of species present in more than three plots. The species count ranges from a high of 150 species present in old growth before the adelgid to 139 species present in second growth after the adelgid. The species counts between the reinventoried plots are not significantly different from one another. In contrast, the number of species present in more than three CVS plots with a cover value ≥ 5 for eastern hemlock is much larger at 281 species.

	Average Species Richness	Evenness	Shannon's Diversity Index	Simpson's Diversity Index	Number of species present in > 3 plots
Old Growth Pre-Adelgid	52.1	0.936	3.630	0.9634	150
Old Growth Post-Adelgid	51.2	0.941	3.647	0.9656	149
Second Growth Pre-Adelgid	52.8	0.937	3.674	0.9667	142
Second Growth Post-Adelgid	43.7	0.937	3.512	0.9628	139
CVS ≥ 5	49.1	0.943	3.583	0.9617	281

Table IV: Average species richness, evenness, diversity indices, and number of species present in > 3 plots for reinventoried plots and CVS plots. Calculated in PC-ORD 5.

E. Species composition comparison between the reinventoried plots and the CVS plots.

Non-metric multidimensional scaling ordinations were calculated in PC-ORD 5 using cover values and the Sorenson distance measure on autopilot mode. As described in the methods, this ordination arranges plots along axes of compositional variation that can be examined for trends in environmental setting and species occurrence. Figure 10 is an NMS ordination of 173 plots and 281 species from 11 projects in the Carolina Vegetation Survey, including the original and reinventoried plot data from this study. The plots included in this ordination are spread throughout western North Carolina, have an eastern hemlock cover value of at least 5, and were inventoried before the introduction of the hemlock woolly adelgid. The species included in the ordination are present in at least three plots; all species that were present from less than three plots were excluded from the analysis to prevent them from distorting the results. The secondary matrix contains 24 environmental variables collected during the original sampling of the plot including elevation, slope, aspect, TSI, LFI, pH, CEC, 1000 m² species richness, and 15 soil nutrient measurements (see Appendix A for a listing of all nutrient data).

The results indicate that a two-dimensional ordination is most appropriate. The first axis explained 51.2% of the variation and the second axis explained 28.3%. Cumulatively, the two axes explained 79.5% of the variation. The orthogonality of Axis 1 and Axis 2 was 93.1%

Vectors representing eleven environmental correlated with the compositional variation at an $R^2 > 0.1$ are displayed in figure 10. Axis 1 is correlated with species richness and cation availability, and Axis 2 is correlated with elevation. The reinventoried plots are spread throughout the CVS plots except for high species richness CVS plots on the left side of the ordination and high elevation CVS plots on the bottom of the ordination.

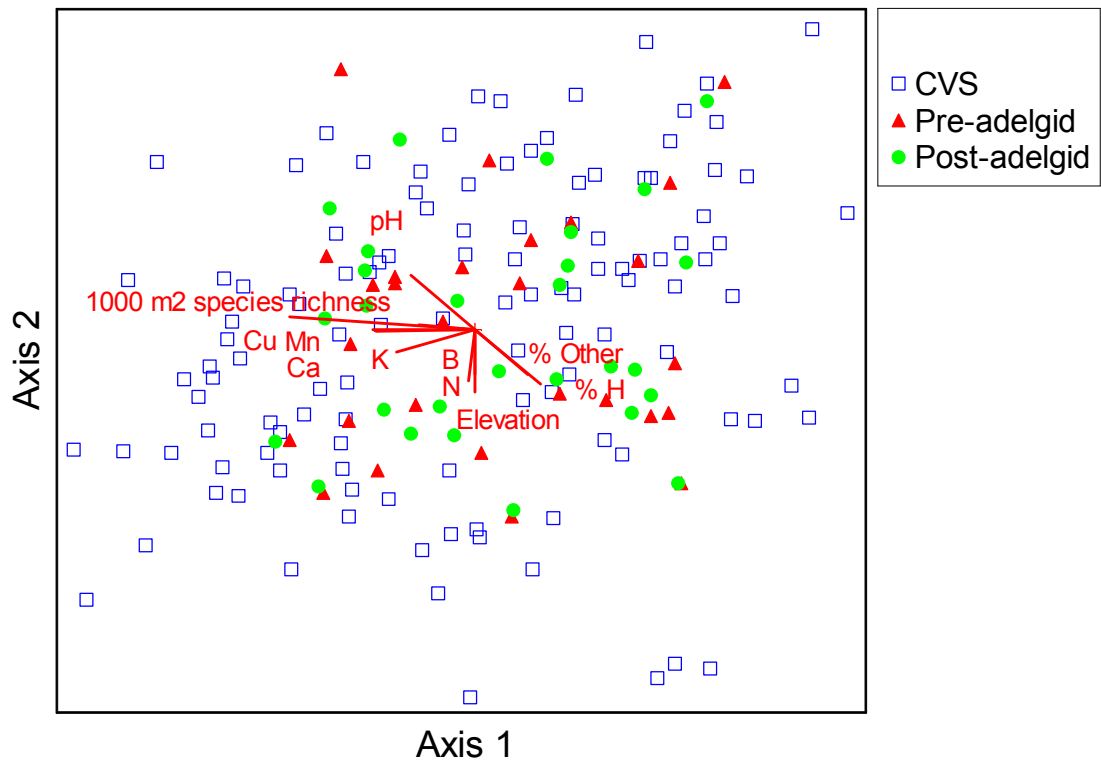


Figure 10: NMS Ordination of 173 plots with eastern hemlock cover values of ≥ 5 in 11 projects in western North Carolina, including the reinventoried plots pre and post-adelgid. The cumulative R^2 value for the first two axes is 0.795. The orthogonality of Axis 1 and Axis 2 is 93.1%. Environmental variables shown in the figure have an $R^2 > 0.1$.

Figure 11 is the same ordination of 173 plots and 281 species as in Figure 10 but the secondary matrix is of species cover values rather than environmental variables. Twelve species with an $R^2 > 0.40$ have their vectors displayed on the ordination, indicating how their cover values change in relation to the axes. *Tsuga canadensis* is not displayed on this ordination because of its consistently high cover value in all of the plots. The species in the left side of the ordination may represent a mesic or rich cove community, with *Tilia americana*, *Acer saccharum*, and *Trillium erectum* present along with *Tsuga canadensis*. *Kalmia latifolia* may indicate an acidic cover community in association with *Tsuga canadensis* in the upper right.

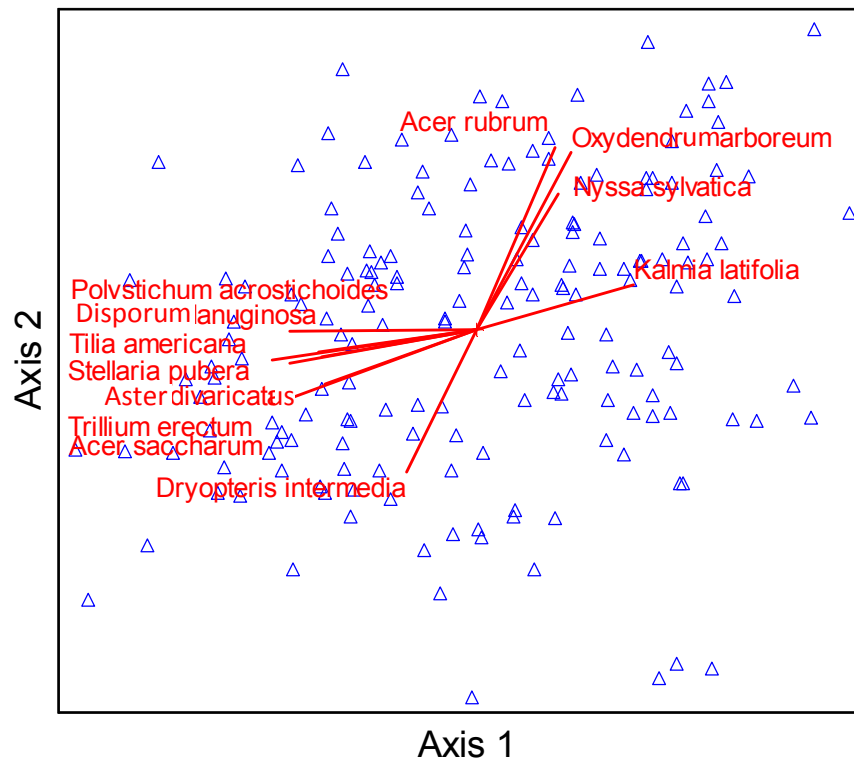


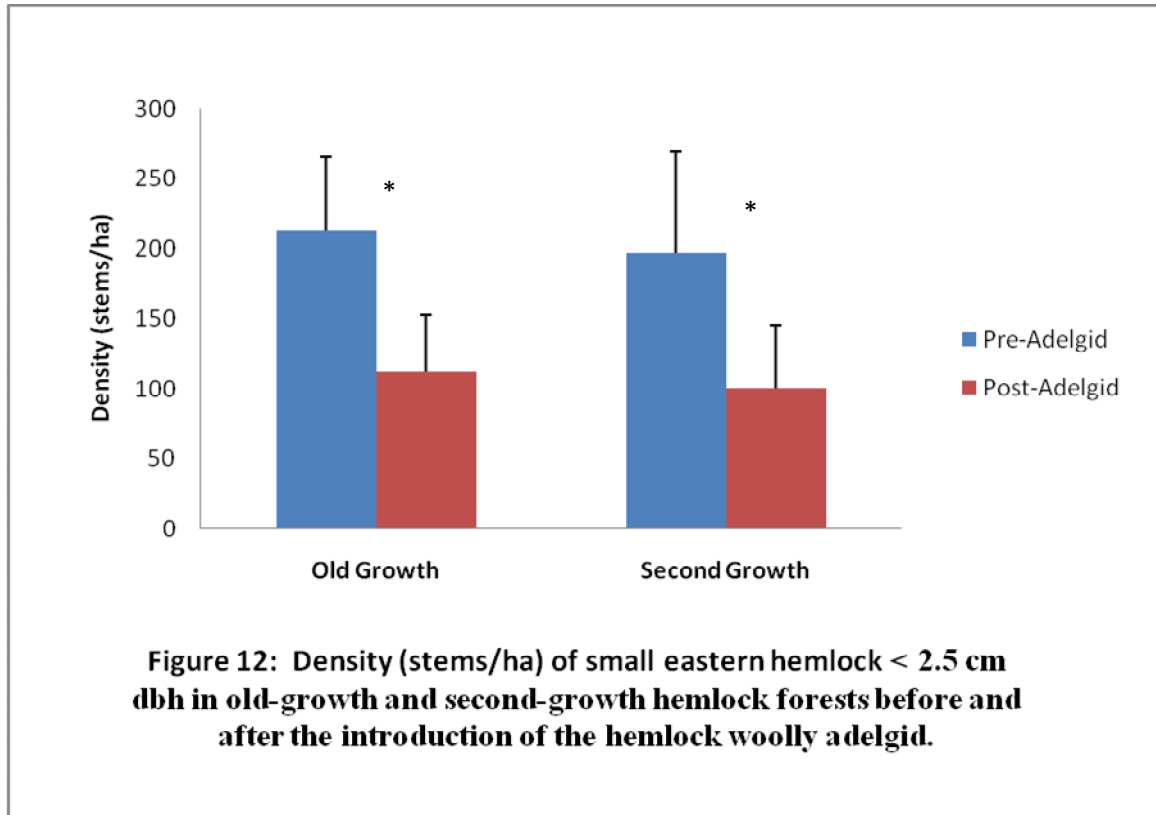
Figure 11: NMS Ordination of 173 plots with eastern hemlock cover values of ≥ 5 in 11 projects in western North Carolina, including the reinventoried plots pre and post-adelgid. The cumulative R^2 value for the first two axes is 0.795. The orthogonality of Axis 1 and Axis 2 is 93.1%. Species shown in the figure have an $R^2 > 0.4$.

(2) Change in eastern hemlock after the introduction of the hemlock woolly adelgid

A. How has eastern hemlock changed in density after the introduction of the hemlock woolly adelgid?

Figure 12 illustrates the average pre-adelgid and post-adelgid density (stems/ha) for small (< 2.5 cm dbh) eastern hemlock stems in old-growth and second-growth forests. Both declines are significant based on paired t-tests at an $\alpha = 0.05$ level. Old growth went from 213 stems/ha to 112

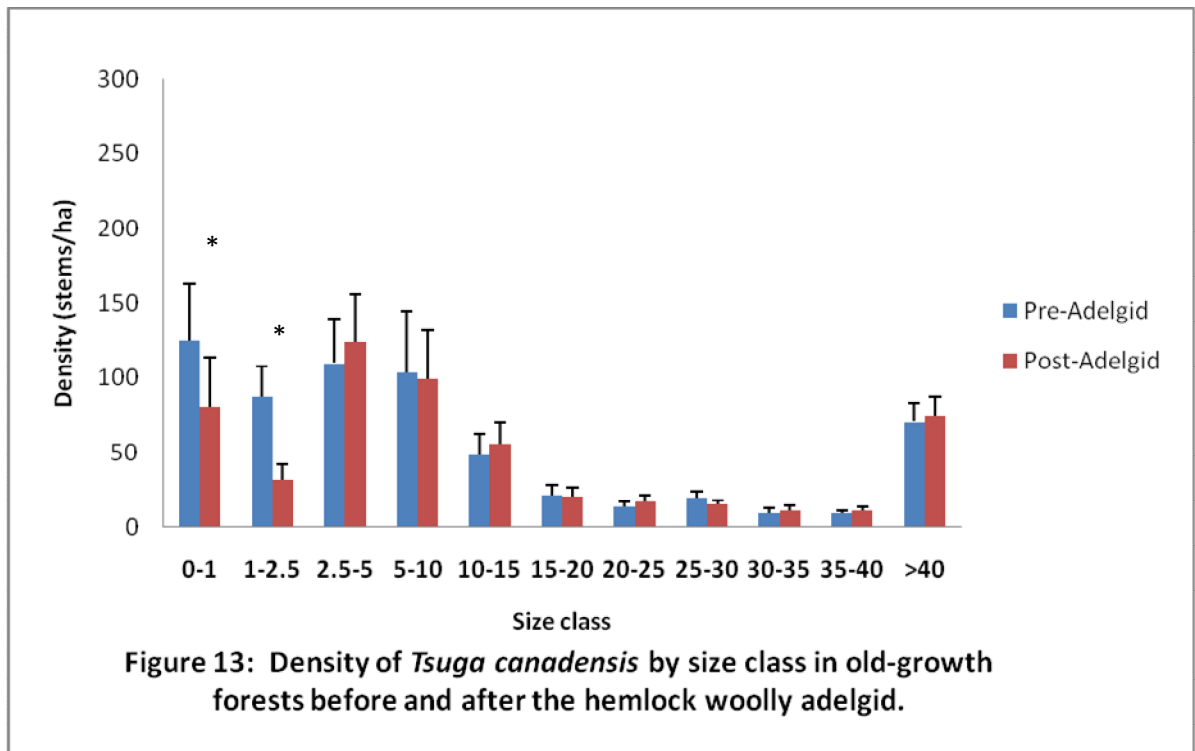
stems/ha and second growth went from 197 stems/ha to 100 stems/ha. The similar decline may indicate that the hemlock woolly adelgid affects small hemlocks independently of successional stage.

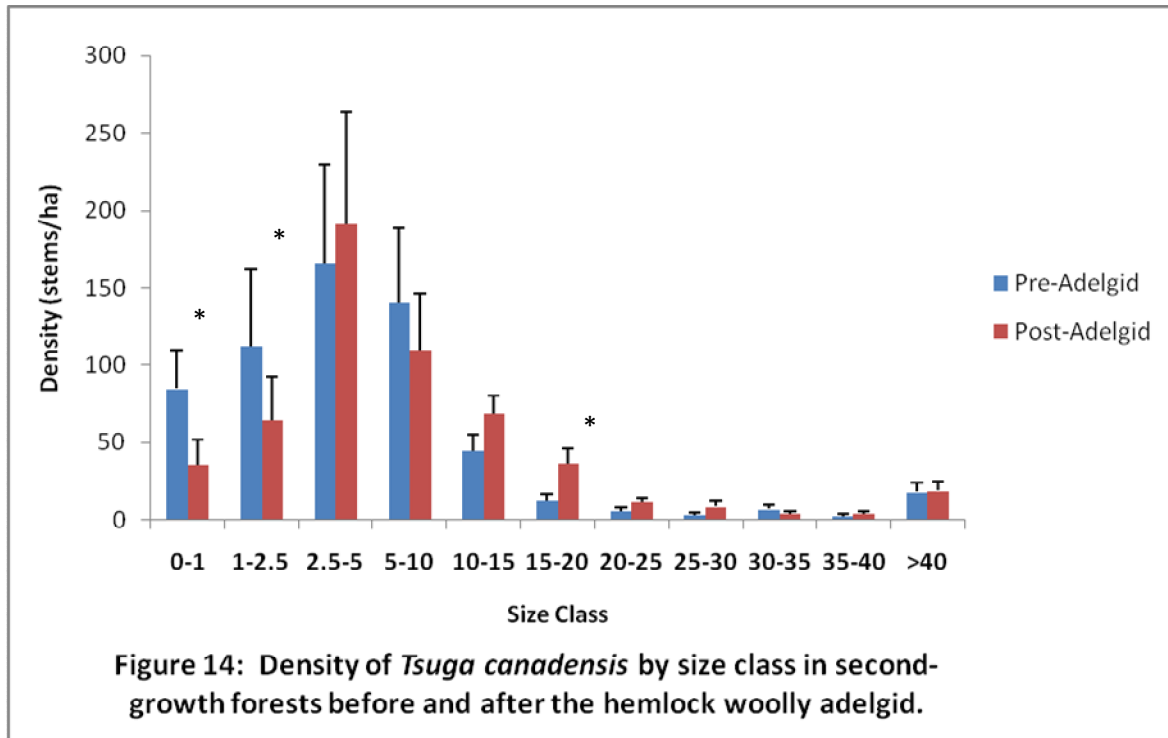


In addition to the decline in small hemlocks, the change in hemlocks by size class may also illustrate the competing processes of succession and eastern hemlock mortality. Figure 13 is the eastern hemlock size class distribution for the reinventoried old-growth plots before and after the adelgid. There is a significant decline in the small size classes but the larger size classes increase a small non-significant amount. There is a gradual decrease in the number of individuals in high size classes after the small hemlocks in the < 5 cm dbh are counted. The apparent high number of individuals in the > 40 cm dbh is an artifact of the aggregation of the larger-size class individuals

together. In general, Figure 13 indicates that the hemlock is not dying in large numbers in the overstory.

Figure 14 is the size class distribution for the reinventoried second-growth plots before and after introduction of the adelgid. It displays the standard small-diameter-skewed unimodal distribution common when reproductive cohorts come in waves. There is a peak at the 2.5 – 5 cm dbh size classes, and decline on either side of that peak. Unlike the old-growth plots in Figure 13, there are not large numbers of > 40 cm dbh trees in the second-growth forest. The eastern hemlocks of size class 15 – 20 cm dbh significantly increased in density from before the adelgid to after the adelgid. This is likely a result of growth over time in the plots and the absence of mortality among the large size classes this early in the infestation.





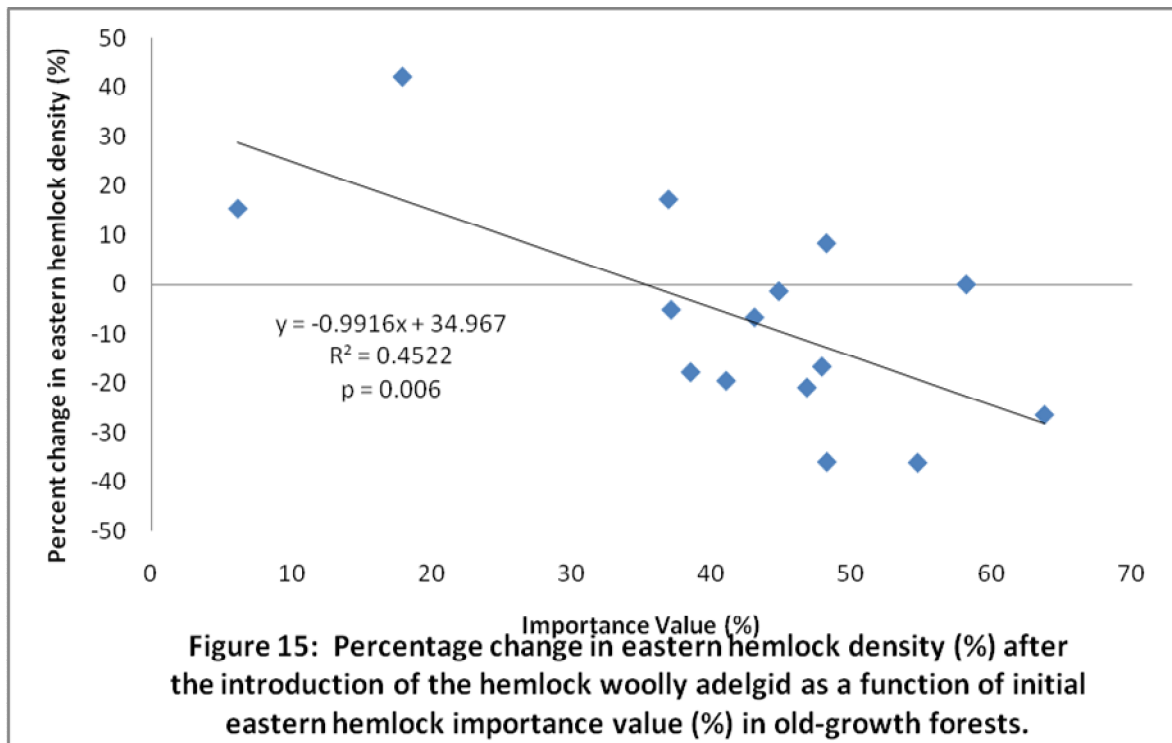
In conclusion, the initial change observed in old-growth and second-growth eastern hemlock plots are consistent with the results in the Northeast. Small hemlocks decline first and successional stage does not seem to affect the rate at which the small hemlocks decline.

B. Do any variables correlate with percentage change in hemlock density?

i. Old growth

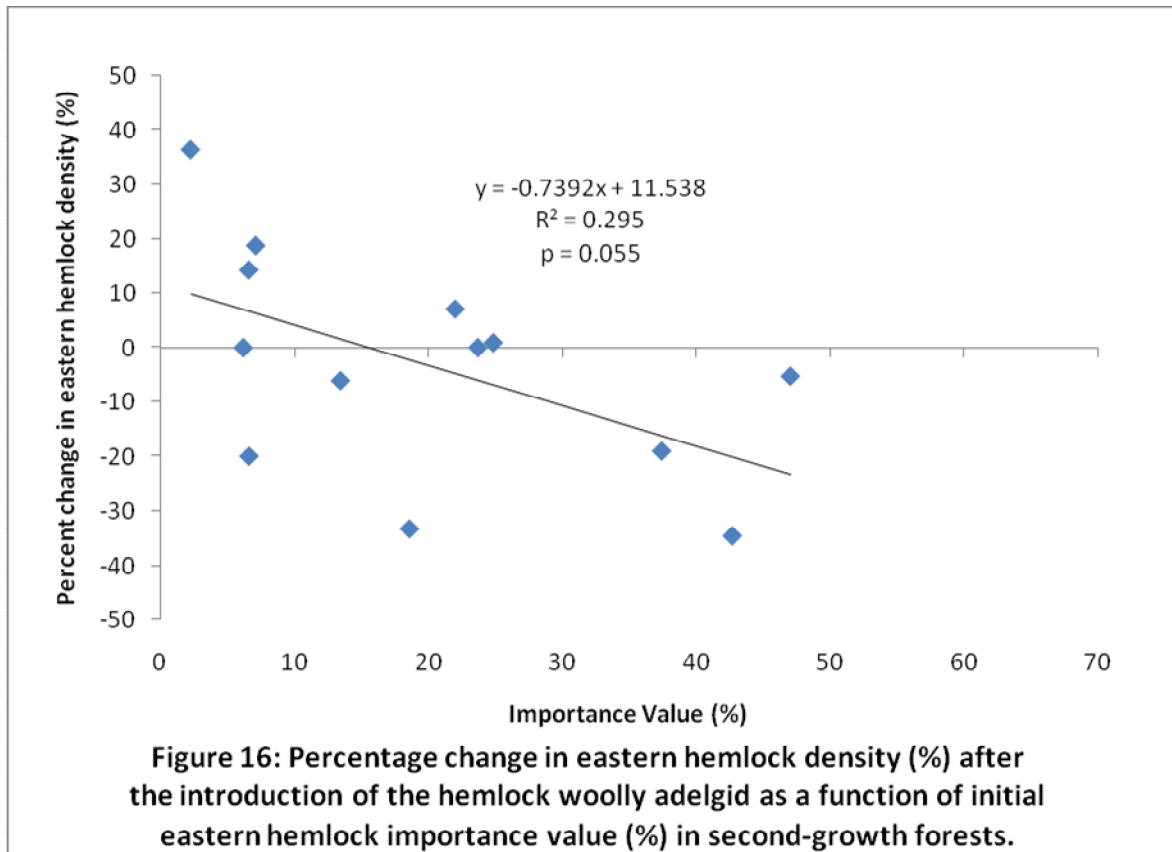
Figure 15 illustrates the correlation between the initial eastern hemlock importance value and the percent change in hemlock density after the introduction of the hemlock woolly adelgid in old-growth forests. The correlation is significant at $\alpha = 0.05$ level ($p = 0.006$) and has an R^2 of 0.45. The relationship is strongly influence by two plots with low eastern hemlock importance values. When these outliers are excluded the result is non-significant. The results are presented here with the outlier plots because such plots represent a range of old-growth plots that have eastern

hemlock as an associate. Here, as the initial importance value of eastern hemlock increases in a plot the hemlock density decreases.



ii. Second growth

Figure 16 illustrates the relationship between initial hemlock importance value and percent change in hemlock density in second-growth forests. The correlation is significant ($p = 0.055$) and the $R^2 = 0.295$. In comparison to the old-growth plots in Figure 15, there are no importance value outliers. Also, the old-growth importance values clustered from 35% - 65% with two low outliers; second-growth plots have consistently lower importance values for eastern hemlock ranging from 5% - 45%. Again, as the initial importance value of eastern hemlock increases in a plot the hemlock density decreases.



C. Conclusion

In conclusion, these results indicate that small eastern hemlocks are declining in the southern Appalachians in both old-growth and second-growth forests and that initial hemlock importance values are correlated with hemlock mortality. The decline is similar to that observed in the northern Appalachian forests affected by the hemlock woolly adelgid.

(3) Change in species composition

A. NMS ordination of reinventoried plots with species vectors

Figure 17 is an ordination of the primary matrix of 56 plots and 159 species with the species also included as the secondary matrix. The data were best analyzed using two dimensions. The orthogonality of the two axes is 98.6% and the cumulative R^2 for both axes is 0.839.

Seven species had an $R^2 > 0.5$ and their vectors are presented in the ordination. These species vectors are correlated with the compositional variation in the ordination. Some of the species from Figure 11, the ordination that included the CVS plots, are also present in Figure 17, including *Acer rubrum*, *Kalmia latifolia*, *Polystichum acrostichoides*, and *Oxydendrum arboreum*. The species in the upper and left regions, *Polystichum acrostichoides*, *Parthenocissus quinquefolia*, *Dryopteris intermedia*, and *Mitchella repens* are indicative of a more mesic environment. The right side of the ordination also may represent a type of *T. canadensis* community associated with *Acer rubrum*. The bottom of the ordination may be representative of *T. canadensis* communities in association with ericaceous shrubs like *Kalmia latifolia*.

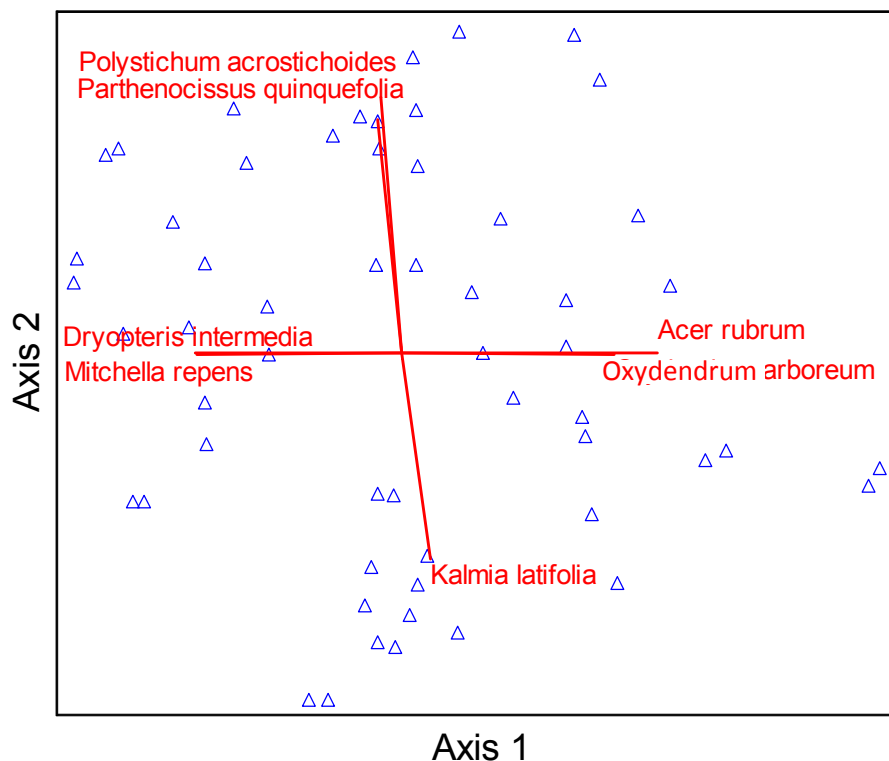


Figure 17: NMS Ordination of 56 plots and 159 species. Two dimensions are most appropriate for the ordination and the cumulative R^2 value for both axes is 0.840. The orthogonality of Axis 1 and Axis 2 is 98.4%. Species vectors displayed have an $R^2 > 0.5$ for one of the axes.

B. NMS ordination of reinventoried plots with environment variable vectors

Figure 18 is the same ordination of 56 plots and 159 species but with 24 environmental variables included in the secondary matrix. The plots are identified by stage and clearly cluster together in ordination space. Two dimensions were the appropriate number of axes for the ordination and the cumulative R^2 for both axes was 0.840. The orthogonality of both axes was 98.4. Nine environmental variables had an $R^2 > 0.40$. Nitrogen appears to be an environmental correlate of the compositional variation along Axis 1. High nitrogen plots are predominantly old growth and low nitrogen plots are predominantly second growth. The compositional variation along Axis 2 appears to be correlated with a species richness and cation gradient. Acidic soils with low species richness are correlated with composition in the lower part of the ordination and less acidic soils with higher species richness are correlated with composition in the upper part of the ordination.

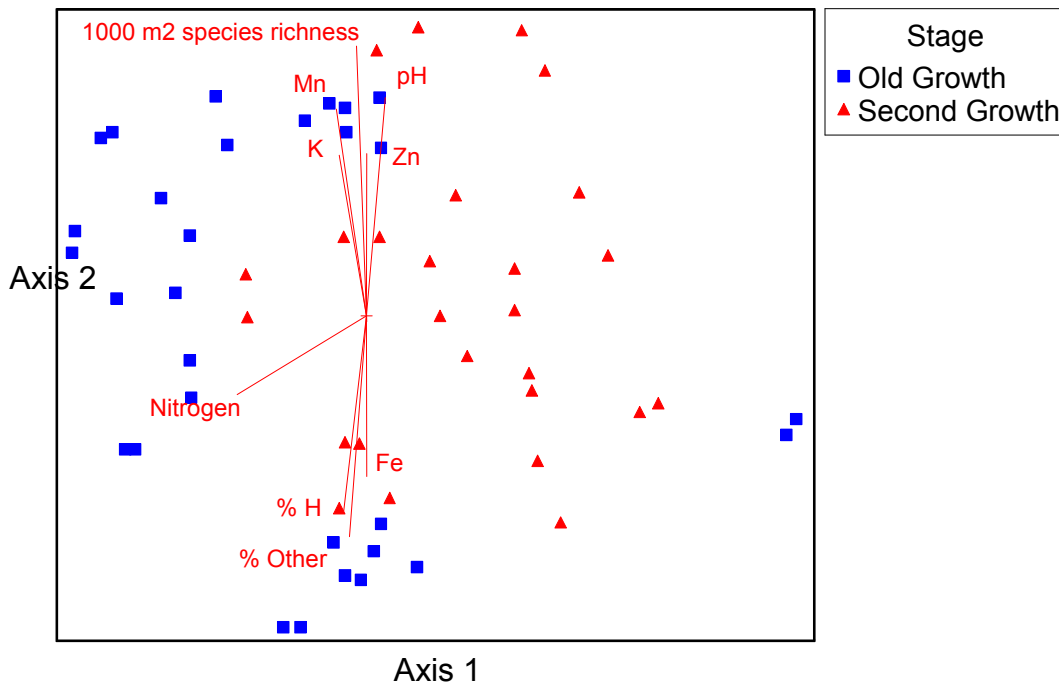


Figure 18: NMS Ordination of 56 plots and 159 species. Two dimensions are most appropriate for the ordination and the cumulative R^2 value for both axes is 0.840. The orthogonality of Axis 1 and Axis 2 is 98.4%. Environmental variable vectors displayed have an $R^2 > 0.4$ for one of the axes.

C. NMS ordination of reinventoried plots with vectors indicating change over time between paired plots

Figure 19 display the ordination in Figure 18 but with vectors of compositional change between paired plots. Based on visual inspection, there does not appear to be a consistent direction of change for old-growth plots. The changes between plots are small and go in all directions. There may be a consistent pattern of change in the second-growth plots, as the majority of the paired second-growth plots (7 of 13 plots) show a movement downward on Axis 2. If Axis 2 is a species richness/cation gradient as described in Figure 18, this could indicate that the species richness of the second-growth plots is decreasing from the first time the plots were inventoried to the second time they were inventoried.

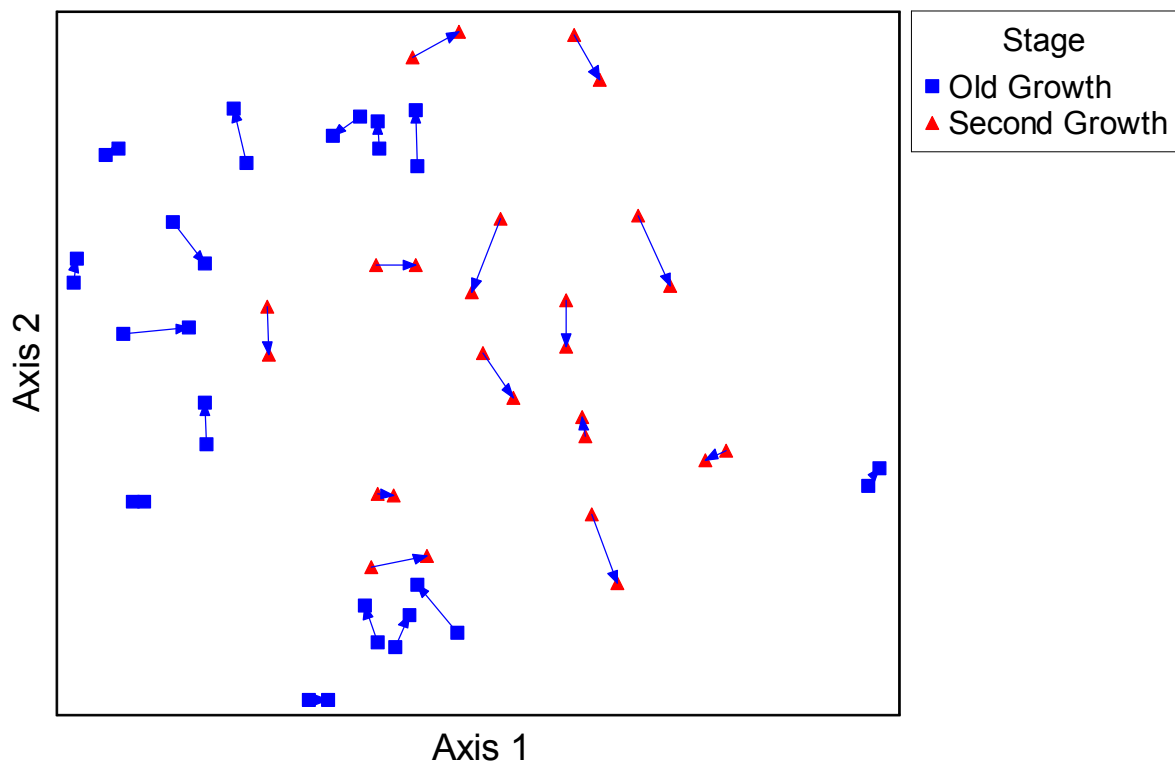
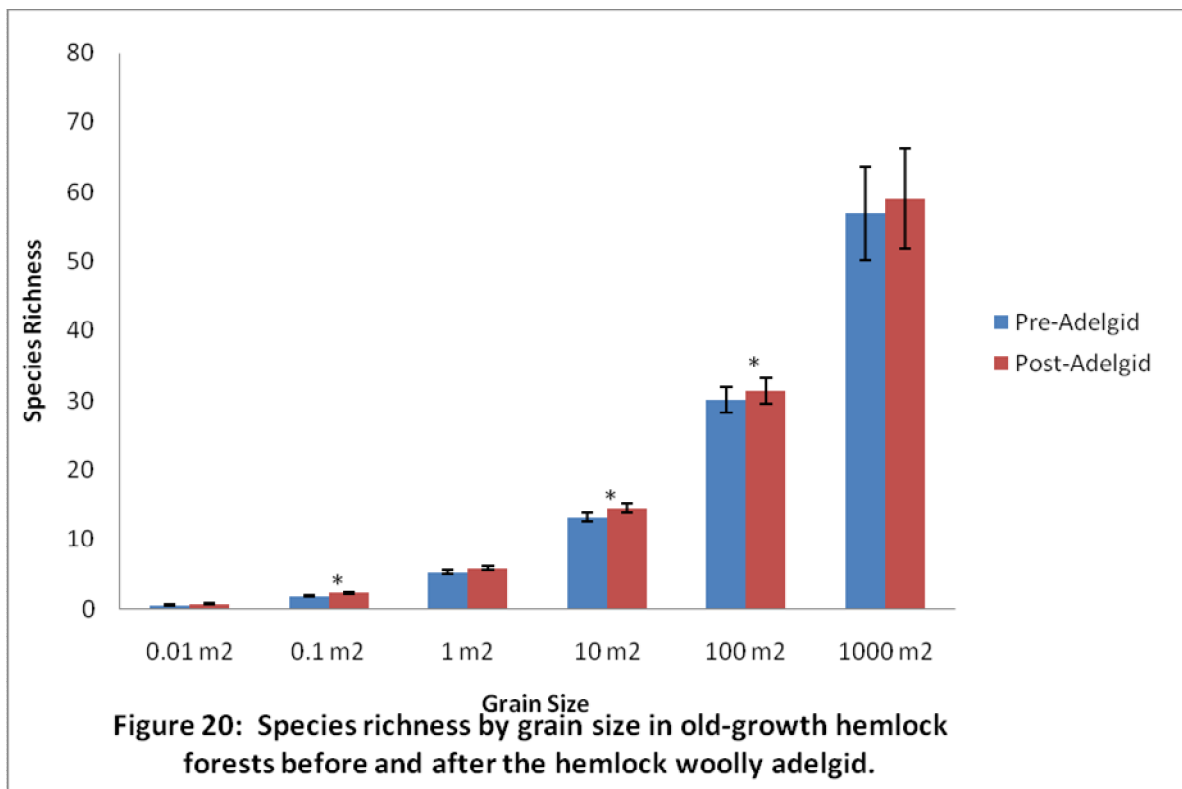


Figure 19: NMS Ordination of 56 plots and 159 species. Two dimensions are most appropriate for the ordination and the cumulative R^2 value for both axes is 0.840. The orthogonality of Axis 1 and Axis 2 is 98.4%. Vectors displayed indicate direction of compositional change between paired plots sampled before and after

(4) Change in species richness

A. How has species richness changed?

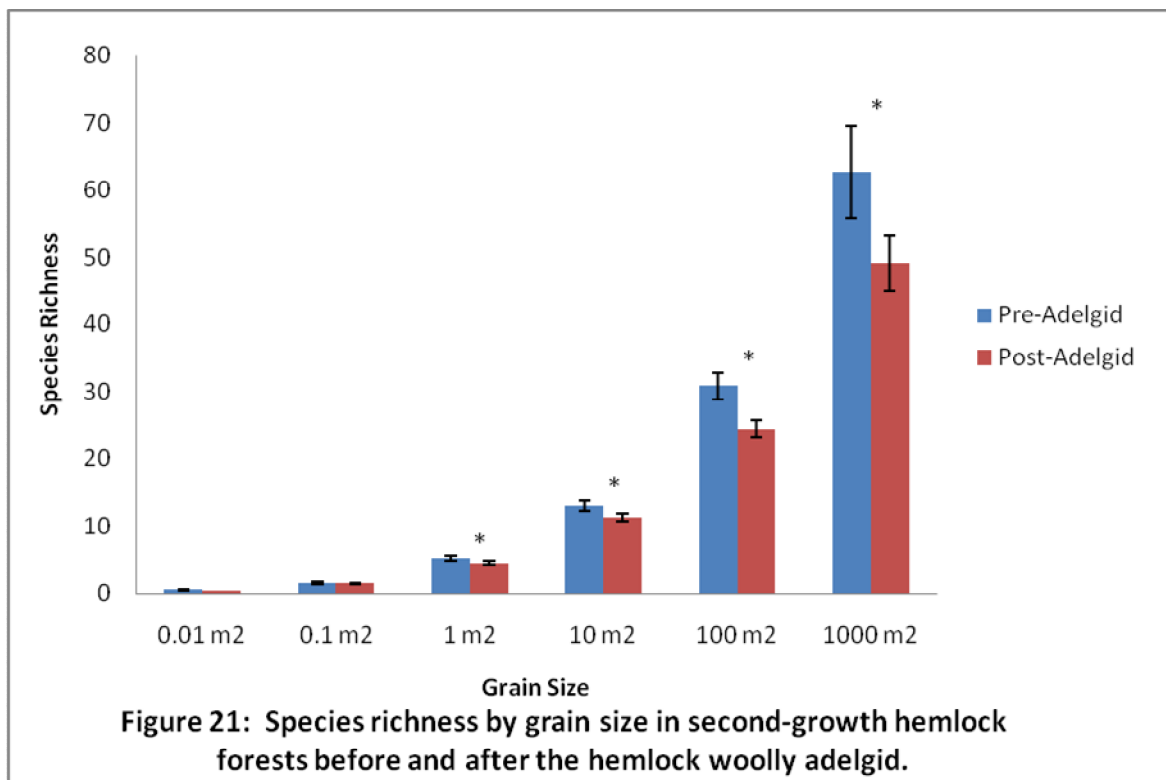
Figure 20 illustrates the average species richness by grain size from both before and after the introduction of the hemlock woolly adelgid in old-growth forests. The change in species richness from before to after the adelgid are small at each grain size but because paired t-tests compare the consistency of change between pairs, some pairs are still significantly different. In old growth, the average species richness differed significantly at 0.1 m², 10 m², and 100 m². There are also non-significant trends of increasing species richness at 0.01 m², 1 m², and 1000 m². See Table V for a complete listing of average species richness by grain size in old-growth eastern hemlock forests.



Grain Size	Pre-Adelgid	Post-Adelgid	Significance
0.01 m ²	0.63	0.74	N.S. (n = 117)
0.1 m ²	1.87	2.31	P = 0.003 (n = 117)
1 m ²	5.39	5.82	N.S. (n = 117)
10 m ²	13.25	14.52	P = 0.0007 (n = 117)
100 m ²	30.10	31.37	P = 0.02 (n = 58)
1000 m ²	56.93	59.00	N.S. (n = 15)

Table V: Average species richness for old-growth eastern hemlock plots before and after the hemlock woolly adelgid at different grain sizes.

Figure 21 displays the average species richness data for second-growth forests after the introduction of the hemlock woolly adelgid at different grain sizes. A different pattern is apparent here with a decline in species richness rather than an increase in species richness at every grain size. The two smallest grain sizes do not have significant differences between the pre and post-adelgid richness values, but there is a significant decrease in species richness from 1 m² up to 1000 m². See Table VI for the complete average richness values for different grain sizes in second-growth forests.



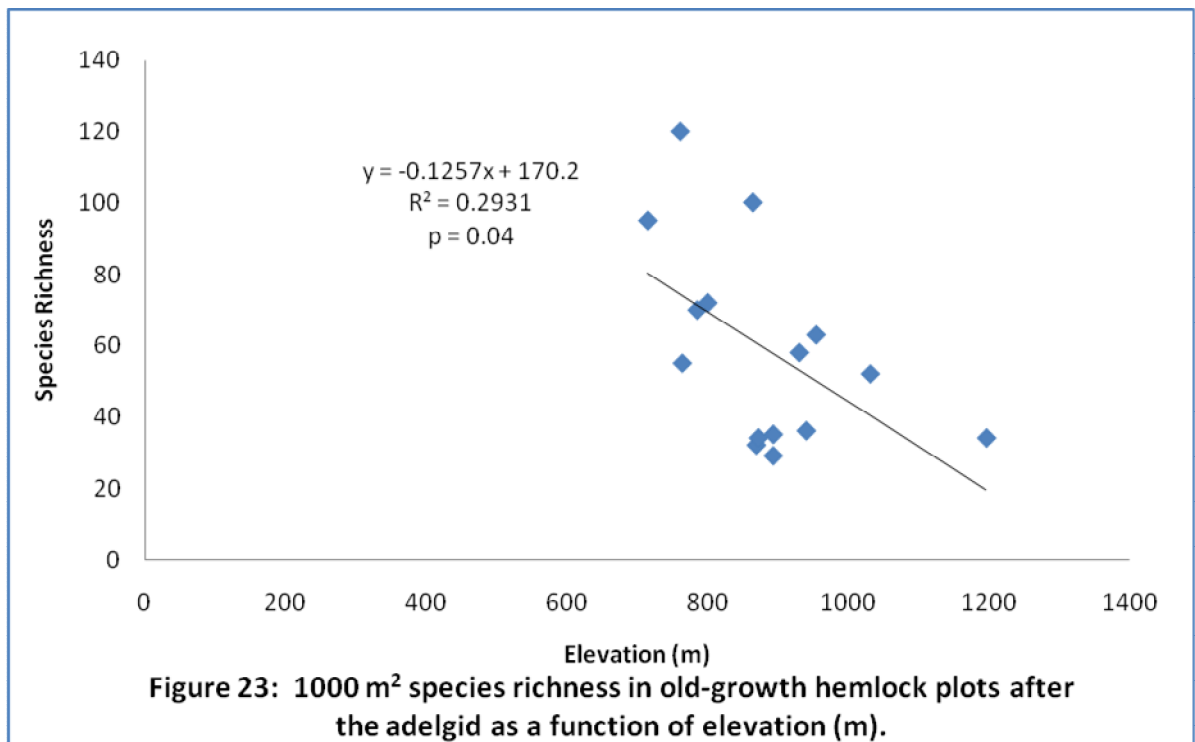
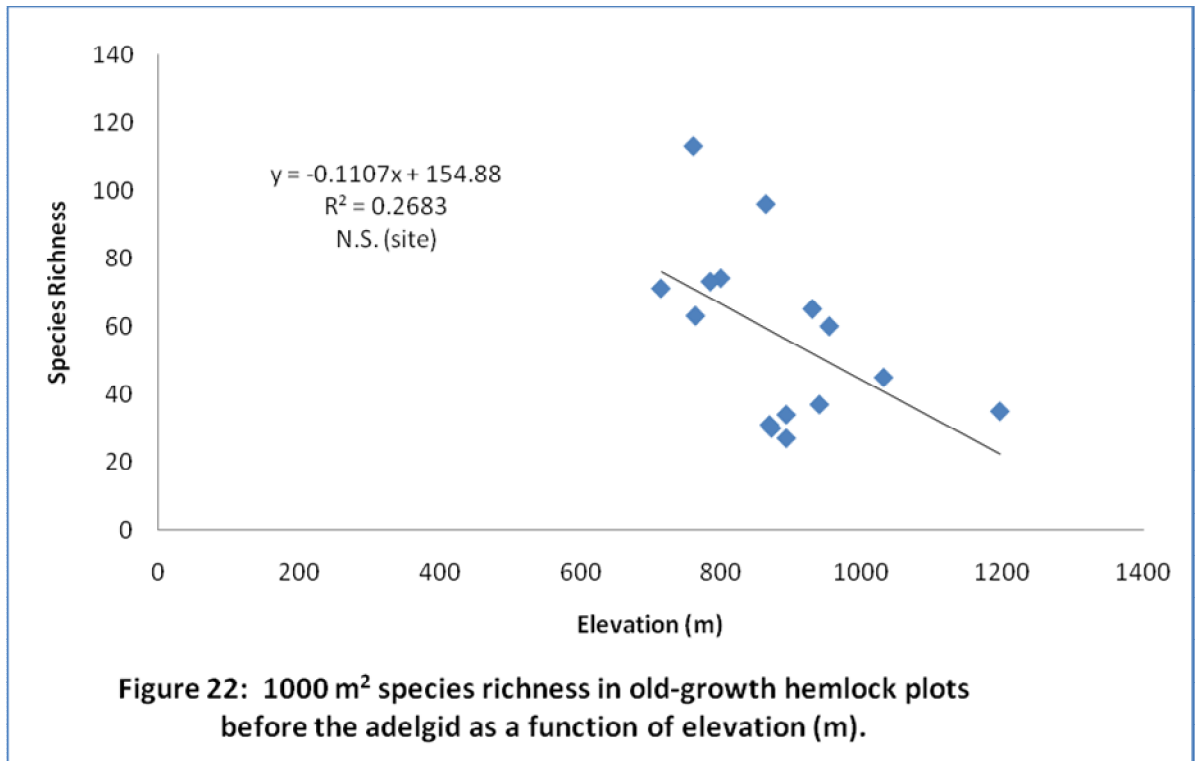
Grain Size	Pre-Adelgid	Post-Adelgid	Significance
0.01 m ²	0.51	0.41	N.S. (n = 104)
0.1 m ²	1.62	1.48	N.S. (n = 104)
1 m ²	5.12	4.47	P = 0.01 (n = 104)
10 m ²	12.96	11.24	P = 0.0002 (n = 104)
100 m ²	30.79	24.42	P < 0.0001 (n = 52)
1000 m ²	62.69	49.08	P = 0.005 (n = 13)
Table VI: Average species richness for second-growth eastern hemlock plots before and after the hemlock woolly adelgid at different grain sizes.			

B. What variables correlate with species richness?

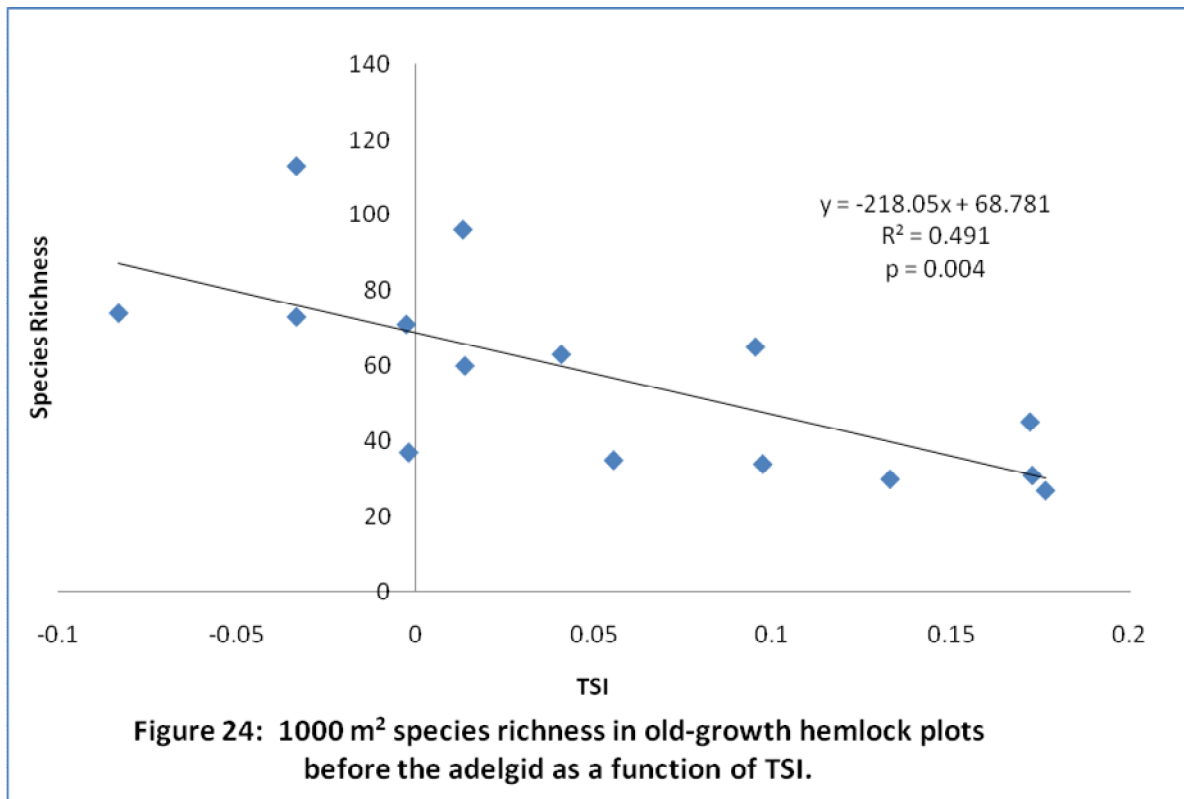
i. *What variables correlate with species richness in old-growth eastern hemlock forests?*

Figure 22 illustrates the relationship between species richness and elevation in old-growth plots before the introduction of the hemlock woolly adelgid. It has a non-significant relationship because the ANCOVA indicated that the regression is only significant based on site effects. The plots in Cataloochee were at higher elevation than the plots in Joyce Kilmer and this prevented combining the two field sites into a single analysis. When analyzed separately, neither field site showed a significant relationship between elevation and species richness before the introduction of the hemlock woolly adelgid.

In comparison, Figure 23 shows the relationship between species richness and elevation in old-growth plots after the hemlock woolly adelgid. Here, the site effects did not prevent elevation from being explanatory ($p = 0.04$, $R^2 = 0.29$). The correlation between species richness and elevation is a common one in Great Smoky Mountains National Park. As elevation increases, species richness decreases. Elevation is often a proxy variable for gradients of temperature and precipitation.



The terrain shape index, as described in the methods, quantifies local topographic shape. It is a metric that ranges from -24 for a convex surface to greater than 15 for a concave surface. Figure 24 illustrates the correlation between species richness and TSI for old-growth plots before the introduction of the hemlock woolly adelgid. Figure 25 present this analysis for the same plots after the introduction of the hemlock woolly adelgid. The correlation is significant in both cases. As a plot becomes more concave, species richness declines. The higher concavity of the plots may increase moisture availability as water drains to those locations. The decreased species richness with higher TSI and more concave topography may be a result of the affinity of *Rhododendron maximum* and eastern hemlock for moist sites. Both of those species can cause a decrease in species richness.



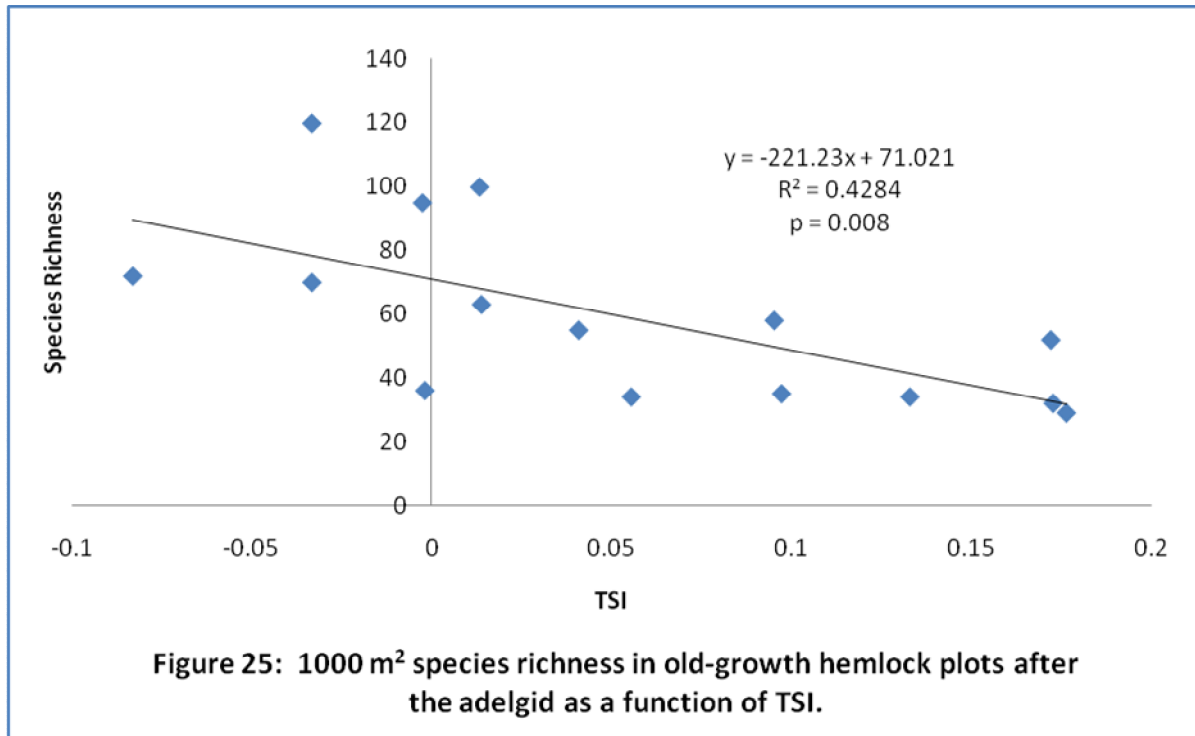


Figure 26 illustrates the correlation between pH and species richness in old-growth plots before the introduction of the hemlock woolly adelgid. Figure 27 displays the same relationship after the introduction of the hemlock woolly adelgid. ANCOVA indicated that the slopes of the line between the two sites were not the same and therefore a single regression was not appropriate. Instead, the linear regression lines for species richness and pH for both Joyce Kilmer and Cataloochee Valley are presented in the same figure for convenience. The relationships have high explanatory power, with an R^2 of 0.87 in Joyce Kilmer pre-adelgid, 0.88 in Joyce Kilmer post-adelgid, 0.69 in Cataloochee pre-adelgid, and 0.67 in Cataloochee post-adelgid. As pH increases, species richness in plots also increases.

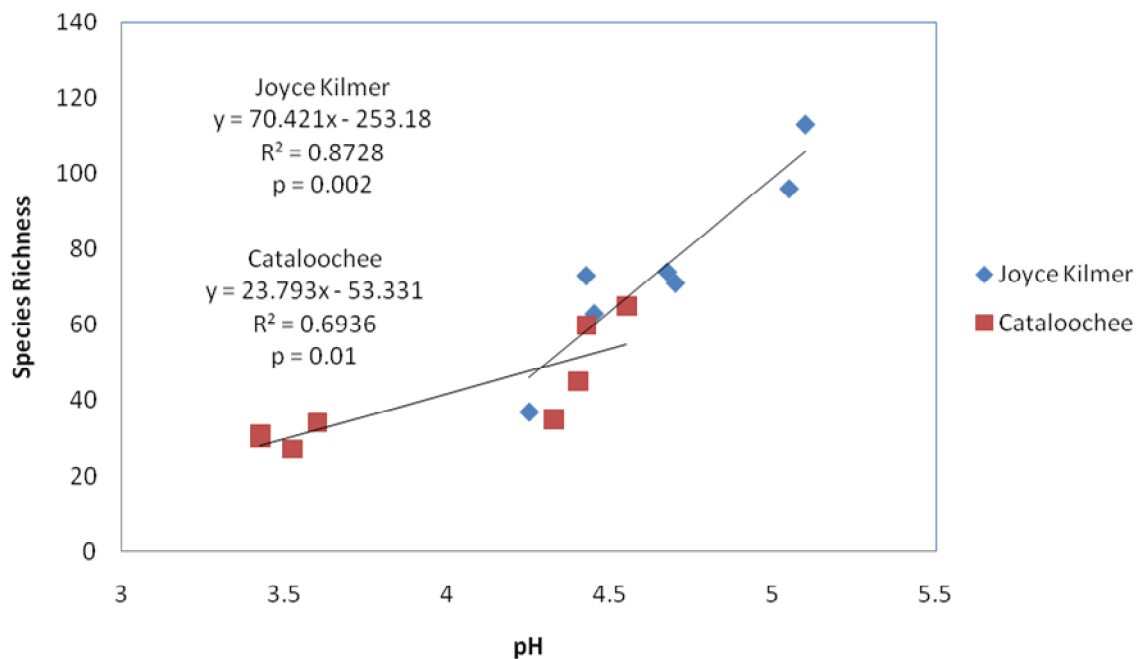


Figure 26: 1000 m² species richness in old-growth hemlock plots before the adelgid as a function of pH.

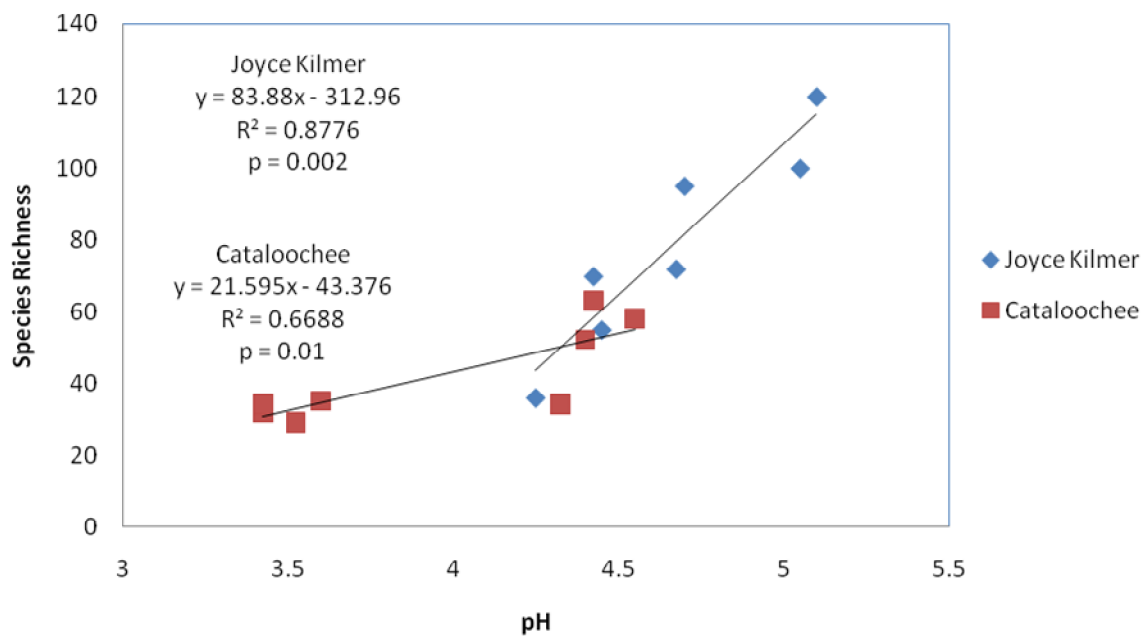
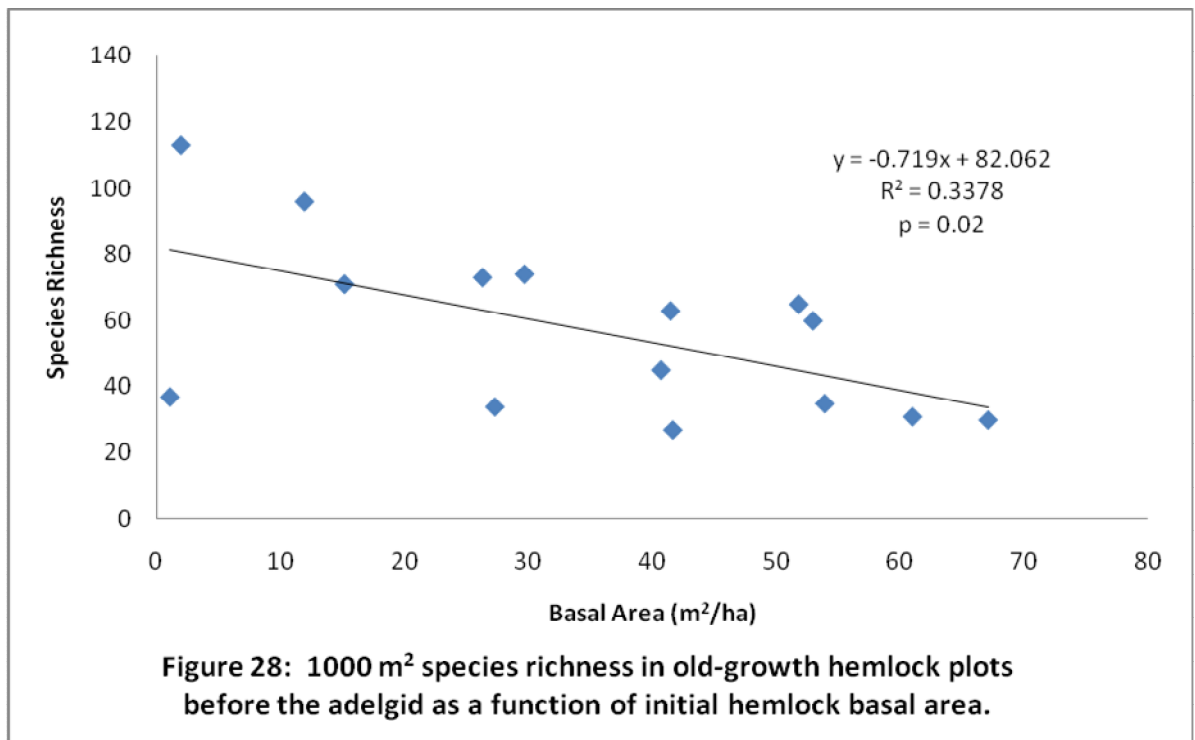
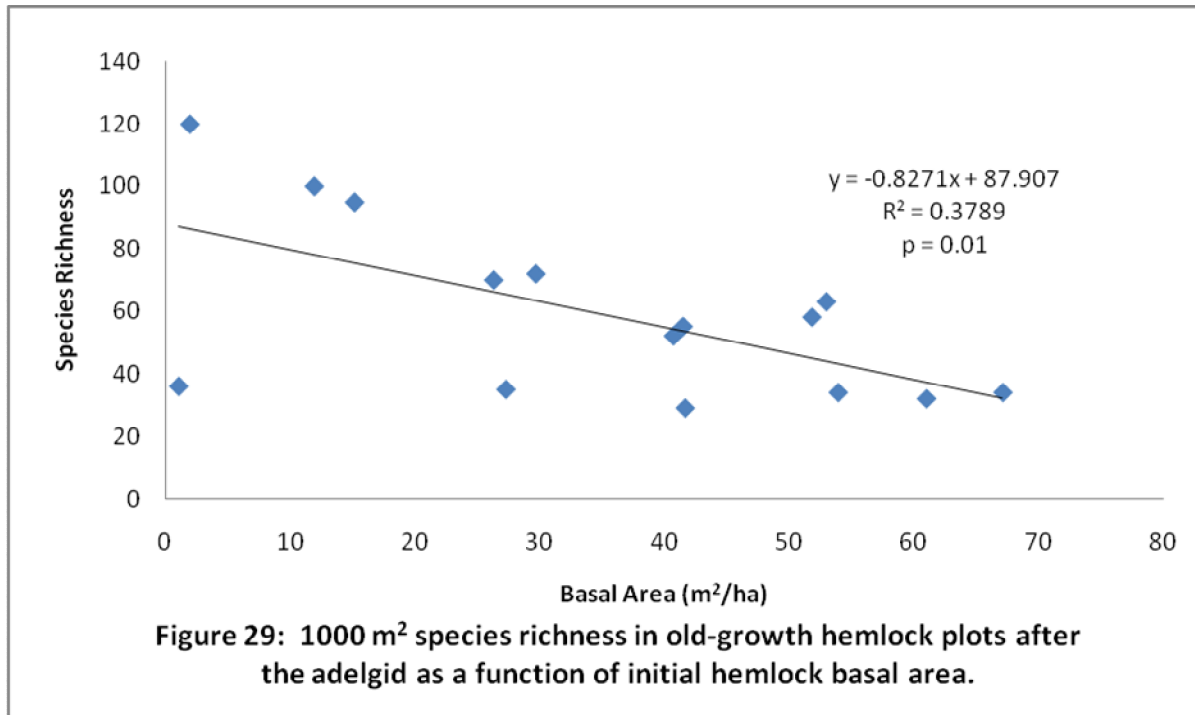


Figure 27: 1000 m² species richness in old-growth hemlock plots after the adelgid as a function of pH.

Finally, Figure 28 shows that initial eastern hemlock basal area is correlated with species richness in the old-growth plots before the introduction of the hemlock woolly adelgid. Figure 29 is the same analysis after the introduction of the hemlock woolly adelgid. The regression lines in Joyce Kilmer and Cataloochee Valley were coincident so the correlations are presented as a single regression line. In both cases, as eastern hemlock basal area increases species richness decreases. This result is consistent with the previous research, which showed that where eastern hemlock is dominant there is low species richness in the understory. Larger basal area trees may have more of an impact on understory conditions, causing more shade, more leaf litter, or a lower pH.



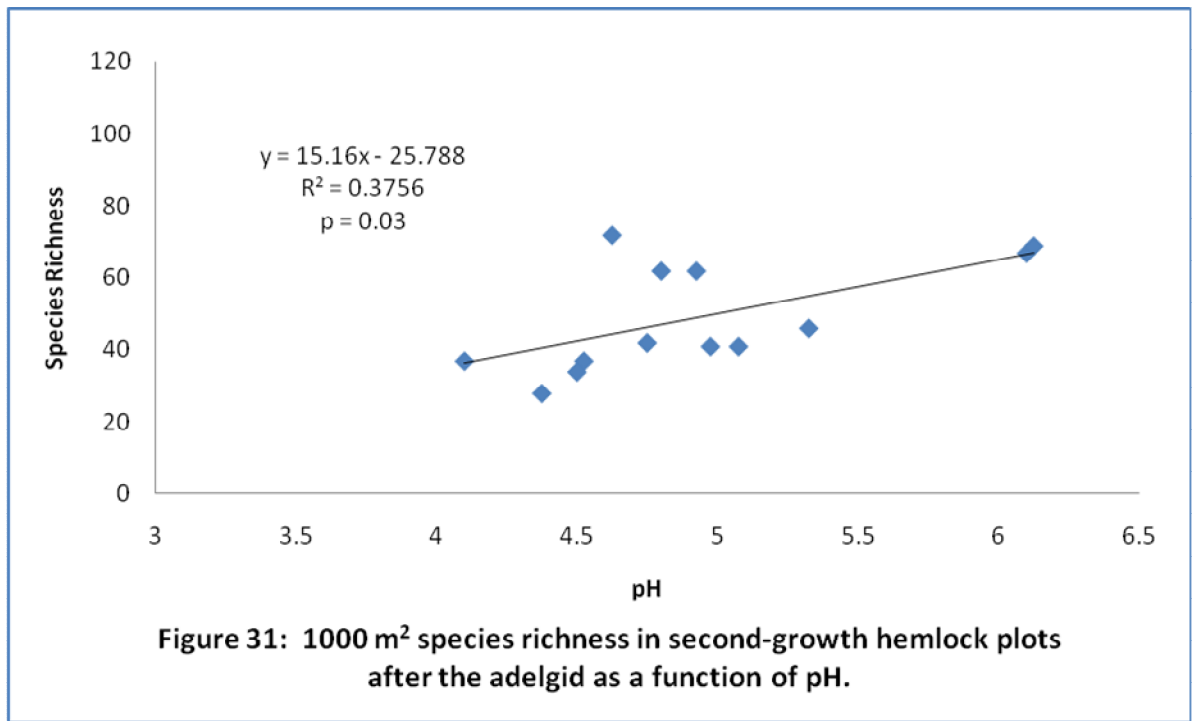
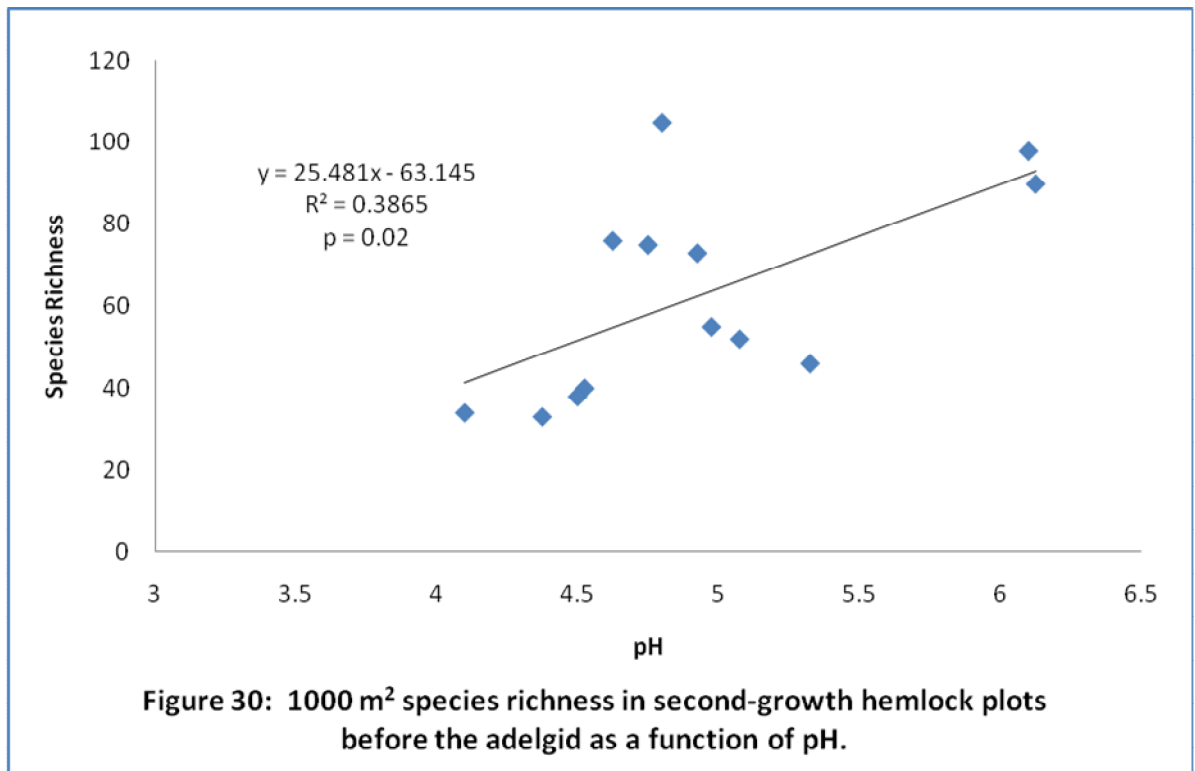


ii. *What variables correlate with species richness in second-growth eastern hemlock forests?*

Unlike old-growth forests, only two of the variables tested were correlated with species richness in second-growth forests: pH and manganese. ANCOVA indicated that the slopes of the lines between all sites were coincident and therefore a single regression is presented for each analysis. The positive correlation between manganese and species richness is not shown. It was significant both before ($p = 0.04$, $R^2 = 0.34$) and after introduction of the hemlock woolly adelgid ($p = 0.001$, $R^2 = 0.62$). Newell (1997) found a similar relationship between species richness and Mn in her data but the mechanism that controls this effect is not understood.

As in old-growth forests, pH was correlated with species richness in second-growth forests both before and after the adelgid. Figure 30 illustrates the relationship before and Figure 31 illustrates the relationship after the introduction of the hemlock woolly adelgid. Species richness

increases as pH increases. Again, this is likely the result of increased nutrient availability as pH increases.



C. What variables correlate with change in species richness?

i. *What variables correlate with change in species richness in old-growth eastern hemlock forests?*

Absolute change in species richness following introduction of the hemlock woolly adelgid was calculated for each plot at each grain size. Environmental variables, including measures of eastern hemlock dominance, were evaluated to determine whether they were significantly correlated with the change in species richness at different grain sizes. There were no variables that were significantly correlated with the change in species richness at 0.01 m², 0.1 m², or 1 m². Larger grain sizes, 10 m², 100 m², and 1000 m², had significant correlations between the change in species richness and initial measures of eastern hemlock dominance.

At 10 m² and 100 m², initial eastern hemlock importance value was correlated with the absolute change in species richness. Figure 32 illustrates the relationship between change in species richness and importance value at 10 m². Figure 33 illustrates the same relationship at 100 m². When eastern hemlock had a high initial importance value, more species were gained after the introduction of the hemlock woolly adelgid. This may be a result of low initial species richness in hemlock dominated forests, increased nutrient throughfall as the eastern hemlock declines, or increased light availability as the canopy thins.

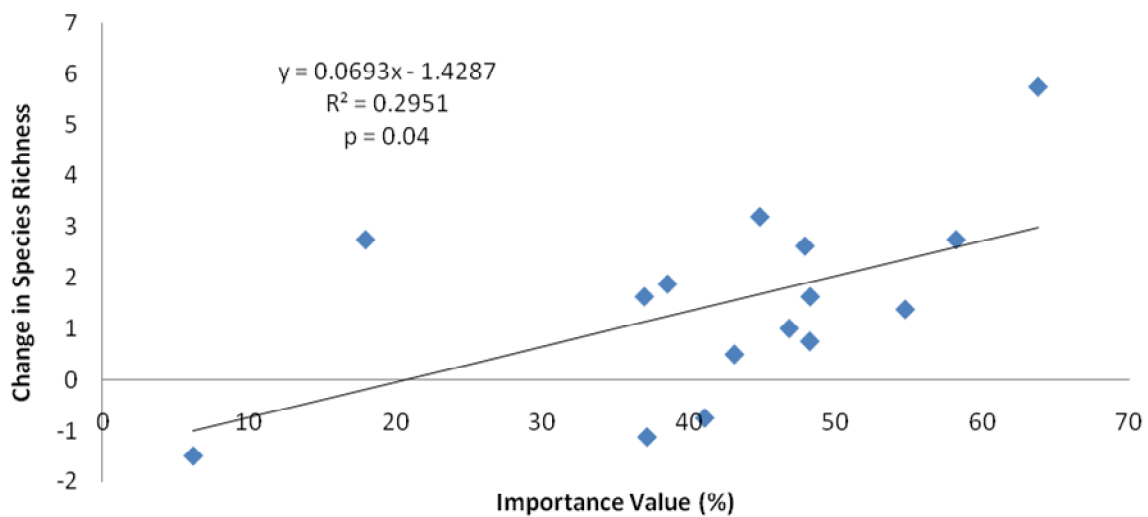


Figure 32: Change in species richness at 10 m² in old-growth hemlock forests before and after the hemlock woolly adelgid as a function of initial eastern hemlock importance value.

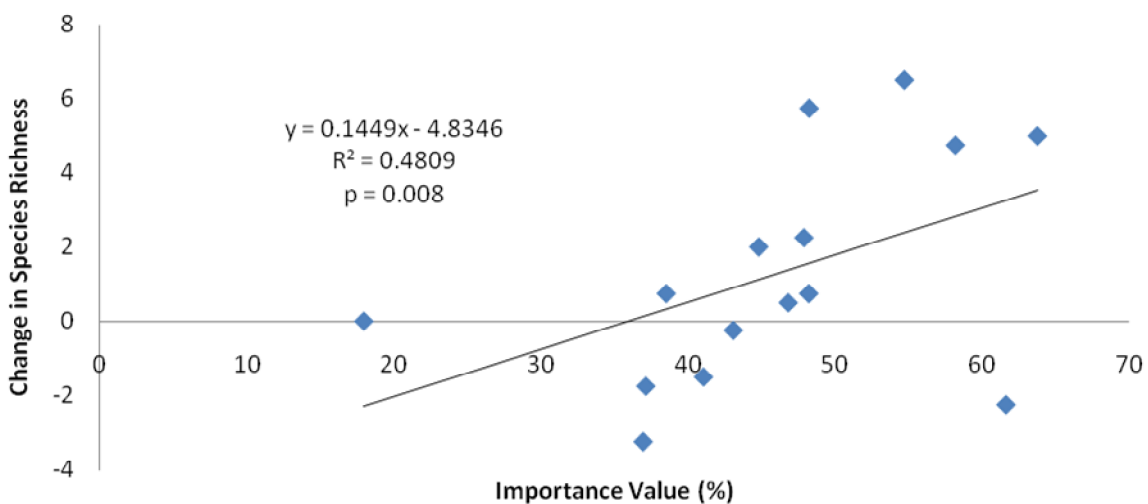
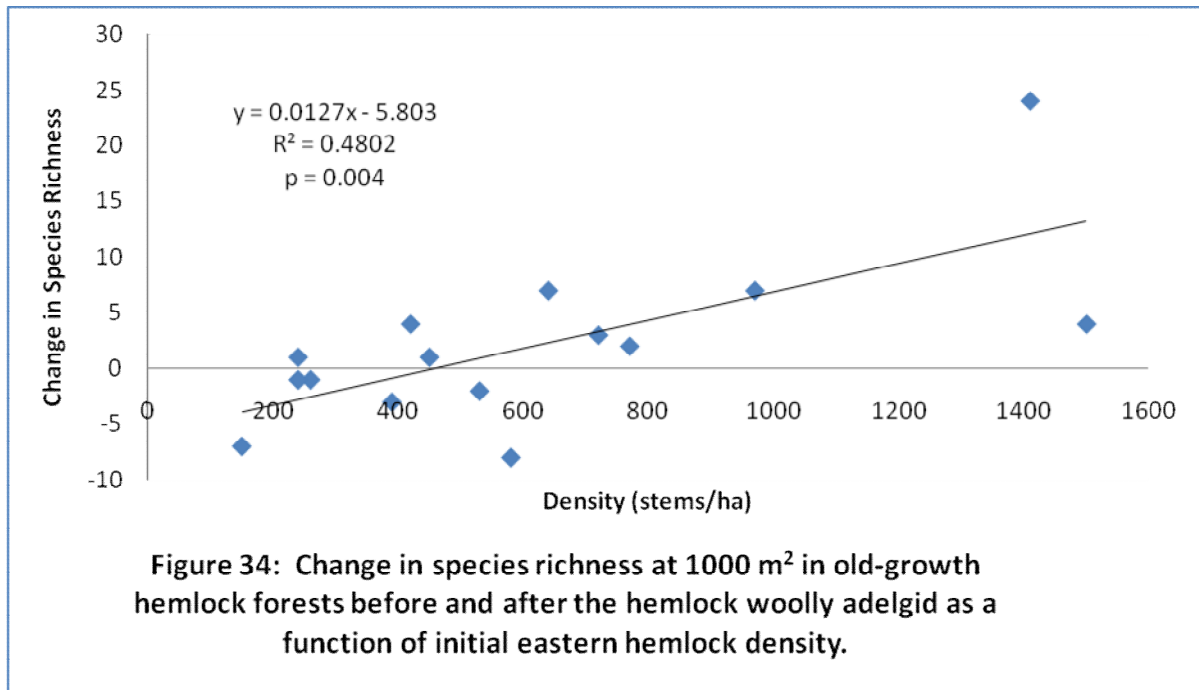


Figure 33: Change in species richness at 100 m² in old-growth hemlock forests before and after the hemlock woolly adelgid as a function of initial eastern hemlock importance value.

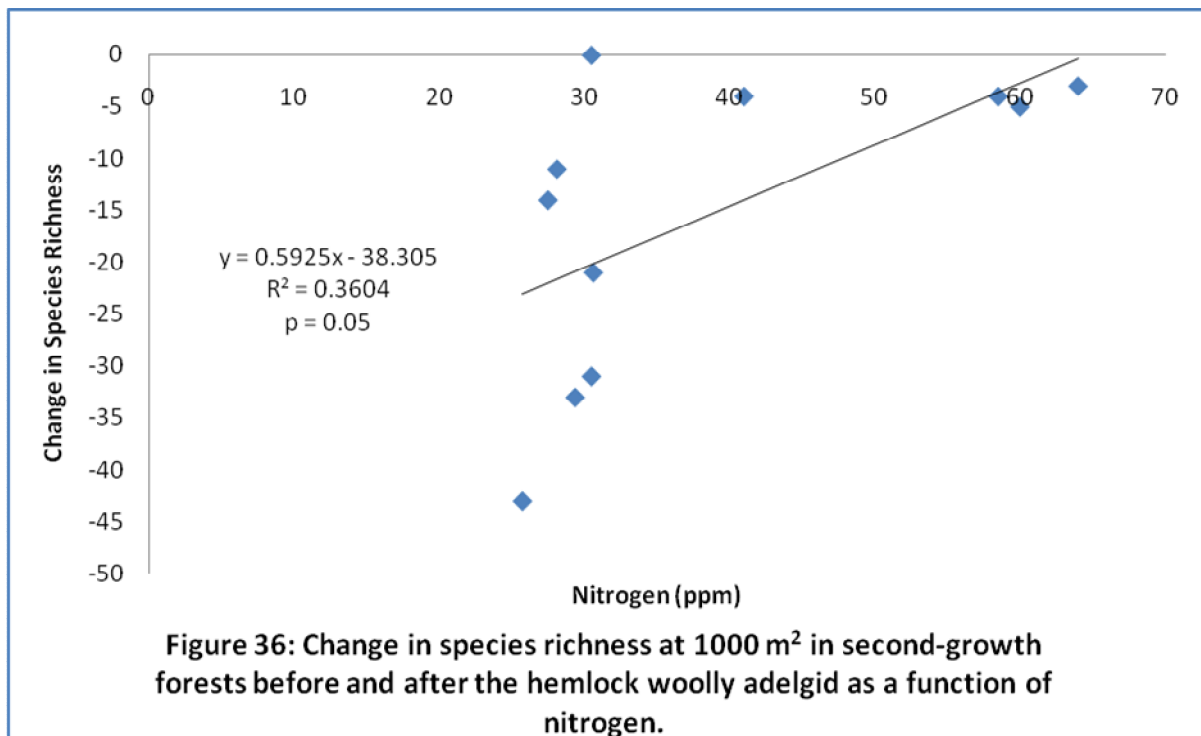
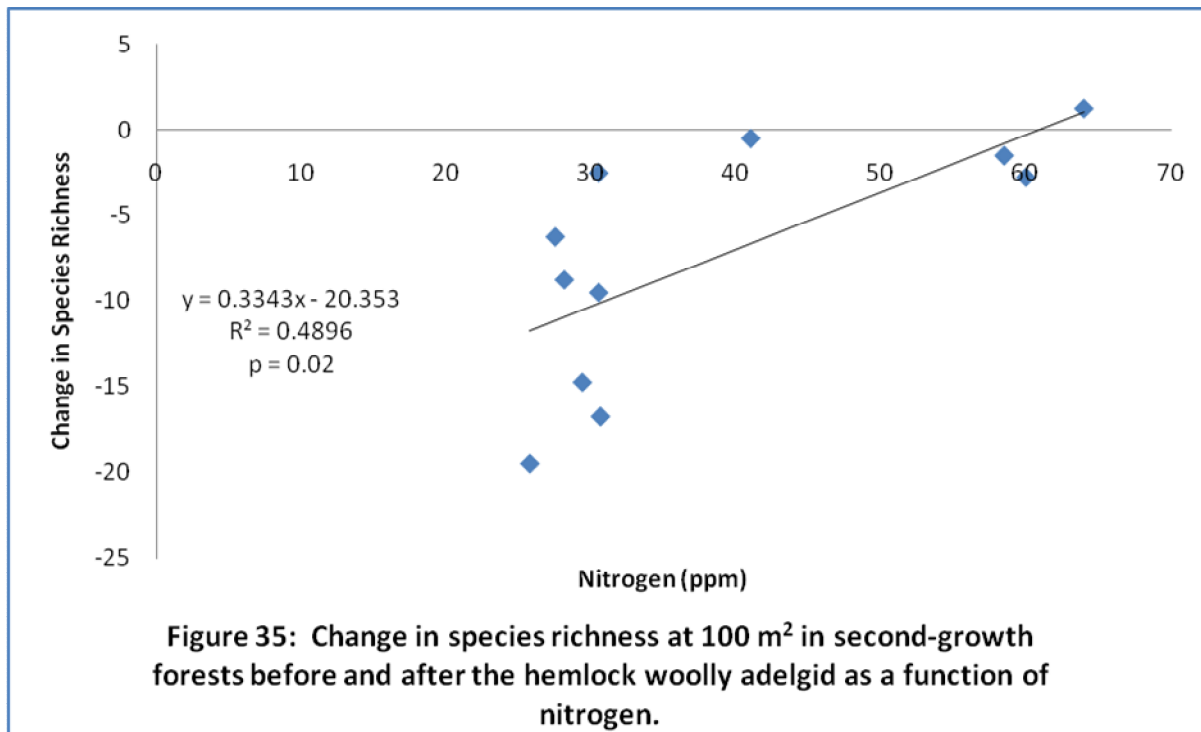
Finally, at 1000 m², initial eastern hemlock density is positively correlated with change in species richness, illustrated in Figure 34. This is similar to the relationship at 10 m² and 100 m²; with greater initial density the effect of the loss of eastern hemlock is more profound. More light may be reaching the understory, more nutrient throughfall from the dying canopies, or less competition can all facilitate the increased species richness with increasing hemlock density.



ii. What variables are correlated with change in species richness in second-growth forests?

Unlike in old growth, the change in species richness in second-growth forests is not correlated with measures of eastern hemlock dominance. At 100 m² and 1000 m² the change in species richness in second-growth forests is correlated with nitrogen. ANCOVA indicated that a single regression line was appropriate to test the correlation for all three field sites. As nitrogen decreases in a plot more species are lost after the introduction of the hemlock woolly adelgid. Figure 35 illustrates that only one plot had an average increase in species richness at the 100 m²

grain size. No plot had an average increase in richness at the 1000 m² grain size, as shown in Figure 36.



D. Conclusion

These results indicate that the hemlock woolly adelgid may influence species richness differently depending on the successional stage of the forest. Old-growth forests show an increase in species richness after the introduction of the hemlock woolly adelgid whereas second-growth forests show a decrease in species richness. Species richness in old-growth forests was correlated with a variety of environmental variables including initial eastern hemlock basal area but species richness in second-growth forests was only correlated with pH and manganese. Finally, the factors influencing the change in species richness differed based on successional stage. Change in species richness in old growth was correlated with initial eastern hemlock dominance values but the change in species richness in second-growth forests was only correlated with nitrogen.

CHAPTER IV

DISCUSSION

The goal of this study was to answer the following three questions:

- (1) How do eastern hemlocks in the southern Appalachians respond to the early stages of hemlock woolly adelgid infestation?
- (2) How does species richness change after the introduction of the hemlock woolly adelgid?
- (3) How does the effect in the southern Appalachians compare to the effect in the northern Appalachians?

(1) How do eastern hemlocks in the southern Appalachians respond to the early stages of hemlock woolly adelgid infestation?

The results of this study clearly indicate that small diameter hemlocks are dying across the southern Appalachians. The decline was consistent across both old-growth and second-growth forests. Location did not affect the decline, in contrast to the findings of Orwig et al. (2002), who showed that latitude was correlated with mortality and acted as a proxy for time since infestation. Orwig et al. (2002) evaluated eastern hemlock health at a later stage of infestation than this study and found that the mortality of larger eastern hemlocks (greater than 8 cm dbh) was spatially autocorrelated and related to time since infestation. Weckel et al. (2006) recognized that small hemlocks die first from the infestation but did not correlate the mortality with time. Small et al.

(2005) saw an increase in hemlock saplings after the introduction of the adelgid but this quickly turned into a 90% decrease after fifteen years in New England. This raises the question of whether large hemlock mortality in the southern Appalachians will follow a latitudinal gradient related to time since infestation.

The hemlock woolly adelgid may have spread through the southern Appalachians faster than it did in the northern Appalachians because of its longer feeding cycle, the milder winters, movement of nursery stock, and the ease with which it spreads through corridors. If it is able to maintain larger population sizes because of the milder winters, this would suggest that we have less time to respond to the hemlock woolly adelgid than predicted based on the patterns described for the Northeast.

Previous research has found very little evidence of environmental variables that correlate with eastern hemlock survival. The most relevant variable was time since infestation. The longer a stand is infested, the greater the hemlock mortality. In the northern Appalachians, time since infestation is often based on location. The hemlock woolly adelgid spread north from Virginia over time, and gradually caused a decline. In this study, however, the decline in eastern hemlocks was not related to location. The far western plots in Joyce Kilmer and southern plots in Ellicott Rock were just as affected as the relatively northeastern plots in Cataloochee Valley. This suggests that the hemlock woolly adelgid did spread throughout the southern Appalachians faster than it did in the northern Appalachians.

Orwig et al. (2002) found weak evidence of aspect and elevation on hemlock health. They suggested that these variables were indicative of stress on trees. My results did not reveal an effect

of aspect or elevation on hemlock mortality. TSI, a measure of moisture availability, was also not correlated with decline in hemlock health. Instead my data show correlations between change in percent hemlock density and initial eastern hemlock importance value, something Orwig et al. (2002) tested for but did not find. This correlation may be explained by larger population sizes of hemlock woolly adelgid in areas where there is a high importance of eastern hemlock. Orwig et al. (2002) also found a relationship between stand size and declining hemlock health, suggesting that larger stands served as larger targets for adelgid dispersal. Areas of high importance value for eastern hemlock also have multiple targets for adelgid dispersal and may influence the correlation between percent change and importance value.

The similar response between old-growth stands and second-growth stands indicates that successional state does not affect the decline in eastern hemlock. In both categories, small hemlocks declined a similar extent. Successional stage also represents different structural characteristics between plots, such as different size class structure, increased density of very large hemlocks, and increased *R. maximum* cover in the understory.

Eastern hemlocks are declining in the southern Appalachians primarily among the small size classes. Large hemlocks were not yet dead at the time of this fieldwork in 2004 and 2005. The implications of these findings for the southern Appalachians include: (1) concern that the hemlock woolly adelgid spread faster in the Southeast than in the Northeast, (2) concern that areas with the largest importance of eastern hemlock may decline the fastest, and (3) concern that the decline is consistent across both old-growth forests and second-growth forests. The long-term prediction for eastern hemlock distribution in the southern Appalachians is not promising based on these results. Biocontrol agents are the greatest hope for controlling the hemlock woolly adelgid but it is too soon to determine their effectiveness.

(2) How does species richness change after the introduction of the hemlock woolly adelgid?

In this study, the change in species richness was correlated with successional stage. Old-growth forests showed a consistent increase in species richness across all scales after the introduction of hemlock woolly adelgid. Second-growth forests showed a consistent decrease across all scales. There are a variety of possible explanations for this pattern, including structural differences, succession, and sampling related issues. No studies have compared the response of old-growth and second-growth forests to the introduction of hemlock woolly adelgid. Small et al. (2005) found an increase in species richness in a hemlock-dominated forest in New England. Their study site was a hemlock-dominated forest that had suffered catastrophic blowdown from a hurricane in 1938. Eastern hemlock increased in basal area and density until the introduction of the hemlock woolly adelgid in approximately 1987. The forest was reinventoried five, ten, and fifteen years after the discovery of the adelgid. Eastern hemlock had a density of 1065 stems/ha five years after the introduction, almost twice the density in my plots. It also had a basal area of 15.5 m²/ha, similar to my second-growth plots but half that of my old-growth plots. The importance value of eastern hemlock in Small's plots was 40%, similar to my old-growth plots but twice that of my second-growth plots. Very little hemlock mortality was seen after five years but species richness increased from 25 to 29 species. The increase in herbaceous species richness was mostly a result of local shade-tolerant species spreading into plots.

Small's study may complement my findings. While their sample site would probably be classified as second growth because of the blow-down event, eastern hemlock importance in their study was very high similar to my old-growth plots. The increase in species richness in Small's study and in my old-growth plots may indicate that species richness response is more a function of hemlock importance value than successional stage. When a plot with a high eastern hemlock

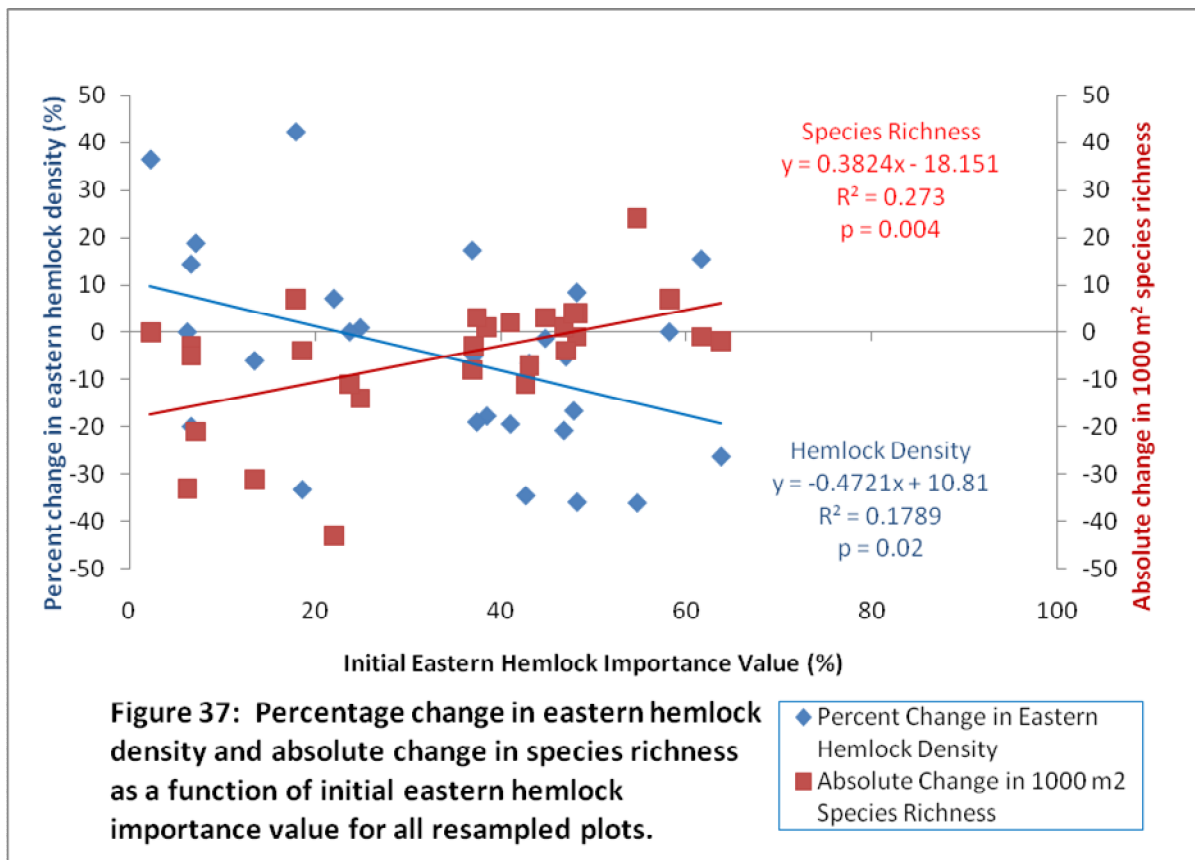
importance value begins to thin, more light reaches the understory and allows locally abundant species to spread soon after the introduction of the adelgid. This hypothesis is consistent with the finding that initial hemlock importance value was correlated with change in species richness in old growth at 10 m² and 100 m².

The species richness in my second-growth forests responded differently to the adelgid, showing a decrease at all scales. Unlike my old-growth plots, my second-growth plots had consistently low values of initial eastern hemlock importance. Rather than opening up a large portion of the canopy, declining eastern hemlocks in these second-growth plots caused small gaps to open up in a mixed hemlock-hardwood forest. The decrease in species richness at low eastern hemlock importance values may be more related to loss of species associated with eastern hemlock such as *Mitchella repens*, *Houstonia sp.*, *Galax aphylla*, *Viola rotundifolia*, and *Listera smallii*.

Initially eastern hemlock may influence both the percent change in hemlock density and the decrease in species richness. Figure 37 correlates initial eastern hemlock importance value in all re inventoried plots with both percent change in eastern hemlock density and absolute change in 1000 m² species richness. Both correlations were significant. As initial eastern hemlock importance value increases, more eastern hemlocks are lost as a percentage of the total number of hemlocks in the plot. Also as importance value increases, the change in species richness goes from being negative at low importance values to positive at high importance values. Successional stage is related to this figure because of the difference in eastern hemlock importance value in old-growth and second-growth forests. In this study, old-growth forests had high importance value and are clustered on the right side of the figure while second-growth forests had low importance value and are usually on the left side of the figure.

This figure may indicate that the effect of the hemlock woolly adelgid is not controlled by successional stage, but by the functional attributes associated with successional stage. Forests with

high importance value of eastern hemlock may act as targets for and support larger populations of hemlock woolly adelgid. When forests with high importance values of eastern hemlock are affected by the adelgid, the effect is more severe than when it is only a part of a mixed hemlock-hardwood forest. More light gets through the canopy, competition decreases, and species richness increases.



(3) How does the effect in the southern Appalachians compare to the effect in the northern Appalachians?

The impact of the hemlock woolly adelgid in the northern Appalachians has been severe. Over 80% of eastern hemlocks have died in forests infested with the hemlock woolly adelgid (Small et al., 2005). No effective resistance has been discovered. Black birch, *Betula lenta*, has been predicted as eastern hemlock's replacement in the northern Appalachians. The species richness

response typically shows an increase in species richness with declining hemlock. Invasive species also increased in small numbers. The effect of the loss of eastern hemlock has been documented for a wide range of species. If southern Appalachian hemlocks respond similarly, a once dominant species will be decimated.

The hemlock woolly adelgid was still in its early stages of infestation when the data were collected in 2004 and 2005. The early stage effect on eastern hemlock seems very similar in the northern and southern Appalachians: an initial widespread decline in small hemlocks. After the decline of the small hemlocks in the northern Appalachians, large hemlocks began to die based on time since infestation. The southern Appalachians were not yet at that stage in 2004 and 2005.

The species most likely to replace the eastern hemlock in the southern Appalachians may differ from that in the north. Black birch is at low densities and has low basal area in southern Appalachian hemlock forests. Instead, other researchers have suggested that *Liriodendron tulipifera* (Ellison et al., 2005), mixed hardwoods (Graham, 2008), or a combination of mixed hardwoods and *Rhododendron maximum* depending on site conditions (Nuckolls et al., 2009; Kincaid, 2007) may replace hemlock. This last suggestion is consistent with Small et al. (2005) who predicted that hemlock communities would diverge based on ravine vs. ledge sites. My results support the hypothesis that initial composition will strongly influence the successional pattern if eastern hemlock is lost. I agree with Nuckolls and Kincaid that when *R. maximum* is present at high densities it will limit canopy replacement. When eastern hemlock has high importance value, species that are able to quickly disperse into the area, such as *B. lenta*, may replace the eastern hemlock. When eastern hemlock has a low importance value, species already present in association with it, such as *A. rubrum* or *L. tulipifera*, are more likely to replace it.

The characteristic herb communities of southern eastern hemlock forests may decline as the hemlock declines and reduce regional species richness, unlike in the northern Appalachians. When

present, *Leucothoe axillaris* and *Gaylussacia ursina* will severely limit herb community development during hemlock decline. Rogers (1980) indicated that northern hemlock communities did not have distinctive herb communities. Therefore, loss of eastern hemlock in northeastern hardwood-hemlock forests would not cause the loss of hemlock-associated species as may happen in the southern Appalachians.

Eastern hemlock communities in the southern Appalachians are at serious risk. If an effective treatment is not found soon, eastern hemlock's functional contribution to the southern Appalachian ecosystem may be lost.

APPENDICES

Appendix A: Plot data

Appendix B: Tree data for reinventoried plots

Appendix C: Herb data for reinventoried plots

Appendix D: Soil data for reinventoried plots

Appendix E: Permission to use Dust of Snow

Appendix A: Plot data

Key	Source	OrigPlot	My_Plot	Stage	Site	MyDate	OrigDate	UTM_E	UTM_N	Elevation	Slope	Aspect
29	CN	012-0C-501	AG-1-501	OG	JK	6/2/2004	5/22/1994	234170	3917590	864	15	212
30	CN	012-0C-507	AG-4-507	OG	JK	6/18/2004	5/26/1994	229720	3923620	940	26	238
31	CN	012-0C-513	AG-1-513	OG	JK	6/3/2004	6/3/1994	234130	3917630	715	13	188
32	CN	012-0C-514	AG-1-514	OG	JK	6/4/2004	6/3/1994	233840	3917850	761	8	105
33	CN	012-0C-519	AG-4-519	SG	JK	6/19/2004	6/8/1994	228110	3923340	612	1	30
34	CN	012-0C-520	AG-4-520	SG	JK	6/20/2004	6/8/1994	228200	3923350	630	29	291
35	CN	012-0C-522	AG-1-522	SG	JK	6/8/2004	6/9/1994	232580	3917050	754	26	239
36	CN	012-0C-525	AG-1-525	OG	JK	6/7/2004	6/13/1994	233560	3916060	800	13	354
37	CN	012-0C-629	AG-4-629	OG	JK	8/21/2004	8/19/1994	232510	3916830	785	32	38
38	CN	012-0C-684	AG-4-684	OG	JK	8/20/2004	8/9/1997	232679	3916298	764	15	47
39	KP	013-0K-0001	AG-1-01	SG	ER	5/28/2004	7/10/1990	304734	3876668	899	21	70
40	KP	013-0K-0002	AG-1-02	SG	ER	5/17/2004	7/11/1990	308935	3872903	701	28	224
41	KP	013-0K-0004	AG-2-04	SG	ER	5/22/2004	7/17/1990	308042	3873273	634	1	300
42	KP	013-0K-0010	AG-3-10	SG	ER	5/25/2004	7/28/1990	311160	3875457	866	30	120
43	KP	013-0K-0011	AG-1-11	SG	ER	5/21/2004	7/30/1990	307218	3872555	638	1	272

44	KP	013-0K-0016	AG-1-16	SG	ER	5/20/2004	8/8/1990	310432	3872674	860	19	316
45	KP	013-0K-0022	AG-1-22	SG	ER	5/27/2004	6/24/1991	306011	3875987	808	3	330
46	KP	013-0K-0033	AG-1-33	SG	ER	5/24/2004	7/9/1991	306294	3875768	872	11	31
47	DP	04-01-0008	AG-4-8	OG	CA	7/12/2005	6/17/1998	305814	3940244	1196	22	300
48	DP	04-01-0016	AG-4-16	OG	CA	7/14/2005	7/7/1998	309888	3942500	893	30	215
49	DP	04-01-0017	AG-4-17	OG	CA	7/15/2005	7/8/1998	307970	3942435	1031	14	260
50	DP	04-01-0018	AG-4-18	OG	CA	7/19/2005	7/9/1998	310269	3943287	869	22	100
51	DP	04-01-0025	AG-5-25	OG	CA	8/2/2005	7/29/1998	307151	3941841	930	20	315
52	DP	04-01-0028	AG-5-28	OG	CA	8/3/2005	8/4/1998	308912	3940778	954	6	316
53	DP	04-01-0029	AG-4-29	OG	CA	8/3/2005	8/5/1998	310150	3942908	893	6	282
54	DP	04-01-0033	AG-4-33	SG	CA	8/18/2005	8/17/1998	309881	3942276	841	21	53
55	DP	04-01-0036	AG-4-36	OG	CA	8/19/2005	8/22/1998	310673	3943754	872	23	310
56	DP	04-01-0041	AG-6-41	SG	CA	10/16/2005	9/24/1998	310896	3944760	818	1	60

Appendix B: Tree Data for Reinventoried Plots

Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
29	012-0C-501	AG-1-501	Acer rubrum				1		1	1		1		
29	012-0C-501	AG-1-501	Aesculus octandra				1							
29	012-0C-501	AG-1-501	Asimina triloba	2										
29	012-0C-501	AG-1-501	Betula lenta				1			1			1	
29	012-0C-501	AG-1-501	Carya cordiformis					3	1					
29	012-0C-501	AG-1-501	Cornus florida					1						
29	012-0C-501	AG-1-501	Halesia carolina	3										
29	012-0C-501	AG-1-501	Hamamelis virginiana	2										
29	012-0C-501	AG-1-501	Liriodendron tulipifera					1		2	1		1	52,45
29	012-0C-501	AG-1-501	Magnolia acuminata					1						
29	012-0C-501	AG-1-501	Magnolia fraseri	1										
29	012-0C-501	AG-1-501	Nyssa sylvatica	1					1					
29	012-0C-501	AG-1-501	Oxydendrum arboreum	1					1					
29	012-0C-501	AG-1-501	Pyrularia pubera	16										
29	012-0C-501	AG-1-501	Quercus alba				1			1				42
29	012-0C-501	AG-1-501	Quercus coccinea							1				49
29	012-0C-501	AG-1-501	Quercus rubra							2			1	45,42
29	012-0C-501	AG-1-501	Tilia americana	4	2		1	1	2			2		
29	012-0C-501	AG-1-501	Tsuga canadensis		1	27	43	13	5	2	3		1	63
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
30	012-0C-507	AG-4-507	Acer rubrum	5	3	8	15	12	6	4		1		
30	012-0C-507	AG-4-507	Amelanchier arboreum					1	1					
30	012-0C-507	AG-4-507	Betula lenta		1									
30	012-0C-507	AG-4-507	Castanea dentata	6	2	5								

[illegible]

[illegible]

32	012-0C-514	AG-1-514	Quercus velutina	4	2									
32	012-0C-514	AG-1-514	Rhododendron maximum		1	1								
32	012-0C-514	AG-1-514	Sassafras albidum						1	1				
32	012-0C-514	AG-1-514	Smilax rotundifolium	10										
32	012-0C-514	AG-1-514	Tilia americana	5	4	2								
32	012-0C-514	AG-1-514	Tsuga canadensis	1	5	45	27	11	1	1				
32	012-0C-514	AG-1-514	Vitis sp.			3	2							
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
33	012-0C-519	AG-4-519	Acer pensylvanicum	4	2	1	1							
33	012-0C-519	AG-4-519	Acer rubrum			1	4	4	1	1	1			
33	012-0C-519	AG-4-519	Amelanchier arboreum	1										
33	012-0C-519	AG-4-519	Betula lenta						1					
33	012-0C-519	AG-4-519	Calycanthus floridus	1										
33	012-0C-519	AG-4-519	Gaylussacia ursina	35 4										
33	012-0C-519	AG-4-519	Halesia carolina	6	1									
33	012-0C-519	AG-4-519	Hamamelis virginiana		3	3	1							
33	012-0C-519	AG-4-519	Ilex opaca	2										
33	012-0C-519	AG-4-519	Kalmia latifolia	14	4	50	11							
33	012-0C-519	AG-4-519	Liriodendron tulipifera					1		1	1			44
33	012-0C-519	AG-4-519	Magnolia fraseri	1										
33	012-0C-519	AG-4-519	Magnolia tripetala	2										
33	012-0C-519	AG-4-519	Nyssa sylvatica	1	1	15	8							
33	012-0C-519	AG-4-519	Oxydendrum arboreum	1	4	7	5	8	3					
33	012-0C-519	AG-4-519	Pinus strobus	5	6	2	5	3						
33	012-0C-519	AG-4-519	Pyrularia pubera	8	2									
33	012-0C-519	AG-4-519	Quercus alba					1	2	2	4	4	1	40,40,49
33	012-0C-519	AG-4-519	Quercus coccinea								1			
33	012-0C-519	AG-4-519	Quercus rubra							1	2	2	1	48,43,65,50
33	012-0C-519	AG-4-519	Rhododendron maximum	2				3						

33	012-0C-519	AG-4-519	Sassafras albidum							1		1		
33	012-0C-519	AG-4-519	Smilax rotundifolium	21										
33	012-0C-519	AG-4-519	Tsuga canadensis	6	5	17	8	8	3	1				
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
34	012-0C-520	AG-4-520	Acer rubrum			8	12	8	8	2	3	2		56
34	012-0C-520	AG-4-520	Amelanchier arboreum	1							1			
34	012-0C-520	AG-4-520	Betula lenta					3	2	2		1		
34	012-0C-520	AG-4-520	Gaylussacia ursina	44										
34	012-0C-520	AG-4-520	Kalmia latifolia	21	27	42	3							
34	012-0C-520	AG-4-520	Liquidambar styraciflua						1					
34	012-0C-520	AG-4-520	Magnolia fraseri	3	1	1	2	1	1	2	1			
34	012-0C-520	AG-4-520	Nyssa sylvatica										1	
34	012-0C-520	AG-4-520	Oxydendrum arboreum	2			3	4	1	2	1			
34	012-0C-520	AG-4-520	Quercus coccinea										2	50,40,48,44
34	012-0C-520	AG-4-520	Quercus prinus						1					
34	012-0C-520	AG-4-520	Quercus rubra						1					46,41
34	012-0C-520	AG-4-520	Rhododendron maximum	9	1	30	44	15						
34	012-0C-520	AG-4-520	Sassafras albidum						1		1			
34	012-0C-520	AG-4-520	Smilax rotundifolium	3										
34	012-0C-520	AG-4-520	Tsuga canadensis	3	1	9	7	6	1	1				
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
35	012-0C-522	AG-1-522	Acer pensylvanicum	4	3	1		1						
35	012-0C-522	AG-1-522	Acer rubrum				1	1		1	1	1		55
35	012-0C-522	AG-1-522	Acer saccharum		1	1								
35	012-0C-522	AG-1-522	Betula allaghaniensis									1		
35	012-0C-522	AG-1-522	Betula lenta				1	2	2	3	3		1	47
35	012-0C-522	AG-1-522	Calycanthus floridus	5	1									
35	012-0C-522	AG-1-522	Carya glabra					1						

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36	012-0C-525	AG-1-525	Oxydendrum arboreum					1		1				
36	012-0C-525	AG-1-525	Pyrularia pubera		1									
36	012-0C-525	AG-1-525	Tilia americana	4	2	2			2					45
36	012-0C-525	AG-1-525	Tsuga canadensis	1	2	6	3		2	3	2	3	3	45,45,46,5 2,49,47,59 ,42,61,60, 49,65,41,4 2
36	012-0C-525	AG-1-525	Vitis sp.				1							
Key	OrigPlot	My_Plot	Species	0-1	1- 2.5	2.5- 5	5- 10	10- 15	15- 20	20- 25	25- 30	30- 35	35- 40	>40
37	012-0C-629	AG-4-629	Acer pensylvanicum	8		5	1	1						
37	012-0C-629	AG-4-629	Acer saccharum	1	1	1	1				1			
37	012-0C-629	AG-4-629	Aristolochia macrophylla	4										
37	012-0C-629	AG-4-629	Betula allaghaniensis			1								
37	012-0C-629	AG-4-629	Betula lenta	2	3	1								60,71,49
37	012-0C-629	AG-4-629	Calycanthus floridus	5										
37	012-0C-629	AG-4-629	Euonymus americana	1										
37	012-0C-629	AG-4-629	Fagus grandifolia		1									
37	012-0C-629	AG-4-629	Fraxinus americana	1										
37	012-0C-629	AG-4-629	Halesia carolina	15	3		2	2		1		1		
37	012-0C-629	AG-4-629	Hydrangea arborescens	1										
37	012-0C-629	AG-4-629	Ilex montana	11	3	3								
37	012-0C-629	AG-4-629	Liriodendron tulipifera	1				1						
37	012-0C-629	AG-4-629	Magnolia acuminata	1										87
37	012-0C-629	AG-4-629	Parthenocissus quinquifolia	3										
37	012-0C-629	AG-4-629	Pyrularia pubera	7	1									
37	012-0C-629	AG-4-629	Tilia americana	2		1							1	73,70
37	012-0C-629	AG-4-629	Tsuga canadensis	6	1	4	5	6	1	2	2	2	3	97,78,81,4 4,45
Key	OrigPlot	My_Plot	Species	0-1	1- 2.5	2.5- 5	5- 10	10- 15	15- 20	20- 25	25- 30	30- 35	35- 40	>40

39	013-OK-0001	AG-1-01	Acer pensylvanicum				1							
39	013-OK-0001	AG-1-01	Acer rubrum	13	16	19	14	4	1				2	50,47
39	013-OK-0001	AG-1-01	Betula lenta							1				
39	013-OK-0001	AG-1-01	Carya glabra			1	1	1						
39	013-OK-0001	AG-1-01	Carya tomentosa											
39	013-OK-0001	AG-1-01	Castanea dentata	1	2	1		1						
39	013-OK-0001	AG-1-01	Chinquipin	1										
39	013-OK-0001	AG-1-01	Gaylussacia ursina	20 5										
39	013-OK-0001	AG-1-01	Ilex opaca		1									
39	013-OK-0001	AG-1-01	Kalmia latifolia	1		2	1							
39	013-OK-0001	AG-1-01	Magnolia fraseri		2	3	1	4						
39	013-OK-0001	AG-1-01	Nyssa sylvatica	1		3	4	2	2					
39	013-OK-0001	AG-1-01	Oxydendrum arboreum					1	1	1	1	2	1	
39	013-OK-0001	AG-1-01	Pinus rigida											77
														45,74,52,5 2,55,44,54 ,54,58,62, 52,49
39	013-OK-0001	AG-1-01	Pinus strobus				1		1					
39	013-OK-0001	AG-1-01	Prunus serotina		1	1								
39	013-OK-0001	AG-1-01	Pyrularia pubera	9										
39	013-OK-0001	AG-1-01	Quercus coccinea								2			
39	013-OK-0001	AG-1-01	Quercus prinus					1	2	1				40
39	013-OK-0001	AG-1-01	Robinia pseudoacacia			1					1			
39	013-OK-0001	AG-1-01	Smilax rotundifolium	3		1								
39	013-OK-0001	AG-1-01	Tsuga canadensis			1	6	8						
39	013-OK-0001	AG-1-01	Rhododendron maximum			5	3	4	1					
Key	OrigPlot	My_Plot	Species	0-1	1- 2.5	2.5- 5	5- 10	10- 15	15- 20	20- 25	25- 30	30- 35	35- 40	>40
40	013-OK-0002	AG-1-02	Acer rubrum			1							1	
40	013-OK-0002	AG-1-02	Aesculus octandra		2	1	1							
40	013-OK-0002	AG-1-02	Betula lenta				2	1	2		1			

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42	013-OK-0010	AG-3-10	Rhododendron maximum		1	1	2		1					
42	013-OK-0010	AG-3-10	Robinia pseudoacacia		2	1								
42	013-OK-0010	AG-3-10	Rubus sp.	4	4									
42	013-OK-0010	AG-3-10	Smilax rotundifolium	7										
42	013-OK-0010	AG-3-10	Tsuga canadensis				2	4	5	3	5			
42	013-OK-0010	AG-3-10	Vitis sp.	3	7	5	2							
42	013-OK-0010	AG-3-10	Quercus alba					1						
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
43	013-OK-0011	AG-1-11	Acer rubrum	0	2	1	0	0	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Betula lenta	0	0	1	1	6	1	0	0	0	0	51
43	013-OK-0011	AG-1-11	Castanea dentata	0	1	0	0	0	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Gaylussacia ursina	4	1	0	0	0	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Halesia carolina	0	2	0	0	0	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Ilex opaca	2	7	5	6	2	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Kalmia latifolia	0	1	0	0	0	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Liriodendron tulipifera	0	0	0	2	5	4	1	0	0	0	
43	013-OK-0011	AG-1-11	Magnolia fraseri	0	2	1	2	0	1	0	0	0	0	
43	013-OK-0011	AG-1-11	Oxydendrum arboreum	0	1	2	0	1	0	1	0	0	0	
43	013-OK-0011	AG-1-11	Pinus strobus	0	0	0	0	0	1	0	3	1	0	72, 50, 48, 75, 44, 79, 67, 56, 55, 70, 49, 55, 52, 44, 55, 58, 40, 42, 69, 49, 49, 52, 47
43	013-OK-0011	AG-1-11	Rhododendron maximum	0	10	10	3	4	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Sassafras albidum	0	0	1	0	0	0	0	0	0	0	
43	013-OK-0011	AG-1-11	Tsuga canadensis	2	22	38	2	14	4	1	2	0	0	59, 43
43	013-OK-0011	AG-1-11	Vitis aestivalis	0	1	1	0	0	0	0	0	0	0	

Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
44	013-OK-0016	AG-1-16	Acer rubrum	0	1	3	5	1	3	1	8	0	1	114, 47
44	013-OK-0016	AG-1-16	Cornus alternifolia	5	28	22	0	0	0	0	0	0	0	
44	013-OK-0016	AG-1-16	Cornus florida	0	0	2	1	0	0	0	0	0	0	
44	013-OK-0016	AG-1-16	Halesia carolina	0	0	0	0	0	1	0	0	0	0	
44	013-OK-0016	AG-1-16	Hamamelis virginiana	0	4	4	0	0	0	0	0	0	0	
44	013-OK-0016	AG-1-16	Kalmia latifolia	0	6	5	2	0	0	0	0	0	0	
44	013-OK-0016	AG-1-16	Liriodendron tulipifera	0	1	1	0	1	0	0	0	0	0	
44	013-OK-0016	AG-1-16	Magnolia fraseri	0	0	0	0	1	0	0	0	0	0	
44	013-OK-0016	AG-1-16	Nyssa sylvatica	0	0	0	2	2	1	0	0	0	0	
44	013-OK-0016	AG-1-16	Oxydendrum arboreum	0	0	0	1	2	0	0	1	0	0	
44	013-OK-0016	AG-1-16	Pinus strobus	0	0	1	4	1	0	0	0	0	0	
44	013-OK-0016	AG-1-16	Quercus alba	0	0	0	0	0	0	0	1	1	0	42, 49
44	013-OK-0016	AG-1-16	Quercus prinus	0	0	0	0	0	0	0	1	0	0	60, 41
44	013-OK-0016	AG-1-16	Quercus rubra	0	0	1	0	0	1	3	0	1	0	45, 61
44	013-OK-0016	AG-1-16	Rhododendron maximum	0	0	3	1	0	0	0	0	1	0	
44	013-OK-0016	AG-1-16	Robinia pseudoacacia	0	0	0	0	0	0	0	0	2	1	52
44	013-OK-0016	AG-1-16	Tsuga canadensis	0	0	4	2	3	5	1	0	0	0	
44	013-OK-0016	AG-1-16	Vitis aestivalis	0	0	0	1	0	0	0	0	0	0	
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
45	013-OK-0022	AG-1-22	Acer rubrum	0	0	0	0	0	0	0	0	0	0	54
45	013-OK-0022	AG-1-22	Betula lenta	0	0	0	0	0	0	0	0	1	1	52
45	013-OK-0022	AG-1-22	Clethra acuminata	0	1	1	3	0	0	0	0	0	0	
45	013-OK-0022	AG-1-22	Halesia carolina	1	1	2	0	0	0	0	1	0	0	
45	013-OK-0022	AG-1-22	Hamamelis virginiana	1	2	2	0	0	0	0	0	0	0	
45	013-OK-0022	AG-1-22	Ilex opaca	1	1	3	1	0	0	0	0	0	0	
45	013-OK-0022	AG-1-22	Kalmia latifolia	0	0	1	1	3	3	1	1	0	0	
45	013-OK-0022	AG-1-22	Liriodendron tulipifera	0	0	1	0	0	0	0	1	0	0	53, 54, 58,

														63
45	013-OK-0022	AG-1-22	Rhododendron maximum	94	45	52	3 9	22	2	0	0	0	0	
45	013-OK-0022	AG-1-22	Tsuga canadensis	1	0	0	2	1	0	0	0	0	1	51, 48, 91, 62, 51
Key	OrigPlot	My_Plot	Species	0-1	1- 2.5	2.5- 5	5- 10	10- 15	15- 20	20- 25	25- 30	30- 35	35- 40	>40
46	013-OK-0033	AG-1-33	Acer rubrum	0	0	0	0	2	0	0	0	1	0	68
46	013-OK-0033	AG-1-33	Halesia carolina	0	1	0	0	1	0	0	0	0	0	
46	013-OK-0033	AG-1-33	Ilex opaca	0	4	1	1	0	1	1	0	0	0	
46	013-OK-0033	AG-1-33	Kalmia latifolia	0	0	0	0	0	1	0	0	0	0	
46	013-OK-0033	AG-1-33	Liriodendron tulipifera	0	0	0	0	0	0	0	0	0	0	98
46	013-OK-0033	AG-1-33	Oxydendrum arboreum	1	0	0	0	1	1	0	1	0	1	40
46	013-OK-0033	AG-1-33	Pinus strobus	0	0	0	0	0	0	0	0	0	0	56
46	013-OK-0033	AG-1-33	Quercus alba	0	1	0	0	0	0	0	0	0	0	53, 69
46	013-OK-0033	AG-1-33	Quercus prinus	0	0	0	0	0	0	0	3	0	0	47
46	013-OK-0033	AG-1-33	Rhododendron maximum	0	2	24	5	4	0	0	0	0	0	
46	013-OK-0033	AG-1-33	Tsuga canadensis	1	10	35	1 6	8	6	1	1	2	2	43, 50, 62
Key	OrigPlot	My_Plot	Species	0-1	1- 2.5	2.5- 5	5- 10	10- 15	15- 20	20- 25	25- 30	30- 35	35- 40	>40
47	04-01-0008	AG-4-8	Acer pensylvanicum	1	1	2	0	0	0	0	0	0	0	
47	04-01-0008	AG-4-8	Acer saccharum	0	0	2	0	0	0	0	0	0	0	
47	04-01-0008	AG-4-8	Amelanchier laevis	1	0	0	0	0	0	0	0	0	0	
47	04-01-0008	AG-4-8	Aristolochia macrophylla	2	0	0	0	0	0	0	0	0	0	
47	04-01-0008	AG-4-8	Betula lenta	0	0	0	0	1	0	0	0	0	0	
47	04-01-0008	AG-4-8	Fagus grandifolia	2	0	1	0	0	0	0	0	0	0	
47	04-01-0008	AG-4-8	Halesia carolina	2	1	2	0	0	0	0	1	2	0	42, 44
47	04-01-0008	AG-4-8	Magnolia fraseri	0	1	1	0	0	0	0	0	0	0	
47	04-01-0008	AG-4-8	Rhododendron maximum	169	61	67	1	6	0	0	0	0	0	

							8							
47	04-01-0008	AG-4-8	Tsuga canadensis	1	0	3	4	3	2	2	0	1	1	71, 103, 68, 66, 72, 83, 45, 97, 84
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
48	04-01-0016	AG-4-16	Acer pensylvanicum	1	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Acer rubrum	1	0	0	0	0	0	0	0	0	0	63
48	04-01-0016	AG-4-16	Amelanchier laevis	1	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Betula alleghaniensis	1	1	0	0	0	0	0	1	0	0	
48	04-01-0016	AG-4-16	Betula lenta	5	0	1	0	0	0	0	0	0	0	63
48	04-01-0016	AG-4-16	Clethra acuminata	2	2	2	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Gaylussacia ursina	1	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Hamamelis virginiana	1	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Kalmia latifolia	61	32	23	8	3	0	0	0	0	0	
48	04-01-0016	AG-4-16	Leucothoe axillaris	270	1	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Magnolia fraseri	1	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Nyssa sylvatica	2	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Oxydendrum arboreum	2	0	1	1	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Rhododendron maximum	170	87	21	9	1	0	0	0	0	0	
48	04-01-0016	AG-4-16	Rubus canadensis	6	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Smilax glauca	1	0	0	0	0	0	0	0	0	0	
48	04-01-0016	AG-4-16	Tsuga canadensis	4	0	2	5	4	3	3	2	3	1	94, 68, 62, 107, 43, 91, 50, 49, 42, 41
48	04-01-0016	AG-4-16	Vaccinium corymbosum	2	0	0	0	0	0	0	0	0	0	
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
49	04-01-0017	AG-4-17	Acer pensylvanicum	27	5	6	1	0	0	0	0	0	0	
49	04-01-0017	AG-4-17	Betula lenta	0	0	0	0	0	0	0	1	0	0	

49	04-01-0017	AG-4-17	Fraxinus americana	1	0	0	0	0	0	0	0	0	0	
49	04-01-0017	AG-4-17	Gaylussacia ursina	6	0	0	0	0	0	0	0	0	0	
49	04-01-0017	AG-4-17	Halesia carolina	3	1	0	0	0	0	0	0	0	0	
49	04-01-0017	AG-4-17	Kalmia latifolia	1	0	0	0	0	0	0	0	0	0	
49	04-01-0017	AG-4-17	Liriodendron tulipifera	0	0	0	0	0	0	0	0	0	0	120
49	04-01-0017	AG-4-17	Magnolia fraseri	0	1	1	0	0	0	0	0	0	1	
49	04-01-0017	AG-4-17	Rhododendron maximum	20	15	34	8	4	0	0	0	0	0	
49	04-01-0017	AG-4-17	Tilia americana	1	1	0	0	0	0	0	0	0	0	
49	04-01-0017	AG-4-17	Tsuga canadensis	49	9	21	3	2	0	0	0	1	1	61, 81, 97, 45, 67, 85, 54, 60, 56, 53, 86
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
50	04-01-0018	AG-4-18	Acer pensylvanicum	3	0	0	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Acer rubrum	1	0	1	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Betula lenta	0	0	1	2	5	4	4	0	0	0	47
50	04-01-0018	AG-4-18	Clethra acuminata	27	8	18	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Halesia carolina	1	0	1	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Hamamelis virginiana	6	0	0	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Ilex opaca	0	0	0	1	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Kalmia latifolia	21	5	10	7	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Leucothoe axillaris	507	0	0	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Magnolia fraseri	1	0	4	0	2	1	0	0	0	0	
50	04-01-0018	AG-4-18	Quercus rubra	3	0	0	1	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Rhododendron maximum	230	58	72	8	3	2	0	0	0	0	
50	04-01-0018	AG-4-18	Rubus canadensis	10	0	0	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Smilax rotundifolia	4	0	0	0	0	0	0	0	0	0	
50	04-01-0018	AG-4-18	Tsuga canadensis	0	0	1	1	1	0	2	1	0	1	92, 50, 86, 111, 121, 90, 59, 52, 64, 62, 67, 80
50	04-01-0018	AG-4-18	Vaccinium corymbosum	0	0	1	0	0	0	0	0	0	0	

Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
51	04-01-0025	AG-5-25	Acer pensylvanicum	61	10	11	4	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Acer saccharum	1	4	3	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Aesculus octandra	9	0	0	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Amelanchier laevis	1	1	0	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Aristolochia macrophylla	10	1	1	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Carpinus caroliniana	0	0	2	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Cornus alternifolia	2	0	0	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Fagus grandifolia	50	6	3	0	0	0	1	0	0	3	55
51	04-01-0025	AG-5-25	Fraxinus americana	2	1	0	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Halesia carolina	24	2	1	1	1	0	0	0	1	0	
51	04-01-0025	AG-5-25	Hamamelis virginiana	0	1	0	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Magnolia acuminata	2	0	0	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Rhododendron maximum	31	20	45	1 5	2	0	0	0	0	0	
51	04-01-0025	AG-5-25	Tilia americana	2	1	2	0	0	0	0	0	0	0	
51	04-01-0025	AG-5-25	Tsuga canadensis	2	0	0	0	0	0	1	1	1	2	127, 102, 76, 84, 99, 110, 119
51	04-01-0025	AG-5-25	Vitis aestivalis	0	0	1	1	1	0	0	0	0	0	
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
52	04-01-0028	AG-5-28	Acer pensylvanicum	11	4	4	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Acer saccharum	0	1	0	0	0	0	0	0	0	0	72
52	04-01-0028	AG-5-28	Amelanchier laevis	4	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Aristolochia macrophylla	1	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Betula alleghaniensis	0	0	1	0	0	1	0	0	0	0	
52	04-01-0028	AG-5-28	Calycanthus floridus	9	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Castanea dentata	1	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Fagus grandifolia	74	17	16	0	0	0	0	0	0	0	

52	04-01-0028	AG-5-28	Halesia carolina	10	5	3	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Hamamelis virginiana	2	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Leucothoe axillaris	33	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Liriodendron tulipifera	0	0	0	0	0	0	0	0	0	0	120
52	04-01-0028	AG-5-28	Magnolia acuminata	4	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Magnolia fraseri	4	1	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Nyssa sylvatica	1	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Pyrularia pubera	4	2	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Rhododendron maximum	46	11	39	4	1	0	0	0	0	0	
52	04-01-0028	AG-5-28	Rubus canadensis	2	0	0	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Tilia americana	0	1	1	0	0	0	0	0	0	0	
52	04-01-0028	AG-5-28	Tsuga canadensis	17	6	13	6	6	1	1	2	3	1	96, 47, 69, 87, 87, 77, 74, 76, 54, 61, 76, 57, 55, 40, 60
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
53	04-01-0029	AG-4-29	Acer pensylvanicum	3	0	0	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Acer rubrum	3	1	1	0	1	0	0	0	0	0	81
53	04-01-0029	AG-4-29	Betula alleghaniensis	2	0	5	0	1	0	0	1	0	2	47, 42
53	04-01-0029	AG-4-29	Calycanthus floridus	1	0	0	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Castanea dentata	1	0	0	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Clethra acuminata	27	12	13	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Gaylussacia ursina	46	0	0	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Hamamelis virginiana	3	0	3	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Ilex montana	1	0	0	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Kalmia latifolia	83	31	60	1 4	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Leucothoe axillaris	56	0	0	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Liriodendron tulipifera	0	0	1	0	0	0	0	0	0	0	
53	04-01-0029	AG-4-29	Magnolia fraseri	1	0	0	1	0	0	0	0	0	1	

[illegible]

54	04-01-0033	AG-4-33	Tilia americana	1	0	0	0	0	0	0	0	0	0	
54	04-01-0033	AG-4-33	Tsuga canadensis	2	0	2	1	3	0	0	0	2	1	90, 42, 98, 66, 47, 101
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
55	04-01-0036	AG-4-36	Acer pensylvanicum	2	1	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Acer rubrum	1	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Betula lenta	4	2	1	0	0	1	0	0	0	0	42
55	04-01-0036	AG-4-36	Castanea dentata	1	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Clethra acuminata	53	21	26	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Gaylussacia ursina	70	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Hamamelis virginiana	4	1	3	1	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Kalmia latifolia	23	12	28	8	4	0	0	0	0	0	
55	04-01-0036	AG-4-36	Leucothoe axillaris	564	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Liriodendron tulipifera	1	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Magnolia fraseri	13	5	7	2	1	0	0	0	1	0	
55	04-01-0036	AG-4-36	Pinus strobus	1	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Prunus serotina	1	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Quercus prinus	1	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Rhododendron maximum	85	15	34	9	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Rhododendron maximum	11	3	11	1	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Rubus canadensis	2	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Smilax rotundifolia	1	0	0	0	0	0	0	0	0	0	
55	04-01-0036	AG-4-36	Tsuga canadensis	7	0	5	2	4	0	0	3	0	1	64, 84, 90, 89, 67, 50, 74, 70, 93, 68, 80, 45, 79
55	04-01-0036	AG-4-36	Vaccinium corymbosum	1	0	0	0	0	0	0	0	0	0	
Key	OrigPlot	My_Plot	Species	0-1	1-2.5	2.5-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
56	04-01-0041	AG-6-41	Acer rubrum	0	0	0	1	0	0	0	3	0	0	41

56	04-01-0041	AG-6-41	Acer saccharum	0	1	1	1	3	0	1	0	0	0	
56	04-01-0041	AG-6-41	Aesculus octandra	0	0	0	0	0	0	0	1	0	0	
56	04-01-0041	AG-6-41	Betula alleghaniensis	6	1	0	1	1	0	2	2	0	2	49, 40
56	04-01-0041	AG-6-41	Betula lenta	0	0	0	0	0	0	0	0	1	0	
56	04-01-0041	AG-6-41	Carpinus caroliniana	0	0	1	1	0	0	0	0	0	0	
56	04-01-0041	AG-6-41	Euonymus americana	1	0	0	0	0	0	0	0	0	0	
56	04-01-0041	AG-6-41	Fagus grandifolia	2	0	3	1	0	0	0	0	0	1	
56	04-01-0041	AG-6-41	Halesia carolina	2	1	2	0	1	0	0	2	0	0	
56	04-01-0041	AG-6-41	Ilex montana	0	1	0	0	0	0	0	0	0	0	
56	04-01-0041	AG-6-41	Juglans nigra	0	0	0	0	0	0	0	0	0	1	
56	04-01-0041	AG-6-41	Leucothoe axillaris	62	0	0	0	0	0	0	0	0	0	
56	04-01-0041	AG-6-41	Lindera benzoin	13	0	0	0	0	0	0	0	0	0	
56	04-01-0041	AG-6-41	Liriodendron tulipifera	0	0	0	0	0	0	0	0	0	0	60
56	04-01-0041	AG-6-41	Magnolia fraseri	0	1	1	0	1	0	0	0	0	0	
56	04-01-0041	AG-6-41	Parthenocissus quinquefolia	10	0	0	0	0	0	0	0	0	0	
56	04-01-0041	AG-6-41	Pinus strobus	0	0	0	0	0	0	0	0	0	0	47, 75, 75
56	04-01-0041	AG-6-41	Quercus rubra	0	0	0	0	0	0	0	0	0	0	43
56	04-01-0041	AG-6-41	Rhododendron maximum	80	28	53	2 3	0	0	0	0	0	0	
56	04-01-0041	AG-6-41	Tilia americana	0	0	0	0	2	0	0	1	0	0	
56	04-01-0041	AG-6-41	Tsuga canadensis	0	0	1	0	2	0	2	1	1	0	45, 68, 64, 125, 72
56	04-01-0041	AG-6-41	Vitis aestivalis	0	0	2	4	1	0	1	0	0	0	

Appendix C: Herb Data for Reinventoried Plots²

Key	OrigPlot	My_Plot	mod	corner	rich_10cm	rich_31cm	rich_1m	rich_3_1m	rich_10m	Total of richness	rich_Plot
29	012-0C-501	AG-1-501	2	2	0	1	5	20	55	55	
			2	4	4	4	8	19	55	55	
			3	2	0	0	7	26	63	63	
			3	3	1	2	9	22	63	63	
			8	2	0	0	3	10	36	36	
			8	4	0	1	2	15	36	36	
			9	2	0	1	4	14	35	35	
			9	3	0	1	7	12	35	35	
			S	1						100	100
30	012-0C-507	AG-4-507	2	2	0	1	3	6	16	16	
			2	4	1	2	3	5	16	16	
			3	2	0	1	4	7	20	20	
			3	3	0	0	4	5	20	20	
			8	2	1	1	4	8	18	18	
			8	4	0	1	6	11	18	18	
			9	2	1	3	7	11	20	20	
			9	3	1	1	5	8	20	20	
			S	1						36	36
31	012-0C-513	AG-1-513	2	2	0	0	1	14	27	27	
			2	4	0	2	3	17	27	27	
			3	2	1	1	3	12	42	42	
			3	3	0	0	2	11	42	42	
			8	2	1	2	7	21	45	45	
			8	4	0	1	6	14	45	45	
			9	2	0	0	1	14	41	41	
			9	3	0	1	6	20	41	41	

² Please contact the author at andy.gerschutz@gmail.com for electronic copies of the data, including herb data identifying species.

			S	1						95	95
32	012-0C-514	AG-1-514	2	2	1	3	7	25	68	68	
			2	4	1	5	10	31	68	68	
			3	2	0	5	9	19	56	56	
			3	3	1	6	10	27	56	56	
			8	2	2	3	5	22	51	51	
			8	4	0	0	3	13	51	51	
			9	2	3	4	9	30	63	63	
			9	3	1	3	8	21	63	63	
			S	1						120	120
33	012-0C-519	AG-4-519	2	2	1	2	4	10	20	20	
			2	4	1	1	4	10	20	20	
			3	2	0	1	3	10	21	21	
			3	3	0	2	4	12	21	21	
			8	2	2	3	4	12	24	24	
			8	4	0	0	2	13	24	24	
			9	2	0	2	4	9	23	23	
			9	3	0	1	7	12	23	23	
			S	1						37	37
34	012-0C-520	AG-4-520	2	2	1	1	2	7	15	15	
			2	4	0	1	3	6	15	15	
			3	2	0	0	1	4	13	13	
			3	3	0	1	3	6	13	13	
			8	2	0	0	1	5	13	13	
			8	4	0	0	6	10	13	13	
			9	2	0	0	2	8	14	14	
			9	3	0	0	0	3	14	14	
			S	1						28	28
35	012-0C-522	AG-1-522	2	2	0	2	13	18	35	35	
			2	4	2	4	9	18	35	35	
			3	2	1	2	5	11	28	28	
			3	3	1	3	8	12	28	28	

			8	2	0	1	6	16	36	36	
			8	4	1	2	5	12	36	36	
			9	2	0	5	11	22	45	45	
			9	3	0	0	3	14	45	45	
			S	1						72	72
36	012-0C-525	AG-1-525	2	2	1	5	10	29	46	46	
			2	4	2	3	6	20	46	46	
			3	2	3	4	5	11	36	36	
			3	3	2	4	11	22	36	36	
			8	2	2	3	5	11	46	46	
			8	4	1	2	7	21	46	46	
			9	2	3	6	7	21	44	44	
			9	3	1	4	6	23	44	44	
			S	1						72	72
37	012-0C-629	AG-4-629	3	2	1	4	7	22	37	37	
			3	4	0	3	6	19	37	37	
			4	2	1	6	12	20	36	36	
			4	3	1	6	8	17	36	36	
			7	2	2	2	8	23	48	48	
			7	4	1	3	11	30	48	48	
			8	2	1	4	11	17	33	33	
			8	3	2	3	7	14	33	33	
			S	1						70	70
38	012-0C-684	AG-4-684	2	2	2	3	9	19	33	33	
			2	4	0	3	8	18	33	33	
			3	2	1	2	6	14	32	32	
			3	3	1	2	7	18	32	32	
			8	2	1	4	10	18	32	32	
			8	4	0	3	8	15	32	32	
			9	2	1	5	6	13	27	27	
			9	3	0	1	5	11	27	27	
			S	1						55	55

39	013-OK-0001	AG-1-01	2	2	0	1	4	12	22	22	
			2	4	0	2	3	14	22	22	
			3	2	0	1	3	10	20	20	
			3	3	0	1	6	12	20	20	
			8	2	0	1	2	12	24	24	
			8	4	0	0	1	11	24	24	
			9	2	0	1	2	6	17	17	
			9	3	1	3	5	7	17	17	
		S	1							46	46
40	013-OK-0002	AG-1-02	2	2	0	5	10	16	32	32	
			2	4	1	2	4	16	32	32	
			3	2	0	2	10	24	37	37	
			3	3	0	1	3	12	37	37	
			8	2	2	4	8	16	39	39	
			8	4	0	1	3	14	39	39	
			9	2	0	1	8	19	34	34	
			9	3	0	3	7	17	34	34	
		S	1							67	67
41	013-OK-0004	AG-2-04	2	2	0	1	8	16	27	27	
			2	4	0	3	5	14	27	27	
			3	2	0	1	4	13	31	31	
			3	3	0	1	6	17	31	31	
			8	2	0	2	7	16	38	38	
			8	4	1	5	10	25	38	38	
			9	2	0	1	4	16	33	33	
			9	3	0	1	3	17	33	33	
		S	1							62	62
42	013-OK-0010	AG-3-10	2	2	0	1	11	20	37	37	
			2	4	2	4	12	22	37	37	
			3	2	0	3	15	27	38	38	
			3	3	1	2	4	12	38	38	
			8	2	1	2	5	14	38	38	

			8	4	2	4	13	18	38	38	
			9	2	1	4	12	23	39	39	
			9	3	1	5	9	13	39	39	
		S	1							69	69
43	013-0K-0011	AG-1-11	2	2	0	2	8	16	25	25	
			2	4	2	2	4	13	25	25	
			3	2	1	1	6	13	24	24	
			3	3	2	2	6	8	24	24	
			8	2	0	1	5	13	21	21	
			8	4	2	3	7	11	21	21	
			9	2	0	2	3	9	19	19	
			9	3	1	2	3	6	19	19	
		S	1							41	41
44	013-0K-0016	AG-1-16	2	2	0	4	7	12	22	22	
			2	4	0	0	4	8	22	22	
			3	2	1	2	4	10	22	22	
			3	3	0	2	4	13	22	22	
			8	2	1	1	3	13	21	21	
			8	4	0	0	2	6	21	21	
			9	2	0	1	5	10	22	22	
			9	3	0	2	3	9	22	22	
		S	1							42	42
45	013-0K-0022	AG-1-22	2	2	0	0	0	6	11	11	
			2	4	1	1	3	7	11	11	
			3	2	0	1	2	7	14	14	
			3	3	1	2	5	8	14	14	
			8	2	0	0	0	10	23	23	
			8	4	0	0	1	8	23	23	
			9	2	1	1	1	5	12	12	
			9	3	0	0	0	7	12	12	
		S	1							34	34
46	013-0K-0033	AG-1-33	2	2	0	1	4	15	27	27	

			2	4	0	0	2	5	27	27	
			3	2	0	0	1	4	22	22	
			3	3	0	0	1	6	22	22	
			8	2	1	1	4	9	19	19	
			8	4	0	2	2	4	19	19	
			9	2	0	0	0	7	16	16	
			9	3	0	0	1	6	16	16	
			S	1						41	41
47	04-01-0008	AG-4-8	2	2	0	4	4	16	24	24	
			2	4	0	1	7	7	24	24	
			3	2	1	2	7	9	22	22	
			3	3	2	3	4	7	22	22	
			8	2	1	2	8	10	23	23	
			8	4	0	2	3	8	23	23	
			9	2	0	2	4	11	22	22	
			9	3	0	2	6	11	22	22	
			S	1						34	34
48	04-01-0016	AG-4-16	2	2	0	3	6	10	14	14	
			2	4	1	2	3	9	14	14	
			3	2	0	1	2	11	19	19	
			3	3	0	2	2	9	19	19	
			8	2	0	1	4	14	23	23	
			8	4	0	0	9	11	23	23	
			9	2	0	1	4	9	15	15	
			9	3	0	1	4	10	15	15	
			S	1						35	35
49	04-01-0017	AG-4-17	2	2	1	3	5	12	26	26	
			2	4	0	1	6	13	26	26	
			3	2	0	1	6	17	32	32	
			3	3	0	1	7	15	32	32	
			8	2	0	1	7	17	34	34	
			8	4	1	3	9	19	34	34	

			9	2	0	1	4	9	27	27	
			9	3	1	2	2	13	27	27	
			S	1						52	52
50	04-01-0018	AG-4-18	2	2	0	1	2	6	12	12	
			2	4	0	0	3	6	12	12	
			3	2	0	1	2	7	16	16	
			3	3	0	1	2	5	16	16	
			8	2	0	0	2	8	19	19	
			8	4	0	2	4	10	19	19	
			9	2	0	1	5	5	12	12	
			9	3	0	3	3	5	12	12	
			S	1						32	32
51	04-01-0025	AG-5-25	2	2	1	6	13	26	43	43	
			2	4	1	6	10	24	43	43	
			3	2	3	7	13	26	42	42	
			3	3	2	3	13	29	42	42	
			8	2	2	5	10	23	37	37	
			8	4	1	6	11	20	37	37	
			9	2	1	3	12	28	37	37	
			9	3	2	5	8	18	37	37	
			S	1						58	58
52	04-01-0028	AG-5-28	3	2	3	7	13	22	45	45	
			3	3	1	3	7	27	45	45	
			8	4	2	4	11	24	37	37	
			9	2	0	0	0	0	1	1	
			9	3	0	2	4	11	35	35	
			S	1						63	63
53	04-01-0029	AG-4-29	2	2	1	1	4	7	11	11	
			2	4	1	2	4	6	11	11	
			3	2	0	0	5	11	15	15	
			3	3	0	2	3	9	15	15	
			8	2	1	1	2	4	15	15	

			8	4	0	1	1	4	15	15	
			9	2	2	2	5	6	16	16	
			9	3	1	1	3	8	16	16	
			S	1						29	29
54	04-01-0033	AG-4-33	2	2	0	1	1	3	16	16	
			2	4	0	0	0	0	16	16	
			3	2	2	3	6	10	16	16	
			3	3	0	1	2	8	16	16	
			8	2	0	1	1	4	21	21	
			8	4	0	0	5	12	21	21	
			9	2	0	1	2	5	9	9	
			9	3	0	1	1	4	9	9	
			S	1						37	37
55	04-01-0036	AG-4-36	2	2	1	2	3	12	18	18	
			2	4	0	0	2	12	18	18	
			3	2	0	1	1	7	19	19	
			3	3	1	2	7	16	19	19	
			8	2	1	2	2	8	16	16	
			8	4	0	0	2	6	16	16	
			9	2	0	1	3	11	19	19	
			9	3	0	3	6	9	19	19	
			S	1						34	34
56	04-01-0041	AG-6-41	2	2	0	1	5	9	27	27	
			2	3	0	0	2	10	28	28	
			3	2	0	0	2	17	31	31	
			3	3	2	4	8	17	31	31	
			8	2	0	0	2	5	21	21	
			8	4	1	1	2	5	21	21	
			9	2	1	1	6	9	16	16	
			9	3	0	0	2	6	16	16	
			S	1						62	62

Appendix D: Soil Data for Reinventoried Plots

OrigPlot	Avg Of CEC	Avg Of pH	Avg Of Org	Avg Of N	Avg Of S	Avg Of P
012-0C-501	6.95	5.05	9.58	60.75	35.75	19.25
012-0C-507	4.33	4.25	9.80	60.50	48.50	14.50
012-0C-513	5.72	4.70	9.23	61.00	34.25	18.50
012-0C-514	6.39	5.10	10.58	63.00	29.75	17.00
012-0C-519	3.27	4.53	14.30	64.00	44.25	12.75
012-0C-520	3.80	4.38	9.05	60.00	50.75	14.50
012-0C-522	1.94	4.63	8.35	58.50	42.50	14.00
012-0C-525	3.08	4.68	9.23	60.25	37.00	17.00
012-0C-629	5.81	4.43	12.10	63.50	39.75	22.75
012-0C-684	9.30	4.45	15.48	64.13	40.00	14.75
013-0K-0001	3.97	5.33	12.93	30.50	39.50	16.50
013-0K-0002	9.34	6.10	14.90	30.50	19.25	14.25
013-0K-0004	4.31	4.80	5.53	25.75	18.75	15.50
013-0K-0010	14.11	6.13	14.28	30.63	19.50	12.75
013-0K-0011	3.21	4.98	7.93	27.50	27.75	14.75
013-0K-0016	3.50	4.75	10.85	29.38	20.75	12.75
013-0K-0022	3.95	4.50	17.00	41.00	16.75	12.50
013-0K-0033	4.34	5.08	10.98	28.13	21.75	10.50
071-01-0008	4.80	4.33	15.71	128.00	37.25	9.25
071-01-0016	4.51	3.60	9.66	119.75	18.75	9.50
071-01-0017	4.05	4.40	10.20	123.25	25.00	10.25
071-01-0018	4.90	3.43	5.18	98.75	17.50	14.00
071-01-0025	10.67	4.55	16.75	128.50	31.25	14.75
071-01-0028	5.73	4.43	12.65	126.50	30.50	11.50
071-01-0029	6.82	3.53	5.82	103.75	19.25	13.50
071-01-0033	4.03	4.10	9.64	122.00	29.75	10.50
071-01-0036	5.35	3.43	6.31	104.00	14.00	20.00
071-01-0041	7.93	4.93	13.56	124.50	26.75	9.25

OrigPlot	Avg Of Ca ppm	Avg Of Mg ppm	Avg Of K ppm	Avg Of Na ppm	Avg Of % Other	Avg Of %H
012-0C-501	518.00	100.25	74.25	14.75	7.30	42.25
012-0C-507	150.75	43.00	67.75	10.25	8.90	60.00
012-0C-513	309.00	68.50	77.75	10.00	8.00	51.00
012-0C-514	502.50	68.25	94.25	8.25	7.20	41.75
012-0C-519	143.25	30.75	79.25	7.25	8.35	54.50
012-0C-520	151.25	38.75	56.50	11.00	8.65	57.50
012-0C-522	76.75	29.25	41.75	6.50	8.15	52.50
012-0C-525	144.75	37.00	56.50	7.25	8.05	51.00
012-0C-629	251.75	58.75	88.50	10.75	8.55	56.50
012-0C-684	491.50	68.00	89.75	12.50	8.50	56.00
013-0K-0001	343.00	59.50	35.00	16.75	6.80	35.00
013-0K-0002	1156.50	138.50	119.25	27.00	5.40	15.00
013-0K-0004	284.50	40.25	35.00	9.50	7.80	49.00
013-0K-0010	2109.50	129.50	64.00	11.50	5.50	16.50
013-0K-0011	213.25	38.25	30.75	13.00	7.45	45.25
013-0K-0016	173.75	49.50	57.00	11.00	7.90	50.00
013-0K-0022	178.00	44.75	48.00	11.75	8.40	55.00
013-0K-0033	316.00	62.25	43.50	10.75	7.25	42.25
071-01-0008	192.00	50.50	60.00	14.25	8.75	58.50
071-01-0016	112.00	29.50	36.75	6.50	10.20	69.00
071-01-0017	154.00	47.25	63.00	11.00	8.60	57.00
071-01-0018	97.50	33.50	32.00	10.25	10.55	70.75
071-01-0025	628.50	56.75	88.25	12.75	8.30	54.00
071-01-0028	296.25	45.75	66.25	8.00	8.55	56.50
071-01-0029	157.25	53.00	28.50	13.00	10.35	69.75
071-01-0033	125.75	33.75	33.25	12.75	9.20	61.50
071-01-0036	108.25	36.25	35.75	11.00	10.55	70.75
071-01-0041	559.50	89.25	75.00	11.75	7.55	45.50

OrigPlot	Avg Of B ppm	Avg Of Fe ppm	Avg Of Mn ppm	Avg Of Cu ppm	Avg Of Zn ppm	Avg Of Al ppm
012-0C-501	0.44	163.75	68.00	0.62	3.65	1187.75
012-0C-507	0.24	260.25	14.50	0.43	2.50	1716.50
012-0C-513	0.29	152.50	70.25	0.49	3.20	1401.00
012-0C-514	0.31	108.25	99.00	1.33	2.65	1457.00
012-0C-519	0.20	155.50	13.50	0.20	1.98	1705.00
012-0C-520	0.20	148.00	19.75	0.32	2.00	1594.25
012-0C-522	0.20	122.00	66.25	0.61	1.38	1382.50
012-0C-525	0.22	185.50	36.50	1.40	2.00	1287.50
012-0C-629	0.40	163.50	46.50	1.26	1.83	1310.25
012-0C-684	0.55	152.00	64.00	1.10	3.00	1443.25
013-0K-0001	0.80	163.75	51.25	1.25	2.48	1271.75
013-0K-0002	0.18	63.50	63.25	0.89	3.40	1266.50
013-0K-0004	0.10	165.75	25.25	0.28	2.80	1022.75
013-0K-0010	0.43	51.75	58.25	3.23	5.13	1061.50
013-0K-0011	0.10	94.50	21.50	0.58	1.53	1291.00
013-0K-0016	0.10	121.25	21.75	0.77	2.23	1035.25
013-0K-0022	0.10	168.75	18.25	0.64	2.30	940.25
013-0K-0033	0.10	119.50	24.75	0.71	2.28	1051.50
071-01-0008	0.65	177.50	18.75	0.66	2.31	1573.75
071-01-0016	0.45	309.75	1.67	0.24	1.26	750.50
071-01-0017	0.45	126.00	71.75	0.86	2.24	1321.00
071-01-0018	0.49	251.00	1.50	0.32	1.32	535.50
071-01-0025	0.61	106.75	63.50	0.69	3.19	1642.00
071-01-0028	0.71	141.75	56.25	0.85	2.80	1435.75
071-01-0029	0.67	322.75	3.50	0.42	1.38	760.50
071-01-0033	0.45	237.75	3.75	0.52	1.49	1313.50
071-01-0036	0.43	167.00	5.00	0.33	1.77	630.75
071-01-0041	0.74	254.00	28.00	0.70	3.08	1202.50

Appendix E: Permission to use Robert Frost's Dust of Snow

April 8, 2009

VIA E-MAIL

Mr. Andy Gerschutz
2500 Booker Creek Rd.
Chapel Hill, NC 27514

Pursuant to your specific request dated: April 6, 2009

Re: "Dust of Snow" by Robert Frost

Your title/project: Master's thesis on hemlock trees – UNC-Chapel Hill

PLEASE NOTE: ONLY THE ITEMS MARKED "X" APPLY TO YOU.

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Sincerely,

//Mimi Ross//

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