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Impacts of Beech Bark Disease on Stand Composition and
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presented by

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Major Professor's Signature

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IMPACTS OF BEECH BARK DISEASE ON

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By

Amy M. Kearney

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ABSTRACT

IMPACTS OF BEECH BARK DISEASE ON STAND COMPOSITION AND WILDLIFE RESOURCES IN MICHIGAN.

By

Amy M. Kearney

Beech bark disease was discovered in Michigan in 2000 and will likely kill at least 50% of mature American beech trees. Our study was designed to collect benchmark data that will allow us, in future studies, to determine how understory composition, wildlife resources, and stand productivity are affected by beech bark disease. We assessed the potential impact of beech bark disease in forest stands with varying beech densities (low, moderate, and high) and infestation of *Cryptococcus fagisuga* (absent, light, and heavy). Variables were measured in 62 stands throughout the Upper and Lower Peninsulas of Michigan in 2002 and 2003. Regenerating beech stem density did not differ among stands and no current evidence suggests dense beech thickets will regenerate in stands impacted by beech bark disease in Michigan. Beech snags were significantly more abundant in stands with heavy *C. fagisuga* infestation than in stands where *C. fagisuga* was absent or infestation was light, suggesting tree mortality from beech bark disease had occurred. Coarse woody debris volume and beech nut mass appeared to be highest in stands with heavy *C. fagisuga* infestation, although means were not statistically different. Long-term monitoring of these stands will be necessary to document the effects of beech bark disease as it progresses throughout Michigan.

Dedicated to
Walter Bartow and
Genevieve Hermann,
who taught the essentials.

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INTRODUCTION

Throughout history, beech trees (*Fagus* sp.) have supplied humans with a variety of resources. Early Europeans and North American settlers used lumber for household furnishings and water wheels, fed beech nuts to domestic hogs and turkeys, and stuffed mattresses with dry, elastic beech leaves (Sand 1991, Tubbs and Houston 1990). Beech wood imparts no taste and was a favored material for food containers and utensils, such as ice cream paddles, cutting boards, and beer casks (Sand 1991). The dense wood continues to be valued for firewood and harvested for pulp and lumber production (Peters 1997, Tubbs and Houston 1990).

American beech, *Fagus grandifolia*, primarily occurs in structurally diverse stands of mixed species. Although previously spanning the Atlantic to Pacific coasts of North America, the post-glacial range of American beech is delimited in the north by Nova Scotia and the Upper Peninsula of Michigan, west by Indiana, Wisconsin and eastern Texas, and south by northern Florida (Little 1971). Annual precipitation across this area ranges from 760-1270 mm and mean annual temperatures vary from 4°–21° C (40°-70° F), with lows of -42° C (-44° F) and highs of 38° C (100° F) (Tubbs and Houston 1990). Beech stands are typically found on loose, dry mesic loams with a pH of 4.1-6.0 (Tubbs and Houston 1990).

Beech is a shade tolerant species that regenerates by both seed and root-sprouting (Ward 1961). Mature beech greater than 40 years of age produce periodic crops of beech nuts every two to three years, while large-scale mast events occur in summers following a drought year (Tubbs and Houston 1990, Piovsean and Adams 2001). Successful germination of beech nuts is highly variable, ranging from 0-81% (Stalter 1982). In northern regions, or where site conditions are poor, regeneration occurs primarily by root-suckering (Graber 1992, Held 1983). Injury to trees or roots can stimulate trees to sprout vigorous root-suckers, although these do not generally form desirable trees (Tubbs and Houston 1990, Ward 1961). Beech grows in cycles of suppression and release, surviving well in a shaded understory but not responding rapidly to sudden gaps (Kobe 1995, Tubbs and Houston 1990). Beech trees are not preferentially browsed by deer, giving them a competitive advantage in stands heavily impacted by herbivory (Kelty and Nyland, 1981).

The bark of beech trees is composed of only a few layers of cork and is easily penetrated by insects (Burns and Houston 1987). The beech scale insect, *Cryptococcus fagisuga* Lind. (Homoptera:Cryptococcidae), has a feeding stylet of only 2 mm, which cannot penetrate the relatively thin bark, but is instead used to feed on the bark parenchyma (Dubeler 1997, Shigo 1972). The scale insects feed on the sap in the inner bark of beech, creating minute wounds that provide entry courts for at least one of three *Nectria* fungus species, *Neonectria galligena* A., *Bionectria ochroleuca* A., or the exotic *Neonectria coccinea* var. *faginata* A; resulting in the beech bark disease complex (Houston and O'Brien 1994). The pathogen progressively kills areas of tissue and eventually girdles the limbs and trunk of the tree. Eventually, secondary factors cause structural weakening and trees often break in high winds during a condition known as "beech snap" (Houston and O'Brien 1994).

Cryptococcus fagisuga disperses ahead of the *Nectria* spp., transported primarily by wind currents, during a phase called the "Advancing Front" and typically colonizes areas of rough bark on the trunks of large, old trees (Houston 1975, Mielke 1982).

Generally within a few years, *Nectria* sp. invades scale-infested trees and completes the beech bark disease etiologic complex (Ehrlich 1934). Tree impact and mortality is high during this phase known as the "Killing Front". Mature trees that are not outright killed by beech bark disease exhibit a substantial growth reduction (Twery and Patterson 1984). Declining trees often produce dense root-sprouts that are genetically identical to the parent trees and equally susceptible to beech bark disease (Houston 1975). In northeastern stands impacted by beech bark disease, understory vegetation shifted to a strongly dominant beech composition of both seed and sprout origin (Hane 2003). Trees originating from root sprouts are generally stunted or deformed, contributing to the characteristic "Aftermath" forest structure that has replaced much of the original beech component of the northeastern United States (Houston 1994, Houston and Valentine 1987, Ostrofsky and McCormack 1986).

Beech bark disease first arrived in North America in Nova Scotia in 1890 on infected nursery stock from Europe and has since spread to Maine, New Hampshire, Vermont, New York, Massachusetts, Pennsylvania, Ohio, Tennessee, West Virginia, Virginia, North Carolina, and Ontario (Houston and O'Brien 1994). The immature crawlers are the mobile form of the insect and are transported primarily by wind, but birds may also transport them over short distances or along migratory routes (Houston and O'Brien 1994, McCullough et al. 2001). Beech bark disease infestations that occur in close proximity to campgrounds suggests that firewood infested with crawlers serves as another means of transporting *C. fagisuga* long distances.

Beech bark disease was discovered near camping areas in Mason and Luce Counties in Michigan in 2000 and now infests at least two regions, one in the Upper

Peninsula and another in the Lower Peninsula (McCullough et al. 2001)(Figure 1-1). Both infestations were estimated to be at least 10 years old, based on observations by Michigan Department of Natural Resources (MDNR) personnel and local residents (O'Brien et al. 2001). The relatively recent occurrence of beech bark disease in Michigan offers a unique opportunity to quantify characteristics of a forest stand before and after infestation. We designed a study to monitor beech bark disease as it spreads in range and intensity throughout Michigan. We established permanent plots to quantify current conditions of stands including overstory composition and species regeneration, availability of wildlife resources, radial growth, and leaf biomass production. Conditions were compared among stands grouped by beech density and levels of *C. fagisuga*. Although we are specifically addressing the impacts of beech bark disease, the broader scope of this research will enhance our understanding of how non-native organisms impact forested ecosystems.

The potential impact of beech bark disease is examined in three chapters; Current stand composition and future regeneration are presented in Chapter One, Chapter Two discusses wildlife resources, and Chapter Three focuses on stand–level productivity. Details specific to the stands sampled in this study are detailed in Appendix One and include location, beech density, and *C. fagisuga* infestation at the time of the study. Occurrence of overstory and regenerating species are listed for each stand in Appendix Two. Appendix three details stand stocking characteristics along with known management histories. Individual tree measurements are listed in Appendix four and include diameter, height, crown vigor, age, and radial growth trends. Data presented in these appendices will be essential background measurements for future comparisons.

SPECIES COMPOSITION AND REGENERATION IN HARDWOOD FORESTS OF MICHIGAN IMPACTED BY BEECH BARK DISEASE.

Introduction

Forests cover 19.3 million acres of the Michigan landscape over two distinct landmasses, the Upper and Lower Peninsulas (Dickmann and Leefers 2003). The mesic-deciduous forest type, also known as northern hardwoods, is most prevalent and is comprised of beech (*Fagus* sp.), maple (*Acer* sp.), birch (*Betula* sp.), and hemlock (*Tsuga* sp.) (Dickmann and Leefers 2003, Woods and Davis 1989). American beech (*Fagus grandifolia* Ehrh.) is typically found in the beech-maple forest type dominant in Michigan and typically occurs in association with sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), eastern hemlock (*Tsuga canadensis*), and northern red oak (*Quercus rubrum* L.) (Tubbs and Houston 1990).

As mature beech trees are impacted by beech bark disease, the composition and structure of the overstory may shift. Species composition may be further impacted by beech bark disease if declining, mature trees produce root sprouts and create dense beech thickets, subsequently limiting regeneration of other species (Hane 2003, Houston 1975, Houston and Valentine 1987, Jenkins 1997, Twery and Patterson 1984).

We designed a study to address the impacts of beech bark disease on overstory species composition and composition of regenerating vegetation in Michigan forests. Our primary objective was to quantify differences in overstory and understory composition among stands with varying levels of *C. fagisuga* infestation and among stands with varying densities of beech. These data will be used to 1) examine the current impact of *C. fagisuga* on species composition, 2) determine future composition of stands impacted by beech bark disease, and 3) serve as a baseline for long-term monitoring and future comparisons as beech bark disease spreads and intensifies throughout Michigan.

Methods

Study Sites

Our research was conducted in the Upper and Lower Peninsulas of Michigan, with study sites located within the infestation, along the periphery, and in areas not yet impacted by the disease. During the time of this study in 2002-2003, known infestations of *C. fagisuga* in Michigan occurred in only five counties (Chippewa, Manistee, Mason, Luce, and Oceana) (Figure 1-1). Data were collected between May 2002 and December 2003 in 34 hardwood stands in the eastern Upper Peninsula and 28 stands in the western Lower Peninsula of Michigan (62 stands total) (Appendix 1). In addition to beech, overstory composition in our study stands included sugar maple, red maple, eastern hemlock, and red oak, with lesser amounts of white ash (*Fraxinus americana*), basswood (*Tilia americana*), black cherry (*Prunus serotina*), birch sp., and aspen sp. (*Populus* sp.)(Appendix 2). Soils in our study sites were primarily sands or sandy loams and occurred on moraine, glacial outwash, lakebeds, or sand dunes (Veatch 1953). Widespread logging occurred in Michigan from approximately 1840 to 1900 and stands in our study have had variable harvest activities since (Appendix 3). We aimed to select stands with no harvest activity since 1998 but were limited in some cases by the availability of accurate management records.

Cooperators from the Michigan Department of Natural Resources (MDNR) and the University of Michigan initially selected stands as part of the long-term Michigan Beech Bark Disease Monitoring and Impact Analysis System (Thompson and Witter

2003). Stands were selected to represent three levels of beech stocking and three levels of beech bark disease infestation.

We assigned classification indices to each stand based on beech basal area and *C. fagisuga* infestation (Appendix 1). Beech density was classified for each stand based on basal area data provided by University of Michigan. Stands were classified as low (<9 m^2/ha), moderate (9-18 m^2/ha), or high (>18 m^2/ha) beech density. Scale density was classified by visually estimating *C. fagisuga* abundance on beech trees located within the plot boundary. Stands were classified according to the percentage of beech trees having greater than 50% coverage of *C. fagisuga* on at least one side of the main bole and assigned to the following categories: absent (no infested trees), light (less than 50% of beech trees infested), or heavy (greater than 50% of beech trees infested).

In each stand, University of Michigan field staff established five circular subplots 14.68 m diameter, one at center and one at 18.28 m from center in each of four azimuths (Figure 1-3). Each subplot was marked with a permanent metal turf stake and geographic positioning coordinates were recorded from the center subplot.

Overstory composition

Overstory species composition was measured in each stand along two perpendicular transects (51 m long) established from subplot 2 to subplots 5 and 3 (Figure 1-3). Species and diameter at breast height, dbh, (1.3 m) were recorded for all live trees > 24.5 cm dbh within 5 m of each transect.

Tree regeneration

Regeneration plots were established beyond the subplots to minimize the effects of trampling likely to occur in the subplots. Four regeneration plots were established at 18 m from the center point of the center subplot, in each cardinal direction (Figure 1-3). From the center of each regeneration plot, we identified number and species of seedlings (< 30.5 cm tall) within a 2.4 m radius, saplings (> 30.5 cm tall and < 2.5 cm dbh) within a 3.5 m radius, and recruits (> 2.5 cm dbh and < 12.5 cm dbh) within a 7.3 m radius.

Statistical analyses

Normality was tested for all variables using the Shapiro-Wilk test (SAS Institute, 1985). Prior to analyses, mean number of stems per hectare of beech and mean number of stems per hectare of all species combined were square root transformed to normalize distribution. (Non-transformed means are referenced in tables.) Two-way ANOVA [proc glm] was used to test the differences in mean number of stems among stands with low, moderate, or high beech density and absent, light, or heavy *C. fagisuga* infestation (SAS Institute 1985). When results of ANOVA were significant ($\alpha = 0.05$), Tukey's Honestly Significant Difference was used to compare means (Tukey 1977). Transformations did not normalize data distributions for mean basal area of overstory trees (each species), number of stems of sugar maple, red maple, other hardwoods (red oak, ash, aspen, basswood, birch, and black cherry), and conifers (eastern hemlock, balsam fir, and white pine) for each stage of regeneration, and species richness, therefore, these variables were ranked and analyzed with nonparametric tests. The nonparametric Kruskal-Wallis test [proc rank] was used to determine if these variables differed among stands with low, moderate, or high beech density and absent, light, or heavy *C. fagisuga* infestation (SAS Institute 1985). For significant tests (α =0.05), means were compared with nonparametric Tukey's-type multiple comparison (Zar 1984). Spearman's nonparametric correlation [proc corr spearman] was used to evaluate the linear relationship between basal area and regeneration of seedlings, saplings, and recruits of selected species and both the correlation coefficient (r_s) and significance value (p) are reported (SAS Institute 1985). All analyses were conducted using SAS 9.1, except for the nonparametric Tukey's-type multiple comparison which was conducted with Microsoft Excel software (Redmond, WA).

Root injury during harvest activity has been shown to stimulate sprouting in beech (Fowells 1965a). Although we attempted to select stands with no recent harvest activity, we later found that two stands (stand ID 121 and 166) had been selectively harvested between 1998 and 2000. To account for possibly confounding impacts of management practices on species regeneration, we analyzed data with and without these two stands. Inclusion of these two stands had no impact on results of analyses or our conclusions and were retained.

Results

Cryptococcus fagisuga was absent in 18 stands with low beech density, 16 stands with moderate beech density, and five stands with high beech density (39 stands total) (Figure 1-3). Light *C. fagisuga* infestation was present in five stands with low beech density, five stands with moderate beech density, and two stands with high beech density (12 stands total). Heavy *C. fagisuga* infestation was present in two stands with low beech density, three stands with moderate beech density, and six stands with high beech density (11 stands total).

Overstory composition

Beech and sugar maple were the most prevalent species in the overstory, although neither species was encountered in our transects in all 62 stands (Appendix 2). Beech was present in 52 stands with basal area ranging from 1.39 to 39.04 m^2/ha. Sugar maple was present in 50 stands with basal area ranging from 1.74 to 29.88 m^2/ha. Red maple was also a common associate, present in 25 stands with basal area ranging from 1.43 to 15.65 m^2/ha (Table 1-1). Aspen was only present in five stands yet comprised the greatest basal area of any species with a maximum of 39.78 m^2/ha in any one stand. Eastern hemlock was encountered in 16 stands; only five of which were in the Lower Peninsula. Red oak, white ash, basswood, black cherry, and birch sp. were also present, but each species occurred in fewer than 20 stands. Balsam fir was encountered in a single stand and white pine was not encountered in the overstory of any stands.

Basal area of overstory beech was not significantly different among stands with absent, light, or heavy *C. fagisuga* infestation (p=0.060) (Table 1-1). There was significantly greater beech basal area in stands classified as moderate beech density than in stands classified as low beech density (df=2,59; F=19.05, p<0.001). The interactive effect between beech density classification and *C. fagisuga* infestation was significant for overstory beech (df=4,57; F=10.65, p<0.001) (Figure 1-4). Basal area of overstory beech was not significantly correlated with basal area of sugar maple, red maple, red oak, other hardwoods, or conifers in the overstory (Table 1-2). Basal area of beech in the overstory was not significantly correlated with mean number of beech saplings, seedlings, or recruits (Table 1-3).

Basal area of overstory sugar maple, red maple, red oak, assorted hardwoods, and conifers were not significantly affected by beech density (Table 1-1). Basal area of red oak, assorted hardwoods, and conifers were not significantly affected by *C. fagisuga* infestation while basal area of overstory sugar maple and red maple were significantly affected by *C. fagisuga* infestation (Table 1-1). In stands with heavy *C. fagisuga* infestation compared to stands with no *C. fagisuga* infestation, basal area of overstory sugar maple was lower (df=2,59;, F= 1.60, p<0.001) and overstory red maple was higher (df=2,59; F= 7.33, p=0.001). Basal area of sugar maple in the overstory was inversely correlated with basal area of red maple, red oak, and other hardwoods in the overstory (Table 1-2). Basal area of overstory sugar maple and red maple were significantly correlated with corresponding species regeneration, except regeneration of red maple saplings (Table 1- 3). The interaction between beech density and *C. fagisuga* infestation was significant for overstory sugar maple (df=4,57; F= 6.01, p<0.001) overstory red maple (df=4,57; F=5.23, p=0.001) (Figure 1-4).

Tree regeneration

In the 11 stands with heavy *C. fagisuga* infestation, seedling regeneration was entirely absent in two stands and another stand had only 2,073 stems per ha, compared with 54,415 ± 15,175.8 stems per ha for the remaining eight stands. Seedling and sapling regeneration was present but highly variable in all 51 stands with absent or light *C. fagisuga*. Number of seedlings ranged from 138 to 733,522 stems per ha and number of saplings ranged from 129 to 52,455 stems per ha in these stands. Sapling regeneration was entirely absent in four of the 11 stands, with an average of 12,569 ± 3,260.5 stems per ha for the remaining seven stands.

Beech seedlings were encountered in 95%, saplings in 90%, and recruits in 89% of all stands (Appendix 2). There were no significant differences in mean stems per ha of beech seedlings, saplings, or recruits among stands with low, moderate, or high beech density (seedlings: p=0.108) (saplings: p=0.681) (recruits: p=0.075) nor among stands with absent, light, or heavy *C. fagisuga* infestation (seedlings: p=0.565) (saplings: p=0.192) (recruits: p=0.593) (Table 1-4). The interaction between beech density classification and *C. fagisuga* infestation was not significant for beech seedlings (p=0.303), beech saplings (p=0.575), or beech recruits (p=0.415).

Sugar maple seedlings were encountered in 79%, saplings in 66%, and recruits in 80% of all stands (Appendix 2). Red maple seedlings were encountered in 60%, saplings in 27%, and recruits in 32% of all stands (Appendix 2). Other hardwood species encountered in regeneration plots included striped maple (*Acer pensylvanicum*), birch sp., aspen sp., black cherry, ash sp., red oak, American basswood, ironwood, serviceberry (*Amelanchier arborea*), common witch-hazel (*Hamamelis virginiana*), and sassafras (*Sassafras albidum*). Striped maple stems were most prevalent and represented 53%, 34%, and 30% of all assorted hardwood seedling, sapling, and recruit regeneration respectively. Regenerating conifer species included eastern hemlock, balsam fir, and white pine, collectively comprising less than 3.9% of total seedling, sapling, and recruit regeneration of all stands combined. Maximum stand densities of all conifer species combined were 599 seedlings/ha, 2455 saplings/ha, and 134 recruits/ha.

Regeneration of sugar maple, red maple, other hardwoods, and conifers was not significantly affected by beech density, except for sugar maple recruits, which were significantly more abundant in stands with low beech density than in stands with moderate beech density (df=2,59; F=3.99, p=0.024) (Table 1-4). Regeneration of sugar maple and red maple stems was significantly affected by *C. fagisuga* infestation (Table 1-4). Significantly fewer sugar maple seedlings, saplings, and recruits occurred in stands with heavy *C. fagisuga* infestation than in stands without *C. fagisuga* infestation (seedlings: df=2,59; F=7.61, p=0.001) (saplings: df=2,59; F=6.21, p=0.004) (recruits: df=2,59; F=6.84, p=0.002). The interaction between beech density classification and *C. fagisuga* infestation was significant for sugar maple seedlings (df=4,57; F=3.80, p=0.008), saplings (df=4,57; F=3.06, p=0.024), and recruits (df=4,57; F=5.17, p=0.001) (Figure 1-5). Red maple sapling and recruit stems were significantly greater in stands with heavy *C. fagisuga* infestation than in stands with no *C. fagisuga* infestation (saplings: df=2,59; F=4.28, p=0.018) (recruits: df=2,59; F= 26.39, p<0.001). The interaction between beech density classification and *C. fagisuga* infestation were significant for red maple saplings (df=4,57; F=2.55, p=0.049) and red maple recruits (df=4,57; F=16.39, p<0.001) (Figure 1-6). Regeneration of red oak, other hardwoods, and conifers were not significantly affected by *C. fagisuga* infestation (Table 1-4). Red oak regeneration was not encountered in any of the 62 stands surveyed.

On average, species richness of understory regeneration was relatively low. There were 3.2 ± 0.02 seedling species, 2.6 ± 0.02 sapling species, and 2.5 ± 0.01 recruit species per stand. Mean number of seedling, sapling, or recruit species did not differ among stands with absent, light, or heavy *C. fagisuga* infestation (seedlings: p=0.163) (saplings: p=0.564) (recruits: p=0.353) nor among stands with low, moderate, or high beech density (seedlings: p=0.830) (saplings: p=0.792) (recruits: p=0.179).

Discussion

Overstory composition

In all but one of the stands, a maple species, either sugar or red, was also present in the overstory. In the northeastern United States, beech bark disease killed 85% of the overstory beech and created gradual gaps (Krasny 1992). If beech bark disease were to progress through our study area with a similar effect on mature beech, we could expect sugar maple and red maple to dominate the forest structure following the "Killing Front". The formation of gaps in the overstory may also enhance the growth of sugar maple, which responds to rapidly to sudden gaps by increasing incremental and terminal growth (Canham 1988). Both species of maple were present at similar levels in the overstory of stands with varying densities of beech but their basal area was inversely related to each other. This indicates one or the other species of maple will likely dominate stands impacted by beech bark disease.

Factors that predispose a stand to beech bark disease are uncertain but likely include density and composition of overstory species (Twery and Petterson 1984). The presence of eastern hemlock in a stand may enhance shading and moisture retention, conditions which have been correlated with *C. fagisuga* colonization and survival (Twery and Patterson 1984). In a New England study, stands impacted by beech bark disease had a greater component of eastern hemlock in the overstory prior to infection than stands that were not impacted by beech bark disease (Twery and Patterson 1984). Results from our study do not support this association; the basal area of eastern hemlock in the overstory was relatively low and similar among stands with absent, light, and heavy *C. fagisuga* infestations.

In our study, the presence of *C. fagisuga* was not related to the density of beech in the stand, contrary to other studies where beech mortality was correlated with beech basal area (Runkle 1990). During the time of our study, the distribution of *C. fagisuga* was geographically limited and therefore, the actual impact of stand composition on beech bark disease susceptibility may not yet be realized. As *C. fagisuga* spreads to additional stands with varying overstory components, comparisons could be made among stands with varying mortality to determine characteristics of the most susceptible stands.

Tree regeneration

Mature beech trees that are diseased or growing in stressful conditions are known to generate root-suckers and create dense thickets (Houston 1975). Studies conducted in northeastern stands impacted by beech bark disease documented increases in beech regeneration in the "Aftermath" forest (Hane 2003, Houston 1994, Houston and Valentine 1987, Ostrofsky 1986). Our results, however, suggest that beech bark disease has not yet altered the overall abundance of beech seedlings, saplings, or recruits in Michigan forests. Although beech bark disease was evident in at least three stands with heavy *C. fagisuga* infestation, as indicated by "beech snap" and beech tree mortality, the disease complex has not yet progressed to the "Aftermath" stage. Future comparisons of beech regeneration with baseline data will account for potential lag time in the response of understory regeneration. There are documented instances in the northeast, however, in which density of regenerating beech did not change despite impacts of beech bark disease (Twery and Patterson 1984).

The overstory basal area of beech in our stands was not correlated with beech regeneration, suggesting that beech regeneration may not be directly impacted by mortality of beech in the overstory. Results from our study demonstrated no reduction in beech regeneration in stands that had been impacted by *C. fagisuga*. A similar study conducted in Wisconsin found no correlation between beech basal area of overstory beech and beech seedlings (Ward 1961).

Sugar maple was the most common associate of beech in our stands. Like beech, it is shade-tolerant and capable of responding to overstory gaps with rapid growth (Canham 1985, Pulson and Platt 1996). Declines in sugar maple regeneration corresponding to increased beech regeneration have been documented for northeastern forests impacted by beech bark disease (Hane 2003, Jenkins 1997, Houston 1975). Sugar maple seedlings decline when competing with dense beech for understory light resources (Hane 2003). Competition for underground resources and beech leaf leachate have also been also shown to reduce sugar maple regeneration (Hane 2003, Hane et. al. 2003, Huntley et.al. 1989). In our stands, sugar maple stems were less abundant in the understory of stands with heavy *C. fagisuga*. Beech regeneration, however, was not related to sugar maple sapling abundance, suggesting direct competition was not the limiting factor. Rather, the low density of sugar maple saplings was likely due to the lower component, relative to beech, of sugar maple basal area in the overstory of stands with heavy *C. fagisuga*. Sugar maple regeneration was directly correlated with overstory composition and therefore, it is likely that future impacts of beech bark disease would increase sugar maple regeneration more dramatically in areas with higher sugar maple canopy basal area.

Red maple is often an early colonizer but may be dominated by sugar maple after approximately 80 years in northern hardwood stands (Fowells 1965b). Red maple is a vigorous sprouter but also regenerates from the light, wind-disseminated seeds that are produced annually. In our stands, regeneration of red maple was highest in stands with heavy *C. fagisuga* infestation, which is likely attributed to the greater basal area of red maple in the overstory of stands with heavy *C. fagisuga* infestation than in stands with light to no *C. fagisuga*. As the canopies of mature beech impacted by beech bark disease become sparse, shade-intolerant red maple seedlings are expected to benefit from increased light levels on the forest floor. No current evidence suggests that abundant beech regeneration will compete with red maple in the understory and consequently, a compositional shift to a increased dominance by red maple may occur.

In addition to beech bark disease, other factors likely affected regeneration in the seven stands we studied in Mason County (Appendix 1). Regardless of *C. fagisuga* infestation, stands in these counties had dramatically fewer stems in the understory than stands sampled in other counties (Appendix 2). Three of the stands were in close proximity to a popular campground and regeneration may have been limited by heavy foot traffic. Nonetheless, other stands in our study, including some with heavy *C. fagisuga*, were located near campgrounds with presumably similar public use, yet regeneration was present. Stand-level factors inhibiting regeneration in these counties are not conclusively explained by beech bark disease or proximity to campgrounds and warrant further investigation.

The data presented in this study represent the conditions of beech in Michigan forests as of 2002-2003 but are largely intended as a baseline for future comparisons. As the range of beech bark disease expands and additional stands are exposed, the significance of overstory composition as a predisposing factor to the severity of infection will be determined. Likewise, the effects of beech bark disease on future species composition will require that stands be revisited to assess regeneration over the long-term.

Table 1-1. Mean basal area (± SE) of overstory species composition in stands with low, moderate, and high beech density and absent, light, and heavy *C. fagisuga* infestation. Means in rows (a-c) and columns (y-z) followed by different letters are significantly different (p<0.05).

***C. fagisuga* infestation**	Beech density low	moderate	high	all stands
American beech				
Fagus grandifolia				
absent	3.70 ± 1.056	9.41 ± 1.468	18.78 ± 6.237	7.97 ± 1.320^{y}
light	8.19 ± 3.699	13.01 ± 2.421	18.66 ± 7.604	11.95 ± 2.258^{y}
heavy	3.14 ± 3.141	8.67 ± 3.410	19.36 ± 3.129	13.50 ± 2.819^{y}
all stands	4.55 ± 1.094^{b}	10.07 ± 1.174	19.03 ± 2.760^{ab}	
Sugar maple				
Acer saccharum				
absent	10.78 ± 1.940	14.53 ± 1.760	13.11 ± 3.838	12.62 ± 1.249^{y}
light	4.94 ± 2.430	4.74 ± 2.441	8.75 ± 6.226	5.49 ± 1.606^{yz}
heavy	5.85 ± 5.847	1.07 ± 1.070	3.14 ± 1.690	3.06 ± 1.309^{z}
all stands	9.22 ± 1.579^{a}	10.81 ± 1.681^{a}	7.84 ± 2.165^{a}	
Red maple				
Acer rubrum				
absent	1.97 ± 0.645	1.86 ± 1.114	0.00 ± 0.000	1.67 ± 0.546^{z}
light	0.96 ± 0.956	4.36 ± 2.762	0.00 ± 0.000	2.21 ± 1.266^{z}
heavy	8.67 ± 0.076	7.15 ± 3.203	4.87 ± 1.730	6.18 ± 1.269^{y}
all stands	2.30 ± 0.629^{a}	3.04 ± 1.037^{a}	2.25 ± 1.033^{a}	
Red oak				
Quercus rubra				
absent	2.85 ± 1.682	1.22 ± 0.943	0.00 ± 0.000	1.82 ± 0.870^{y}
light	5.56 ± 4.923	0.36 ± 0.362	0.00 ± 0.000	2.47 ± 2.077^{y}
heavy	10.43 ± 10.429	2.36 ± 2.356	2.91 ± 2.540	4.13 ± 2.220^{y}
all stands	4.00 ± 1.677^{a}	1.19 ± 0.682^{a}	1.34 ± 1.190^{a}	
Other hardwood sp.[1]				
absent	7.72 ± 2.605	3.60 ± 0.811	7.86 ± 0.905	6.05 ± 1.276^{y}
light	4.00 ± 1.706	0.98 ± 0.630	1.19 ± 1.188	2.27 ± 0.847^{y}
heavy	16.97 ± 14.797	2.41 ± 1.755	3.45 ± 1.664	5.63 ± 2.790^{y}
all stands	7.72 ± 2.165^{a}	2.91 ± 0.619^{a}	4.80 ± 1.092^{a}	
Eastern hemlock				
Tsuga canadensis				
absent	2.27 ± 1.227	2.04 ± 1.237	0.00 ± 0.000	1.89 ± 0.757^{y}
light	2.96 ± 2.274	0.00 ± 0.000	0.00 ± 0.000	1.23 ± 0.989^{y}
heavy	0.83 ± 0.828	4.33 ± 2.224	3.37 ± 2.602	3.17 ± 1.506^{y}
all stands	2.30 ± 0.976^{a}	1.90 ± 0.886^{a}	1.55 ± 1.240^{a}	

[1]Other hardwood species included ash (*Fraxinus* sp.), aspen (*Populus* sp.), basswood (*Tilia* sp.), birch (*Betula* sp.), and black cherry (*Prunus serotina*).

Table 1-2. Spearman's correlation coefficients (r_s) and significance value (p) for basal area (m^2/ha) among different overstory of 62 stands. Correlation coefficients with $p<0.05$ are significantly different.

	American beech	Sugar maple	Red maple	Red oak	Other hardwood sp.[a]	Conifer sp.[b]
American beech						
r_s	1.000					
Sugar maple						
r_s	-0.181	1.000				
p	(0.160)					
Red maple						
r_s	-0.002	-0.427	1.000			
p	(0.987)	(0.001)				
Red oak						
r_s	-0.142	-0.479	0.152	1.000		
p	(0.271)	(0.000)	(0.239)			
Other hardwoods[a]						
r_s	-0.253	-0.219	0.038	0.446	1.000	
p	(0.047)	(0.087)	(0.768)	(0.000)		
Conifer sp.[b]						
r_s	-0.052	-0.183	0.035	0.099	0.078	1.000
p	(0.686)	(0.155)	(0.788)	(0.443)	(0.546)	

[a]Other hardwood species included ash (*Fraxinus* sp.), aspen (*Populus* sp.), basswood (*Tilia* sp.), birch (*Betula* sp.), and black

[b]Other conifer species included hemlock (*Tsuga canadensis*), balsam fir (*Abies balsamea*), and white pine (*Pinus monticola*).

Table 1-3. Spearman's correlation coefficients (r_s) and significance values (*p*) for basal area (m^2/ha) among overstory species and corresponding species of seedlings, saplings, and recruits in 62 stands. Correlation coefficients with $p<0.05$ are significantly different.

	Seedlings	Saplings	Recruits
American beech			
r_s	0.216	0.072	0.115
p	0.092	0.579	0.373
Sugar maple			
r_s	0.552	0.517	0.290
p	<0.001	<0.001	0.022
Red maple			
r_s	0.229	0.253	0.434
p	0.074	0.047	<0.001
Other hardwood sp.[a]			
r_s	-0.258	-0.024	0.029
p	0.043	0.855	0.821
Conifer sp.[b]			
r_s	0.049	0.092	0.182
p	0.704	0.476	0.157

[a]Other hardwood species included red oak (*Quercus rubra*) ash (*Fraxinus* sp.), aspen (*Populus* sp.), basswood (*Tilia* sp.), birch (*Betula* sp.), and black cherry (*Prunus serotina*).

[b]Other conifer species included hemlock (*Tsuga canadensis*), balsam fir (*Abies balsamea)*, and white pine (*Pinus monticola*).

Table 1-4. Mean number of stems (± SE) per m^2 of American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), other hardwoods, conifers, and all species of seedlings, saplings, and recruits in stands with low, moderate, and high beech density and absent, light, and heavy *C. fagisuga* infestation. Means followed by different letters within rows are significantly different ($p<0.05$).

Seedlings		**Beech density**			***C. fagisuga* infestation**	
Species	low	moderate	high	absent	light	heavy
Beech	0.87 ± 0.044	1.35 ± 0.057	1.87 ± 0.129	1.08 ± 0.032	1.72 ± 0.110	1.44 ± 0.162
Sugar maple	4.47 ± 0.218	8.15 ± 0.643	4.69 ± 0.569	5.56 ± 0.180[a]	11.63 ± 1.676[a]	1.09 ± 0.235[b]
Red maple	0.09 ± 0.088	0.06 ± 0.060	0.07 ± 0.066	0.54 ± 0.029	1.94 ± 0.245	1.00 ± 0.106
Other hardwoods [1]	0.05 ± 0.008	0.16 ± 0.032	0.10 ± 0.022	0.04 ± 0.004	0.22 ± 0.084	0.20 ± 0.049
Conifers	0.00 ± 0.000	0.01 ± 0.001	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.001
All species	7.23 ± 0.231	11.10 ± 0.641	7.48 ± 0.614	7.92 ± 0.180	15.98 ± 1.639	3.98 ± 0.398
Saplings		**Beech density**			***C. fagisuga* infestation**	
Species	low	moderate	high	absent	light	heavy
Beech	0.54 ± 0.021	0.60 ± 0.028	0.87 ± 0.084	0.71 ± 0.020	0.51 ± 0.033	0.47 ± 0.069
Sugar maple	0.38 ± 0.032	0.44 ± 0.024	0.12 ± 0.017	0.49 ± 0.019[a]	0.18 ± 0.023[a]	0.04 ± 0.008[b]
Red maple	0.01 ± 0.008	0.00 ± 0.004	0.01 ± 0.010	0.04 ± 0.0041	0.02 ± 0.007[b]	0.15 ± 0.016[a]
Other hardwoods	0.01 ± 0.001	0.04 ± 0.006	0.03 ± 0.008	0.01 ± 0.001	0.05 ± 0.014	0.05 ± 0.014
Conifers	0.02 ± 0.000	0.01 ± 0.002	0.01 ± 0.002	0.01 ± 0.001	0.00 ± 0.000	0.00 ± 0.002
All species	1.17 ± 0.046	1.24 ± 0.036	1.16 ± 0.090	1.41 ± 0.028	0.86 ± 0.059	0.80 ± 0.084
Recruits		**Beech density**			***C. fagisuga* infestation**	
Species	low	moderate	high	absent	light	heavy
Beech	0.01 ± 0.001	0.03 ± 0.001	0.02 ± 0.001	0.02 ± 0.001	0.03 ± 0.002	0.02 ± 0.001
Sugar maple	0.03 ± 0.001[a]	0.01 ± 0.000[b]	0.02 ± 0.002[a]	0.03 ± 0.001[a]	0.02 ± 0.002[a]	0.01 ± 0.002[b]
Red maple	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.001	0.00 ± 0.000[b]	0.01 ± 0.001[a]	0.02 ± 0.002[a]
Other hardwoods	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000
Conifers	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000
All species	0.06 ± 0.046	0.06 ± 0.002	0.05 ± 0.002	0.06 ± 0.001	0.06 ± 0.002	0.05 ± 0.003

[1] Other hardwood species include red oak (*Quercus rubra*), ash (*Fraxinus* sp.), aspen (*Populus* sp.), basswood (*Tilia* sp.), birch (*Betula* sp.), and black cherry (*Prunus serotina*).

Figure Legends

Figure 1-1. Distribution of beech bark disease research sites and *Cryptococcus fagisuga* infestation indices throughout Michigan, 2003.

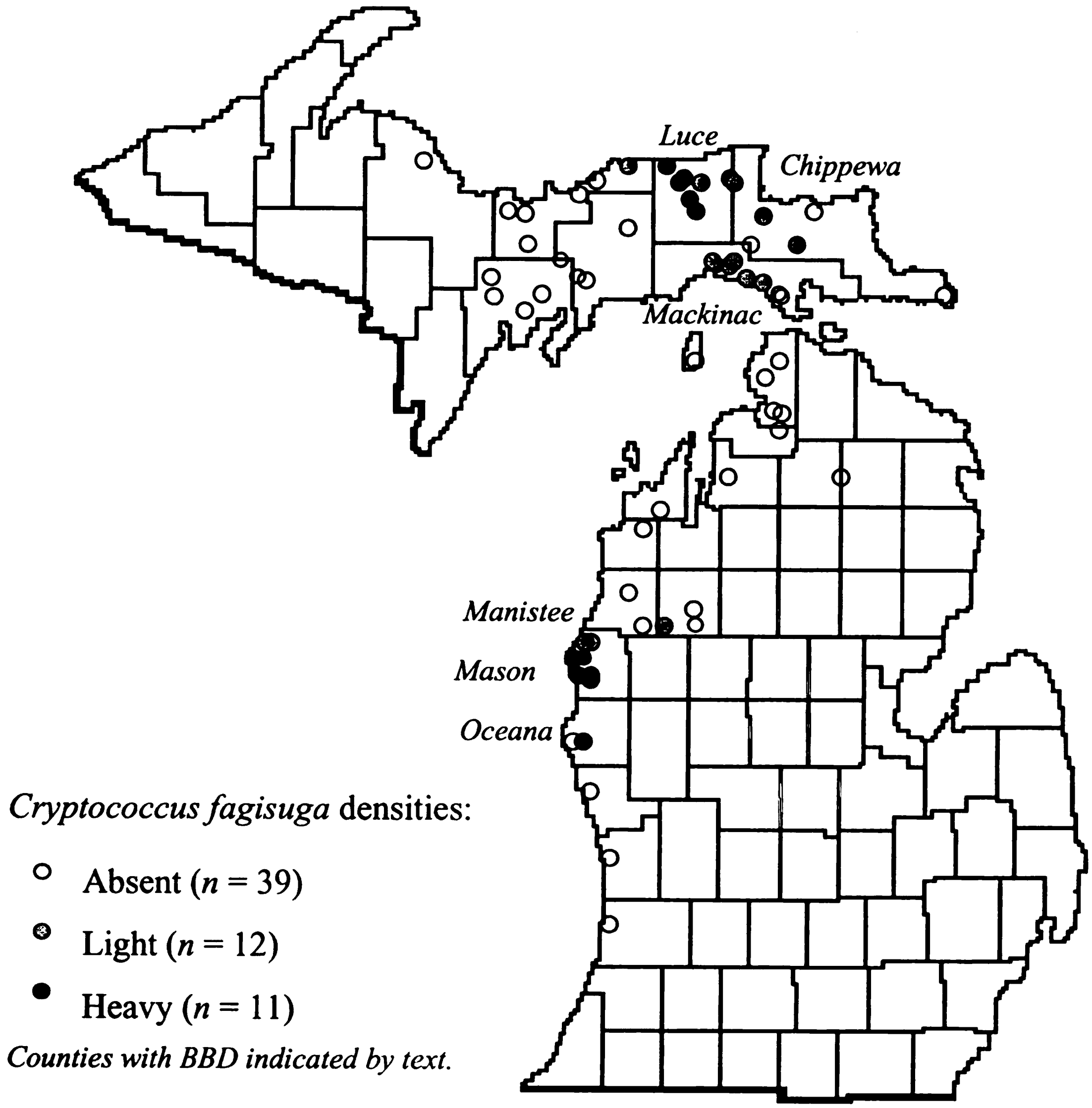
Figure 1-2. Intensive research plot design indicating arrangement of subplots 1-5, overstory composition transects, and regeneration plots.

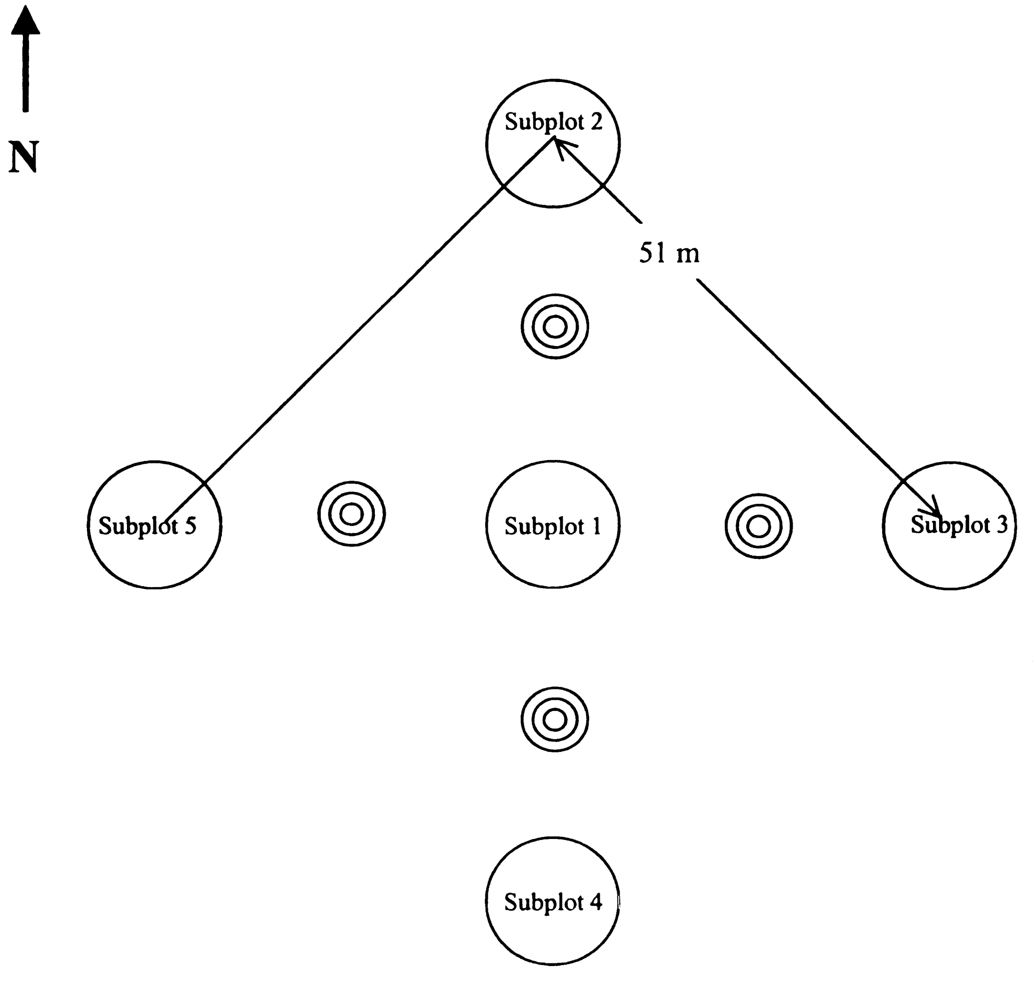
Figure 1-3. Number of stands with absent, light, and heavy *Cryptococcus fagisuga* abundance among stands with low, moderate, and high beech densities.

Figure 1-4. Interactive effects between beech density classification and *C. fagisuga* infestation for basal area of overstory a) beech, b) sugar maple, and c) red maple.

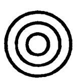
Figure 1-5. Interactive effects between beech density classification and *C. fagisuga* infestation for sugar maple a) seedlings, b) saplings, and c) recruits.

Figure 1-6. Interactive effects between beech density classification and *C. fagisuga* infestation for red maple a) seedlings, b) saplings, and c) recruits.


Luce
Chippewa
Mackinac
Manistee
Mason
Oceana
Cryptococcus fagisuga densities:
Absent (n = 39)
Light (n = 12)
Heavy (n = 11)
Counties with BBD indicated by text.

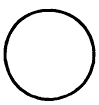


Key to plot diagram:

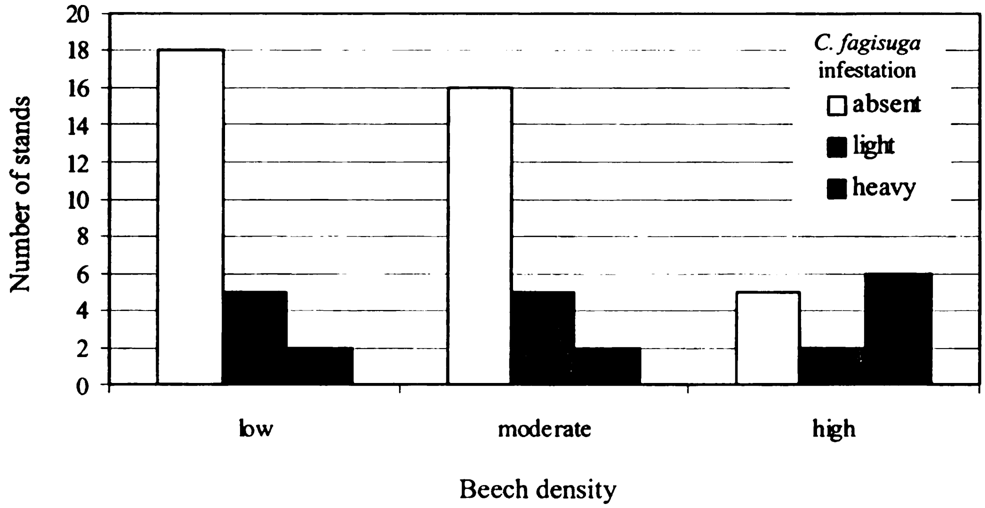


Regeneration plot

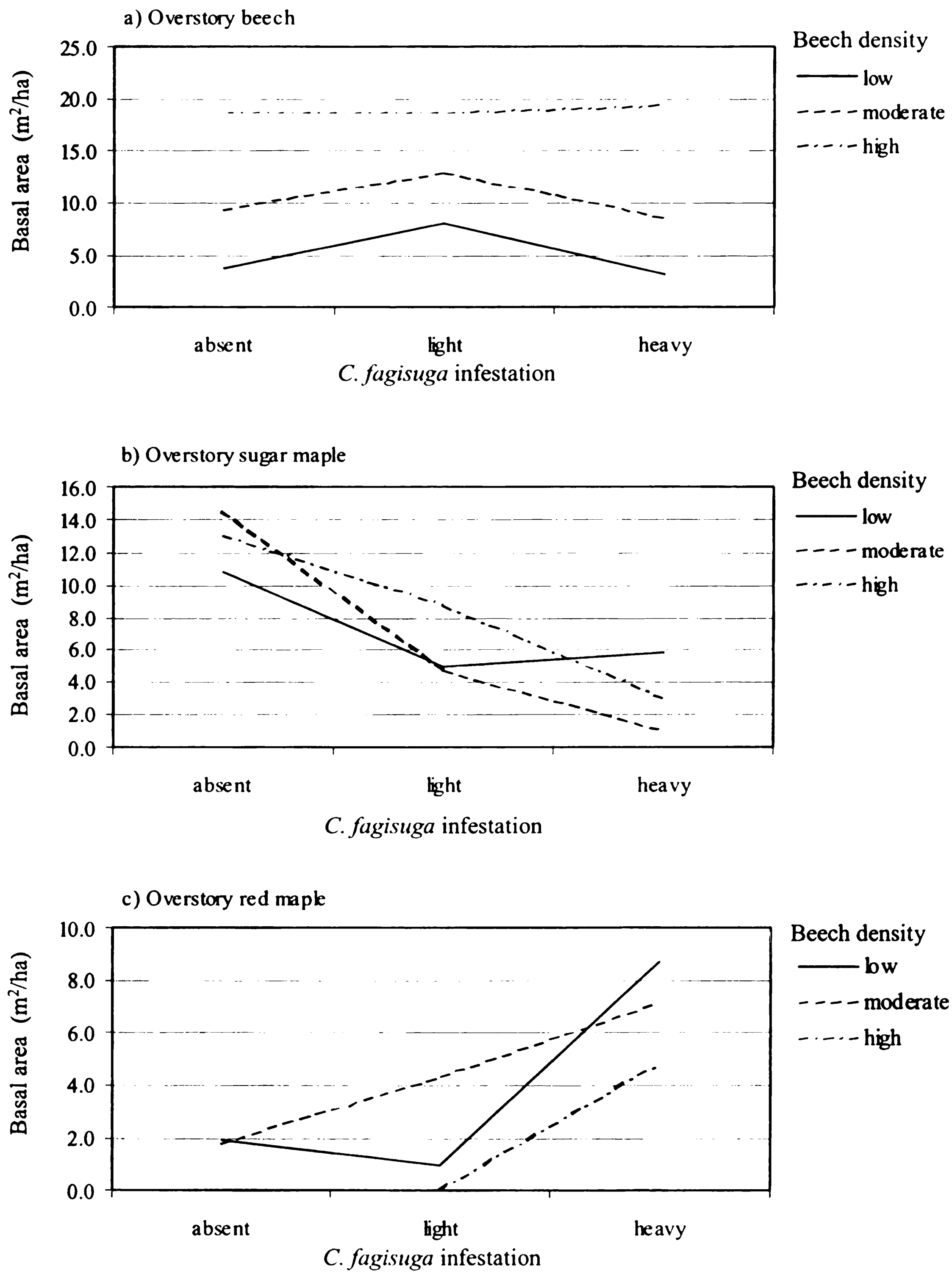
——— Overstory basal area sampling transect

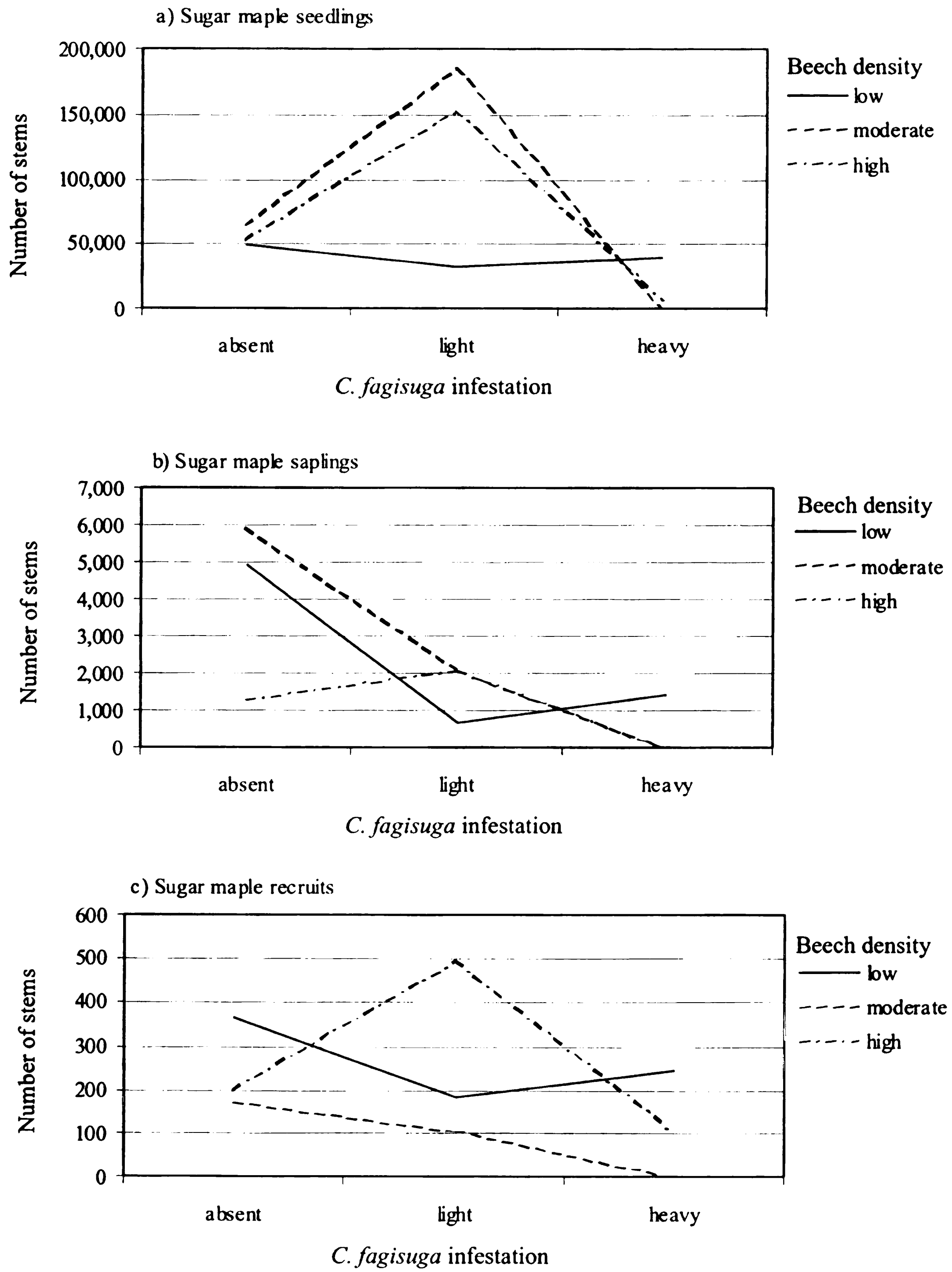


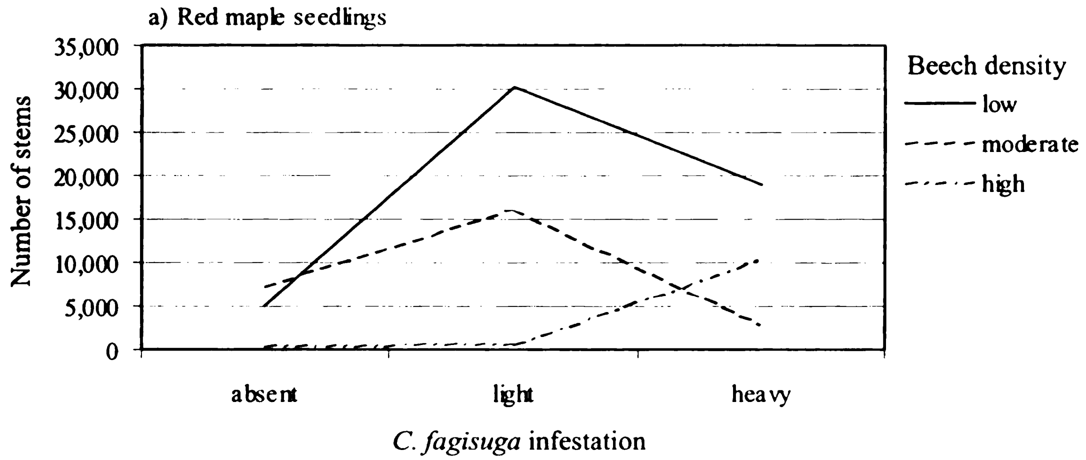
Subplot

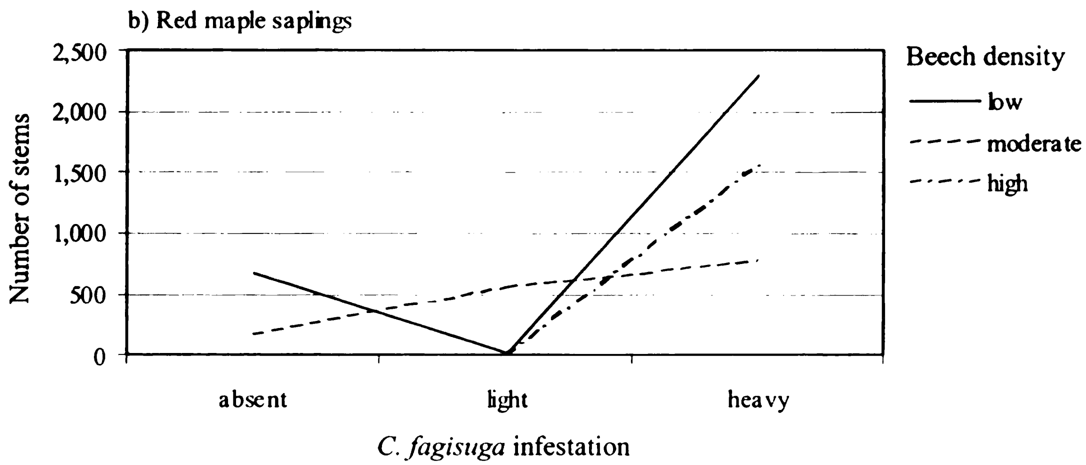


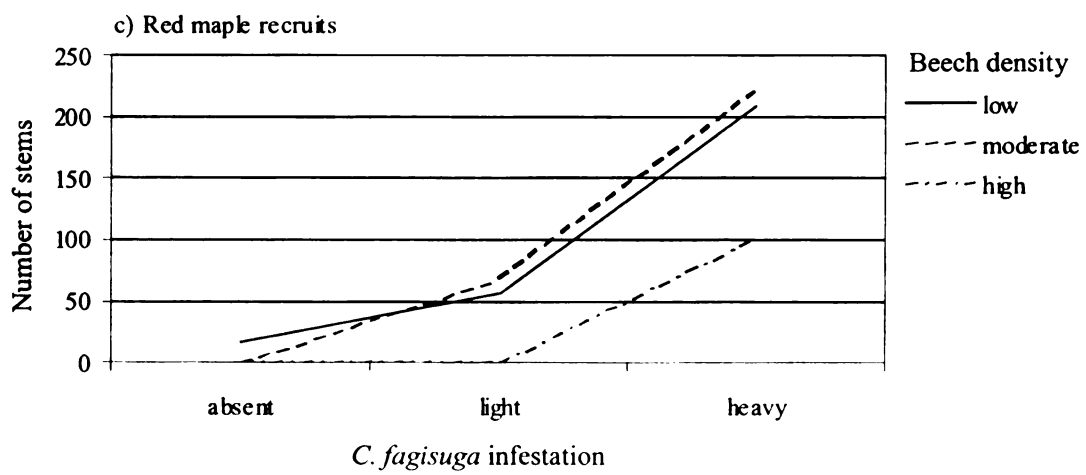
20
18
16
14
12
10
8
6
4
2
0
Number of stands
C. fagisuga infestation
absent
light
heavy
low
moderate
high
Beech density


a) Overstory beech
Basal area (m2/ha)
25.0
20.0
15.0
10.0
5.0
0.0
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high
b) Overstory sugar maple
Basal area (m2/ha)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high
c) Overstory red maple
Basal area (m2/ha)
10.0
8.0
6.0
4.0
2.0
0.0
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high


a) Sugar maple seedlings
Number of stems
200,000
150,000
100,000
50,000
0
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high
b) Sugar maple saplings
Number of stems
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high
c) Sugar maple recruits
Number of stems
600
500
400
300
200
100
0
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high


a) Red maple seedlings
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Number of stems
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high


b) Red maple saplings
2,500
2,000
1,500
1,000
500
0
Number of stems
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high


c) Red maple recruits
250
200
150
100
50
0
Number of stems
absent
light
heavy
C. fagisuga infestation
Beech density
low
moderate
high

IMPACT OF VARYING STAGES OF BEECH BARK DISEASE ON WILDLIFE RESOURCES IN MICHIGAN.

Introduction

American beech (*Fagus grandifolia* Ehrh.) provides important food and habitat resources for diverse bird, mammal, and amphibian species. Beech, a shade tolerant species, is characteristic of late successional communities. It is a major component of Michigan hardwood forests, typically associated with sugar maple (*Acer saccharum*), eastern hemlock (*Tsuga canadensis*), red maple (*Acer rubrum*), red oak (*Quercus rubra*), black cherry (*Prunus serotina*), and birch (*Betula* sp.).

Mature beech trees, greater than 40 years of age, periodically produce crops of highly nutritious nuts (Dix 1975, Forcier 1973, Fowles 1965, Piovesan 2001, Tubbs and Houston 1990, but see Statler 1982). After one year of maturation, beech nuts ripen between September and October and fall after the first heavy frost (Tubbs and Houston 1990). Blue jays (*Cyanocitta cristata*) are among the many animals that utilize this source of hard mast and, through caching behavior, contribute to long-range dispersal of beech (Held 1983, Johnson and Adkisson 1985). Many wildlife species rely on concentrated fat resources in the fall prior to hibernation and beech nuts, which have a high fat content, are particularly valuable in stands without other mast-producing species such as oak and hickory (*Carya* sp.) (Piovesan 2001, Tubbs and Houston 1990). Fertility of black bears (*Ursus americanus*), for example, is influenced by females attaining a threshold weight prior to hibernation and fecundity has been shown to cycle synchronously with hard mast production (Larivière 1994, Rogers 1987). Populations of white-footed mice (*Peromyscus leucopus*), deer mice (*P. maniculatus*), and red-backed voles (*Clethrionomys gapperi*) also cycle in synchrony with beech mast years (Schnurr et al 2002).

Mature beech trees are susceptible to many cavity-forming pathogens and these cavities provide shelter, nesting, and hibernation resources for a diverse array of wildlife species that rely upon them (Allen 1990, Conner et al. 1975, Goodburn and Lorimer 1998, Mannan et al. 1980, Paragi 1996, Raphael and White 1984,Robb and Bookhout 1995, Runde and Capen 1987, Sadlon, Steele 1995, Stribling 1990, Welsh et. al. 1992). In addition, as beech trees decline and die, they provide critical habitat for a variety of wildlife species. Standing dead trees, termed "snags", create important forage, hunting, and roosting habitat for birds (Conner et. al 1975, Mannan et. al 1980, Raphael and White 1984, Paragi 1996, Stribling 1990). Fallen trees and branches accumulate on the forest floor as coarse woody debris, which provides shelter, travel corridors, and forage substrate for many small mammals, reptiles, and amphibians (Bowman et.al. 2000, Dueser 1978, Harmon et.al. 1986, Jaeger 1980).

As beech bark disease spreads throughout hardwood forests of Michigan, beech nut production, cavity abundance, snag density, and coarse woody debris characteristics will likely be altered. Beech trees killed by beech bark disease may be replaced by other species that produce less energetically valuable seeds, such as maple, or by dense thickets of stunted, beech root-sprouts that fail to reach nut-producing maturity (Houston 1994). Availability of suitable wildlife cavities may decline as mature beech are removed from the overstory and replaced by species less prone to cavity-formation. As mature beech decline in vigor, changes in the abundance of snags and coarse woody debris may occur, potentially increasing habitat for certain wildlife species, for at least a period of time.

We initiated a long-term study to address how wildlife resources will be affected as beech bark disease spreads in range and intensity throughout Michigan. Our specific objectives were to *i*) collect baseline data related to beech nut masting and abundances of cavities, snags, and coarse woody debris in stands not yet affected by beech bark disease infestation; *ii*) compare current abundance of wildlife resources among stands with varying levels of beech bark disease and *C. fagisuga* infestation; and *iii*) establish long-term research plots to monitor changes in wildlife resources over time.

Methods

Study Sites

Study site selection was described in detail in Chapter One.

Beech nut production

Beech nuts were collected using four leaf litter/seed traps set between subplots 2 and 5 in each stand (Figure 2-1). Traps were constructed from industry standard 1.9 cm diameter (¾ in) pvc pipe assembled into a horizontal one m^2 square frame. The horizontal frame was elevated approximately 70 cm from the ground and supported by legs of varying length (to account for variable terrain). Shade cloth (40%) was attached to the frame to collect beech nuts , as well as acorns (red oak mast), that fell from overstory trees. Traps were placed in the 40 stands established in 2002 by 15 August and retrieved by 5 December. In 2003, traps were placed in 54 of the 62 total stands by 15 August and were retrieved by 7 December, after leaf drop was complete. Traps were not set in eight stands in 2003 because of heavy timber harvesting (three stands), seasonal inaccessibility (two stands), and vandalism (three stands). Due to these limitations and because of damage to traps, seed was collected from only five stands with heavy *C.*

fagisuga infestation. Leaves and seeds from each trap were bagged and returned to the Forest Entomology laboratory at Michigan State University. All seed, beech nut, and acorn samples were sorted to species, oven-dried at 38°C (100° F) for 72 hours, and weighed. To test viability, beech nuts were floated in de-ionized water for 40 hours (Williams and Hanks 1976). Beech nuts remaining in suspension were not considered viable seeds. Preliminary dissection tests indicated that this method accurately separated green, viable seeds from the nonviable. Mean values for number of beechnuts, number of viable beechnuts, and mass of beechnuts were calculated from the number of successful traps in each stand.

Cavities

Cavity abundance in standing live trees was assessed after leaf senescence in all stands between 21 November and 7 December 2003. We recorded species, dbh, and number of cavities of each of three size classifications for all trees greater than 25.4 cm dbh in the five subplots in each stand. Trees less than 23.4 cm were not sampled because previous studies have shown cavities occur predominantly in large diameter trees (Goodburn and Lorimer 1998, Gysel 1961, Welsh and Capen 1992). Cavity diameter, visually estimated from the ground, was classified as small (<7.0 cm diameter), moderate (7.0-30.0 cm diameter), or large (>30.0 cm diameter). The main bole and limbs of trees were examined for cavities when leaves did not obstruct the view of the crown.

Cavity abundance and size was also assessed for individual beech trees selected for long-term monitoring (Appendix 4). In each stand, 12 beech trees were selected 10.7 m from the center of each of the four outer subplots in each cardinal direction, excluding the azimuth leading toward the center subplot, and marked with round blue tree tags (Figure 2-1). When more than one beech tree fell within the designated distance and azimuth, we preferentially selected a tree by the following prioritized criteria: 1) the largest tree with a canker, 2) any tree (pole-sized or larger) with a canker, 3) large tree with *C. fagisuga* present, 4) any tree (pole-sized or larger) with *C. fagisuga*, or 5) any large tree (closest to the azimuth used). During full leaf expansion in the summer, canopy dieback was visually estimated for each of the 12 trees as low (<30%), moderate (30-60%), and high (>60%).

Coarse woody debris and snags

Abundance and volume of coarse woody debris and basal area and number of snags were measured in each stand along two transects, 51 m long by 1 m wide, running between subplots 2 and 5 and subplots 2 and 3 (Figure 2-1). Each piece of coarse woody debris greater than 7.6 cm diameter and occurring within 0.5 m of the transects was measured and decay recorded as 0 (freshly downed, no discoloration of sapwood, bark intact, no visible decay), 1 (discoloration of sapwood, bark intact, no visible decay), 2 (form maintained under impact, bark peeling, visible decay), 3 (crushes under impact, bark removed, mosses and advanced visible decay), or 4 (little structural integrity, mixing with soil)(Daniels 1997). Volume of coarse woody debris was calculated as cylinders (length $\times$ π (1/diameter)^2) for pieces in decay classes 0-3 and as rectangles (length $\times$ width $\times$ height) for pieces in decay class 4. All standing dead trees, within five meters of each transect, greater than 12.7 cm diameter at breast height (dbh) (1.3 m) were counted, identified to species, and dbh was measured.

Statistical analyses

Normality was tested for all variables using the Shapiro-Wilk test (SAS Institute, 1985). Mean oven-dried beech nut masses and mean volume of coarse woody debris (all decay classes pooled) were log transformed to achieve normality. Mean number of snags (all species combined) and mean number of beech snags were square-root transformed to achieve normality. (Non-transformed means are referenced in tables.) Two-way ANOVA [proc glm] was used to determine if mean beech nut mass, number of beech nuts collected in 2002 and 2003, volume of coarse woody debris in each decay class, number of all species of snags, and number of beech snags differed among stands with low, moderate, or high beech density and absent, light, or heavy *C. fagisuga* infestation (SAS Institute 1985). When ANOVA results were significant (α=0.05), means were separated by Tukey's Honestly Significant Difference (Tukey 1977). Transformation did not normalize data distributions for mean number of viable beech nuts per stand, number of cavities in each size class, number of cavities in trees of each dieback rating, volume of coarse woody debris in each decay class, basal area of all species of snags, and basal area of beech snags. These variables, therefore, were ranked and the nonparametric Kruskal-Wallis test [proc rank] was used to determine if these variables differed among stands with low, moderate, or high beech density and absent, light, or heavy *C. fagisuga* infestation (SAS Institute 1985). For significance tests (α =0.05), means were compared with nonparametric Tukey's-type multiple comparison (Zar 1984). Spearman's nonparametric correlation analysis was used to assess the relationship between basal area of beech and red oak in the overstory with the mass of beech nuts and acorns, respectively (SAS Institute 1985). Spearman's nonparametric correlations were also used to determine if total overstory basal area and beech basal area were related to basal area of snags (all species combined) and beech snags, respectively. All analyses were done using SAS 9.1, except for the nonparametric Tukey's-type multiple comparison which was done with Microsoft Excel software (Redmond, WA).

Three stands with recent selective harvest activity were omitted from coarse woody debris analyses to avoid confounding effects of logging slash and beech bark disease impacts (stand ID 104, 107, 121) (Appendix 3).

Results

Beech nuts

In 2002, beech nuts were collected from all 36 stands we surveyed. Mean beech nut mass in 2002 averaged 18.4 ± 2.31 g/m^2 and did not significantly differ among stands with absent, light, or heavy *C. fagisuga* infestation (p=0.234), nor among stands with low, moderate, or high beech density (p=0.162) (Figure 2-2). Mean beech nut mass varied considerably among stands, ranging from 0.1 to 51.8 g/m^2. Mean beech nut mass within stands was also variable. In one stand, for example, mean beech nut mass among the four traps varied from 0.38 g/m^2 to 119.00 g/m^2. Basal area of beech in the overstory was significantly correlated with beech nut mass produced in 2002 (r_s=0.393, p=0.018). Mean number of beech nuts collected in 2002 averaged 98 ± 11.3 /m^2 and was not significantly affected by *C. fagisuga* infestation (p=0.614), nor beech density (p=0.490) (Figure 2-2). An average of 51% of the beech nuts collected in 2002 were viable.

In 2003, beech nuts were collected from 27 of the 51 stands we surveyed. Only four stands in 2003 produced more than 1.0 g/m^2 beech nut mass; three of the four were in stands classified as low beech density. Mean beech nut mass in 2003 averaged 0.3 ± 0.09 g/m^2 and number of beech nuts only averaged 2.0 ± .06 $/m^2$. Neither mass nor number of beech nuts was significantly affected by *C. fagisuga* infestation level (p=0.053, p=0.221, respectively) or beech density (p=0.771, p=0.534, respectively) (Figure 2-2). Only 10% of beech nuts collected in 2003 were viable. There was no significant correlation between beech basal area and beech nut mass produced in 2003 (p=0.205). For the 32 stands sampled for two consecutive years, total beech nut production decreased by an overall mean of 99.5 ± 2.31 beech nuts/m^2 and viable beech nut production decreased by a mean of 52.8 ± 1.35 beech nuts/m^2.

Red oak was encountered in the overstory of 13 stands with basal area ranging from 1.47 to 26.32 m^2/ha. In 2002, acorns were collected from six of the 36 stands, all in the Lower Peninsula. Mean acorn mass in 2002 averaged 1.0 ± 0.50 g/m^2. In 2003, acorns were collected from seven of the 51 stands, all in the Lower Peninsula except for one stand. Mean acorn mass in 2002 averaged 0.9 ± 0.54 g/m^2. Basal area of oak in the overstory was significantly correlated with acorn mass in 2002 (r_s=0.647, p<0.001) and in 2003 (r_s =0.467, p<0.001).

Cavities

Cavity size and number were recorded for a total of 683 trees representing 12 species (Table 2-1). At least one tree of each species, except black cherry, contained small cavities (<7.0 cm diameter). Small cavities occurred in trees ranging from the smallest tree sampled (10.0 cm dbh) to the largest tree sampled (29.0 cm dbh). There were significantly more small cavities in American beech trees than in any other species sampled (df=8,673; F=17.01, p<0.001) (Table 2-1). Tree age was significantly correlated with diameter (r_s=0.494, p<0.001) and number of cavities (r_s=0.215, p=0.038). Diameter and number of cavities were also significantly correlated (r_s=0.336, p=0.001).

Beech trees contained significantly more moderately sized (7.0 to 30.0 cm diameter) cavities than sugar maple trees (df=8,673; F=3.64, p<0.001) but differences between beech and other species were not significant. A beech tree that was 48.1 cm dbh contained the maximum number of moderately sized cavities encountered (11) and occurred in a stand with light *C. fagisuga* infestation. A total of 89 trees comprised of red oak, black cherry, ash, hemlock, and basswood trees were examined; none had moderate seized cavities.

Large diameter cavities (>30.0 cm diameter) occurred on only six of the 683 trees and did not significantly differ among species, likely due to the limited sample size (p=0.697). Five of the large cavities were on the main bole of beech treesand one was on the main bole of a sugar maple; no single tree had more than one large cavity. The six trees with large cavities ranged from 13.3 cm to 28.4 cm in dbh with an average of 21.3 ± 2.85 cm.

Individual trees selected for long-term monitoring (n=94) from the perimeter of subplots had a mean diameter of 31.8 cm and were 82 years old on average (see Chapter 3). The number of cavities per tree was significantly correlated with age (r_s=0.215, p=0.038), diameter (r_s=0.336, p=0.001), and canopy dieback (r_s= 0.156, p=0.134) (Table

2-2). Age was significantly correlated with diameter (r_s=0.394, p=0.000) and dieback (r_s=0.255, p=0.013). Dieback was significantly correlated with diameter (r_s=0.339, p=0.001) (Table 2-2).

Coarse Woody Debris and Snags

Coarse woody debris was encountered in every stand and ranged from 2.5 to 235.0 m^3/ha. A total of 746 pieces were encountered on the transects. Size of pieces ranged from 0.08–12.2 m length; 49% of the pieces less than 1 m length, 48% were between 1 and 3 m length, and 3% were greater than 3 m long. Only 64% of the coarse woody debris pieces sampled retained characteristics that allowed identification to species. Identified pieces were predominantly beech (24% of total) and white birch (*Betula papyrifera*) (12% of total) and a lesser component of sugar maple, hemlock, aspen (*Populus* sp.), and black cherry.

Volume of coarse woody debris did not vary among stands with low, moderate, or high beech density (p=0.061) and absent, light, or heavy *C. fagisuga* infestation (p=0.192) (Table 2-2). The interaction between beech density classification and *C. fagisuga* infestation level was not significant for coarse woody debris volume (p=0.314).

Volume of coarse woody debris in decay classes 0, 1, 2, 3, and 4 was not significantly affected by *C. fagisuga* infestation level (decay class 0: p=0.226) (decay class 1: p=0.557) (decay class 2: p=0.467) (decay class 3: p=0.735) (decay class 4: p=0.153) (Table 2-2). Only 1% of total coarse woody debris volume was of decay class 0. These relatively fresh pieces were encountered only in seven stands, three of which had heavy *C. fagisuga* infestation. The majority of total coarse woody debris volume (62%) was assigned to decay classes 2 and 3.

Snags were present in 45 of the 62 stands we sampled, but only 12 stands contained beech snags. A total of 112 snags with a mean dbh of 31 ± 1.6 cm were examined. Snags were predominantly beech (24), sugar maple (17), white birch (17), and black cherry (11). Basal area of snags of all species combined (including beech) did not significantly differ among stands with low, moderate, or high beech density (p=0.528) and absent, light, or heavy *C. fagisuga* infestation (p=0.155) (Table 2-3). Mean number of snags of all species also was not significantly affected by beech density (p=0.113) or *C. fagisuga* infestation (p=0.100) (Table 2-3). Basal area of all species of trees in the overstory was not correlated with basal area of all species of snags (p=0.273).
Mean basal area of beech snags was significantly higher in stands with high beech density (df=2,59; F=4.57, p=0.014) and in stands with heavy *C. fagisuga* infestation (df=2,59; F=4.65, p=0.013) than in other stands. Similarly, significantly more beech snags occurred in stands with high beech density (df=2,59; F=5.17, p=0.009) and in stands with heavy *C. fagisuga* infestation (df=2,59; F=4.08, p=0.022) than in other stands. The interactive effect between beech density classification and *C. fagisuga* infestation was significant for basal area of beech snags (df=2,59; F=2.34, p=0.083) and number of beech snags (df=2,59; F=3.57, p=0.012). Basal area and number of beech snags were at least two times more abundant in stands with high beech density and heavy *C. fagisuga* infestation than in other stands.

Discussion

Beech nut production

The effect of beech bark disease on mature beech trees will eventually reduce beech nut abundance and may affect the animals that nutritionally depend on them. Our study results, however, indicate that stand-level *C. fagisuga* infestation had not yet impacted nut production. Stands with heavy *C. fagisuga* infestation were in heavily used recreation areas where leaf litter traps were often disturbed by humans or damaged by falling trees and limbs. Consequently, our results might have been affected by the limited sample size (n=5 stands) of intact beech nut collections. Beech bark disease may, however, progressively stress mature trees and reduce the overstory component of mature, nut-producing trees as it reaches the "Aftermath" forest structure in Michigan. Therefore, continued monitoring will be needed to quantify effects of beech bark disease on nut production.

Beech nut production can fluctuate annually by up to 65% and the phenomenon of even year mast events has been well documented (Gysel 1971, Piovesan 2001, Schnurr 2002). Our results indicate a mast event occurred in 2002 followed by a substantially reduced intermast crop in 2003. Levels of beech nut production we documented in the mast event of 2002 (98 beech nuts/m^2) are similar to a previous study in Michigan. Gysel (1971) reported beech nut production in mast years averaged 40 beech nuts/m^2 among stands, with production in one stand exceeding 250 beech nuts/m^2. The viability of beech nuts in our study also varied between mast and intermast years, ranging from 58% in 2002 to less than 10% in 2003. Viability in 2002 was markedly higher than that reported by Gysel (1971) who found only 10% of nuts were viable during mast years.

Our methods did not account for the possible consumption of beech nuts by blue jays in early August before seed drop and often before seeds are fully ripe. (Johnson and Adkisson 1985). Blue jays select only viable seeds, potentially increasing the proportion of non-viable seeds in our traps. We collected beech nuts throughout the caching period but from near the forest floor and consequently, may have underestimated actual production (Johnson and Adkisson 1985).

Cavities

Our results demonstrate that cavities of all diameter classes were more abundant in beech than in other overstory species, except white birch. Other studies conducted in hardwood forests found that beech had more small cavities than other species (Gysel 1961, Robb and Bookhout 1995). Tree diameter was correlated with number of cavities, indicating that declines in mature beech from beech bark disease will likely reduce the abundance of cavities available for wildlife. Gysel (1961) found that cavities greater than 10 cm diameter occurred more often in trees of declining vigor. This suggests that mature trees impacted by beech bark disease may contain an abundance of moderate to large size cavities. Our data indicated no difference in cavity abundance among stands with varying levels of beech bark disease nor among trees with varying degrees of dieback.

Both size and location of cavities can influence habitat suitability for specific species. For example, downy woodpeckers (*Picoides pubescens* L.) prefer to nest in 20-cm diameter cavities located 6 m above ground, whereas large pileated woodpeckers (*Dryocopus pileatus* L.) prefer 56-cm diameter cavities 18 m aboveground (Sadlon

1992). In addition to external cavity dimensions, internal dimension can also be critical, as in the case of wood ducks (*Aix sponsa*) that prefer entrances of 7 x 9 cm with bottom dimensions of at least 12 x 17 cm (Robb and Bookhout 1995). In our study, five of the six large cavities we encountered were in beech trees. Eventual loss of large diameter beech and the corresponding loss of large cavities may have negative consequences for certain wildlife species.

Coarse woody debris and snags

Coarse woody debris volume was consistently greater in stands with heavy *C. fagisuga* infestation, although means were not statistically different because of the limited number of stands with heavy *C. fagisuga* infestation. Studies conducted in northeastern states impacted by beech bark disease showed a consequent increase in coarse woody debris volume of 20-30% with volumes exceeding 166 ± 42 m^3/ha, whereas stands unaffected by beech bark disease contained 15-45 m^3/ha (Carbonneau 1986, McGee 2000). Mean volumes of coarse woody debris from our stands with heavy *C. fagisuga* exceeded the maximum volume measured in uninfested stands, but, this was likely due to stand-level variations in productivity.

Decay characteristics of coarse woody debris can determine species-specific values for wildlife (Bowman 2000, Jaeger 1980). For example, red-backed voles (*C. gapperi*) use highly decayed logs for shelter and fresh, solid form logs for runways, thereby requiring a diversity of decay classes (Bowman et. al. 2000, Maser and Trappe 1994). Highly decayed logs also serve as critical nutrient and moisture sinks on the forest floor (Covington 1981, Fraver et al. 2002). In our study, coarse woody debris volumes in stands with heavy infestations of *C. fagisuga* were evenly distributed among decay classes, indicating no recent accumulation of freshly downed material, as might be expected from declining, breaking trees.

The greater number and basal area of beech snags in stands with heavy *C. fagisuga* suggests beech bark disease has begun to affect individual trees and that stands have progressed to the "Killing Front". Abundance of snags of other species remained constant among stands, further supporting that beech bark disease was specifically contributing to greater snag abundance. The great diversity of wildlife using snags may benefit from this alteration of forest structure for some period of time, although specific characteristics, such as decay stage and remaining branches, influence actual value. Hardwood and conifer stands in which snags were retained supported a greater diversity of wildlife in eastern and western states, although surpassing minimum density thresholds may not proportionately benefit wildlife (Gunn and Hagan 2000, Raphael and White 1984, Paragi 1996, Robb and Bookhout 1995, Scott 1979, Stribling 1990, Yahner 1987).

To date, beech bark disease has likely contributed to an increase in snag abundance in stands with heavy infestation of *C. fagisuga*, but other wildlife resources have not been significantly altered. More cavities were found in beech trees than in any other species occurring in the stands we examined. Beech was typically the only hard mast-producing species except in seven stands where red oak also occurred. As mature beech succumb to beech bark disease and are replaced by other species, the abundance of hard mast and cavities will be reduced. Snags and coarse woody debris, however, will likely continue to increase as beech bark disease progresses and trees die. The data presented here provide a valuable baseline to compare with data acquired from long-term monitoring in the same plots as beech bark disease expands in range and intensity throughout Michigan.

Table 2-1. Basal area, mean diameter, and number of trees examined and number of cavities of three size classes by tree species.

				Number (*and percentage*) of trees containing cavities by each class[b]						Density (number/m^2 basal area) of cavities by each class		
Tree species	Total basal area surveyed (m^2/ha)	Mean diameter[a]	Number of trees surveyed	small		moderate		large		small	moderate	large
American beech	40.64	15.02	260	116	*56%*	49	*19%*	5	2%	6.20	1.87	0.12
Sugar maple	26.12	14.40	223	24	*11%*	17	*8%*	1	0%	1.30	0.65	0.04
Eastern hemlock	4.43	16.14	41	7	*17%*	1	*2%*	0	0%	5.64	0.23	0.00
Red maple	2.93	13.17	40	4	*10%*	1	*3%*	0	0%	1.71	0.34	0.00
Red oak	10.82	15.36	38	3	*8%*	1	*3%*	0	0%	0.37	0.09	0.00
White birch	1.53	14.23	31	5	*16%*	2	*6%*	0	0%	12.41	9.80	0.00
Bigtooth aspen	2.21	14.55	19	2	*11%*	2	*11%*	0	0%	0.91	0.91	0.00
Misc. species[c]	2.34	14.66	31	3	*10%*	0	*0%*	0	0%	1.28	0.00	0.00

[a] Mean diameter measeured at breast height (1.3m).

[b] Cavities were classified according to size class as small (<7.62 cm diameter), moderate (7.62-30.48 cm diameter), or large (>30.48 cm diameter).

[c] Miscellaneous species included basswood (*n* =8 trees), elm (*n* =8 trees), black cherry (*n* =7 trees), ash sp. (*n* =3 trees), hickory sp. (*n* =2 trees), sassafrass (*n* =1 tree), and white pine (*n* =1 tree).

Table 2-2. Volume of coarse woody debris (m^3/ha ± SE) grouped by decay class among stands with low, moderate, and high beech density and absent, light, and heavy *C. fagisuga* infestation.

Beech density	absent	light	heavy	all stands
		***C. fagisuga* infestation**		
Decay Classes Pooled				
low	46.2 ± 3.21	29.4 ± 3.44	50.6 ± 4.82	43.1 ± 1.95
moderate	62.3 ± 3.78	77.6 ± 15.51	125.3 ± 19.69	74.8 ± 1.89
high	43.8 ± 6.01	40.8 ± 22.33	70.2 ± 7.82	55.5 ± 3.06
all stands	52.4 ± 1.41	51.4 ± 4.59	81.7 ± 4.68	
Decay Class 0[a]				
low	0.3 ± 0.08	0.4 ± 0.17	0.0 ± 0.00	0.3 ± 0.05
moderate	0.1 ± 0.03	0.0 ± 0.00	0.4 ± 0.25	0.1 ± 0.01
high	0.2 ± 0.09	0.0 ± 0.00	5.3 ± 2.06	2.5 ± 0.65
all stands	0.2 ± 0.03	0.2 ± 0.04	3.0 ± 0.83	
Decay Class 1				
low	3.9 ± 0.32	0.4 ± 0.17	4.5 ± 3.18	3.3 ± 0.21
moderate	10.2 ± 0.61	16.9 ± 4.61	4.7 ± 1.00	11.0 ± 0.40
high	7.1 ± 1.85	5.3 ± 3.76	8.5 ± 2.26	7.5 ± 0.81
all stands	6.8 ± 0.21	8.1 ± 1.35	6.7 ± 0.92	
Decay Class 2				
low	13.0 ± 0.68	10.0 ± 1.73	6.2 ± 0.28	11.8 ± 0.44
moderate	20.5 ± 1.17	13.0 ± 3.13	57.8 ± 15.69	23.9 ± 0.78
high	17.1 ± 1.99	20.3 ± 13.55	17.1 ± 3.09	17.6 ± 1.19
all stands	16.5 ± 0.38	13.0 ± 1.17	26.2 ± 2.94	
Decay Class 3				
low	10.9 ± 0.70	13.2 ± 1.93	11.0 ± 0.41	11.4 ± 0.45
moderate	19.7 ± 2.14	22.6 ± 5.32	52.3 ± 11.04	24.8 ± 0.95
high	15.5 ± 2.26	13.7 ± 4.87	9.9 ± 2.22	12.6 ± 0.88
all stands	14.9 ± 0.57	17.2 ± 1.50	21.7 ± 2.40	
Decay Class 4				
low	6.6 ± 0.71	5.3 ± 1.60	28.9 ± 8.13	8.2 ± 0.53
moderate	12.5 ± 1.92	25.1 ± 8.37	10.0 ± 3.36	15.0 ± 0.90
high	3.8 ± 1.71	1.4 ± 0.15	29.5 ± 9.21	15.3 ± 2.96
all stands	8.5 ± 0.52	12.9 ± 2.32	24.1 ± 3.70	

[a] Decay classes recorded as 0 (freshly downed, no discoloration of sapwood, bark intact, no visible decay), 1 (discoloration of sapwood, bark intact, no visible decay), 2 (form maintained under impact, bark peeling, visible decay), 3 (crushes under impact), and 4 (little strucutral integrity, mixing with soils).

Table 2-3. Mean number (± SE) and basal area (m^2/ ha ± SE) of beech snags and snags of all species among stands with low, moderate, and high beech density and among stands with absent, light, and heavy *C. fagisuga* infestation Means followed by different letters are significantly different among rows (a-b) or among columns (y-z).

Number of snags /ha

All species — *C. fagisuga* abundance

Beech density	absent	light	heavy	all stands
low	15 ± 1.0	25 ± 3.0	5 ± 3.5	16 ± 0.7
moderate	12 ± 0.8	14 ± 3.0	23 ± 7.5	13 ± 0.4
high	24 ± 3.8	15 ± 10.4	36 ± 4.6	28 ± 1.8
all stands	15 ± 0.4	19 ± 1.3	27 ± 2.3	

Beech

Beech density	absent	light	heavy	all stands
low	1 ± 0.1	4 ± 1.1	0 ± 0.0	1 ± 0.1^{z}
moderate	1 ± 0.2	0 ± 0.0	3 ± 1.9	1 ± 0.1^{z}
high	6 ± 2.6	10 ± 6.9	21 ± 4.6	14 ± 1.6^{y}
all stands	2 ± 0.1^{b}	3 ± 0.5^{ab}	12 ± 1.5^{a}	

Basal area of snags (m^2/ha)

All species

Beech density	absent	light	heavy	all stands
low	1.0 ± 0.08	1.2 ± 0.26	0.6 ± 0.42	1.0 ± 0.05
moderate	0.8 ± 0.07	2.0 ± 0.56	4.8 ± 1.46	1.6 ± 0.10
high	44.8 ± 0.34	1.5 ± 1.07	2.5 ± 0.58	1.9 ± 0.20
all stands	1.0 ± 0.03	1.6 ± 0.17	2.8 ± 0.32	

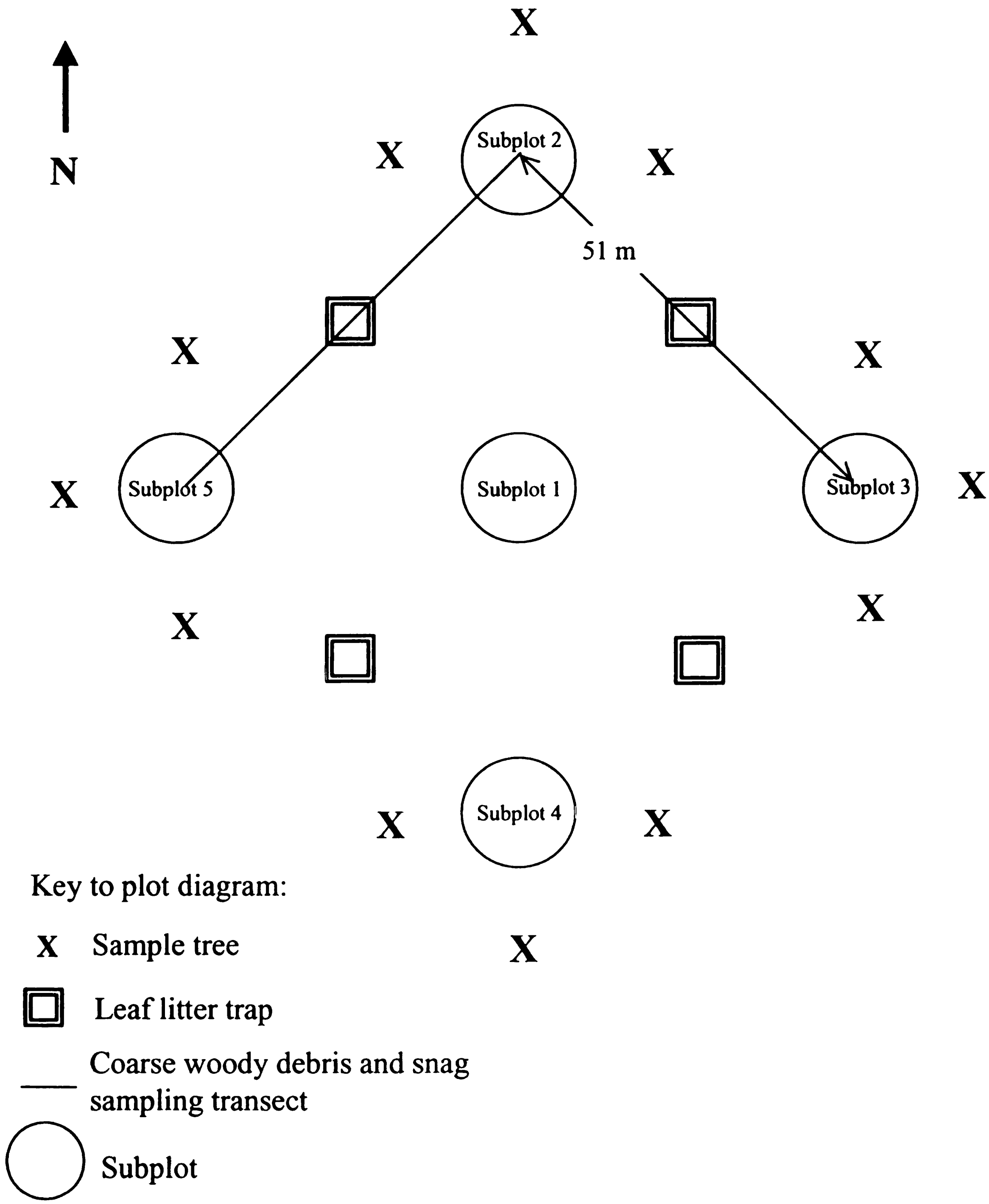
Beech

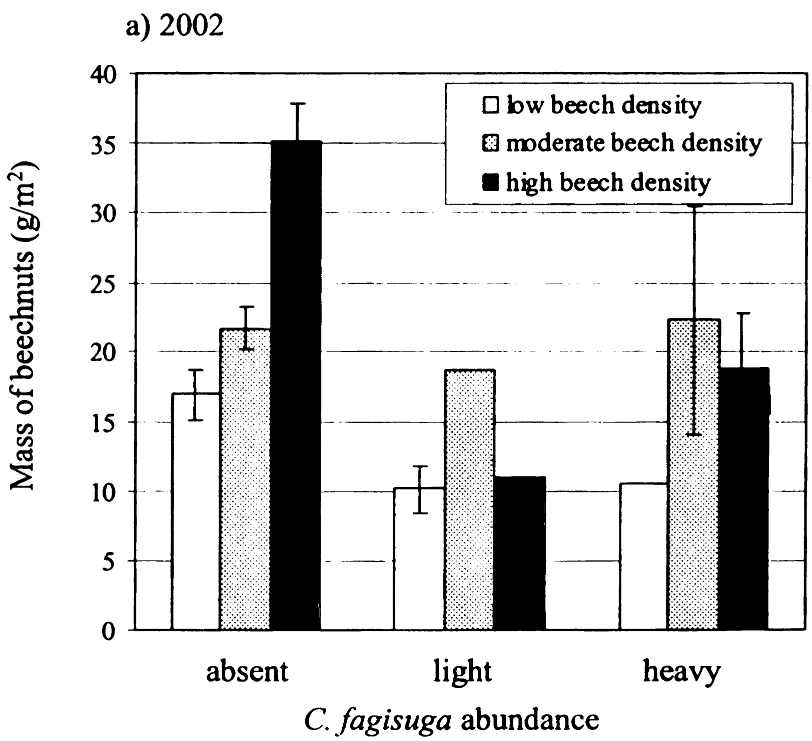
Beech density	absent	light	heavy	all stands
low	0.1 ± 0.03	3.5 ± 1.09	0.0 ± 0.00	0.8 ± 0.11^{z}
moderate	0.8 ± 0.14	0.0 ± 0.00	2.2 ± 1.28	0.8 ± 0.09^{z}
high	1.6 ± 0.70	5.6 ± 3.97	12.5 ± 2.62	7.2 ± 0.91^{y}
all stands	0.6 ± 0.05^{b}	2.4 ± 0.39^{ab}	7.4 ± 1.16^{a}	

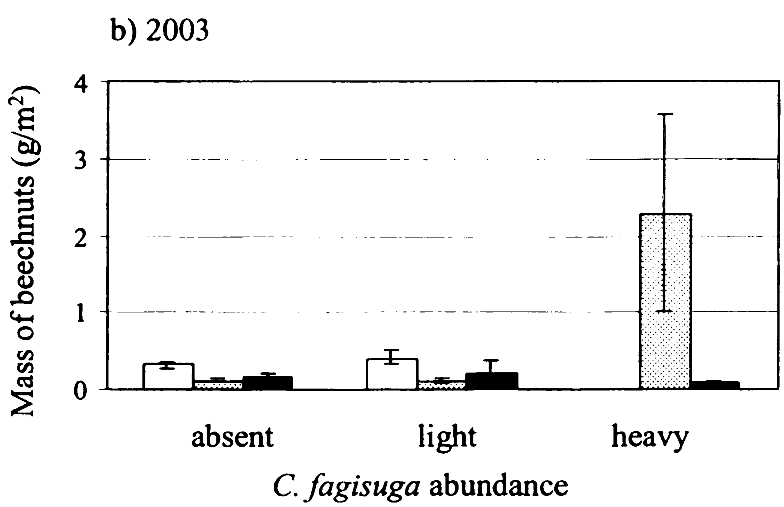
Figure legends

Figure 2-1. Intensive research plot design indicating arrangement of subplots 1-5, individual beech trees selected for long-term monitoring, beech nut collection traps, and coarse woody debris and snag measurement transects.

Figure 2-2. Beech nut mass ($g/m^2 \pm SE$) among stands with low, moderate, and high beech density and absent, light, and heavy *C. fagisuga* infestation in a) 2002 and b) 2003.


N
Subplot 2
51 m
Subplot 5
Subplot 1
Subplot 3
Subplot 4
Key to plot diagram:
X Sample tree
Leaf litter trap
Coarse woody debris and snag sampling transect
Subplot


a) 2002
40
35
30
25
20
15
10
5
0
Mass of beechnuts (g/m2)
low beech density
moderate beech density
high beech density
absent
light
heavy
C. fagisuga abundance


b) 2003
4
3
2
1
0
Mass of beechnuts (g/m2)
absent
light
heavy
C. fagisuga abundance

RADIAL GROWTH AND LEAF BIOMASS OF MICHIGAN BEECH FORESTS IMPACTED BY VARYING LEVELS OF BEECH BARK DISEASE.

Introduction

Beech bark disease has been advancing throughout the range of beech in North America and, in 2000, was discovered in Mason County in the northwest Lower Peninsula Michigan and Luce County in the eastern Upper Peninsula Michigan (McCullough et.al. 2001, O'Brien et.al. 2001). In 2001, we initiated a study to collect baseline data for long-term comparisons of forest productivity as beech bark disease spreads and intensifies throughout Michigan. The primary objective of this project was to determine the impacts of beech bark disease on total biomass production in stands by quantifying radial growth and foliage production of beech in stands with varying levels of beech bark disease and beech densities. Our research addressed the following questions: *i*) Does infestation of *C. fagisuga* impact radial growth of individual trees and if so, are stand-level trends evident? *ii*) Is there a difference in foliar biomass of beech and other species produced among stands with varying levels of beech bark disease?

Although beech bark disease can kill trees, some beech trees survive decades after infection, persisting in a state of decline and contributing limited biomass production to the stand (Hane 2003, Shigo 1972, Twery and Patterson 1984). Reductions in radial growth lead to lower timber and fiber production in a stand. Predicting the impact of beech bark disease, therefore, is important for long-term management of sustainable forests.

Methods

Study Sites

These data were collected from the study sites described in Chapter One and classified by the same beech density and *C. fagisuga* infestation criteria.

Radial growth

We selected 12 beech trees, 10.67 m from the center of each of the four outer subplots in each cardinal direction, excluding the azimuth leading toward the center subplot (Figure 3-1) for long-term monitoring. Each tree was marked with a round, blue tree tag nailed into the base of the tree facing the subplot center. When more than one beech tree fell within the designated distance and azimuth, we preferentially selected a tree by the following prioritized criteria: 1) the largest tree with a canker, 2) any tree (pole-sized or larger) with a canker, 3) large tree with C. fagisuga present, 4) any tree (pole-sized or larger) with beech scale, or 5) any large tree (closest to the azimuth used).

Abundance of *C. fagisuga* on each of the 12 trees was estimated by overlaying a transparent, acetate grid containing 50 cells, each 1.91 cm^2, at 1.3 m aboveground on the north and south azimuths of the main bole. Each cell was assigned a rating based on the area occupied by *C. fagisuga* as absent, light (<10%), or heavy (>10%). Overall values were then assigned to each tree as 1) the percentage of the main bole with *C. fagisuga* present and 2) the percentage of the main bole heavily covered by *C. fagisuga*. Canopy dieback was visually estimated for each tree and, based on the percentage of mortality in the crown, classified as absent (0), low (< 30%), moderate (30-60%), and high (>60%).

To analyze radial growth of beech trees before and after the onset of beech bark disease, increment cores were extracted from the 12 beech trees in each stand between May and August 2002 or June and August 2003. Because trees were actively growing when cored, current year increments were not included in analyses to eliminate partial increments. Increment cores were extracted at approximately 1 meter above ground perpendicular to the main bole of each of the 12 beech trees using a cordless drill and case-hardened coring bit. Coring tools were dipped in alcohol and flamed before sampling each tree to prevent possible artificial inoculation of *Nectria* sp. to uninfected trees. Increment cores were mounted on wooden holders, sanded four times with progressively finer paper (100 grit, 220 grit, 600 grit, and emery cloth) to create a flat surface, then scanned into a digital image for annual increment measurements with WinDENDRO® (Regent Instruments, Inc.). To distinguish between effects of site conditions and beech bark disease, cores were also extracted from two non-beech trees within each stand. Approximately half the cores were either damaged in the preservation and measurement process or did not have sufficiently visible annual growth rings and were excluded from analyses. To eliminate the effect of crown position on growth pattern, only trees in the dominant and codominant dominance classes were included in the analyses. Consequently, a total of 90 trees with intermediate crown class and 15 suppressed trees were removed from analyses. A total of 376 cores were analyzed; 304 were from beech and 72 were from non-host trees.

Mean distances between annual growth rings (mm/yr) were calculated for each tree in 5, 10, and 15-year intervals. To identify any changes in growth in the last 5, 10, or 15 years, ratios were established for mean annual growth during 1997-2001 and 1992-1996 (5 years), 1992-2001 and 1982-1991 (10 years), and 1987-2001 and 1986-1972 (15 years). Intervals were established around the last 5, 10, and 15-year periods because, as of 2000, beech bark disease had likely been present in Mason and Luce Counties for at least 10 years (O'Brien et al. 2001). The established intervals were also intended to account for the expansion of beech bark disease into previously uninfected stands over time. Although trees cored in 2003 included a complete increment for 2002, all analyses were initiated from 2001 to maintain consistency. Annual increments (mm/yr) were plotted for each tree and distinct reductions in growth were identified. To distinguish regularly oscillating fluctuations growth patterns from distinct reductions in growth, only annual increments that decreased below the average growth increment and did not recover to previous growth increments for at least 10 years were considered growth reductions.

We were not able to determine the age of 210 beech trees from which cores were extracted due to light annual rings that were not detectable by WinDENDRO® or because the heartwood was decayed with no pith remaining as a reference point. Tree age was quantified for 94 beech trees from 45 stands. Some stands had no beech cores successfully extracted and aged while others had up to six cores with complete analysis. Fifty five beech cores were aged from stands with absent *C. fagisuga* infestation (27 low, 23 moderate, and five high beech density), 24 stands with light *C. fagisuga* infestation (11 low, 10 moderate, and three high beech density), and 15 stands with heavy *C. fagisuga* infestation (one low, two moderate, and 12 high beech density).

Age was determined from 28 of the 72 non-host cores extracted, representing 28 stands, with a maximum of one core successfully aged from each stand. Non-host cores were aged from 18 stands with absent *C. fagisuga* infestation (six low, eight moderate, and four high beech density), four stands with light *C. fagisuga* infestation (zero low, three moderate, and one high beech density), and six stands with heavy *C. fagisuga* infestation (two low, two moderate, and two high beech density).

Leaf biomass

Leaves were collected in the $1m^2$ pvc traps described in Chapter Two. Traps were not set in eight stands in 2003 because of heavy harvesting (three stands), seasonal inaccessibility (two stands), and vandalism (three stands). Due to these limitations and to site damage to traps, leaf collections were only made from five stands with heavy *C. fagisuga* infestation; none of these five stands had a heavy infestation of *C. fagisuga*. Leaves from each trap were bagged and returned to the forest entomology lab at Michigan State University. All leaf samples were sorted to species, oven-dried at 38°C (100° F) for 72 hours, and weighed.

Statistical analyses

Normality was tested for all variables using the Shapiro-Wilk test (SAS Institute, 1985). Data distributions for growth ratios for 5, 10, and 15-year intervals and overstory basal area by species could not be normalized by transformation, thus these variables were ranked and analyzed with nonparametric tests. The nonparametric Kruskal-Wallis test was used to determine if growth ratios for 5, 10, and 15-year intervals differed among stands with low, moderate, or high beech density and absent, light, or heavy *C. fagisuga* infestation (SAS Institute 1985). Spearman's correlations were used to determine if the percent of the main bole with *C. fagisuga* or with heavy *C. fagisuga* correlated with annual growth ratios for 5, 10, and 15-year intervals. Spearman's nonparametric correlation coefficients were also calculated to assess linear associations among age, dieback, and annual growth ratios for 5, 10, and 15-year intervals.

Leaf biomass for each stand was calculated as the mean of all traps collected in each stand. A paired t-test was used to test the differences in mean leaf mass produced in 2002 and 2003. Two-way ANOVA was used to test the differences in mean leaf mass of (1) all species and (2) beech among stands with low, moderate, or high beech density and among stands with absent, light, and heavy *C. fagisuga* infestation. When results of ANOVA were significant ($\alpha = 0.05$), Tukey's Honestly Significant Difference was used to compare means (Tukey 1977). Basal area of overstory species were not normalized by transformation, thus were ranked and analyzed with nonparametric tests. Spearman's correlation coefficients were calculated for basal area of each overstory species (beech, sugar maple, red maple, red oak, other hardwoods, and all species combined) and their respective leaf mass. All data analyses were conducted using the Statistical Analysis System ($\alpha = 0.05$) (SAS Institute 1985).

Results

Radial growth

A total of 304 beech cores from 59 stands were successfully extracted and measured, an average of 5 ± 0.3 cores per stand (Appendix 4). Continuous, detectable annual growth rings from bark to pith were present for only 94 beech trees, which averaged 81± 2.5 years of age. Mean increments calculated for all 304 beech trees averaged 2.2 ± 0.06 mm in the last 5 years, 2.1 ± 0.05 mm in the last 10 years, and 2.1 ± 0.05 mm in the last 15 years (Table 3-1). Of the 304 beech trees examined, only 29 exhibited a reduction in radial growth, with onsets occurring between 1956 and 1997. The 29 trees exhibiting growth reductions were from 21 different stands. Only four stands contained more than one tree exhibiting growth reductions; none of these trees had *C. fagisuga*.

Cryptococcus fagisuga was present on 73 of the 304 individual beech trees measured. The percentage of the main bole covered with *C. fagisuga* varied greatly. Five of the 73 infested trees exhibited a reduction in radial growth, with onsets of decline occurring between 1956 and 1993. Two of the beech trees exhibiting decline (trees 776 and 820) had trace amounts of *C. fagisuga* present on the main bole (Appendix 4). The other three declining beech trees had a heavy infestation of *C. fagisuga* on virtually all of the main bole, with 40-55% of the main bole heavily covered. Each of the five heavily infested trees that exhibited growth reduction were from separate stands, thus no consistent reduction in radial growth was evident at a stand level.

Of the 304 beech trees cored, 101 exhibited no canopy dieback, 159 exhibited low dieback, 35 exhibited moderate dieback, and nine exhibited heavy dieback. *Cryptococcus fagisuga* was present on the main bole of ten trees exhibiting no dieback (10%), 40 trees exhibiting low dieback (25%), 18 trees exhibiting moderate dieback (51%) and five trees exhibiting high dieback (56%).

Ratios for 5, 10, and 15-year intervals of mean annual growth in beech trees did not significantly differ among stands with absent, light, or heavy *C. fagisuga* infestation (5-yr interval: p=0.966) (10-yr interval: p=0.076) (15-yr interval: p=0.338), or among stands with low, moderate, or high beech density (Table 3-1) (5-yr interval: p=0.884)(10-yr interval: p=0.696)(15-yr interval: p=0.873). The percentage of the main bole with *C.*

fagisuga present was not correlated with growth ratios of 5, 10, or 15-year intervals (5-yr interval: p=0.52) (10-yr interval: p=0.948) (15-yr interval: p=0.842), nor was the percentage of the main bole heavily covered by *C. fagisuga* (5-yr interval: p=0.982) (10-yr interval: p=0.477) (15-yr interval: p=0.584). Tree age was not correlated with the annual growth ratios for 5, 10, and 15-year intervals (5-yr interval: p=0.127) (10-yr interval: p=0.774) (15-yr interval: p=0.687) (Figure 3-2). Dieback was not correlated with the annual growth ratios for 5, 10, and 15-year intervals (5-yr interval: p=0.173) (10-yr interval: p=0.981) (15-yr interval: p=0.377).

Non-beech tree cores were extracted to serve as a baseline for comparison with growth reduction in beech. Sixty-two cores from non-beech trees from 45 stands were successfully extracted and measured, an average of 1 ± 0.9 non-beech cores per stand. Non-beech trees that were cored were primarily sugar maple (44 trees from 32 stands) and red maple (15 trees from 12 stands). Continuous, detectable annual growth rings from bark to pith were present for 25 non-beech trees and averaged 78 ± 4.8 years of age. Mean increments for individual non-beech trees averaged 2.1 ± 0.13 mm in the last 5 years, 2.10 ± 0.12 mm in the last 10 years, and 2.0 ± 0.11 mm in the last 15 years (Table 3-1). As no reductions in beech growth were detected, no further analyses were conducted on the non-beech cores.

Leaf biomass

Mean leaf biomass of all species combined was 289 ± 15.0 g/m^2 in 2002 and 311 ± 16.0 g/m^2 in 2003 (Table 3-2). Although differences in leaf biomass were not substantial, they differed significantly among years (df=30, t=-2.81, p=0.008). Beech and sugar maple comprised the greatest portion of leaf litter in both 2002 and 2003 (Figure 3-3).

In 2002, mean leaf biomass of all species combined was significantly greater in stands with no *C. fagisuga* infestation than in stands with heavy *C. fagisuga* (df=2,33; F=4.60, p=0.017), but not different among stands with low, moderate, or high beech density (p=0.304). Mean leaf biomass of beech did not significantly differ among stands with absent, light, or heavy *C. fagisuga* (p=0.213), but was greater in stands with high beech density than in stands with low beech density (df=2,33; F=0.12, p=0.014).

In 2003, mean leaf biomass of all species was not significantly affected by *C. fagisuga* infestation (p=0.458), nor beech density (p=0.238). Mean leaf biomass of beech did not significantly differ among stands with varying levels of *C. fagisuga* (p=0.437), but was significantly greater in stands with moderate and high beech density than in stands with low beech density (df=2,48; F=7.64, p=0.001).

Basal area of beech, sugar maple, red maple, red oak, and other hardwoods was significantly correlated with species leaf biomass of each corresponding in 2002 and 2003 (Table 3-3).

Discussion

Radial growth

Examination of radial growth trends for all beech trees (n=304) did not elicit any marked reductions in growth attributable to beech bark disease. Only five of the 73 cores from beech trees infested with *C. fagisuga* exhibited distinct reductions in growth. Each was from a different stand, indicating no stand-level reduction in growth. In at least three of our 11 stands with heavy *C. fagisuga*, signs and symptoms of beech bark disease were evident (including perithecia of *Nectria* sp.) and mortality and breakage of mature beech had begun by the onset of our study. We extracted cores from only the remaining live trees with *C. fagisuga* in these stands and likely included the effects of the changing canopy structure on radial growth in our analyses. Mature beech trees increase radial growth when growing in open gaps, such as those created by the mortality of a neighboring tree (Canham 1990, Poage and Peart 1993). The availability of increased light may have outweighed the effects of beech bark disease on radial growth. Such an occurrence was documented in New York stands affected by beech bark disease, where radial growth of surviving beech was highest in stands with greatest mortality (Runkle 1990).

Beech bark disease occurs with greatest frequency on poor sites where trees are subject to greater physiological stress, particularly when moisture is limited (Lonsdale 1980, Shigo 1964). Under poor conditions, beech may have "missing" rings (Peters 1997). We did not cross-date our cores and therefore did not account for this possible discrepancy among trees growing under various site conditions.

Beech bark disease had not yet impacted the radial growth patterns of beech trees sampled from our study stands. Other studies demonstrated a 25-40% reduction in radial growth of beech that had been impacted by beech bark disease for 8 to 30 years (Gavin and Peart 1993, Mize and Lea 1979, Runkle 1990). Our study accounts for roughly 10 years of cumulative impact of *C. fagisuga*. Because *C. fagisuga* cannot live on dead tissue, trees in our stands with heavy *C. fagisuga* infestation were probably not yet infected with *Nectria* spp. We cannot assume, therefore, that presence of *C. fagisuga* equates to beech bark disease. Long-term monitoring will be necessary to evaluate the radial growth of trees with *C. fagisuga* as they are progressively impacted by beech bark disease and dieback occurs.

Leaf biomass

In both 2002 and 2003, the beech component of mean leaf biomass did not differ among stands with varying levels of *C. fagisuga* infestation. In other words, *C. fagisuga* had not affected foliar productivity of beech and infested and uninfested stands produced similar amounts of foliage. In a study conducted in New York stands transitioning from the Killing Front to the Aftermath Stage of beech bark disease, annual litter production remained constant, beech foliar biomass did not change, and soil chemistry was not altered by changes in beech leaf leachate, likely because basal area of regenerating beech compensated for declines in mature overstory mature trees (Forrester et al. 2003). Although our study was primarily conducted in stands at the Advancing Front, our results are consistent with conditions reported after 15 years of cumulative beech bark disease impact in the New York stand.

Stand-level *C. fagisuga* classifications were derived from density estimates made on individual large diameter trees, which are more readily infested by *C. fagisuga* (Houston and Valentine 1987), yet foliage was collected at the stand level and included leaf production from all classes of trees positioned above the traps. Collecting leaf litter from trees of all classes and conditions likely included productivity from smaller trees not infected with *C. fagisuga* in the understory. As trees succumb to beech bark disease and crowns become sparse, suppressed trees of other species in the understory respond to increased light levels with rapid growth (Canham 1990).

Published equations are useful for estimating foliar biomass of individual trees based on dbh along with total aboveground productivity for a given stand (Briggs et al. 1989, Forrester et al. 2003, Ter-Mikaelian 1997). In our study, basal area of red maple, red oak, and other hardwood species were correlated with leaf mass of respective species. Basal area for beech and sugar maple, however, were not linearly associated with leaf mass suggesting long-term studies are needed to assess that relationship between foliage production with basal area.

The complete etiologic complex of beech bark disease was not conclusively determined in our study and therefore, conclusions are limited to the impacts of *C. fagisuga* infestation. Future studies on the impacts of beech bark disease on Michigan forests should include *Nectria* sp. present, as tree vigor measurements have been reported to be more closely correlated with *Nectria* sp. than *C. fagisuga* infestation (Jones and Raynal 1987).

It is plausible that, by the time of this study, beech bark disease had only recently begun to impact individual trees and stands. One long-term study in New Hampshire demonstrated that at low levels of infestation, individual tree growth trends varied widely and occasionally included overall increases (Gavin and Peart 1993). The results presented here were largely intended to provide a baseline for comparisons of long-term data and will be useful in elucidating the period over which any changes in radial growth and biomass production occur.

Table 3-1. Mean annual increment ratios (mm:mm) for 5, 10, and 15-year intervals for beech (n =304) and non-beech (n =62) trees among stands with absent, light, and heavy *C. fagisuga* infestation and among stands with low, moderate, high beech density.

	***C. fagisuga* infestation**			**Beech density**		
Ratios for mean annual growth	absent	light	heavy	low	moderate	high
Beech						
5-year interval						
1997-2001/1992-1996	1.10 ± 0.025	1.14 ± 0.053	1.09 ± 0.043	1.13 ± 0.04	1.10 ± 0.03	1.09 ± 0.04
10-year interval						
1992-2001/1982-1991	1.17 ± 0.031	1.21 ± 0.056	1.06 ± 0.043	1.15 ± 0.03	1.17 ± 0.04	1.15 ± 0.05
15-year interval						
1987-2001/1972-1986	1.19 ± 0.033	1.20 ± 0.062	1.08 ± 0.044	1.20 ± 0.04	1.17 ± 0.040	1.13 ± 0.04
Non-beech						
5-year interval						
1997-2001/1992-1996	1.22 ± 0.08	0.93 ± 0.07	1.03 ± 0.09	1.25 ± 0.10	1.06 ± 0.08	0.99 ± 0.02
10-year interval						
1992-2001/1982-1991	1.12 ± 0.06	0.97 ± 0.08	1.17 ± 0.14	1.09 ± 0.07	1.08 ± 0.08	1.16 ± 0.04
15-year interval						
1987-2001/1972-1986	1.07 ± 0.05	1.03 ± 0.11	0.98 ± 0.07	1.05 ± 0.06	1.03 ± 0.08	1.07 ± 0.03

Table 3-2. Mean leaf mass (g/m^2) of American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), red oak (*Quercus rubra*), and other hardwood species among stands with absent, light, or heavy *C. fagisuga* infestation. Data represents 36 samples from 2002 and 51 samples from 2003.

	2002				2003			
	Beech density				Beech density			
C. fagisuga infestation	low	moderate	high	all stands	low	moderate	high	all stands
				Fagus grandifolia				
absent	50 ± 8.5	73 ± 10.3	112 ± 20.5	74 ± 8.3	52 ± 6.9	84 ± 9.5	121 ± 24.4	75 ± 6.9
light	46 ± 15.9	61 ± 0.0	84 ± 0.0	55 ± 11.9	73 ± 22.0	96 ± 6.6	105 ± 33.2	88 ± 10.6
heavy	54 ± 0.0	40 ± 6.4	61 ± 8.9	55 ± 6.4	n/a	55 ± 28.7	97 ± 10.3	80 ± 14.9
all stands	49 ± 6.8	67 ± 8.5	86 ± 12.2		57 ± 7.5	84 ± 7.2	110 ± 12.4	
				Acer saccharum				
absent	72 ± 18.7	94 ± 14.0	79 ± 28.3	83 ± 10.6	117 ± 13.2	128 ± 15.6	93 ± 14.6	119 ± 9.2
light	26 ± 19.9	0 ± 0.0	92 ± 0.0	32 ± 17.9	54 ± 35.5	82 ± 37.0	149 ± 24.1	81 ± 22.5
heavy	51 ± 0.0	1 ± 0.9	12 ± 11.8	14 ± 9.0	n/a	1 ± 1.2	0 ± 0.0	0 ± 0.5
all stands	56 ± 13.9	71 ± 16.0	50 ± 17.1		101 ± 14.2	106 ± 15.5	75 ± 21.4	
				Acer rubrum				
absent	48 ± 14.3	26 ± 10.7	7 ± 3.0	30 ± 7.4	43 ± 9.6	24 ± 9.4	4 ± 4.1	30 ± 6.3
light	46 ± 15.5	104 ± 0.0	33 ± 0.0	54 ± 14.2	43 ± 15.3	61 ± 18.5	21 ± 18.8	47 ± 10.5
heavy	54 ± 0.0	105 ± 16.6	30 ± 4.4	52 ± 12.7	n/a	139 ± 7.1	50 ± 10.0	86 ± 22.5
all stands	48 ± 9.6	46 ± 13.1	20 ± 4.3		43 ± 7.9	43 ± 10.5	23 ± 8.5	

Table 3-2. Cont'd.

	2002				2003			
	Beech density				Beech density			
C. fagisuga infestation	low	moderate	high	all stands	low	moderate	high	all stands
				Quercus rubra				
absent	55 ± 44.5	11 ± 10.7	0 ± 0.4	25 ± 16.9	60 ± 54.0	9 ± 6.9	0 ± 0.0	30 ± 24.0
light	17 ± 10.0	28 ± 0.0	0 ± 0.0	16 ± 7.3	6 ± 4.0	7 ± 7.1	0 ± 0.0	6 ± 3.3
heavy	0 ± 0.0	10 ± 10.3	24 ± 15.1	18 ± 9.9	n/a	9 ± 8.9	27 ± 27.1	20 ± 15.7
all stands	39 ± 27.5	12 ± 8.1	11 ± 7.5		46 ± 40.5	9 ± 4.9	9 ± 9.0	
				Other hardwood species[b]				
absent	27 ± 8.3	13 ± 5.2	27 ± 7.0	21 ± 4.1	49 ± 11.3	23 ± 5.8	33 ± 11.6	36 ± 6.0
light	27 ± 22.0	8 ± 0.0	1 ± 0.0	19 ± 14.7	37 ± 17.0	4 ± 1.3	6 ± 3.2	18 ± 8.2
heavy	12 ± 0.0	16 ± 14.8	19 ± 18.3	18 ± 11.3	n/a	23 ± 16.0	15 ± 12.4	19 ± 8.7
all stands	26 ± 8.0	13 ± 4.3	21 ± 8.7		46 ± 9.3	19 ± 4.4	21 ± 7.2	
				All species combined				
absent	277 ± 29.7	240 ± 16.3	249 ± 16.7	255 ± 13.2	344 ± 49.9	289 ± 11.5	275 ± 14.1	312 ± 22.7
light	191 ± 23.7	226 ± 0.0	219 ± 0.0	201 ± 16.4	248 ± 17.0	262 ± 22.4	303 ± 11.9	263 ± 12.4
heavy	198 ± 0.0	203 ± 36.6	177 ± 23.0	186 ± 16.1	n/a	252 ± 56.9	207 ± 62.0	225 ± 40.0
all stands	244 ± 22.4	232 ± 13.5	213 ± 16.3		320 ± 38.5	279 ± 10.3	258 ± 23.2	

[a] Standard errors of 0 indicate a sample size of one.

[b] Other hardwood species include ash (*Fraxinus* sp.), aspen (Populus sp.), basswood (Tilia sp.), birch (*Betula* sp.), and black cherry (*Prunus serotina*).

Table 3-3. Spearman's correlation coefficients (r_s) and significance value (p) for the relationship between basal area (m^2/ha) of overstory species and corresponding leaf biomass from 40 stands in 2002 and 54 stands in 2003. Correlation coefficients with $p<0.05$ are significantly different.

	2002	**2003**
American beech		
r_s	0.588	0.664
p	<0.001	<0.001
Sugar maple		
r_s	0.587	0.638
p	<0.001	<0.001
Red maple		
r_s	0.632	0.679
p	<0.001	<0.001
Red oak		
r_s	0.761	0.797
p	<0.001	<0.001
Other hardwoods[a]		
r_s	0.598	0.696
p	<0.001	<0.001

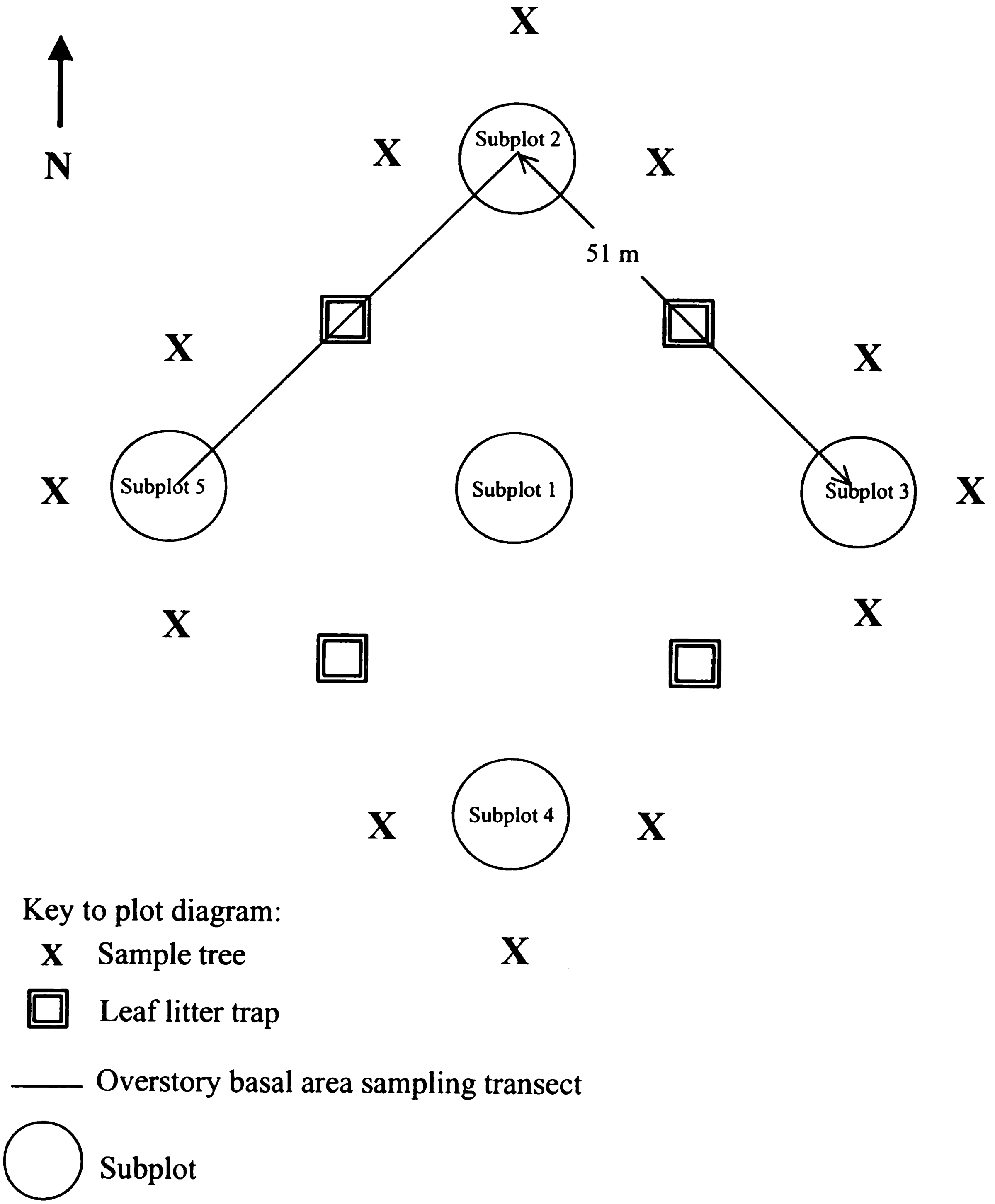
[a]Other hardwood species included ash (*Fraxinus* sp.), aspen (*Populus* sp.), basswood (*Tilia* sp.), birch (*Betula* sp.), and black cherry (*Prunus serotina*).

Figure legends

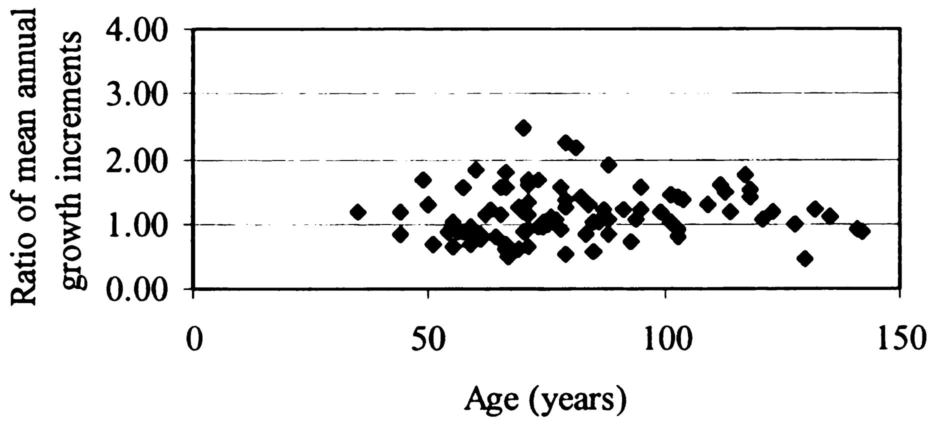
Figure 3-1. Intensive research plot design indicating arrangement of subplots 1-5, overstory composition measurement transects, individual beech trees selected for long-term monitoring, and leaf litter traps.

Figure 3-2. Age of beech trees (*n*=94) plotted against the ratio of mean annual increment for intervals of a) 5-year, b) 10-year, and c) 15-years.

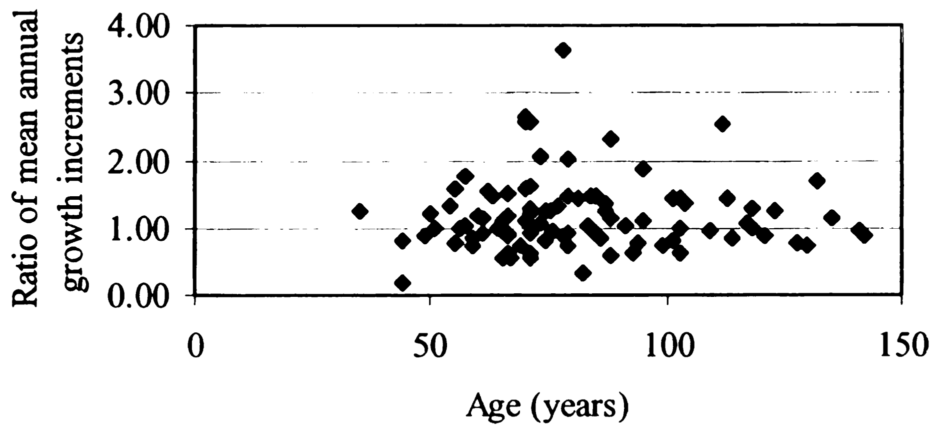
Figure 3-3. Composition of leaf biomass (g/m^2) by species from a) 40 stands in of stands in 2002 and from b) 54 stands in 2003.


N
X
Subplot 2
51 m
Subplot 5
Subplot 1
Subplot 3
Subplot 4
Key to plot diagram:
X Sample tree
Leaf litter trap
Overstory basal area sampling transect
Subplot

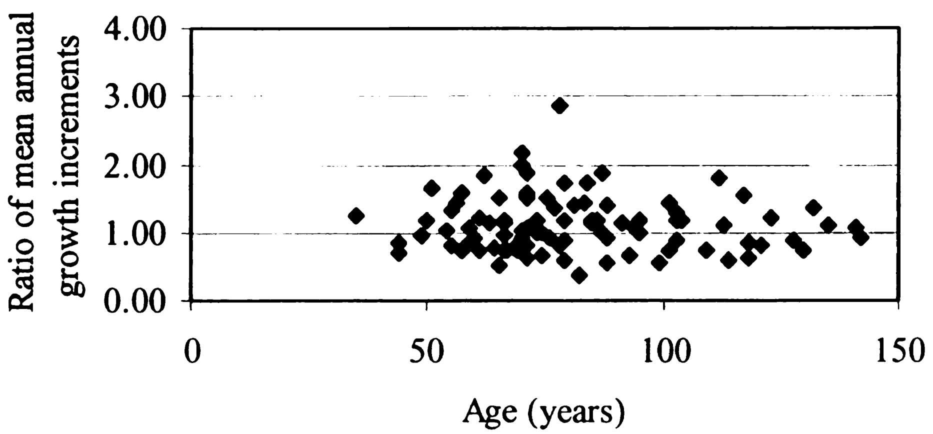
A) 5-year intervals: 1997-2001 and 1992-1996



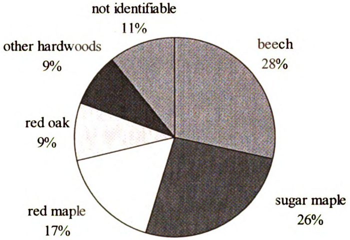
B) 10-year intervals: 1992-2001 and 1982-1991



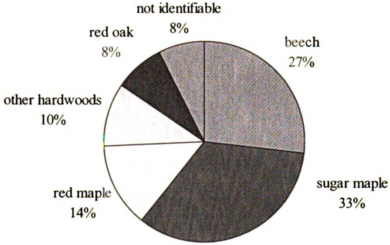
C) 15-year intervals: 1987-2001 and 1986-1972



a) 2002


not identifiable
11%
beech
28%
other hardwoods
9%
red oak
9%
red maple
17%
sugar maple
26%

b) 2003


not identifiable
8%
red oak
8%
beech
27%
other hardwoods
10%
red maple
14%
sugar maple
33%

APPENDICES

Appendix 1. Stand locations, ownership, Michigan State University beech density index, and *Cryptococcus fagisuga* infestation index.

Stand ID	County	Legal Description	Compartment	Stand	GPS coordinates lat nad8	GPS coordinates long nad83	Owner	Beech Density Index [a]	*C. fagisuga* Infestation Index [b]	Year of Intial Survey
001	Emmet	T36N R5W S1	116	2	45.54709	-84.85587	State	1	0	2002
002	Emmet	T36N R5W SEC23	15	8	45.49298	-84.87668	State	3	0	2002
005	Kalkaska	T28N R7W SEC17	174	61	44.82962	-85.18621	State	1	0	2002
010	Wexford	T21N R11W SEC5	80	89	44.24810	-85.67460	Federal	3	0	2002
016	Benzie	T27N R14W SEC3	6	14	44.77566	-85.99676	State	1	0	2003
019 [†]	Mason	T19N R18W SEC17	Ludington	-	44.04245	-86.49628	State	3	2	2002
020	Mason	T19N R18W SEC17	Ludington	-	44.04473	-86.49657	State	3	2	2002
021 [†]	Mason	T19N R18W SEC17	Ludington	-	44.03781	-86.50489	State	2	2	2002
024	Mason	T30N R17W SEC32	352	31	44.09212	-86.36683	Federal	2	1	2002
026	Mason	T20N R18W SEC35,31	354	19	44.08524	-86.38715	Federal	2	2	2002
027	Mason	T20N R18W SEC24	356	21	44.11176	-86.41854	Federal	1	1	2002
028	Manistee	T23N R13W SEC1	37	54,55	44.41761	-85.83914	State	2	0	2002
030	Manistee	T22N R15W SEC31	426	2	44.26729	-86.17830	Federal	1	1	2002
034	Allegan	T4N R16W SEC28	Saugatuck	-	42.69918	-86.20190	State	1	0	2002
035 [†]	Ottawa	T6N R15W SEC5	Pigeon Crk	-	42.93481	-86.10136	County	3	0	2002
036	Muskegon	T9N R16W	Hoffmaster	-	43.12455	-86.26438	State	2	0	2002
039	Oceana	T15N R18W SEC31	Silver Lk.	-	43.64818	-86.51383	State	3	2	2002
042	Oceana	T15N R18W SEC31	Silver Lk.	-	43.64959	-86.51917	State	1	0	2002
047	Mason	T20N R18W SEC35,31	357	19	44.08550	-86.43546	Federal	1	2	2003
058	Wexford	T21N R12W SEC1	81	36	44.24682	-85.70331	Federal	1	0	2002
062	Leelanau	T28N R12W SEC30	2	21	44.79087	-85.81084	State	2	0	2003
067	Antrim	T31N R5W SEC16	47	31,38	45.07507	-84.92284	State	1	0	2002
075	Emmet	T34N R4W SEC25	28	28	45.31316	-84.74682	State	1	0	2003
077	Charlevoix	T33N R4W SEC12,1	34	64	45.27382	-84.73797	State	1	0	2003
080 [††]	Charlevoix	T37N R11W SEC13,14	69	14	45.58875	-85.61037	State	2	0	2002
083	Wexford	T21N R11W SEC17	34	64	n/a	n/a	Federal	2	0	2003
092	Cheboygan	T33N R3W SEC 26	158	17	n/a	n/a	State	1	0	2003
095	Montmorency	T31N R1E SEC 31	33	31	n/a	n/a	Federal	1	0	2003

Appendix 1 cont'd.

Stand ID	County	Legal Description	Compartment	Stand	GPS coordinates lat nad8	long nad83	Owner	Beech Density Index [a]	*C. fagisuga* Infestation Index [b]	Year of Intial Survey
102	Luce	T47N R11W SEC1	89	14	46.49592	-85.62265	State	1	1	2002
104	Luce	T47N R11W SEC17	Bass Lk.	–	46.46211	-85.70561	Private	3	2	2002
107	Luce	T47N R11W SEC29	–	–	46.44078	-85.71517	Private	1	2	2002
111	Alger	T46N R21W SEC13	20	4	46.38479	-86.83864	Federal	1	0	2002
115	Delta	T42N R19W SEC 10,11	136	37	46.05198	-86.65533	Federal	2	0	2003
117	Schoolcraft	T44N R18W SEC5,6,7	103	20	46.23098	-86.59106	Federal	2	0	2002
120	Schoolcraft	T41N R16W SEC7	Indian Lk.		45.96719	-86.35959	State	3	0	2002
121	Schoolcraft	T41N R17W SEC1	81	318	45.98192	-86.37237	State	1	0	2003
123	Luce	T47N R12W SEC13	6	39	46.64583	-85.75324	State	3	2	2002
125	Luce	T49N R11W SEC26	20	2,3	46.60354	-85.65593	State	2	2	2002
126	Chippewa	T49N R7W SEC32	Tahquamenon	–	46.60696	-85.21789	State	3	2	2002
127	Luce	T48N R8W SEC1	Tahquamenon	–	46.58284	-85.25329	State	2	1	2003
129	Chippewa	T47N R3W SEC21	4	20	46.45074	-84.67729	Federal	1	0	2003
131	Chippewa	T47N R5W SEC34	21	3	46.42285	-84.90877	Federal	1	1	2002
134 †††	Chippewa	T47N R7W SEC5	–	–	46.50171	-85.20870	Private	2	1	2003
135	Mackinac	T41N R5W SEC22	35	21	45.92861	-84.91298	Federal	2	0	2002
136	Mackinac	T41N R5W S11	164	36	45.96190	-84.89825	Federal	2	0	2002
137	Mackinac	T42N R7W SEC2	120	5	46.06251	-85.14702	State	3	1	2002
143	Chippewa	T42N R6E SEC27	8	1	45.99870	-83.66749	State	2	0	2002
149	Mackinac	T44N R9W SEC34	–	380	46.16359	-85.41529	Private	2	1	2003
150	Mackinac	T44N R9W SEC28	–	364	46.17741	-85.44576	Private	2	1	2003
151	Mackinac	T43N R9W SEC 20	–	227	46.11434	-85.44919	Private	1	1	2003
152	Mackinac	T45N R9W SEC18	–	179	46.21057	-85.46715	Private	3	1	2002
166	Alger	T46N 19W SEC24	34	81	46.37214	-86.61638	Federal	2	0	2002
167	Alger	T46N R19W SEC29	31	25	46.36180	-86.70848	Federal	3	0	2002
170	Delta	T42N R19W SEC21	110	6	46.01952	-86.69258	Federal	2	0	2002
171	Delta	T43N R20W SEC29	142	32	46.09056	-86.83028	Federal	1	0	2002
172	Delta	T43N R20W SEC17	165	43	46.13722	-86.83723	Federal	1	0	2003
173	Alger	T48N R17W SEC13	PRNL	–	46.55536	-86.36626	Federal	2	0	2002

Appendix 1 cont'd.

Stand ID	County	Legal Description	Compartment	Stand	GPS coordinates lat nad8	GPS coordinates long nad83	Owner	Beech Density Index [a]	*C. fagisuga* Infestation Index [b]	Year of Intial Survey
184 ††	Alger	T47N R17W SEC6	–	–	n/a	n/a	State	1	0	2003
186 †††	Schoolcraft	T44N R13W SEC4	Seney WR	–	n/a	n/a	Federal	2	0	2003
189	Marquette	T50N R27W SEC33	–	–	n/a	n/a	Private	2	0	2003
197	Chippewa	T45N R6W SEC36	100	79	n/a	n/a	Federal	1	0	2003
198	Mackinac	T34N R37W SEC 34	142	80	n/a	n/a	State	2	0	2003

[a] Beech Density Index (according to absolute basal area): 1 = Low (<9 m2/ha), 2 = Moderate (9-18 m2/ha), 3 = High (>18 m2/ha)

[b] *C. fagisuga* Infestation Index (according to percentage of heavily infested trees within stand boundary at time of initial year of survey): 0 = absent (no trees), 1 = light (less than 50%), 2 = heavy (greater than 50%)

† Stands 019, 021, 035: no leaf litter traps set due to proximity to recreation areas.

†† Stands 080, 184: no leaf litter traps set due to seasonal inaccessibility.

††† Site 134: MSU inspection confirms *C. fagisuga* within intensive site boundaries (U. of M. does not); Site 186: MSU inspection confirms no *C. fagisuga* within intensive site boundaries, although U. of M. confirms presence on refuge property.

Appendix 2. Occurrence of species in the overstory and in each stage of regeneration.

ID	*Overstory* [a]	*Seedling* [b]	*Sapling*	*Recruit*
001	*Fg* [c], *As, Ar, Ba, Fa*	*Fg, As, Ar, Ap, Fa*	*Fg, As, Ar, Fa*	*Fg, As, Ap*
002	*As, Fa*	*Fg, As, Ar, Ap*	*Fg, Ap*	*Fg, As*
005	*As, Ar, Ps*	*Fg, As, Ar, Ps, Aa*	*Fg, As, Aa*	*Fg, As, Ar, Aa*
010	*Fg, As, Ps, Cc*	*Fg, As, Ar, Ps*	*Fg, As*	*Fg*
016	*As, Ar, Ps*	*Fg, As, Ps*	*Fg*	*Fg, As, Pst*
019	*Fg, Ar, Bp, Qr*	*(none)*	*(none)*	*Fg, Tc*
020	*Fg, Ar, Ps*	*Fg*	*(none)*	*Fg, Ar, Tc*
021	*Fg, Ar, Bp, Tc*	*(none)*	*(none)*	*Fg, Ar, Tc*
024	*Fg, Ar, Qr*	*Fg*	*Pst*	*Fg, Ar, Pst*
026	*Fg, Ar, Bp, Qr*	*Fg*	*Fg*	*Fg, Ar*
027	*Ar, Bp, Qr, Tc*	*Fg*	*As*	*Fg, Ar, Bp,Tc, Pst*
028	*Fg, As, Ar*	*Fg, As, Ar, Ps, Aa*	*Fg, Aa, Pst*	*Fg, As, Aa*
030	*Fg, As, Qr*	*Fg, As, Ar, Ps, As*	*Fg, Ps, Qr, Hv*	*Fg, As, Ar*
034	*Fg, Qr, Tc*	*Fg, As, Sa*	*Fg*	*Fg, As, Cc*
035	*Fg, As, Ps*	*Fg, As, Ps*	*Fg, As, Ps*	*Fg, As, Hv*
036	*Fg, As, Qr, Ta, Tc*	*Fg, As*	*Fg, Ta, Cc*	*Fg, As, Cc, Hv, Tc*
039	*Fg, Ar, Bp, Pg, Qr*	*Fg, Ar, Ps*	*Fg, Ar*	*Fg, Ar*
042	*Fg, As, Ar, Pg, Qr*	*Fg, Ar, Ps, Qr*	*Fg, Ar*	*Fg, As, Ar, Bp, Qr, Aa, Hv*
047	*Ar, Bp, Pg, Qr*	*Fg, Ar, Qr, Pst*	*(none)*	*Fg, Ar, Pst*
058	*As*	*Fg, As, Ar, Ps, Fa, Qr*	*Fg, Ps*	*Fg, As*
062	*Fg, As, Ta*	*Fg, Sm, Aa*	*Fg, As, Ta, Aa*	*Fg, As, Aa*
067	*Fg, As*	*Fg, As, Aa*	*Fg As, Aa*	*Fg, As, Aa*
075	*As, Fa, Ta, Cc*	*Fg, As, Fa, Cc*	*Fg, As, Ar, Ta, Cc*	*Fg, As*
077	*As, Ta*	*Fg, As, Fa, Cc, Aa*	*Fg, As, Ar, Fa, Cc*	*Fg, As,Cc*

Appendix 2. cont'd.

ID	*Overstory*	*Seedling*	*Sapling*	*Recruit*
080	*Fg, As, Bp*	*Fg, As, Ar*	*Fg, As*	*Fg, As, Ba*
083	*Fg, As, Pg, Ta*	*Fg, As, Ps, Fa*	*Fg, As, Fa, Hv*	*Fg, As*
092	*Fg, As, Pg, Ta*	*Fg, As, Fa, Ta, Cc*	*Fg, As, Fa, Cc*	*Fg, As, Cc*
095	*Fa, Qr, Ta, Tc*	*Fg, As, Fa, Cc*	*Fg, As, Cc*	*As*
102	*Fg, As, Ba*	*Fg, As*	*Fg, As, Cc*	*Fg, As*
104	*Fg, As, Tc*	*Fg, As, Ar, Ap*	*Fg, As, Ar, Ap*	*Fg, As*
107	*Fg, As, Ar, Ba, Tc*	*Fg, As, Ar, Ap*	*Fg, As, Ar, Ap*	*Fg, As, Ar, Ba*
111	*Fg, Ar, Ba*	*Fg, As*	*Fg, As*	*Fg, As*
115	*Fg, As, Ar*	*Fg, As, Ar*	*Fg*	*Fg, As*
117	*Fg, As, Ba, Tc*	*Fg, As, Ar*	*Fg, As*	*Fg, As*
120	*Fg, As, Ba, Ps*	*Fg, As, Ps*	*Fg, As*	*As*
121	*Fg, As, Ar, Ps, Tc*	*Fg, As, Ps*	*Fg, As, Ar*	*Fg, As*
123	*Fg, As, Tc, Ab*	*Fg, Ar, Ap, Ab*	*Fg, Ar, Ap, Ab, Pst*	*Fg, Ar, Tc, Ab*
125	*Fg, As, Ar, Tc*	*Fg, Ar, Ap, Ab, Pst*	*Fg, Ar, Ap, Tc, Ab, Pst*	*Ar, Bp, Tc, Ab, Pst*
126	*Fg, As, Ar, Ba, Tc*	*Fg, As, Ar*	*Fg, Ar, Tc, Ab, Pst*	*Fg, Ar, Tc, Ab*
127	*Fg, As*	*Fg, As*	*Fg, As*	*Fg, As*
129	*Fg, As, Ar*	*Fg, As, Ar, Ap, Fa*	*Fg, As, Ar, Fa*	*Fg, As, Ab*
131	*Fg, As, Ba, Ps*	*Fg, As, Ar, Ps*	*Fg, As*	*Fg, As, Abr*
134	*Fg, As, Ar, Ba*	*Fg, As, Ar*	*Fg, As, Ar, Ps*	*Fg, As*
135	*Fg, As, Qr*	*Fg, As, Ar, Ap, Ab*	*Fg, As,Ap, Ab*	*Fg, As, Ab*
136	*Fg, As, Ba*	*Fg, Ar, Ab*	*Fg, Ap, Ab*	*Fg, As, Ba, Aa*
137	*Fg, As, Bp*	*Fg, As, Ar, Ap*	*Fg, As, Ap*	*Fg, As, Ap*
143	*Fg, As, Ba, Bp*	*Fg, As, Ap*	*Fg, As, Ap*	*Fg, As*
149	*Fg, Ar, Bp*	*Fg, Ar*	*Fg,Ab*	*Fg, As, Ar, Ap, Ab*

Appendix 2. cont'd.

ID	*Overstory*	*Seedling*	*Sapling*	*Recruit*
150	*Fg, As*	*Fg, As, Ar, Ap, Ps*	*Fg, As, Ap*	*Fg, As, Ar, Ap*
151	*Fg, As, Bp, Tc*	*Fg, As, Ar, Ap*	*Fg, As, Ap*	*Fg, As, Ar, Ap*
152	*Fg, As*	*Fg, As, Ap*	*Fg, As, Ap*	*Fg, As*
166	*Fg, As, Ps*	*Fg, As, Ar, Ps, Pst*	*Fg, As, Ar*	*Fg, As, Ab*
167	*Fg, As, Bp*	*Fg, As, Ar,*	*Fg, As*	*Fg, As*
170	*Fg, As, Ps*	*Fg, As, Ps*	*Fg, As, Aa*	*As*
171	*Fg, As, Bp, Tc*	*Fg, As, Ar*	*Fg, As,*	*Fg, As*
172	*Fg, As, Ar, Ps, Tc*	*Fg, As, Ar*	*Fg, As,Ar*	*Fg, As*
173	*Fg, As*	*Fg, As, Ar, Ap*	*Fg, As, Ap, Ab*	*Fg, As*
184	*As*	*As*	*Fg, As, Ab*	*As, Ab*
186	*Fg, As, Ar, Bp, Tc*	*Fg, As, Ar*	*Fg, As, Ar*	*Fg, As*
189	*Fg, As, Ba, Qr*	*Fg, As, Ar, Ap*	*Fg, As, Ba*	*As, Cc*
197	*Fg, As, Ar*	*Fg, As, Ar, Ap*	*Fg, As, Fa, Tc*	*As, Tc*
198	*Fg, As*	*Fg, As, Ap*	*Fg, As, Ap*	*Fg, As, Ap*

[a] Overstory = >24.5 cm dbh (diameter at 1.3m)

[b] Seedlings = < 30.5 cm height, saplings = > 30.5 cm height and < 2.5 cm dbh, recruits = > 2.5 cm dbh and < 12.5 cm dbh

[c] Species: *Fg (Fagus grandifolia), Ac (Acer saccharum), Ar (Acer rubrum), Ap (Acer pensylvanicum),Ba (Betula alleghaniensis), Bp (Betula papyrifera), Pg (Populus grandidentata), Ps (Prunus serotina), Fa (Fraxinus americana), Qr (Quercus rubra), Ta (Tilia americana), Cc (Carpinus caroliniana), Hv (Hamamelis virginiana), Tc (Tsuga canadensis), Ab (Abies balsamea), Pst (Pinus strobus).*

Appendix 3. Beech stocking, *Cryptococcus fagisuga*, tree dimensions, and management profiles of stands.

Stand ID	Beech Basal Area (m^2/ha)[a]	Percentage of Beech of Total Basal Area[a]	Presence of *C. fagisuga*	Mean DBH of Beech Sample Trees (cm)	Mean Height of Beech Sample Trees (m)	Year of Recent Management	Recent Management Activity
001	6.53	0.18	no	17.04	15.20	1981	selection cut (incl. 7 mbf beech)
002	21.09	0.52	no	32.47	15.13	1978	non-commercial thinnning (57 cords mixed)
005	5.75	0.21	no	32.74	16.15	n/a	
010	22.94	0.54	no	37.56	18.85		no prior cutting
016	0.82	0.28	no	31.80	15.78		no prior cutting
019	26.53	0.62	yes	31.35	16.85		no prior cutting
020	22.54	0.73	yes	24.12	14.85		no prior cutting
021	14.92	0.29	yes	21.37	12.63		no prior cutting
024	17.83	0.61	yes	40.72	14.28		no prior cutting
026	13.57	0.34	yes	32.21	15.83		no prior cutting
027	4.20	0.08	yes	29.27	14.08		no prior cutting
028	11.56	0.21	no	22.31	15.08		no prior cutting
030	7.65	0.31	yes	46.74	16.15	1985	thinning (oak, maple, beech)
034	2.60	0.06	no	33.36	18.00		no prior cutting
035	19.68	0.68	no	40.81	19.23		no prior cutting
036	10.46	0.26	no	33.16	15.43		no prior cutting
039	20.19	0.67	yes	32.51	18.43		no prior cutting
042	7.70	0.30	no	31.18	17.85		no prior cutting
047	5.36	0.18	yes	17.48	13.10		no prior cutting
058	2.69	0.08	no	30.18	16.65		no prior cutting
062	17.42	0.43	no	31.21	16.63		no prior cutting
067	1.93	0.06	no	27.17	14.38	1997	thinning (hardwood mixed pulp)
075	1.01	0.03	no	19.00	15.40	1976	selection cut, non-commercial thinning

Appendix 3. cont'd.

Stand ID	Beech Basal Area (m^2/ha)	Percentage of Beech of Total Basal Area	Presence of *C. fagisuga*	Mean DBH of Beech Sample Trees (cm)	Mean Height of Beech Sample Trees (m)	Year of Recent Management	Recent Management Activity
077	3.59	0.11	no	30.28	16.15		no prior cutting
080	16.85	0.48	no	34.88	17.33	1998	hardwood selection cut
083	11.21	0.30	no	27.85	15.15	n/a	
092	3.28	0.11	no	19.59	13.80		no prior cutting
095	0.00	0.00	no	40.13	18.90	n/a	
102	4.42	0.15	yes	24.82	16.63		no prior cutting
104	19.76	0.10	yes	32.64	17.70	2002-2003	selective harvest (beech and sugar maple)
107	4.70	0.02	yes	25.42	14.08	2003	selective harvest (all species >6 in dbh)
111	4.95	0.19	no	34.61	17.03	1990	improvement harvest (even-aged)
115	14.34	0.66	no	35.62	14.38	1994	improvement harvest (even-aged)
117	15.37	0.45	no	30.63	15.18	1996	selection harvest (uneven-aged)
120	25.98	0.68	no	37.19	17.28		no prior cutting
121	6.46	0.28	no	27.83	15.25	2000	mixed hardwood harvest
123	19.75	0.35	yes	29.76	15.38		no prior cutting
125	17.35	0.41	yes	39.04	15.55		no prior cutting
126	27.44	0.38	yes	41.55	17.75		no prior cutting
127	12.07	0.33	yes	45.11	16.60		no prior cutting
129	3.21	0.10	no	20.68	13.80	1982	thinning harvest (even-aged)
131	7.95	0.26	yes	21.42	15.78		no prior cutting
134	9.40	0.39	yes	30.09	13.25	1990	12 inch DBH harvest (hard maple and beech)
135	14.64	0.43	no	31.11	18.23		no prior cutting

Appendix 3. cont'd.

Stand ID	Beech Basal Area (m^2/ha)	Percentage of Beech of Total Basal Area	Presence of *C. fagisuga*	Mean DBH of Beech Sample Trees (cm)	Mean Height of Beech Sample Trees (m)	Year of Recent Management	Recent Management Activity
136	11.37	0.37	no	31.36	16.38	1980	improvement harvest (even-aged)
137	26.78	0.52	yes	37.75	18.20	1995	thinning (1.5 mbf maple, 0.3 beech)
143	14.64	0.45	no	26.23	15.83	1994	selection cut
149	14.83	0.45	yes	26.42	14.90		no prior cutting
150	12.98	0.45	yes	39.14	16.00	1978	
151	6.14	0.30	yes	29.54	14.65	1983	improvement harvest
152	24.57	0.75	yes	34.98	16.10	1985	1.2 mbf/ac maple, 1.75 mbf/ac beech
166	13.39	0.52	no	42.90	16.70	1998	selection harvest (uneven-aged)
167	23.59	0.72	no	31.26	16.78	1980	improvement harvest (even-aged)
170	17.19	0.46	no	35.14	16.85	1989	thinning harvest (even-aged)
171	2.78	0.09	no	34.26	15.80	1991	selection harvest (uneven-aged)
172	3.03	0.13	no	43.45	16.30	1994	thinning harvest (even-aged)
173	16.12	0.47	no	38.49	16.13		no prior cutting
184	2.10	0.07	no	31.39	14.40		no prior cutting
186	11.30	0.24	no	45.81	17.63		no prior cutting
189	10.11	0.34	no	34.16	14.68	n/a	
197	6.51	0.16	no	44.92	16.85		no prior cutting
198	11.75	0.40	no	33.33	16.75	1994	selection cut

[a] Basal area data collected by University of Michigan.

Appendix 4. Individual tree values of diameter at breast height (dbh)(1.3m), height, class, crown ratio, dieback, age, and growth increment ratios.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr increment ratio [d]	10-yr increment ratio [e]	15-yr increment ratio [f]
10	125	45.03	16.2	C	40	3	E	n/a	0.80	0.88	1.18
11	125	45.44	16.5	D	40	1	W	n/a	n/a	n/a	n/a
12	125	29.36	13.8	I	40	2	W	n/a	n/a	n/a	n/a
13	125	38.51	13.5	C	40	1	W	35	1.18	1.24	1.24
14	125	27.28	14.7	C	40	0	W	n/a	1.08	1.05	1.37
15	125	37.19	15.3	D	70	1	N	n/a	1.19	1.18	1.05
16	125	22.99	15.3	I	30	2	S	n/a	n/a	n/a	n/a
17	125	49.71	17.4	D	60	3	E	n/a	1.00	0.76	0.65
18	125	46.91	16.2	D	60	3	E	n/a	n/a	n/a	n/a
19	125	38.63	17.1	C	50	2	E	n/a	0.58	0.90	1.21
20	125	51.56	15.6	C	40	3	E	n/a	n/a	n/a	n/a
21	125	35.81	15	C	40	1	W	n/a	1.44	1.40	1.27
26	126	38.28	18.9	C	50	1	E	n/a	1.03	0.95	0.90
27	126	40.18	18.6	C	50	0	N	n/a	n/a	n/a	n/a
28	126	56.24	22.2	D	40	0	N	n/a	1.26	0.69	0.97
29	126	48.03	16.5	D	60	1	E	n/a	1.09	1.00	0.66
30	126	26.82	17.1	I	60	0	E	n/a	n/a	n/a	n/a
31	126	14.27	16.2	I	80	0	W	n/a	n/a	n/a	n/a
32	126	79.22	18.3	D	50	1	E	n/a	n/a	n/a	n/a
33	126	27.79	17.1	C	40	1	S	n/a	n/a	n/a	n/a
34	126	40.18	15.9	C	40	1	S	n/a	n/a	n/a	n/a
35	126	53.75	18.3	D	60	1	E	n/a	0.61	0.85	0.97
36	126	39.42	16.2	C	60	2	S	69	0.61	0.73	0.72
37	126	34.42	17.7	C	30	1	E	n/a	1.09	0.69	0.48
38	136	23.04	14.7	I	20	1	W	n/a	n/a	n/a	n/a
39	136	41.20	17.7	D	50	0	W	n/a	n/a	n/a	n/a
40	136	36.96	16.2	I	40	1	N	n/a	n/a	n/a	n/a
41	136	29.49	16.2	C	50	2	N	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
42	136	34.19	17.7	C	40	0	E	n/a	n/a	n/a	n/a
43	136	41.96	18.9	D	50	1	N	n/a	n/a	n/a	n/a
44	136	25.50	16.2	C	30	1	N	67	0.50	0.54	0.73
45	136	31.72	18	C	40	0	N	n/a	0.48	0.74	0.95
46	136	42.06	16.8	D	60	1	E	n/a	1.10	1.10	1.54
47	136	20.78	14.7	I	30	1	E	n/a	n/a	n/a	n/a
48	136	23.95	14.4	I	40	1	N	n/a	n/a	n/a	n/a
49	136	25.45	15	C	60	1	N	n/a	n/a	n/a	n/a
50	135	32.23	18	C	40	1	E	n/a	n/a	n/a	n/a
51	135	30.18	16.8	I	30	1	E	n/a	n/a	n/a	n/a
52	135	30.96	18.9	I	50	0	E	n/a	n/a	n/a	n/a
53	135	19.23	16.2	I	20	0	N	n/a	n/a	n/a	n/a
54	135	35.76	17.4	C	40	1	W	n/a	0.86	1.32	1.10
55	135	38.56	17.4	C	40	1	W	n/a	n/a	n/a	n/a
56	135	36.22	19.2	C	30	1	W	55	1.03	1.56	1.34
57	135	42.85	20.4	C	30	1	W	n/a	n/a	n/a	n/a
58	135	34.39	19.2	C	40	1	W	95	1.58	1.86	0.98
59	135	31.14	18.9	C	30	1	E	65	1.13	1.09	1.51
60	135	22.81	18	I	30	0	S	n/a	n/a	n/a	n/a
61	135	18.97	18.3	I	20	0	W	n/a	n/a	n/a	n/a
62	102	22.63	17.4	C	20	0	E	n/a	1.11	1.25	1.36
63	102	27.15	17.1	C	40	2	E	n/a	1.37	1.17	1.19
64	102	17.83	16.2	I	80	0	W	n/a	n/a	n/a	n/a
65	102	30.02	17.4	C	40	0	W	n/a	n/a	n/a	n/a
66	102	28.12	18	C	20	1	W	74	0.97	0.81	0.66
67	102	25.43	17.4	D	10	1	W	n/a	n/a	n/a	n/a
68	102	22.33	16.2	C	60	1	E	70	2.49	2.64	1.99
69	102	24.26	15	C	40	2	N	n/a	n/a	n/a	n/a
70	102	15.70	14.4	I	90	0	S	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
71	102	35.31	17.1	C	70	1	S	n/a	0.79	1.34	1.54
72	102	24.64	16.2	C	30	2	W	n/a	n/a	n/a	n/a
73	102	24.49	17.1	C	50	1	N	n/a	1.07	1.12	1.21
74	111	51.56	17.4	D	80	0	N	n/a	n/a	n/a	n/a
75	111	20.50	18.6	C	40	0	SW	n/a	1.25	1.44	1.06
76	111	27.94	17.7	C	30	1	E	66	0.70	0.88	0.72
77	111	38.15	17.4	C	40	1	S	n/a	1.14	1.23	1.08
78	111	43.10	16.5	C	50	1	N	n/a	0.80	1.17	2.17
79	111	52.22	16.2	D	50	1	E	n/a	n/a	n/a	n/a
80	111	26.90	15.3	C	70	1	N	n/a	1.41	1.06	1.15
81	111	31.19	14.4	C	60	1	S	n/a	0.89	1.20	1.39
82	111	27.05	17.4	C	30	1	N	n/a	1.28	0.81	0.87
83	111	25.40	17.1	C	40	0	E	n/a	n/a	n/a	n/a
84	111	38.94	18.3	D	40	0	E	n/a	1.15	1.38	1.48
85	111	32.39	18	C	30	0	S	n/a	0.75	0.93	0.95
86	104	40.41	17.7	D	50	1	S	n/a	n/a	n/a	n/a
87	104	34.67	15.6	C	70	1	E	n/a	0.47	0.62	1.19
88	104	32.00	18.6	C	50	1	N	103	0.90	0.98	0.87
89	104	21.01	19.5	I	70	1	S	n/a	n/a	n/a	n/a
90	104	21.46	17.7	I	40	1	S	n/a	n/a	n/a	n/a
91	104	24.33	18	C	40	1	E	n/a	n/a	n/a	n/a
92	104	24.94	16.2	I	20	3	E	n/a	n/a	n/a	n/a
93	104	54.79	17.1	C	40	1	E	n/a	1.40	1.28	0.86
94	104	18.26	16.5	I	60	0	W	n/a	n/a	n/a	n/a
95	104	57.73	19.5	D	50	2	N	n/a	0.85	1.04	0.87
96	104	29.44	18.3	C	40	0	W	n/a	n/a	n/a	n/a
97	104	39.47	19.2	C	0	3	NW	142	0.88	0.88	0.90
101	019	47.93	16.2	D	50	1	E	n/a	n/a	n/a	n/a
102	019	39.40	20.1	C	60	2	S	109	1.28	0.95	0.72

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
103	019	22.02	15.6	I	40	3	N	n/a	n/a	n/a	n/a
104	019	45.01	22.5	D	40	2	E	135	1.10	1.15	1.12
105	019	20.35	13.5	I	40	2	N	n/a	n/a	n/a	n/a
106	019	38.76	15	C	30	1	W	n/a	1.51	1.19	1.02
107	019	0.00	20.1	D	30	2	S	n/a	n/a	n/a	n/a
108	019	26.80	13.8	C	40	2	W	n/a	1.36	0.86	0.74
109	019	35.66	17.4	C	40	1	E	n/a	1.15	1.29	1.22
110	019	21.69	14.7	I	20	3	S	n/a	n/a	n/a	n/a
111	019	15.88	14.7	I	10	1	S	n/a	n/a	n/a	n/a
112	019	0.00	18.6	C	30	1	S	n/a	0.76	0.76	1.24
115	020	30.12	14.4	I	10	1	SE	n/a	n/a	n/a	n/a
116	020	16.74	13.5	I	50	1	SW	n/a	n/a	n/a	n/a
117	020	24.74	15	I	10	2	W	n/a	n/a	n/a	n/a
118	020	12.73	11.1	S	30	2	W	118	n/a	n/a	n/a
119	020	21.18	15.6	I	30	0	S	n/a	n/a	n/a	n/a
120	020	15.04	14.1	I	40	2	W	n/a	n/a	n/a	n/a
121	020	38.05	17.7	C	20	1	E	n/a	0.89	1.12	1.21
122	020	14.20	14.1	I	10	2	N	n/a	n/a	n/a	n/a
123	020	34.16	15.6	C	50	1	S	n/a	1.99	0.91	1.47
124	020	42.49	17.7	C	30	2	E	n/a	0.93	1.07	1.04
125	020	15.82	11.7	I	20	2	E	n/a	n/a	n/a	n/a
126	020	0.00	17.7	C	30	2	S	n/a	1.00	1.52	1.06
129	021	52.27	17.4	D	40	3	n/a	n/a	n/a	n/a	n/a
130	021	19.79	15.3	I	30	3	N	n/a	n/a	n/a	n/a
131	021	15.27	13.2	S	40	2	W	n/a	n/a	n/a	n/a
132	021	19.23	11.4	I	20	3	E	n/a	n/a	n/a	n/a
133	021	7.57	7.5	S	50	0	E	n/a	n/a	n/a	n/a
134	021	22.45	16.8	I	40	3	E	n/a	n/a	n/a	n/a
135	021	9.88	9	S	60	2	E	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
136	021	20.27	13.5	C	40	2	E	85	1.05	1.47	1.16
137	021	9.47	9.3	S	30	3	E	n/a	n/a	n/a	n/a
138	021	56.01	18	D	60	2	W	n/a	1.23	1.51	1.83
139	021	10.46	6.3	S	40	2	W	n/a	n/a	n/a	n/a
140	021	13.79	13.8	I	60	1	W	n/a	n/a	n/a	n/a
143	027	18.92	13.2	I	70	1	N	n/a	n/a	n/a	n/a
144	027	21.92	6.6	S	10	1	N	n/a	n/a	n/a	n/a
145	027	25.20	16.5	C	40	1	E	n/a	1.63	1.09	1.17
146	027	14.10	12.9	I	70	1	S	n/a	n/a	n/a	n/a
147	027	39.32	15.9	D	70	1	S	77	1.08	1.32	1.34
148	027	16.10	12.9	I	70	0	S	n/a	n/a	n/a	n/a
149	027	34.42	15	C	30	1	N	n/a	0.64	1.44	1.61
150	027	48.06	16.8	D	40	1	N	n/a	1.49	1.16	1.08
151	027	41.71	16.5	D	60	0	S	n/a	0.92	1.32	1.13
152	027	24.54	13.2	I	60	2	S	n/a	n/a	n/a	n/a
153	027	36.40	15.9	C	60	1	S	n/a	n/a	n/a	n/a
154	027	30.58	13.5	C	50	1	E	n/a	n/a	n/a	n/a
157	024	63.02	16.5	D	60	1	N	n/a	0.89	1.62	1.62
158	024	61.42	17.7	D	50	1	N	n/a	0.96	1.29	1.65
159	024	17.88	13.2	I	30	2	N	n/a	n/a	n/a	n/a
160	024	20.22	12.9	I	50	1	S	n/a	n/a	n/a	n/a
161	024	66.37	18	D	80	1	N	n/a	n/a	n/a	n/a
162	024	91.95	16.8	D	70	1	S	n/a	1.23	1.06	0.91
163	024	79.98	18.3	D	70	1	S	n/a	n/a	n/a	n/a
164	024	17.30	15.9	I	10	1	N	n/a	n/a	n/a	n/a
165	024	8.18	9.3	S	30	1	W	n/a	n/a	n/a	n/a
166	024	34.85	7.2	S	10	1	W	103	1.40	1.45	1.28
167	024	16.61	14.7	I	40	1	S	n/a	n/a	n/a	n/a
168	024	10.90	10.8	I	30	1	S	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
171	026	35.23	18.6	C	40	3	S	n/a	1.31	0.75	1.08
172	026	55.70	18	C	50	1	N	n/a	1.50	1.64	1.75
173	026	20.83	15	I	80	2	D	n/a	n/a	n/a	n/a
174	026	32.00	18.6	C	40	2	N	n/a	n/a	n/a	n/a
175	026	7.44	8.1	S	70	1	N	n/a	n/a	n/a	n/a
176	026	34.80	18	C	30	2	N	n/a	1.18	1.11	1.39
177	026	50.44	18.3	C	50	2	S	n/a	0.78	1.59	1.55
178	026	5.87	6.9	S	60	1	N	n/a	n/a	n/a	n/a
179	026	34.49	15.9	C	60	1	N	n/a	1.17	1.25	1.34
180	026	43.94	19.8	C	40	1	N	n/a	0.82	0.80	0.92
181	026	46.71	18.6	C	40	2	NW	n/a	1.15	0.74	1.09
182	026	19.02	14.1	I	10	3	S	n/a	n/a	n/a	n/a
185	123	12.17	14.1	S	40	0	E	n/a	n/a	n/a	n/a
186	123	40.44	14.4	D	50	1	N	n/a	n/a	n/a	n/a
187	123	18.75	15	I	30	1	N	n/a	n/a	n/a	n/a
188	123	45.64	17.1	C	50	2	E	n/a	1.28	1.31	1.19
189	123	13.77	12	S	70	1	N	n/a	n/a	n/a	n/a
190	123	43.89	15.9	C	50	1	E	n/a	1.36	0.65	0.71
191	123	40.54	13.5	C	50	2	E	128	0.98	0.78	0.90
192	123	11.86	15.3	I	40	0	E	n/a	n/a	n/a	n/a
193	123	27.28	16.5	C	70	1	N	n/a	n/a	n/a	n/a
194	123	31.06	17.4	C	40	2	W	n/a	n/a	n/a	n/a
195	123	38.61	17.4	C	60	2	S	n/a	1.00	0.90	0.87
196	123	33.07	15.9	C	50	1	W	n/a	0.70	0.72	0.87
201	107	19.10	13.2	I	50	0	S	n/a	n/a	n/a	n/a
202	107	17.70	14.4	I	50	0	W	n/a	n/a	n/a	n/a
203	107	20.68	14.4	I	40	0	S	n/a	n/a	n/a	n/a
204	107	38.63	14.1	C	50	2	S	n/a	1.20	1.09	0.79
205	107	14.33	12.6	I	10	0	W	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
206	107	21.92	13.8	C	80	0	N	n/a	n/a	n/a	n/a
207	107	16.38	13.8	I	70	0	N	n/a	n/a	n/a	n/a
208	107	28.70	13.2	C	50	1	N	54	0.86	1.30	1.04
209	107	32.00	15	C	50	2	E	n/a	n/a	n/a	n/a
210	107	31.24	15.6	C	40	3	N	n/a	1.05	0.79	0.99
211	107	29.26	13.5	C	60	2	E	n/a	n/a	n/a	n/a
212	107	35.13	15.3	C	60	2	S	n/a	0.97	1.65	1.46
223	010	27.38	17.7	C	20	0	N	n/a	n/a	n/a	n/a
224	010	42.52	18.9	C	60	0	S	n/a	n/a	n/a	n/a
225	010	26.44	18.9	C	20	0	E	n/a	n/a	n/a	n/a
226	010	63.88	19.2	C	60	0	E	n/a	1.02	1.18	1.42
227	010	36.12	18.3	C	40	1	S	n/a	n/a	n/a	n/a
228	010	35.66	19.8	C	30	0	N	n/a	1.65	1.16	1.06
229	010	27.64	18.3	C	50	0	S	66	1.56	1.16	1.18
230	010	26.37	18.9	C	30	0	S	n/a	n/a	n/a	n/a
231	010	45.77	18.9	D	20	1	E	83	0.82	1.04	1.41
232	010	34.34	18.9	C	30	1	N	n/a	0.95	1.49	1.47
233	010	28.80	18.6	C	30	0	E	n/a	0.89	1.55	1.93
234	010	55.83	19.8	C	30	1	S	n/a	n/a	n/a	n/a
237	039	19.81	15.6	I	70	0	E	n/a	n/a	n/a	n/a
238	039	32.87	20.4	C	40	1	S	n/a	1.43	0.88	0.78
239	039	38.68	18.3	C	50	0	N	79	2.25	2.01	1.72
240	039	35.36	18.3	C	80	0	S	n/a	0.62	1.47	2.02
241	039	39.70	17.1	C	50	2	W	82	1.41	0.33	0.36
242	039	38.53	19.8	C	50	1	N	91	1.20	1.01	1.15
243	039	20.07	16.8	I	50	1	W	n/a	n/a	n/a	n/a
244	039	38.89	19.5	C	40	0	N	n/a	0.85	1.00	0.95
245	039	46.63	20.1	D	70	1	E	n/a	1.12	1.11	1.07
246	039	25.55	16.8	C	40	0	N	79	1.28	0.92	0.89

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
247	039	32.74	18	C	40	1	E	71	0.90	1.30	1.49
248	039	21.29	20.4	I	70	0	S	n/a	n/a	n/a	n/a
251	042	28.24	18.9	C	40	0	S	93	0.72	0.63	0.64
252	042	28.58	15.9	I	70	0	W	n/a	n/a	n/a	n/a
253	042	22.53	15.3	I	70	0	W	n/a	n/a	n/a	n/a
254	042	42.88	20.4	D	40	1	S	n/a	n/a	n/a	n/a
255	042	28.93	19.2	C	50	1	W	n/a	1.35	1.31	1.13
256	042	56.69	18.6	D	50	0	N	n/a	1.42	0.71	0.94
257	042	28.98	18.6	C	70	0	W	n/a	n/a	n/a	n/a
258	042	24.18	16.5	C	60	0	N	n/a	1.16	0.60	0.70
259	042	25.63	18	C	50	2	E	n/a	n/a	n/a	n/a
260	042	26.44	18.3	C	70	0	N	n/a	1.44	1.38	1.28
261	042	25.63	15.9	C	30	0	E	n/a	n/a	n/a	n/a
262	042	35.46	18.6	D	70	0	S	n/a	n/a	n/a	n/a
265	034	41.25	21.6	C	30	0	W	n/a	n/a	n/a	n/a
266	034	29.92	19.5	C	40	0	W	n/a	1.60	1.11	1.38
267	034	24.49	12.3	S	50	1	N	n/a	n/a	n/a	n/a
268	034	38.76	18.9	C	50	1	E	n/a	n/a	n/a	n/a
269	034	41.63	20.1	C	40	0	S	n/a	n/a	n/a	n/a
270	034	46.00	19.5	C	40	0	N	n/a	n/a	n/a	n/a
271	034	35.23	19.5	C	60	0	E	n/a	1.37	0.86	0.74
272	034	32.36	18.6	C	40	1	N	n/a	1.25	0.66	0.94
273	034	27.28	18.6	C	70	1	N	n/a	n/a	n/a	n/a
274	034	44.93	19.2	D	60	1	N	n/a	0.46	1.02	0.84
275	034	14.76	13.5	I	10	0	N	n/a	n/a	n/a	n/a
276	034	23.72	14.7	I	40	0	N	n/a	n/a	n/a	n/a
277	035	32.64	20.1	C	40	0	S	n/a	n/a	n/a	n/a
278	035	38.46	18.6	C	70	0	S	n/a	1.23	1.25	1.39
279	035	37.19	19.5	C	30	0	E	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
280	035	36.04	19.8	C	20	1	E	n/a	1.16	1.10	1.15
281	035	30.58	17.4	I	50	0	E	n/a	n/a	n/a	n/a
282	035	45.52	20.4	C	40	0	E	n/a	0.93	1.26	1.51
285	035	46.33	19.8	C	50	0	E	n/a	0.74	1.04	1.06
286	035	33.71	18.3	C	30	1	E	n/a	n/a	n/a	n/a
287	035	48.90	17.7	C	40	0	W	n/a	n/a	n/a	n/a
288	035	52.81	18.9	C	50	1	E	n/a	n/a	n/a	n/a
289	036	23.85	14.4	I	50	0	E	n/a	n/a	n/a	n/a
290	036	13.34	12	S	30	0	E	n/a	n/a	n/a	n/a
291	036	39.32	16.5	D	50	0	N	121	1.08	0.88	0.80
292	036	57.10	18.9	C	50	0	S	n/a	0.72	1.23	1.17
293	036	26.39	16.8	C	40	0	N	118	1.52	1.01	0.61
294	036	36.30	15.6	C	70	1	E	n/a	n/a	n/a	n/a
295	036	40.39	16.8	C	60	0	S	n/a	n/a	n/a	n/a
296	036	19.79	15.6	I	70	0	S	n/a	n/a	n/a	n/a
297	036	34.80	15.6	C	60	0	E	n/a	1.66	0.80	0.95
298	036	29.51	15.6	C	70	0	N	n/a	1.77	1.52	1.50
299	036	41.45	17.1	C	60	0	S	n/a	0.79	1.09	1.26
300	036	35.71	10.2	I	70	0	W	n/a	n/a	n/a	n/a
301	152	27.25	16.8	I	30	1	E	n/a	n/a	n/a	n/a
302	152	38.53	15.3	C	50	1	N	n/a	n/a	n/a	n/a
303	152	49.35	17.7	D	50	1	W	n/a	1.18	1.83	2.06
304	152	26.37	16.5	I	40	1	S	n/a	n/a	n/a	n/a
305	152	43.48	16.8	D	60	1	W	n/a	n/a	n/a	n/a
306	152	46.08	17.1	D	60	1	E	n/a	0.86	1.34	1.26
307	152	26.54	16.5	I	40	0	N	n/a	n/a	n/a	n/a
308	152	47.24	16.5	D	50	1	S	n/a	n/a	n/a	n/a
309	152	36.25	15.3	C	40	1	N	123	1.19	1.25	1.21
310	152	24.56	14.1	I	30	1	N	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
311	152	27.23	15.6	C	30	1	S	61	0.84	1.13	1.21
312	152	26.87	15	I	40	1	N	n/a	n/a	n/a	n/a
315	005	38.18	18.3	C	30	1	N	n/a	n/a	n/a	n/a
316	005	12.55	12.6	I	50	0	S	n/a	n/a	n/a	n/a
317	005	24.94	15.3	I	50	0	W	n/a	n/a	n/a	n/a
318	005	24.97	16.5	C	40	1	E	n/a	n/a	n/a	n/a
319	005	32.33	17.1	C	50	1	E	n/a	n/a	n/a	n/a
320	005	35.71	17.1	D	40	1	E	n/a	n/a	n/a	n/a
321	005	54.05	16.2	D	60	1	N	n/a	n/a	n/a	n/a
322	005	55.35	17.7	D	60	0	S	n/a	0.83	0.87	0.94
323	005	14.81	12.6	I	40	0	S	n/a	n/a	n/a	n/a
324	005	50.24	18.3	D	60	1	S	n/a	n/a	n/a	n/a
325	005	13.82	13.2	I	50	0	S	n/a	n/a	n/a	n/a
326	005	35.92	18.9	D	40	1	S	65	1.57	0.56	0.50
327	028	13.28	8.4	I	80	0	N	n/a	n/a	n/a	n/a
328	028	13.67	13.8	I	30	0	W	n/a	n/a	n/a	n/a
329	028	26.19	17.4	C	40	1	S	n/a	n/a	n/a	n/a
330	028	27.15	17.1	C	30	1	S	n/a	n/a	n/a	n/a
331	028	22.23	15.6	I	50	0	W	n/a	n/a	n/a	n/a
332	028	29.77	17.1	C	40	1	W	n/a	n/a	n/a	n/a
333	028	8.81	9.3	S	80	0	W	n/a	n/a	n/a	n/a
334	028	35.15	17.4	C	50	1	N	n/a	n/a	n/a	n/a
335	028	30.94	17.7	C	50	1	S	n/a	n/a	n/a	n/a
336	028	26.77	17.1	C	40	1	E	n/a	n/a	n/a	n/a
337	028	19.20	15	I	80	0	E	n/a	n/a	n/a	n/a
338	028	14.53	15	I	30	1	S	n/a	n/a	n/a	n/a
339	030	63.60	19.2	C	70	1	W	n/a	n/a	n/a	n/a
340	030	45.11	11.7	I	80	1	W	n/a	n/a	n/a	n/a
341	030	51.16	18	C	40	1	N	n/a	0.57	1.01	1.41

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
342	030	73.79	18.6	D	60	0	S	n/a	n/a	n/a	n/a
343	030	61.04	19.2	D	50	0	S	n/a	0.75	0.72	0.60
344	030	60.93	18.9	C	30	1	S	n/a	1.18	1.28	1.39
345	030	19.58	15	I	80	0	W	n/a	n/a	n/a	n/a
346	030	18.03	13.5	I	50	0	N	n/a	n/a	n/a	n/a
347	030	16.18	12.9	I	80	0	S	n/a	n/a	n/a	n/a
348	030	54.66	18	C	70	0	W	n/a	n/a	n/a	n/a
349	030	88.47	17.7	D	60	0	E	n/a	2.97	1.22	0.99
350	030	8.33	11.1	S	70	0	S	n/a	n/a	n/a	n/a
351	058	35.38	17.7	C	40	0	W	n/a	0.79	0.93	1.00
352	058	15.82	13.2	I	80	0	S	n/a	n/a	n/a	n/a
353	058	35.28	17.7	C	60	0	N	56	0.89	0.98	1.42
354	058	24.87	15.6	I	30	0	E	n/a	n/a	n/a	n/a
355	058	15.16	14.1	I	50	0	E	n/a	n/a	n/a	n/a
356	058	23.98	15	I	60	0	S	n/a	n/a	n/a	n/a
357	058	35.38	16.8	C	40	1	S	n/a	0.90	0.99	1.17
358	058	30.53	18	C	50	1	S	n/a	1.07	1.37	1.23
359	058	36.27	18	C	40	1	S	64	0.81	0.98	0.78
360	058	43.99	18.3	D	50	1	W	71	1.15	0.56	0.82
361	058	28.17	17.4	C	30	1	S	70	0.88	1.10	0.93
362	058	37.29	18	C	50	0	N	n/a	n/a	n/a	n/a
363	137	13.87	17.4	I	70	0	E	n/a	n/a	n/a	n/a
364	137	58.62	19.5	D	50	1	N	n/a	0.96	1.09	1.74
365	137	44.45	18.3	C	40	0	W	n/a	n/a	n/a	n/a
366	137	45.47	17.1	C	50	1	S	n/a	n/a	n/a	n/a
367	137	28.75	18.6	C	30	1	W	n/a	1.01	1.08	1.29
368	137	51.89	20.1	D	40	1	N	n/a	1.08	0.84	0.91
369	137	31.37	18.6	C	30	1	S	87	1.22	1.25	1.00
370	137	44.70	18.9	D	40	2	S	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
371	137	43.51	18	C	40	1	E	n/a	1.27	1.07	0.85
372	137	21.23	16.5	I	60	0	E	n/a	n/a	n/a	n/a
373	137	32.82	17.7	C	40	1	E	n/a	n/a	n/a	n/a
374	137	36.37	17.7	C	50	0	W	n/a	n/a	n/a	n/a
377	001	18.08	17.7	I	30	0	S	n/a	n/a	n/a	n/a
378	001	13.56	9.9	S	70	0	N	n/a	n/a	n/a	n/a
379	001	16.56	15	I	40	0	W	n/a	n/a	n/a	n/a
380	001	11.43	12.3	S	50	0	N	n/a	n/a	n/a	n/a
381	001	9.86	10.8	S	80	0	W	n/a	n/a	n/a	n/a
382	001	26.06	19.2	C	40	2	E	n/a	n/a	n/a	n/a
383	001	14.99	17.7	I	80	0	E	n/a	n/a	n/a	n/a
384	001	13.54	11.4	S	40	0	S	n/a	n/a	n/a	n/a
385	001	24.97	20.4	C	30	1	W	n/a	n/a	n/a	n/a
386	001	16.33	15	I	80	0	S	n/a	n/a	n/a	n/a
387	001	27.41	20.7	C	60	0	S	n/a	n/a	n/a	n/a
388	001	11.68	12.3	S	40	0	S	n/a	n/a	n/a	n/a
389	002	7.98	8.1	S	60	0	E	n/a	n/a	n/a	n/a
390	002	7.29	9.6	S	20	0	S	n/a	n/a	n/a	n/a
391	002	35.86	15.6	C	50	1	E	n/a	n/a	n/a	n/a
392	002	22.56	16.8	I	50	0	S	n/a	n/a	n/a	n/a
393	002	64.19	20.7	D	40	0	E	n/a	n/a	n/a	n/a
394	002	6.81	7.5	S	10	0	N	n/a	n/a	n/a	n/a
395	002	60.33	18.9	D	50	0	W	n/a	n/a	n/a	n/a
396	002	17.60	13.2	I	60	0	S	n/a	n/a	n/a	n/a
397	002	33.07	17.7	C	30	0	W	n/a	n/a	n/a	n/a
398	002	16.76	15	I	30	0	S	n/a	n/a	n/a	n/a
399	002	61.67	19.8	C	40	1	W	n/a	0.81	1.31	1.11
400	002	55.55	18.6	C	40	1	W	n/a	0.57	0.72	1.09
401	047	11.76	13.8	I	50	L	S	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
402	047	13.31	12.6	I	30	O	W	n/a	n/a	n/a	n/a
403	047	16.87	14.1	I	80	L	S	n/a	n/a	n/a	n/a
404	047	17.83	14.7	I	60	O	W	n/a	n/a	n/a	n/a
405	047	9.02	9.9	S	40	L	W	n/a	n/a	n/a	n/a
406	047	26.26	14.4	I	80	O	S	n/a	n/a	n/a	n/a
407	047	7.24	7.2	S	80	O	S	n/a	n/a	n/a	n/a
408	047	17.22	13.5	I	60	O	S	n/a	n/a	n/a	n/a
409	047	16.81	13.8	I	80	O	W	n/a	n/a	n/a	n/a
410	047	17.40	11.7	I	80	O	W	n/a	n/a	n/a	n/a
411	047	35.92	18	C	40	L	W	n/a	n/a	n/a	n/a
412	047	20.14	13.5	I	40	L	S	n/a	n/a	n/a	n/a
415	117	31.93	18	C	30	1	N	n/a	0.42	0.49	0.82
416	117	19.56	12.3	I	70	0	S	n/a	n/a	n/a	n/a
417	117	33.63	18.3	C	40	0	E	n/a	n/a	n/a	n/a
418	117	34.90	18	C	60	0	S	n/a	1.15	0.96	1.60
419	117	51.79	16.8	C	50	1	E	n/a	n/a	n/a	n/a
420	117	39.24	16.8	C	30	1	E	n/a	n/a	n/a	n/a
421	117	10.52	14.7	I	20	0	N	n/a	n/a	n/a	n/a
422	117	6.22	6.6	S	80	0	N	n/a	n/a	n/a	n/a
423	117	36.65	18	C	40	1	E	n/a	n/a	n/a	n/a
424	117	47.32	16.2	D	60	0	N	n/a	1.13	1.07	1.01
425	117	45.06	18	D	40	1	N	n/a	0.53	0.53	0.81
426	117	10.72	8.4	S	40	0	S	n/a	n/a	n/a	n/a
429	171	48.64	18	D	50	1	W	n/a	1.04	1.01	1.39
430	171	46.30	17.7	D	50	1	N	n/a	1.33	1.49	1.97
431	171	33.71	16.8	C	40	0	W	n/a	1.32	1.12	1.34
432	171	25.98	17.1	I	50	0	W	n/a	n/a	n/a	n/a
433	171	37.52	17.1	D	40	1	S	n/a	n/a	n/a	n/a
434	171	6.63	5.1	S	10	0	E	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
435	171	32.69	17.1	C	40	0	W	n/a	1.76	1.93	1.79
436	171	45.95	17.4	C	40	1	W	n/a	n/a	n/a	n/a
437	171	38.53	18.9	C	40	1	E	n/a	1.97	1.89	2.17
438	171	17.81	12.6	S	70	0	N	n/a	n/a	n/a	n/a
439	171	15.19	12.6	I	80	0	W	n/a	n/a	n/a	n/a
440	171	62.20	19.2	D	60	1	W	n/a	n/a	n/a	n/a
455	120	21.69	16.5	I	30	0	E	n/a	n/a	n/a	n/a
456	120	41.63	17.7	D	40	1	N	70	1.20	2.58	1.03
457	120	29.54	16.5	C	20	1	S	n/a	n/a	n/a	n/a
458	120	43.28	17.4	C	40	1	S	n/a	n/a	n/a	n/a
459	120	30.71	17.1	C	40	1	W	n/a	0.75	1.62	1.94
460	120	31.90	16.5	C	30	1	N	n/a	1.27	1.45	1.68
461	120	44.96	18.3	D	50	1	W	n/a	0.88	1.13	1.19
462	120	36.88	17.1	C	30	1	W	n/a	n/a	n/a	n/a
463	120	37.64	17.1	C	40	1	S	n/a	n/a	n/a	n/a
464	120	41.76	17.1	C	30	1	N	88	0.82	0.58	0.55
465	120	46.61	18.9	D	50	1	N	n/a	1.08	2.27	1.07
466	120	39.65	17.1	C	30	1	S	88	1.90	2.31	1.41
469	166	33.22	15	I	50	1	E	n/a	n/a	n/a	n/a
470	166	46.33	15	C	70	1	W	n/a	n/a	n/a	n/a
471	166	46.96	17.1	D	50	1	W	n/a	n/a	n/a	n/a
472	166	10.36	9.6	S	50	0	S	n/a	n/a	n/a	n/a
473	166	57.00	19.8	D	50	1	E	n/a	1.23	1.30	1.97
474	166	24.71	16.2	C	40	0	N	103	0.82	0.64	1.19
475	166	51.51	18.6	C	50	1	E	n/a	n/a	n/a	n/a
476	166	52.53	20.7	D	70	1	E	104	1.35	1.35	1.18
477	166	48.21	16.5	D	30	2	S	n/a	0.93	1.40	0.92
478	166	34.16	16.5	C	50	0	N	n/a	1.00	0.94	0.79
479	166	54.99	18.6	D	50	1	E	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
480	166	54.84	16.8	D	40	2	W	n/a	n/a	n/a	n/a
483	167	40.51	20.1	D	60	1	E	n/a	0.73	1.11	1.29
484	167	26.92	18.6	I	30	1	S	n/a	n/a	n/a	n/a
485	167	31.52	16.2	D	50	1	N	n/a	n/a	n/a	n/a
486	167	39.70	16.8	C	70	0	W	n/a	n/a	n/a	n/a
487	167	27.99	15.6	I	30	0	W	n/a	n/a	n/a	n/a
488	167	28.65	16.8	I	30	1	N	n/a	n/a	n/a	n/a
489	167	25.04	15.6	I	70	0	S	n/a	n/a	n/a	n/a
490	167	35.97	17.1	C	60	0	N	n/a	0.97	0.93	0.76
491	167	39.01	16.2	C	40	0	W	n/a	n/a	n/a	n/a
492	167	29.90	15.6	C	40	1	S	n/a	n/a	n/a	n/a
493	167	22.61	14.7	I	50	0	I	n/a	n/a	n/a	n/a
494	167	27.33	18	C	40	0	C	n/a	1.46	1.50	1.04
501	016	37.39	17.7	D	40	1	S	n/a	n/a	n/a	n/a
502	016	18.75	12.9	I	50	0	W	n/a	n/a	n/a	n/a
503	016	73.36	20.4	D	80	1	W	n/a	0.63	1.50	0.89
504	016	10.85	14.4	S	70	1	S	n/a	n/a	n/a	n/a
505	016	16.10	12.9	I	30	1	N	n/a	n/a	n/a	n/a
506	016	11.38	12	S	40	1	N	n/a	n/a	n/a	n/a
507	016	36.80	16.8	D	50	0	W	79	1.38	1.48	1.16
508	016	50.50	17.4	D	60	1	N	n/a	1.20	0.94	1.03
509	016	62.23	19.5	D	40	1	E	n/a	0.96	0.73	0.99
510	016	18.72	15	I	60	2	N	n/a	n/a	n/a	n/a
511	016	9.35	13.2	I	40	0	S	n/a	n/a	n/a	n/a
512	016	36.17	17.1	D	40	0	S	n/a	0.74	0.77	0.84
519	067	38.28	18.6	D	60	0	N	75	1.00	1.27	1.50
520	067	6.45	6.3	S	20	1	N	n/a	n/a	n/a	n/a
521	067	57.38	19.5	D	40	1	W	n/a	1.32	0.69	0.65
522	067	20.17	17.7	I	60	0	N	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
523	067	5.61	6.6	S	80	0	N	n/a	n/a	n/a	n/a
524	067	56.13	18.6	D	50	1	N	n/a	n/a	n/a	n/a
525	067	51.49	19.5	D	60	0	W	n/a	1.08	1.23	1.45
526	067	20.50	17.7	I	30	1	N	n/a	n/a	n/a	n/a
527	067	31.22	19.8	C	30	0	W	71	1.61	1.62	1.53
528	067	6.25	6	S	10	0	N	n/a	n/a	n/a	n/a
529	067	4.62	4.8	S	30	0	W	n/a	n/a	n/a	n/a
530	067	27.99	17.4	C	60	1	W	85	0.58	0.93	1.14
531	173	30.07	19.2	C	30	0	E	99	1.18	0.74	0.56
532	173	63.73	19.5	D	50	1	W	n/a	n/a	n/a	n/a
533	173	40.49	17.7	D	40	1	S	n/a	n/a	n/a	n/a
534	173	29.31	14.7	I	20	0	E	n/a	n/a	n/a	n/a
535	173	58.27	16.5	D	40	0	E	n/a	n/a	n/a	n/a
536	173	24.92	12.3	I	30	1	N	n/a	n/a	n/a	n/a
537	173	45.52	16.2	C	30	1	W	n/a	n/a	n/a	n/a
538	173	39.09	15.6	C	50	1	W	132	1.22	1.70	1.35
539	173	40.31	13.5	I	60	1	W	n/a	n/a	n/a	n/a
540	173	19.96	15.6	I	40	1	W	n/a	n/a	n/a	n/a
541	173	32.13	16.2	C	50	1	W	101	1.05	0.81	0.74
542	173	38.02	16.5	C	40	1	S	n/a	1.14	1.45	1.19
549	080	26.39	15.9	I	40	0	E	n/a	n/a	n/a	n/a
550	080	38.30	17.7	D	40	1	S	113	1.48	1.43	1.09
551	080	42.67	17.4	D	50	1	W	n/a	1.37	1.49	1.18
552	080	35.84	19.5	D	30	1	E	n/a	1.07	0.92	0.94
553	080	38.89	18	C	30	1	N	114	1.18	0.83	0.60
554	080	39.70	18.3	C	50	0	N	n/a	n/a	n/a	n/a
555	080	29.67	18.9	C	30	1	W	n/a	n/a	n/a	n/a
556	080	53.75	18.9	D	60	1	N	n/a	n/a	n/a	n/a
557	080	32.26	16.5	C	30	1	S	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
558	080	21.16	12.3	S	30	0	E	n/a	n/a	n/a	n/a
559	080	32.16	18.3	C	40	1	W	n/a	n/a	n/a	n/a
560	080	27.79	16.2	I	40	0	E	n/a	n/a	n/a	n/a
563	143	9.50	9.9	S	70	0	E	n/a	n/a	n/a	n/a
564	143	28.02	19.2	C	70	0	N	n/a	n/a	n/a	n/a
565	143	17.53	14.4	I	40	0	E	n/a	n/a	n/a	n/a
566	143	37.19	17.1	D	60	0	W	n/a	1.04	0.96	1.42
567	143	30.05	17.4	C	40	1	W	n/a	1.13	0.93	0.76
568	143	26.85	15.9	C	70	0	N	n/a	n/a	n/a	n/a
569	143	16.41	14.7	I	60	1	E	n/a	n/a	n/a	n/a
570	143	43.79	16.5	D	40	0	N	n/a	0.82	1.01	1.23
571	143	30.58	17.4	C	50	1	E	n/a	1.38	1.00	0.84
572	143	28.02	17.4	D	60	0	E	n/a	n/a	n/a	n/a
573	143	14.66	12.6	I	70	0	N	n/a	n/a	n/a	n/a
574	143	32.16	17.4	C	50	0	S	n/a	n/a	n/a	n/a
577	131	35.38	18.9	D	40	1	S	n/a	1.14	1.02	1.02
578	131	21.11	18	C	10	1	S	66	1.80	1.51	1.15
579	131	15.47	15	I	70	0	N	n/a	n/a	n/a	n/a
580	131	30.43	16.2	C	30	2	W	n/a	1.02	2.35	3.40
581	131	10.16	8.7	S	60	0	S	n/a	n/a	n/a	n/a
582	131	22.56	16.8	I	70	1	E	n/a	n/a	n/a	n/a
583	131	28.55	17.7	C	50	1	W	n/a	0.93	0.99	0.89
584	131	18.85	14.4	I	60	0	N	n/a	n/a	n/a	n/a
585	131	17.65	16.2	I	70	1	E	n/a	n/a	n/a	n/a
586	131	20.83	16.2	I	30	2	N	n/a	n/a	n/a	n/a
587	131	18.14	16.8	C	40	1	E	71	0.65	0.93	0.64
588	131	17.91	14.4	I	30	1	E	n/a	n/a	n/a	n/a
589	170	27.00	18	C	40	1	S	n/a	n/a	n/a	n/a
590	170	19.76	14.4	I	30	1	W	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
591	170	51.89	18.9	D	50	0	W	n/a	1.63	2.03	2.31
592	170	54.08	18.3	C	40	1	W	n/a	n/a	n/a	n/a
593	170	46.58	18.9	C	40	1	S	n/a	n/a	n/a	n/a
594	170	45.42	18.6	C	40	1	W	n/a	1.44	1.49	1.52
595	170	46.36	17.7	D	50	0	N	n/a	1.10	0.49	0.45
596	170	31.70	17.1	C	30	1	E	n/a	1.12	1.34	1.36
597	170	39.40	15.9	C	40	1	S	n/a	n/a	n/a	n/a
598	170	12.65	12.6	I	70	2	E	n/a	n/a	n/a	n/a
599	170	29.51	16.5	C	30	1	N	71	1.33	1.21	1.57
600	170	17.37	15.3	I	70	0	N	n/a	n/a	n/a	n/a
603	127	42.04	18.6	D	40	1	W	n/a	n/a	n/a	n/a
604	127	55.93	18.9	D	20	3	E	n/a	1.29	1.35	1.09
605	127	27.10	17.4	C	80	1	S	141	0.90	0.97	1.07
606	127	14.66	10.2	I	50	0	N	n/a	n/a	n/a	n/a
607	127	49.96	18.3	C	50	2	N	n/a	1.14	1.48	1.42
608	127	64.72	18.6	C	50	3	W	n/a	0.76	0.72	0.88
609	127	22.28	10.2	I	80	0	S	n/a	n/a	n/a	n/a
610	127	37.01	17.7	C	40	2	N	n/a	n/a	n/a	n/a
611	127	65.46	17.4	D	50	2	S	n/a	n/a	n/a	n/a
612	127	58.45	16.5	C	40	3	W	n/a	n/a	n/a	n/a
613	127	47.50	19.2	C	40	3	N	57	0.86	1.04	0.73
614	127	56.21	16.2	C	40	2	E	n/a	n/a	n/a	n/a
617	197	47.35	17.7	D	60	0	E	n/a	1.53	0.83	0.99
618	197	61.47	16.2	C	40	3	E	n/a	0.88	1.12	1.13
619	197	43.79	17.4	D	60	2	W	n/a	1.43	1.31	1.30
620	197	29.87	15.9	I	50	2	N	n/a	n/a	n/a	n/a
621	197	51.89	17.1	C	40	2	E	n/a	1.25	1.26	1.38
622	197	56.57	16.5	C	40	1	N	n/a	0.92	1.08	0.89
623	197	48.11	17.7	C	40	2	W	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
624	197	47.93	19.5	D	50	3	S	n/a	n/a	n/a	n/a
625	197	68.20	19.5	D	50	2	E	n/a	0.80	1.20	1.03
626	197	14.07	13.8	I	70	0	E	n/a	n/a	n/a	n/a
627	197	53.06	16.8	D	50	2	N	n/a	n/a	n/a	n/a
628	197	16.69	14.1	I	80	0	S	n/a	n/a	n/a	n/a
631	115	22.35	14.4	C	30	0	N	51	0.70	0.99	1.66
632	115	47.83	13.8	C	40	0	W	n/a	n/a	n/a	n/a
633	115	33.76	14.7	C	20	1	W	n/a	n/a	n/a	n/a
634	115	32.54	16.2	C	60	1	N	n/a	n/a	n/a	n/a
635	115	31.67	16.2	C	50	1	W	n/a	0.65	0.74	0.94
636	115	29.16	15.6	C	30	1	W	n/a	0.88	1.49	2.45
637	115	39.80	13.2	C	30	1	N	n/a	n/a	n/a	n/a
638	115	52.83	13.5	C	50	2	E	n/a	1.49	1.55	1.26
639	115	31.75	13.8	C	80	0	N	n/a	1.31	1.76	1.67
640	115	44.27	14.1	D	60	1	S	n/a	1.55	1.63	1.55
641	115	28.14	12	C	50	1	S	69	1.26	0.75	0.80
642	115	33.32	15	C	50	0	S	71	0.64	0.62	0.81
645	172	49.71	16.8	D	40	0	E	n/a	1.60	1.06	1.18
646	172	37.16	18	D	50	0	S	n/a	1.03	1.58	1.55
647	172	60.45	17.4	D	50	0	S	n/a	n/a	n/a	n/a
648	172	54.97	17.7	D	50	1	W	n/a	1.13	1.26	1.14
649	172	47.24	17.7	D	50	0	E	n/a	0.86	1.13	1.17
650	172	28.24	15	C	30	0	W	n/a	1.06	0.78	0.99
651	172	44.53	15.9	C	30	1	W	n/a	0.97	0.92	1.20
652	172	48.06	17.7	D	40	1	W	n/a	n/a	n/a	n/a
653	172	53.44	17.7	C	70	1	E	n/a	1.16	1.03	1.21
654	172	34.32	14.4	C	50	0	E	50	1.28	1.19	1.19
655	172	27.43	13.5	C	50	0	E	59	0.94	0.84	0.85
656	172	35.86	13.8	C	40	0	E	63	1.21	1.48	1.15

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
659	095	53.72	20.7	C	60	0	N	n/a	n/a	n/a	n/a
662	095	29.51	19.8	C	30	1	S	n/a	n/a	n/a	n/a
663	095	40.23	19.2	C	50	1	W	n/a	n/a	n/a	n/a
664	095	50.04	20.7	C	60	2	E	n/a	n/a	n/a	n/a
665	095	30.51	18.6	C	60	0	N	n/a	0.74	0.64	0.84
666	095	51.31	18.6	C	40	2	N	n/a	n/a	n/a	n/a
667	095	26.31	18	C	40	0	N	n/a	1.54	2.25	2.05
668	095	48.11	20.1	D	50	0	N	n/a	n/a	n/a	n/a
669	095	32.61	17.4	C	50	0	W	n/a	n/a	n/a	n/a
670	095	37.57	17.4	C	60	1	S	n/a	n/a	n/a	n/a
673	077	24.26	18	C	40	1	E	n/a	0.96	1.05	1.30
674	077	31.22	15.3	C	50	0	N	81	2.17	1.45	1.40
675	077	17.86	13.8	I	50	0	E	n/a	n/a	n/a	n/a
676	077	27.99	17.7	C	60	0	W	n/a	n/a	n/a	n/a
677	077	48.16	17.1	D	60	1	W	n/a	n/a	n/a	n/a
678	077	17.58	15.9	C	80	0	E	70	1.22	1.59	2.16
679	077	27.94	15.6	C	40	1	E	n/a	0.90	0.60	0.96
680	077	19.56	15	C	30	1	N	n/a	n/a	n/a	n/a
681	077	44.09	17.7	D	40	1	N	n/a	0.87	0.88	0.73
682	077	39.40	16.8	C	50	1	E	n/a	1.17	1.30	1.46
683	077	42.88	15.9	C	40	1	N	n/a	0.82	1.13	0.97
684	077	22.43	15	I	80	0	S	n/a	n/a	n/a	n/a
687	075	20.73	16.2	C	70	0	W	n/a	0.87	1.29	0.84
688	075	20.27	13.8	I	30	0	S	n/a	n/a	n/a	n/a
689	075	14.10	14.1	I	50	0	S	n/a	n/a	n/a	n/a
690	075	19.10	16.2	C	60	0	S	n/a	n/a	n/a	n/a
691	075	12.75	13.8	I	70	0	S	n/a	n/a	n/a	n/a
692	075	21.26	16.8	C	40	0	E	n/a	n/a	n/a	n/a
693	075	30.51	19.8	D	40	0	E	n/a	0.77	1.08	1.18

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
694	075	22.86	16.5	C	40	1	S	n/a	n/a	n/a	n/a
695	075	24.51	18	C	30	1	E	n/a	n/a	n/a	n/a
696	075	9.88	13.8	I	60	0	N	n/a	n/a	n/a	n/a
697	075	7.09	9.3	S	70	0	N	n/a	n/a	n/a	n/a
698	075	24.97	16.5	C	40	1	S	n/a	n/a	n/a	n/a
707	092	24.94	15.9	D	50	1	E	n/a	1.07	1.03	1.08
708	092	13.61	12.3	I	70	0	N	n/a	n/a	n/a	n/a
709	092	23.47	15.9	C	70	1	N	n/a	n/a	n/a	n/a
710	092	18.14	12.9	C	70	0	E	n/a	0.68	0.65	0.62
711	092	11.84	11.1	S	40	1	W	n/a	n/a	n/a	n/a
712	092	25.25	15.9	C	40	1	W	n/a	n/a	n/a	n/a
713	092	29.90	17.4	C	80	0	E	44	0.85	0.79	0.84
714	092	12.40	13.5	I	60	1	W	n/a	n/a	n/a	n/a
715	092	20.68	11.4	S	70	0	S	n/a	n/a	n/a	n/a
716	092	3.99	6	S	80	0	N	n/a	n/a	n/a	n/a
717	092	19.41	15.3	C	40	0	E	62	1.13	1.55	1.82
718	092	31.47	18	D	80	2	N	n/a	n/a	n/a	n/a
721	121	33.02	16.2	C	40	0	E	n/a	n/a	n/a	n/a
722	121	53.14	17.7	C	50	0	W	n/a	n/a	n/a	n/a
723	121	13.56	12	I	80	0	W	n/a	n/a	n/a	n/a
724	121	24.61	12.9	I	30	0	S	n/a	n/a	n/a	n/a
725	121	14.61	13.8	I	40	0	S	n/a	n/a	n/a	n/a
726	121	31.52	16.8	C	20	0	N	n/a	n/a	n/a	n/a
727	121	30.53	12.3	I	20	1	E	n/a	n/a	n/a	n/a
728	121	37.49	16.2	C	30	0	W	n/a	1.34	1.58	1.60
729	121	30.71	18.6	C	30	1	S	94	1.07	0.77	1.05
730	121	28.50	18	C	30	1	W	n/a	n/a	n/a	n/a
731	121	18.85	15.6	I	40	0	E	n/a	n/a	n/a	n/a
732	121	17.45	12.9	I	40	0	S	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
735	186	36.75	18.3	D	50	1	S	n/a	n/a	n/a	n/a
736	186	24.21	15.6	I	60	0	E	n/a	n/a	n/a	n/a
737	186	44.17	17.4	D	40	2	E	130	0.47	0.72	0.74
738	186	50.19	17.7	C	30	1	S	n/a	n/a	n/a	n/a
739	186	60.43	16.8	C	40	1	E	n/a	n/a	n/a	n/a
740	186	61.34	17.4	D	40	0	W	n/a	1.10	1.23	1.40
741	186	47.35	20.1	D	40	1	W	n/a	n/a	n/a	n/a
742	186	45.42	17.4	C	50	1	W	n/a	1.22	1.49	0.41
743	186	32.97	18	I	30	2	E	n/a	n/a	n/a	n/a
744	186	48.62	19.5	D	30	1	N	n/a	n/a	n/a	n/a
745	186	47.27	16.5	D	50	2	N	n/a	0.96	1.39	1.07
746	186	50.98	16.8	D	60	1	N	n/a	n/a	n/a	n/a
749	149	15.57	14.4	I	70	0	E	n/a	n/a	n/a	n/a
750	149	25.45	14.1	C	70	0	E	60	1.81	1.16	0.92
751	149	17.07	12.3	I	40	0	W	n/a	n/a	n/a	n/a
752	149	37.92	17.1	D	60	0	W	n/a	n/a	n/a	n/a
753	149	32.18	17.4	C	30	1	N	n/a	n/a	n/a	n/a
754	149	8.79	11.1	I	20	0	W	n/a	n/a	n/a	n/a
755	149	22.58	14.7	C	40	0	N	44	1.19	0.17	0.68
756	149	25.35	14.7	C	40	1	E	n/a	n/a	n/a	n/a
757	149	37.06	16.2	C	60	1	S	n/a	0.76	1.08	1.04
758	149	31.42	14.1	C	60	0	S	n/a	n/a	n/a	n/a
759	149	39.80	14.4	D	60	1	E	n/a	n/a	n/a	n/a
760	149	23.90	18.3	C	40	1	W	73	0.95	2.05	1.00
765	150	40.74	16.2	C	40	1	S	n/a	1.68	1.34	1.44
766	150	38.18	15.9	C	30	2	N	n/a	n/a	n/a	n/a
767	150	47.52	16.2	D	40	1	E	n/a	n/a	n/a	n/a
768	150	36.17	17.7	C	50	0	N	n/a	n/a	n/a	n/a
769	150	38.74	15.9	C	30	0	S	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
770	150	32.13	15.6	C	30	1	W	n/a	n/a	n/a	n/a
771	150	31.47	13.8	I	50	0	N	n/a	n/a	n/a	n/a
772	150	43.13	15.3	C	40	1	W	n/a	n/a	n/a	n/a
773	150	36.07	15.9	C	30	1	N	n/a	n/a	n/a	n/a
774	150	46.91	16.8	C	40	1	E	n/a	n/a	n/a	n/a
775	150	31.90	15.9	C	50	0	W	n/a	n/a	n/a	n/a
776	150	46.66	16.8	D	40	1	E	n/a	0.77	1.71	0.52
777	083	41.68	15.9	C	30	0	E	n/a	n/a	n/a	n/a
778	083	49.07	15.9	C	60	0	N	n/a	1.22	1.08	1.26
779	083	22.10	12	S	20	0	S	n/a	n/a	n/a	n/a
780	083	7.85	10.8	S	20	0	E	n/a	n/a	n/a	n/a
781	083	34.70	19.2	D	30	0	N	n/a	n/a	n/a	n/a
782	083	46.18	19.2	D	60	1	N	n/a	0.75	1.12	1.25
783	083	26.70	15.3	C	30	0	E	n/a	1.86	1.65	0.88
784	083	40.28	18	D	50	1	N	n/a	n/a	n/a	n/a
785	083	24.77	16.2	C	20	0	E	59	0.67	0.74	1.07
786	083	10.97	11.7	I	20	0	E	n/a	n/a	n/a	n/a
787	083	12.14	11.1	I	30	0	N	n/a	n/a	n/a	n/a
788	083	17.81	16.5	C	20	0	E	n/a	n/a	n/a	n/a
789	062	46.28	18.6	C	30	1	E	n/a	n/a	n/a	n/a
790	062	37.92	17.7	C	30	0	W	n/a	n/a	n/a	n/a
791	062	22.00	14.7	S	40	0	W	n/a	n/a	n/a	n/a
792	062	49.58	18	D	60	0	S	n/a	n/a	n/a	n/a
793	062	22.71	17.1	I	30	0	W	n/a	n/a	n/a	n/a
794	062	15.09	12.9	I	30	0	S	n/a	n/a	n/a	n/a
795	062	24.18	15.6	C	30	1	E	66	0.67	0.64	0.96
796	062	31.83	17.7	C	40	1	W	n/a	n/a	n/a	n/a
797	062	40.97	19.2	D	60	1	N	n/a	n/a	n/a	n/a
798	062	33.10	15.6	C	40	1	N	n/a	n/a	n/a	n/a

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
799	062	28.50	15.6	C	40	0	E	n/a	n/a	n/a	n/a
800	062	22.35	16.8	C	30	1	W	n/a	n/a	n/a	n/a
817	198	38.74	18.6	C	30	1	W	101	1.47	1.44	1.44
818	198	27.86	16.2	C	40	0	W	n/a	0.73	1.84	2.23
819	198	30.99	16.5	C	50	1	E	78	1.56	3.63	2.86
820	198	38.61	17.7	C	50	0	W	n/a	1.14	1.15	0.96
821	198	27.51	16.5	C	50	0	N	n/a	0.97	1.16	1.01
822	198	24.87	13.8	I	40	0	N	n/a	n/a	n/a	n/a
823	198	29.82	18.3	C	80	0	S	n/a	n/a	n/a	n/a
824	198	30.78	15.9	C	80	1	N	n/a	1.02	1.28	1.87
825	198	27.05	14.4	C	20	0	W	n/a	n/a	n/a	n/a
826	198	44.75	18	D	40	0	E	n/a	1.05	1.32	1.42
827	198	35.10	17.1	C	30	1	E	88	1.06	1.15	0.91
828	198	43.92	18	C	30	1	N	n/a	0.88	1.07	1.45
831	151	31.57	15.9	C	40	0	N	n/a	0.82	0.84	0.72
832	151	26.06	15	C	50	0	W	n/a	n/a	n/a	n/a
833	151	13.08	10.8	I	20	0	N	n/a	n/a	n/a	n/a
834	151	22.96	13.8	C	30	0	N	84	1.28	1.48	1.71
835	151	28.09	17.1	D	30	1	W	n/a	0.88	1.07	1.85
836	151	29.26	14.7	C	40	0	W	78	0.93	0.87	0.81
837	151	30.43	15.9	C	20	1	S	95	1.23	1.09	1.17
838	151	35.89	14.7	D	60	1	W	87	1.20	1.36	1.89
839	151	33.07	14.4	C	60	0	N	117	1.75	1.07	1.54
840	151	45.21	16.5	D	50	1	N	86	1.05	0.86	1.18
841	151	36.42	15.9	D	80	0	W	n/a	0.65	0.62	0.65
842	151	22.48	11.1	S	50	1	N	n/a	n/a	n/a	n/a
845	189	32.26	12.9	C	30	2	W	n/a	1.83	1.44	1.28
846	189	26.90	12.6	C	40	0	W	n/a	0.84	0.92	0.98
847	189	25.88	13.5	C	20	1	N	n/a	0.74	0.41	

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
848	189	34.11	15.9	C	20	2	W	n/a	0.91	0.83	1.08
849	189	37.08	13.5	C	40	1	W	n/a	0.71	0.87	0.72
850	189	37.08	16.5	C	40	2	N	n/a	0.87	1.35	0.62
851	189	23.22	14.7	I	30	1	E	n/a	n/a	n/a	n/a
852	189	50.11	17.1	D	60	1	S	n/a	1.04	1.27	1.08
853	189	41.05	15.6	C	30	1	N	n/a	0.82	1.28	1.22
854	189	36.73	12.9	C	50	2	W	n/a	0.70	1.08	1.64
855	189	22.71	15.6	C	80	1	W	n/a	1.46	1.02	1.19
856	189	42.80	15.3	C	40	2	N	n/a	2.08	1.21	0.74
859	184	10.44	12	I	80	O	S	n/a	n/a	n/a	n/a
860	184	46.71	16.5	D	30	O	N	n/a	n/a	n/a	n/a
861	184	10.57	7.8	S	80	O	N	n/a	n/a	n/a	n/a
862	184	31.78	14.1	C	40	O	N	n/a	n/a	n/a	n/a
863	184	11.79	10.8	S	60	O	N	n/a	n/a	n/a	n/a
864	184	12.70	10.2	S	40	M	S	n/a	n/a	n/a	n/a
865	184	34.09	15.9	C	50	O	E	49	1.66	0.88	0.97
866	184	30.15	15.6	C	50	O	E	71	1.68	2.57	1.88
867	184	22.33	15.6	C	60	O	E	n/a	1.62	0.95	0.89
868	184	55.25	18.9	D	50	O	W	n/a	0.99	1.30	0.97
869	184	66.65	17.4	D	60	O	E	n/a	n/a	n/a	n/a
870	184	44.25	18	C	60	L	W	n/a	1.26	1.89	3.90
873	129	24.79	14.4	C	30	O	E	n/a	0.87	1.03	1.22
874	129	27.56	14.4	C	40	L	S	n/a	n/a	n/a	n/a
875	129	19.46	13.5	C	30	L	N	n/a	n/a	n/a	n/a
876	129	22.15	15	C	30	L	S	55	0.65	0.76	0.82
877	129	18.82	14.1	C	40	L	W	73	1.66	1.07	1.16
878	129	25.65	13.2	C	40	M	N	79	0.54	0.72	0.57
879	129	23.09	13.5	C	30	M	E	n/a	n/a	n/a	n/a
880	129	19.00	13.8	C	30	L	W	66	0.59	0.93	0.96

Appendix 4. cont'd.

Tree tag #	Stand ID	Dbh (cm)	Height (m)	Class [a]	Crown Ratio	Dieback [b]	Core azimuth [c]	Tree age (yrs)	5-yr growth ratio [d]	10-yr growth ratio [e]	15-yr growth ratio [f]
881	129	15.60	13.8	C	30	O	N	n/a	n/a	n/a	n/a
882	129	15.16	13.2	I	30	O	W	n/a	n/a	n/a	n/a
883	129	17.12	13.5	C	40	L	S	57	1.57	1.75	1.59
884	129	19.79	13.2	C	20	L	W	71	1.13	1.22	1.08
887	134	31.12	13.5	C	40	O	W	74	1.04	1.25	0.97
888	134	36.27	12.9	C	60	L	W	n/a	n/a	n/a	n/a
889	134	43.48	14.1	D	50	L	S	n/a	1.18	1.36	1.70
890	134	16.38	12	I	80	O	E	n/a	n/a	n/a	n/a
891	134	30.56	14.7	C	70	O	W	n/a	1.15	1.66	0.70
892	134	26.06	13.8	C	60	O	W	112	1.59	2.53	1.81
893	134	28.91	13.5	C	50	L	N	n/a	0.90	0.44	0.36
894	134	29.67	12.3	C	50	L	W	n/a	1.44	0.59	0.78
895	134	23.83	12	C	80	O	S	61	0.75	0.93	0.73
896	134	35.92	13.2	C	50	M	W	n/a	n/a	n/a	n/a
897	134	37.26	14.7	D	60	L	W	n/a	n/a	n/a	n/a
898	134	21.69	12.3	C	70	O	S	76	1.12	0.95	0.91

[a]Class (position of tree in canopy): S = suppressed, I = intermediate, C = codominant, D = dominant

[b]Dieback (percentage of mortality in crown): 0 = none, 1 = <30%, 2 = 30-60%, 3= >60%

[c] Core Azimuth = cardinal direction from which increment core was extracted.

[d] 5-yr Increment Ratio = length of increment from 2001-1997 / length of increment from 1996-1992

[e] 10-yr Increment Ratio = length of increment from 2001-1992 / length of increment from 1991-1982

[f] 15-yr Increment Ratio = length of increment from 2001-1987 / length of increment from 1966-1972

Appendix 5

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2004-02

Title of thesis or dissertation (or other research projects):

IMPACTS OF BEECH BARK DISEASE ON TIMBER AND WILDLIFE RESOURCES IN MICHIGAN.

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Investigator's Name(s) (typed)
Amy M. Kearney

Date 7/27/04

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America. Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:
Original: Include as Appendix 5 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 5 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

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