THE ECOLOGICAL EFFECTS OF BEECH BARK DISEASE ON AMERICAN BEECH (*FAGUS GRANDIFOLIA,* EHRH.) AND NORTHERN HARDWOOD FORESTS IN MICHIGAN

by
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A practicum submitted
in partial fulfillment of the requirements
for the degree of
Master of Science
(School of Natural Resources and Environment)
at the University of Michigan
December 2009

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Acknowledgments

This body of work would not have been completed without the support of numerous people in the School of Natural Resources and Environment. Many thanks to Dr. John Witter for taking me in as a student, getting me interested in entomology, and offering me the chance to undertake this project. When Dr. Witter was no longer able to work on the project, Dr. Mark Hunter stepped in and offered guidance, and funding, so that our contract with the Michigan Department of Natural Resources could be met. And thank you to Dr. David Allan for volunteering his assistance as a second reader at the last minute.

Thank you to Dr. Inés Ibáñez for helping me along the last part of this journey, for making sure I could finally submit a comprehensive document, and for offering insight and moral support when I needed it most.

Funding for this project was provided by the Michigan Department of Natural Resources. I would like to give special thanks to Roger Mech for his patience while the project was in limbo.

Many thanks to my field crew who worked long hours even when stress levels were high: Michael Gerowitz, Ricardo Aguirre, Jenny Thomas and Aaron Sluis. They did excellent work in oftentimes inclement conditions.

My parents have been an important pillar of support when the going got tough, and were willing to drop everything for me. Backpacking trips with the family as a child fostered my love of the outdoors, and I appreciate them encouraging me to follow my dreams of working in the forestry field.

And special thanks to Nic Enstice, who stayed up late nights to work alongside me, and showed amazing patience through every step of the way.

ABSTRACT

Beech bark disease (BBD) was first reported in Michigan in 2000, though experts believe it to have been present in the state for 10-15 years prior to that. The exotic insect/fungal complex is composed of the beech scale (*Cryptococcus fagisuga* Lind.), and at least one of three species of *Nectria* fungi. BBD has caused mortality of American beech (*Fagus grandifolia* Ehrh.) in some of Michigan's northern hardwood forests, and it is a threat to those forests not yet infested. The purpose of this study was to 1) determine the continuing impacts of beech bark disease on the state's beech resource, and 2) monitor changes to forest composition and health in disease infested stands. Plots that were first sampled in 2001 were visited again in 2007, and comparisons made on the progress of the disease. Stands visited were divided between the Upper Peninsula and Lower Peninsula. Evidence of disease was noted in 9 plots where it was previously undocumented, showing a pattern of rapid westward movement of the disease.

Overall, stands infested with beech bark disease exhibited reduced health (exhibited by poorer levels of foliage transparency, higher levels of crown dieback, and higher severities of damage) and high mortality of beech trees, with a 16% increase in dead basal area in infected areas. The disease is more advances in the Lower Peninsula, likely due to a more recent establishment of the disease there. However, most of the new cases were in the Upper Peninsula. A significant factor contributing to variation in tree and stand condition throughout the state is the wide range of climatic conditions and geomorphologic features over which beech occurs in Michigan.

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Introduction

Forest pests and pathogens

Threats to global biodiversity are increasing at an extraordinary rate, in response to human-induced changes in the global environment (IPCC 2007). While the impacts of the threats vary across biomes, land-use change is expected to have the most drastic effect on global biodiversity, followed by climate change (especially at high latitudes), changes in atmospheric CO_2, biotic exchange (in the form of successful establishment of exotic species), and nitrogen deposition (Sala, Chapin et al. 2000). Invasive species have long threatened the productivity and stability of forest ecosystems throughout the world.

There is some debate over the correlation between species richness and ecosystem function (Chapin, Zavaleta et al. 2000). For instance, early theoretical models show that species-poor communities on islands are more susceptible to invasion because they offer more empty niches, whereas studies of more intact ecosystems found positive correlations between species richness and propensity for invasion (Levine and HilleRisLambers 2009). There is no doubt that northern temperate forests are heavily affected by biotic exchange, and the most severe current threat to the forests of eastern North America is exotic pests and pathogens (Lovett, Canham et al. 2006).

Pathogens and pest insects are major forces driving the disturbance patterns in these ecosystems. Forests can be altered either directly (from predation on specific tree species) or indirectly (for example, from insect frass falling to the forest floor, increasing soil nutrient inputs). The allocation of resources by plants to chemical and structural defenses against pathogens and herbivores decreases growth by diverting resources away from leaf growth and other vegetative structures (Herms and Mattson 1992). Disturbances caused by insects and pathogens are as important a function of ecosystem dynamics as the more sudden abiotic disturbances such as wind and fire. An additional factor to take into consideration is current climate change. Changing climate and increased pollution levels alter the susceptibility of trees to pests and pathogens, making forecasting disease outbreaks more difficult (Simberloff 2000).

Forests in eastern North America host a variety of invasive pests and pathogens that are problems unique to this area. The gypsy moth (introduced in 1869), which feeds primarily on oaks but will feed on more than 300 species of trees and shrubs, is a major defoliator of eastern forests (Liebhold, Elmes et al. 1994). The gypsy moth populations are cyclical, with severe and relatively synchronous outbreaks at roughly 10 year intervals. However, over the last decade, the moth populations have been kept in check by pathogens (particularly the fungus *Entomophaga maimaiga*). The insect is continuing to spread but its outbreaks may become less severe. For instance, the moth larvae can be an important food for some birds and mammals, when at high density (Ostfeld, Jones et al. 1996), and the nitrogen pulse resulting from insect feces, dead caterpillars, and leaching of nitrogen from unconsumed green foliage can be incorporated into soil organic matter or taken up by growing plants(Lovett and Ruesink 1995). However, unused nitrogen may be leached from the ecosystem in drainage water, resulting in a dramatic rise in stream water nitrate concentrations (Eshleman, Morgan et al. 1998).

The hemlock wooly adelgid was first observed in the United States in the 1950s in Virginia. It is destructive to forest and ornamental hemlock trees, feeding on the phloem of small hemlock twigs. In the Eastern U.S., the only two species susceptible to foliar attack are the eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*Tsuga caroliniana*). When infestations are high and populations have grown rapidly, tree death can occur in 4-5 years (Young, Shields et al. 1995). This problem is specific to eastern forests, as the insect does not appear to attack western hemlock (*Tsuga heterophylla*) in western forests.

Most recently, the emerald ash borer (*Agrilus planipennis)* has decimated the majority of the ash (*Fraxinus*) populations in Michigan. Introduced from Asia, most likely via shipping crates, this insect has received a great deal of attention due to the importance of the ash as a street tree, and therefore its economic significance to the state (Poland and McCullough 2006). The larvae feed on the inner bark of the ash trees, disrupting its ability to transport nutrients and water.

Among these pests, beech bark disease stands out as particularly damaging from the ecological point of view, as it affects the most dominant late successional species in Eastern North American, the American beech (*Fagus grandifolia*) (Houston 1980). Along with sugar maple (*Acer saccharum*), beech trees dominate the canopy in beech-maple mesic forests which were once the most common forest type in the northeastern United States (Fahey 1998).

History and biology of BBD

Beech bark disease (BBD) is a disease complex consisting of a scale insect, *Cryptococcus fagisuga* Lind. in the family *Erioccidae*, and at least one of three species of *Nectaria* fungi. BBD was introduced into Nova Scotia around 1890 on nursery stocks imported from Europe (Bouvarel 1980). The current range extends south to North Carolina, and as far west as Michigan (Witter, Stoyenoff et al. 2005).

The scale insects are small (under 10 mm), and easily identifiable by the white wooly material the female secretes as a covering. This material aids in the dispersal of the insect, being windborn and attaching to mobile sources, due to its somewhat sticky nature. One generation occurs annually, overwintering as small nymphs. The insect is disseminated primarily via wind in the late summer to early winter (Houston, Parker et al. 1979). The nymphs resume their feeding in the spring, and the parthenogenetic females begin laying eggs in early June. Surveys to determine scale cover are best conducted around this time, as the females are present along the bole of the tree. Once the first-instar nymphs hatch after approximately 4 weeks, they move about until an acceptable feeding site is found, and nymphs then insert their mouthparts into the host beech. When the nymph begins feeding, the waxy covering is secreted, and the insect remains immobile under this protective covering, feeding through the thin beech bark, until spring. This feeding ruptures the smooth bark and creates an entry point for infection by one of three fungal pathogens of the genus *Neonectaria: N. galligena* which is native, *N. coccinia* var. *faginata*, which is believed to be introduced (Houston 1994), and a second exotic species (*N. ochroleuca*) which has been found associated with BBD in Pennsylvania, West Virginia, and Ontario, Canada (McCulloush et al. 2001). All three of these Nectaria species are present in Michigan (Witter, Stoyenoff et al. 2005). The fungi are identifiable by their bright red perithecia (Shigo 1972), which are visible during the wet seasons. This fungus penetrates the cambium and sapwood, interrupting many functions of the tree's conduction and nutrient storage. Beech scale alone rarely causes tree death. It is a combination of the scale creating a wound, along with an infection by the secondary fungus that causes tree mortality (Shigo 1964).

Impact and management

Beech bark disease has not received the media attention or resources for research that chestnut blight or gypsy moth have, in part because the American beech is not valued as highly as some other tree species (Twery and Patterson 1984). However, interest has increased as recent research has focused on the adverse effects of the loss of beech overstory on other trees, such as a decline in sugar maples (DiGregorio, Krasny et al. 1999). Although the American beech is used for a variety of wood products, its ecological significance as a climax species in the northern hardwood forest type of eastern North America outweighs its economic significance (Munck and Manion 2006). Beech trees provide habitat for several species of mammals and birds, including raptors, fishers, and woodpeckers (Johnson and Adkisson 1985), and the importance of beech mast for wildlife (the trees produce nutrient-rich nuts), especially for black bear (*Ursus americanus*), is well documented (Costello and Sage 1994). This is especially important for Michigan in the eastern UP where oaks are not abundant and therefore acorns are not an available seed source.

Models have been used to predict the rate and extent of the spread of BBD across the country. Using historical maps of confirmed BBD presence in combination with the ordinary kriging procedure to interpolate a surface basal area/ha for the host species, the estimated rate of spread is 14.7 +/- 0.9 km/year (Morin, Liebhold et al. 2007). The greatest concentration of beech is in the Adirondacks, and smaller concentrations are in Maine, New Hampshire, Vermont, West Virginia, and northern Pennsylvania, and in low levels through a range that extended over most forested areas of the Eastern United States. Current occupation of the disease is estimated at only 27% of its potential range in land area (factoring in all the locations with beech present). However, the disease has already invaded more than 54% of its potential area in total host density, with eastern Kentucky, northern Ohio, and northern Indiana as areas with the highest risk that are currently infected (Liebhold, Morin et al. 2005).

Changes in stand dynamics

One of the major consequences of BBD is the loss of a late successional dominant species. For example, in the Catskill Mountains of New York, some forests formerly co-dominated by American beech (*Fagus grandifolia* Ehrh.) and sugar maple (*Acer saccharum* Marsh.) are shifting to sugar maple dominance (Griffin, Lovett et al. 2005). However, other studies have concluded that with the removal of large beech from the overstory, there is a decrease in sugar maple seedlings and sprout survival (Hane 2003). The heavy vegetative reproduction of beech from root sprouts shades out the sugar maple seedlings, and below ground competition for resources is favorable for beech (Houston 1975). Gap dynamics are an important part of the succession of a beech-maple forest where natural disturbances are common and allow for the continuous generation of moderate-sized gap sites where beech regeneration can occur in canopy openings (Krasny and Whitmore 1992). However, the rate and overall spread off BBD results in more and larger gaps than are usual, as old, large beech are killed. Studies of beech bark disease in infested stands in New-England concluded that the highest mortality of beech occurs in stands with heavy eastern hemlock dominance, which then replace the beech (Twery and Patterson 1984). Later studies in the same forests have concluded that there is an associated decline in yellow birch (*Betula alleghaniensis*) (Runkle 1990), though this may be attributable to a pathogen or insect specific to that species.

It has been known for a long time that some beech trees are resistant to the disease (Houston 1980). Those that support only low populations or do not show any sign, in high infestation areas, have bark that contains less total amino nitrogen than do susceptible trees (Wargo 1988). The low nitrogen concentration is known to limit the establishment and the growth of sucking insects (Gange and West 1994). Resistant trees in a stand are generally observed in close proximity to one another; the spatial arrangement of these trees has led researchers to conclude that there is a genetic resistance that is transferable both vegetatively and sexually (Mielke, Houston et al. 1986, March 24- 27). More recent research on DNA analysis from cross pollinated trees confirms that resistance to scale is a hereditary trait (Koch and Carey 2005).

In light of this knowledge, foresters debate if it is the best management strategy to encourage natural resprouting of resistant trees in forest stands, or to utilize propagation techniques in a greenhouse and then replant. Conventional techniques have not worked well. Grafting has proven useful for resistance screening and developing seed orchards, but is not a practical solution for mass production of resistant genotypes (Loo, Ramirez et al. 2005).

Management practices in the past have varied. Houston originally thought that a winter harvest in diseased stands, when roots and soil are frozen or snow covered (resulting in fewer root wounds and fewer sprouts compared to summer harvests), would be the optimal time to remove diseased trees (Houston 2001). However, there were no significant differences in sprout numbers. Further analysis showed that resistant trees have greater number of root sprouts than susceptible trees, whether cut or not. The most effective way to encourage healthy grow-back is to leave the resistant trees standing (resulting in the largest number of sprouts), but to clear out all diseased trees (Houston 2001).

Biological control does not appear to be a viable option. There are no known insect parasites of the *C. fagisuga* in Europe or the U.S. Some predators are known, such as the twice-stabbed lady beetle, *Chilocorus stigma*. However, the predation appears to be limited to the sedentary life forms of *C. fagisuga*, and other predators are limited to the heavily infested trees. They can be productive in reducing populations on individual trees, but influence over the spread of the disease is inconsequential (Morris, Small et al. 2002)l. While bark epiphytes typically provide favorable habitats for establishing *C. fagisuga*, not all lichens are favorable. In Nova Scotia, some stems of beech trees on steep south-facing slopes remain free of beech scale and BBD defect, despite presence in nearby sites. The stems of these trees were heavily colonized by the crustose lichen *Graphis scripta*, which have thalli that are thick and elevated above the bark surface, with smooth surfaces that provide limited spatial habitat for the scale (Houston 1994). The conditions that favor this lichen include a low level of damaging air pollution and slow tree diameter growth due to the lower moisture availability on steep slopes.

Climatic warming could be beneficial to insect populations by reducing insect mortality from extreme cold in northern latitudes (Ayres and Lombardero 2000; Bale, Masters et al. 2002), while also facilitating the scale's spread north where temperatures are increasing. Conversely, in cold winter climates where dieback is common, residual scale colonies are often able to persist in low levels below the snowline on trees and in root collars. There, a reduction of snow cover could lead indirectly to insect population decline, attributed to the reduction of these refugia (Dukes, Pontius et al. 2009). As for increases in atmospheric pollutants, observations of beech bark disease affected trees in more or less severely polluted areas and in a non-polluted control areas in Europe where development of beech bark disease decreased with increasing pollution levels. The development of both disease agents is modified, *Nectaria* development is clearly slowed down and the distribution of *Cryptococcus* outbreak is modified in a complex manner (Decourt, Malphettes et al. 1980). In Poland, there is evidence that sulfur pollution in the form of acid rain may decrease beech bark disease populations on European beech (*Fagus sylvatica*) (Godbold and HÃ¼tterman 1994). Research has been, as of yet, inconclusive as to the exact effects of climate change and increased pollutants in the atmosphere on the rate of spread of beech bark disease.

BBD in Michigan

The presence of beech scale with the corresponding BBD symptoms was first noted in Michigan in the summer of 2000 in Ludington State Park in the Lower Peninsula, and several locations in Luce County in the Upper Peninsula. Upon inspection, experts familiar with the disease etiology estimated that the disease had been there from 10-15 years (Houston 2001).

For centuries, Michigan's hardwood forests have faced disturbances. Periods of moderate drought have been fairly common throughout Michigan during the past 30 years and severe drought more prevalent in the last decade (Witter, Leutscher et al. 1999). These summers of low moisture have put forests under tremendous stress, and have most likely made beech trees more susceptible to attack. Lack of adequate moisture during the growing season is one important type of stress that has been shown to increase susceptibility to the disease (Lonsdale 1980). By 2004, the beech scale had spread to six counties in the LP and five counties in the UP, with the disease confirmed in most of these locations. Michigan is the western boundary of where the scale and disease have spread to, and potential spread to neighboring states is cause for alarm for state foresters.

BBDMIAS: history, goals, results to date

The Beech Bark Disease Monitoring and Impact Analysis System (BBDMIAS) was established in the summer of 2001 to survey Michigan's forests with the following objectives: 1) assess the presence or absence of the scale, 2) monitor the effects of BBD, where present, over time 3) understand the outbreak dynamics of BBD in Michigan and 4) determine current and potential impacts on hardwood forests in the region (Yocum 2002). A total of 206 monitoring sites were set up in both diseased and non-diseased stands to provide baseline information on beech health prior to disease infection, and make comparisons to stands with and without well established disease.

The work done in previous years to analyze data collected from the BBDMIAS has given new insight into the effects of BBD on beech radial growth (Yocum 2008) and overall effects on forest composition (Thompson 2003). The long term effects of this disease in Michigan forests will not be known for many years. However, from data collected over the span of 2001 to 2007, we can begin to answer some pressing questions about how the beech resource in Michigan will be impacted, which species will experience adverse effects due to BBD presence in an ecosystem, as well as BBD's distribution and rate of spread throughout the state. My goal in continuing this research was to utilize the data over the course of the seven years the project was run by Dr. John Witter with the assistance of his students in the Forest Pests lab and determine any further changes in the disease spread in Michigan, and impact on beech health.

This information can subsequently be used to look at mode of spread and how to control the disease. Results to date have been on par with research in more eastern forests (Petrillo, Witter et al. 2005). In general, north and east –facing sides of beech boles have greater abundance of beech scale than the south and west-facing sides (Witter 2004). The greater temperature fluctuations and increased solar radiation on those sides places scales under greater environmental stress. Larger diameter trees are favored by beech scale populations because they have a greater amount of bark surface area available to colonize. Tree crown conditions can also affect beech scale populations on trees, partially due to microclimate effects. Trees with below-normal crown transparency and reduced foliage allow more light to penetrate the crown and warm the tree bole (Petrillo and Witter 2005). Also, the tree is less able to photosynthesize, potentially reducing food quality and quantity available to the scales. However, trees of lower vigor appear to be the first to succumb to the disease in an area (Witter 2004, Yocum 2002, Thompson 2003).

Overall, stands containing BBD exhibit significantly reduced radial wood growth relative to stands without the disease. The magnitude of growth reduction and overall impact of beech bark disease has been greater in the Lower Peninsula than in the Upper Peninsula. These differences could be attributed to the temporal and spatial differences in scale arrivals, abundance levels of the scale, and the relative abundance of the different *Nectaria* species in different forest stands. Figures generated from the monitoring of the 206 plots in the study, along with field data from other sources, make readily apparent that the advancing front of disease is spreading more rapidly in the Upper Peninsula as compared to the Lower. This difference is thought to be correlated with the much more contiguous nature of the Upper Peninsula beech stands compared to the highly fragmented nature of stands in the Lower Peninsula. However, the scale's spread is not abated by fragmentation of forests or lack of habitat alone. Spatially continuous range expansion has dominated the spread of the disease, as short-range continuous spread is typical for a disease of this nature, owing to the dispersal of scale insects by wind. But a simple model for the spread of an invading species, like that proposed by (Skellam 1951), predicting that invading organisms proceed at a constant radial rate does not account for isolated populations of an insect. A stratified dispersal results in a pattern colonized by the formation of several isolated colonies ahead of the advancing front. Though rare, the 10 "jumps" of smaller scale populations from the larger advancing front (Morin, Liebhold et al. 2007) are important to consider when determining where the disease will continue its spread. Natural barriers (e.g. the Great Lakes or large areas of farmland) exist across the northern U.S. that could impede the spread of the beech scale, but much evidence that such feature function as barriers is lacking. In reality, observations of the spread of gypsy moth over an area of concern for future beech bark disease spread (from Michigan to Wisconsin) has not indicated that the Great Lakes has impeded its spread (Tobin and Blackburn 2008).

Building on seven years of monitoring collected by the Witter lab this project expanded to answer these specific questions:

1) Has beech bark disease affected beech health and mortality in Michigan?

2) Is the level of infestation correlated with higher mortality of beech and other species?

3) Where is the rate of spread greater, and what are the outlying factors possibly contributing to this increased spread?

4) Are certain trees thriving (increased growth) in plots with or without the disease? Which species? To answer these questions I specifically looked into the effect of continued BBD on radial growth of beech and the radial growth of other tree species (in plots with BBD and those without).

As the disease moves from its advancing front to its killing front stage, the final aftermath forest phase results in the ecological accommodation of the disease, with either a change in species composition or the reemergence of beech after high mortality. With the continued monitoring of these BBDMIAS stands, researchers will be able to witness the transition of the forests into this final stage and answer more specific questions about what Michigan forests will look like in the future.

Beech bark disease impact in Michigan

Objectives

Beech bark disease was first discovered in Michigan in 2000, although experts now believe that it has been present in the state for at least 20 years. The University of Michigan and the Michigan Department of Natural Resources established the Michigan Beech Bark Disease Monitoring and Impact Analysis System (BBDMIAS) in 2001 in response to the presence of BBD in Michigan's northern hardwood forests. The objectives of BBDMIAS are to: 1) identify the extent of Michigan's beech resource that is affected by BBD, 2) collect baseline data on current conditions of the beech resource and northern hardwood stands containing beech before this resource is affected by BBD, and 3) monitor changes in the condition of beech resources and northern hardwood forests due to BBD and other disturbances.

General Methods

The BBD monitoring system consists of two types of sampling plots, "extensive" and "intensive". Extensive plots are composed of a matrix of 30 sampling points (Figure 1). Data taken at extensive plots are: diameter at breast height, measured at 1.37 meters above the forest floor from the uphill side of the tree (DBH), tree crown and damage data (described below), along with presence and abundance of BBD indicators, collected from the individual American beech (*Fagus grandifolia*) tree nearest each sampling point. Currently, 202 extensive plots have been established throughout the western Lower Peninsula (LP) and eastern Upper Peninsula (UP). Extensive plots are sampled every three years.

Intensive plots were established during the first three years of BBDMIAS (2001, 2002, and 2003). They consist of five circular subplots established within the sampling point matrix of an extensive plot (Figure 2). Currently, a total of 62 intensive plots have been established within a subset of the extensive plots, with 30 intensive plots in the LP and 32 in the UP. In intensive plots, data are collected from all tree species and from both live and dead trees. Intensive plots are sampled yearly.

During the 2006 field season of BBDMIAS, extensive plots established in 2003 were re-sampled along with all intensive plots. In 2007, we revisited extensive plots that were established in 2001 and re-sampled in 2004. We also re-sampled a majority of intensive plots.

Detailed Methods

A. Extensive Plots. Extensive plots were designed to provide baseline data on northern hardwood forests and American beech trees before major disturbances due to beech bark disease occur. Extensive plots generally follow one of two transect matrix layouts: 5 X 6 prism points or 3 X 10 prism points (Figure 1). The particular transect matrix depends on stand dimensions. If possible, the matrix is positioned so that one edge is parallel to the nearest road. Observations within the plot are made at 30 prism points that are spaced 40 meters apart, with the first sample point being at least 40 meters into the plot.

An example of a layout is six transect lines of five sampling points each, running parallel to one another (Figure 1). The azimuth and distance from the first sampling point to the reference point on the road is recorded. The location of the first sampling point in the plot is determined using a Trimble Geoexplorer® GPS unit. If the location of the first prism point cannot be determined due to GPS interference, a GPS location for the witness tree is taken. The azimuth and distance from each prism point to the beech tree sampled at that point is recorded. In most cases, sampled beech trees are tagged with a numbered metal tag placed on the buttress root. Exceptions to this are on National Park Service and some Michigan State Parks and Recreation lands where metal tags are not allowed. At these sites, trees were marked with white paint. A site description data sheet is filled out for each stand, including a detailed description and small map indicating how to locate the plot and first prism point. For each beech tree sampled, the following variables are measured: infestation status, DBH, tree number, live crown ratio, crown density, crown dieback, foliage transparency, crown light exposure, tree vigor/condition, crown class/position, tree damage, and % beech scale coverage. Extensive plots are re-sampled every three years.

B. Intensive Plots. Intensive plots are sub-plots located within extensive plots. About 30% of the extensive plots host intensive plots. Intensive plots are equally divided between the Lower Peninsula and Upper Peninsula. Plots are occasionally located on private land to ensure examples of certain silvicultural treatments, beech densities, levels of beech scale infestation, and forest types. Intensive plots were chosen based on level of beech scale infestation, beech tree density, and geographic location. Beech scale infestation levels are represented by including control plots that contain no scale and plots ranging from slight infestation to those plots with heavy scale, beech snap, and heavy cankering. Intensive plots allow us to collect long-term information on the impact of beech bark disease on beech trees in Michigan and can be used to address additional questions concerning the impact of beech bark disease on northern hardwood forests in general. In the intensive plots, health data on all species is taken. This is used to determine the impact of beech mortality and poor health due to BBD, on any other tree species.

After sampling of the surrounding extensive plot, the center of the intensive plot is located. Intensive plots consist of a series of fixed-area, circular subplots tied to a cluster of five points with a subplot at the center and four others 36.6 m (120 ft) apart radiating in the four cardinal directions (Figure 2). Each subplot center is marked with a metal stake and a ribbon wrapped around the stake. A GPS location of each subplot center is recorded so that the stands can be relocated for additional sampling. These GPS locations are used to produce a stand map showing the layout of all subplot centers. The individual circular subplots are 1/59th ha (1/24th ac) in size with a 7.32 m radius (24 ft). In each subplot, every living and dead tree 12.5 cm (5 in) or greater in diameter at DBH is marked with a numbered metal tag attached to the base of the tree (buttress root). The azimuth and distance from subplot center to the midpoint of these trees also is recorded. For each tree within the subplot the following variables are measured (methods below): tree status, DBH, tree number, live crown ratio, crown density, crown dieback, foliage transparency, crown light exposure, tree vigor/condition, crown class/position, tree damage, and % beech scale coverage. Intensive plots are re-sampled annually.

A brief description of each measured variable is provided below. Unless otherwise stated, variables listed are measured in both extensive and intensive plots.

Tree Status—Tree status is the condition of the tree at the time of sampling. It is determined using the following codes: 1=live tree; 2=dead tree; 3=removal; 4=missed live tree; 5=missed mortality tree; 6=missed dead tree; and 7=no history (USDA Forest Service 2006).

DBH—DBH is recorded to the nearest 0.1 cm using a metric diameter tape at 1.37 m from ground level on the uphill side of the tree. Standardized methods to handle DBH measurements in unusual circumstances follow Forest Inventory Analysis (FIA) protocol (USDA Forest Service 2006).

Tree Number and Location—An aluminum tag is placed at the base of each American beech tree sampled in extensive plots. In intensive plots, each tree greater than 12.5 cm receives a base tag. Trees are mapped spatially using GPS coordinates.

Live Crown Ratio (LCR)—LCR is recorded in both plot types as a percentage determined by dividing the live crown length by the total live tree height, according to FIA protocol (USDA Forest Service 2006).

Crown Density—Crown density estimates the amount of plant material, such as leaves, branches and fruit that block skylight from shining through the tree crown. It is measured as the % of total light that is blocked by tree material, according to FIA protocol (USDA Forest Service 2006).

Crown Dieback—Crown dieback is measured as the % of branch tips in the crown that are dead, according to FIA protocol (USDA Forest Service 2006).

Foliage Transparency—Foliage transparency measures the amount of light that shines through the live portion of a tree's crown as a % of total light that would be visible if the light were unblocked, according to FIA protocol (USDA Forest Service 2006).

Crown Light Exposure—Crown light exposure estimates the number of sides of the tree that would receive direct sunlight if the sun was directly above the tree, according to FIA protocol (USDA Forest Service 2006).

Tree Vigor/Condition—Each of the 30 beech trees in extensive plots and all trees in the intensive plots greater than 12.5 cm DBH are assigned a tree crown condition rating from 1 to 8 based on the amount of dead wood in the crown.

Crown Class/Position—Crown class/position is recorded for each tree and is a composite of light exposure and tree height (USDA Forest Service 2006). Values range from 1 (open-grown) to 5 (overtopped).

Tree Damage—Identifying the signs and symptoms of damage provides valuable information concerning the forest condition and indicates possible causes of deviation from expected conditions. Damage signs and symptoms are only recorded if, by definition in FIA protocol (USDA Forest Service 2006), the damage could kill the tree or affect the long-term survival of the tree.

Beech Scale Measurements—Presence or absence of the beech scale is recorded for each American beech tree in both plot types. If the scale is present, there are a number of other measurements recorded at the tree level. The level of scale infestation is the first of these measures. Infestation level is estimated using a transparency frame of size 12.5 cm x 28 cm that is placed on the northern, eastern, southern, and western sides of the bole of the tree at a level of 1.5 to 2.0 m above the ground. The level of infestation is recorded as a percentage of the tree bark covered by scale. The presence or absence of both tarry spots and *Nectria* fungi spores is recorded. The lower bole of the tree from approximately 0.33 m up to 2.0 m is examined for signs of *Nectria* fungal spores and tarry spots. Discolored foliage and the amount of foliage that is affected is recorded if 30% or greater of the foliage is affected.

Results and Discussion

The following analysis is from the results from sampling of extensive plots conducted during 2007 (i.e. those established in 2001 and re-sampled in 2004) and sampling of intensive plots conducted during 2006 and 2007. While all intensive plots were sampled in

2006, only 42 of the 62 intensive plots were sampled in 2007, largely because of illness of the PI. Nonetheless, the 42 intensive plots sampled during 2007 provide excellent coverage of established plots in Michigan. We detected some observer bias in certain estimates of stand and tree health (e.g. transparency, dieback, and crown density) that may influence the comparison of measurements among sampling years. As a consequence, we have chosen to analyze some of the 2007 data independently, while other data can be safely analyzed and compared among years.

<u>1. Distribution and Severity of Infestations.</u> Between 2005 and 2007, BBD has continued its spread throughout Michigan's northern hardwood forests. In 2007, 59% of the plots in Michigan's BBD monitoring system had documented scale presence (9 new plots), compared to 54% in 2005, 36% in 2004 and 30% in 2001. A caveat here is that not every plot was sampled every year, due either to time restrictions, safety or changes in the forest management type (a recent harvest, for example). In the first several years of the project, there was a more significant spread of beech scale in the LP compared to the UP, as many of the plots in the UP were established in 2001 with beech scale already pervasive. Beech scale is still much more widespread in the UP compared to the LP. However, the concentrated severity of BBD in the Lower Peninsula (notably in the plots along Lake Michigan, Figure 3) has made it devastating in some areas. Beech scale is known to occur in 7 counties in the LP (Emmet, Grand Traverse, Leelanau, Oceana, Mason, Manistee, and Wexford) and 5 counties in the UP (Alger, Chippewa, Luce, Mackinac, and Schoolcraft). In recent years, the majority of the newly infested plots have been located in the Upper Peninsula, correlated with more areas of moderate to high beech density (Figure 3).

Overall, BBD in Michigan continues to expand in distribution and increase in severity. Infestation levels (measured by the scale index) in plots previously noted with scale have generally increased from moderate to high (Table 1). Counties in the Lower Peninsula with new or increasing infestations included Mason, Oceana, and Wexford Counties (Table 1). For example, scale was observed for the first time in Plot 10 in Wexford County, the most northerly observation of scale in the county to date. Although scale infestations on individual trees in Plot 10 were still quite low, 48% of trees in the plot were already infested by the first recording of scale in 2007 (Table 1). On a brighter note, a few plots that exhibited low scale infestation intensities during 2004, 2005, and 2006 appeared to be free of scale in 2007. We conclude that scale spread following establishment within a stand, although clearly the norm is not a foregone conclusion. We also note that some stands with a high proportion of infested trees nonetheless exhibit low infestation levels within individual trees (i.e. the proportion of the bark covered by scale remains quite low over several sampling seasons).

Elsewhere in the Lower Peninsula, mortality of beech has increased most dramatically in Ludington State Park (where up to 100% of trees exhibit infection in some plots) and basal area of dead trees is near that of live beech trees (mean 3.1 m2 Ha-1 dead and 3.5 m2Ha-1 live). We noted potential infection in one plot in Benzie County, in the form of dried *Nectaria spp*. on beech trees. Future surveys will be required to monitor possible infection in the county which remains putatively scale-free.

More severe infestations have occurred in the Upper Peninsula, in conjunction with a more rapid spread of the killing front of the disease. Luce and Mackinac Counties are heavily infected and several new cases were found north of the previous boundary in Schoolcraft County, most notably in Pictured Rocks National Park (Table 1). New infections were noted in plots 108, 109, 113 (all around Pictured Rocks) and at plot 121 near Manistique in southern Schoolcraft County. A low scale index in plot 121, with the health of scale trees averaging that of non-scale trees (mean transparency of 15%) indicates a very recent infection. Although it already has a high scale index, the infestation in plot 108 is recent as well, and has not yet had an effect on tree growth: average DBH for beech is up from 34.6cm to 35.2cm, and transparency and dieback have both decreased (transparency from 30% to 18%). A more rapid spread of scale in the county may be due to high public use of the park and transportation of scale into remote areas.

In Tahquamenon Falls State Park where over 90% of the beech overstory is either dead or severely declining, scale index has increased and tree health has decreased dramatically. Mortality is so high in some UP plots that it is skewing the scale index that we have been using to this point. This is shown in Figure 4, where the scale index appears to be declining in the UP over time. Trees with the heaviest infestations have already died, and dead trees are not included in the scale index. As a result, only trees with lower infections remain, making it appear as though the health of these stands is improving (Figure 4). Figure 5 illustrates that declines in scale index between 2004 and 2007 are associated with high rates of beech mortality. In the UP, therefore, a decrease in scale index correlates with a higher dead basal area of beech rather than an increase in stand health. One recommendation to emerge from our analysis this year is to develop a new scale index that captures in a single value the impact of past infestation as well as the current state of infestation. We will explore the development of such an index in future analyses. The alternative is to consider past and current infestation separately, with different indices. Rather trivially, scale index will decline to zero if and when no beech remain alive in a stand.

Despite the rising beech mortality in the UP (and their concomitant loss as "infected trees"), most UP counties are still exhibiting increases in the percentage of trees infested and the severity of those infestations. Simply put, the disease is getting worse and more mortality will very likely follow. For example, in plot 123 in Luce County, the number of dead beech trees increased from 2 to 10 trees in a single year (from 2006 to 2007); this represents a substantial increase in dead basal area. Infection levels in Chippewa County have been relatively low (compared with high scale index counties further west in the UP) but surveys in 2007 documented severe infection in two new areas (Table 1), indicating a rapid movement of scale north-east in the county toward Whitefish Bay.

2. Effects on Tree and Stand Health. Beech scale tends to occur at highest densities on trees with the greatest surface area, as reported in previous years when the heavier scale cover was on larger diameter trees. New analyses now show that the average diameter of infected trees has fallen from 31.1cm to 28.67 cm between 2004 and 2007 (Table 2). This indicates that the larger beech trees that were infected in the advancing front of the disease have died, leaving behind smaller diameter trees that are also infected.

Beech bark disease weakens trees, leaving them more susceptible to damage and other infections. In 2007, a higher percentage of beech trees exhibiting scale infection showed evidence of other kinds of damage than did trees without scale (56% compared with 46%, Table 2). It is important to note that only live trees with obvious scale were factored into this analysis. However, a comparison of damage on all beech trees, between diseased and disease-free stands, shows an even stronger pattern; 65% of beech trees in diseased stands show evidence of other kinds of damage whereas only 38% of beech trees in disease-free stands show evidence of damage. It is not possible to tell from these data alone if BBD is responsible for increasing beech susceptibility to other kinds of damage. It is certainly possible that beech trees that appear to be disease-free may be weakened by low-level infections invisible to the observer. Conversely, stands with a propensity toward other kinds of damage may be more susceptible to BBD infection. Detailed temporal analysis of changes in damage over time may distinguish between these possibilities.

Higher damage indices have also been recorded on other tree species (notably, ash and basswood) in scale-infested plots than on the same tree species in plots without scale present (Figure 6). Again, it appears as if the presence of scale in the stand in some way compromises the health of other tree species. However, as we just noted, it is possible that trees in stands with a propensity for damage are in some way susceptible to scale. In this particular case, our previous years of sampling may provide an indication of what is taking place; in years 2001 through 2004, scale infestation was negatively associated with damage to other tree species, suggesting perhaps that declines in beech health had a positive impact on other species. This early result is not consistent with the hypothesis that damaged stands *per se* are in some way better for scale. Rather, we suggest that ongoing beech mortality after several years of infestation changes forest stand structure in a way that results in more damage to associated tree species. Detailed studies should be designed to investigate this phenomenon in more depth.

Beech trees in stands infested with BBD show declines in all measures of vigor and canopy health (Figure 7). For example, DBH, crown density, and live crown ratio of beech trees all decline if stands are infested with BBD. In concert, measures of crown transparency and dieback increase with infestation (Figure 7). We should note, however, that the loss of severely infested beech trees from stands will leave behind those that have lower levels of infestation, reducing the apparent difference in canopy health between infested and un-infested stands (dead trees are not included in measurements of canopy health). As a result, the differences shown in Figure 7 will greatly underestimate the effects of BBD on canopy health as mortality rates start to rise and severely infested trees are lost to mortality. We recommend that crown variables are always analyzed along with basal area of living and dead trees to get a more representative picture of the status of a particular stand.

It has already been noted that the Scale Index will decrease over time in stands that are suffering significant mortality from BBD because the dead trees are no longer measured as part of the scale index (Figures 4 & 5, above). Similarly, declines in Scale Index between the 2001, 2004 and 2007 samples are associated with an overall decrease in beech basal area (Table 3), and subsequently less host area for the scale to infest. Stands dominated by beech (> 20% basal area) are highly vulnerable to damage and exhibit an increase in beech dead basal area in plots with scale. The proportion of total dead beech basal area has increased drastically from 43% in 2004 to 59% in 2007. Areas with higher basal area (greater DBH and overall greater proportion of beech) have a higher scale index than those without. This is especially clear if large, old and/or decayed trees are abundant. As the beech trees are decimated (largely the greater DBH trees) and the scale level drops from high to low, there is a greater chance of recovery in the future, with some of the smaller diameter trees surviving the infestation and in time, growing to become more dominant trees. It is strongly recommend that future surveys measure the rate of beech recovery in areas with high mortality, especially where smaller diameter trees have withstood the killing front and have low scale cover. There may also be some trees that are resistant to the disease, as is suggested by the occurrence of plots with little to no scale, surrounded by high infestation areas (as witnessed in some areas of the LP).

Future work

Further sampling was completed of intensive and extensive plots during the 2008 field season. These data will be analyzed in the future to further monitor the spread and effects of BBD infestations, and will include a consideration of directionality of spread and its potential causes. Continued monitoring will be conducted by another Michigan research institution, as Dr. John Witter, the Primary Investigator at the University of Michigan, will not be able to complete the study. The continuation of this project is crucial, and offers the unique opportunity to study closely the aftermath effects of beech bark disease in Michigan's forests, as the disease progresses.

Conclusions

Beech trees are an integral part of northern hardwood forests, as a source of food for wildlife and of wood for furniture, although it's most significant role is as a climax species. Beech-maple forests were once much more widespread across the United States, but forest clearing and fragmentation have reduced their cover. In most of the forested areas in the Eastern U.S. where beech is still prevalent, beech bark disease has become endemic. Evidence shows that the loss of large overstory beech changes the growth pattern of other species, such as a decline in the regeneration of sugar maples, ultimately affecting the structure and composition of these forests.

Data collected for the 2007 stage of the Beech Bark Disease Monitoring and Impact Analysis System in the state of Michigan revealed beech scale infestations in numerously previously undetected areas, with several new areas of infestation found further west and north of the previous boundary. The contiguous nature of forested land in the Upper Peninsula favors the scale method of spread, leading to a more rapid increase in cover. In areas of heavy beech mortality, such as in Mason county (where Ludington State Park is located) and Chippewa county (specifically the Tahquamenon Falls State Park area), the understory is characterized by thickets of beech saplings that prevent regeneration of other tree species.

Reduced average diameter of live beech trees in diseased plots indicates a shift of the disease pattern into the aftermath stage. The mean diameter of infected trees fell from 31.1cm to 28.67 cm from 2004 to 2007. While the disease is slowing down the radial growth of infected trees, it is important to note that trends are mainly due to an increase in infection of smaller diameter trees as high mortality of older, larger diameter trees occurs.

Beech bark disease presence and severity is very important in its effect on beech tree radial growth, but it is important to remember that numerous other factors are components of annual wood growth, such as the presence of other insects or diseases, inadequate nutrient supply, competition, available light levels, and weather conditions. Of these factors, the most important in terms of effect on annual radial growth is precipitation levels and average temperatures to which beech are exposed to in a given year (Fritts 1958, Tardif et al 2001). Much of the Michigan had experienced levels of severe to extreme drought by the end of summer 2007, and in Michigan, this was particularly pronounced in the Upper Peninsula (NOAA report, August 2007). By the end of 2007, Marquette, Michigan had experienced its driest summer on record, receiving 7.20 inches of rain. The previous record was a total of 8.28 inches in May-August 1998. This reduced precipitation during the years prior to data collection on beech radial growth over the last seven years (the duration of the BBDMIAS project) may account for slower radial growth in recent years.

Drought summer months, along with warmer winters has also likely contributed to the increase in scale intensity and subsequent mortality. The already weakened trees are more susceptible to attack from disease. In areas of northern Michigan where the scale insect may have been limited by low winter temperature, the harsh conditions have given way to a milder climate, favoring the overwintering stage.

Overall, negative effects on tree and stand health due to beech scale and BBD were visible throughout Michigan's northern hardwood forests. Higher levels of beech mortality were positively correlated with stands with scale. Higher levels of crown dieback, poor crown transparencies, and higher levels of damage were also associated with the infected trees.

Despite the research that has been done on beech bark disease, there is still a great deal unknown. The first sign of BBD infection is the "white wool" covering of the scale on the bark. However, *Nectaria* is more difficult to detect, and so better means of identifying and quantifying perithecia are sorely needed.

In the forests in eastern North America where beech bark disease has passed into its aftermath stage, root sprouts from trees that have succumbed to beech snap (which occurs when rot has so heavily damaged the cambium that the weight of the tree causes it to snap somewhere along the bole) have become part of the overstory. The disease has, unfortunately killed off many of the large old trees that dotted the landscape. However, some trees have been left uninfected, and tests have shown that there is a genetic resistance in some beech trees to the devastating effects of the disease. While it may not be practical to replant large forested areas via propagation, an effort should be made to plant small-size stands, in the near future, with these genetically BBD-resistant trees. Removal of infected or susceptible trees from newly infested stands along the western front of the disease, and diligent monitoring to assure that the trees remain scale free, might be the best way to keep the disease isolated to present populations. It is realistic to say that the resources necessary to eliminate the disease from most heavily infested stands is not available, and so it will inevitably take its toll in these forests.

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Table 1. Levels of beech bark disease recorded in long-term monitoring plots in Michigan. Sites in bold are those in which scale was detected for the first time during 2006 or 2007 surveys.

County	Plot ID	Trees With Scale (%)	Mean Scale Cover (% per tree)	Scale Index	Infestation Level
Alger	**113**	**6.7**	**8.1**	**7.4**	**Low**
Alger	122	100	27.9	63.9	High
Alger	173	69	5	5.1	Low
Alger	190	23.3	1	12.2	Low
Charlevoix	77	3.3	3.8	3.5	Low
Chippewa	126	94.1	22.4	58.2	High
Chippewa	128	92.6	12.1	52.3	Moderate
Chippewa	**129**	**66.7**	**7.9**	**37.3**	**Moderate**
Chippewa	131	6.7	0.1	3.4	Low
Chippewa	132	100	16	58	High
Chippewa	134	93.3	34.1	63.7	High
Chippewa	178	96.6	20.3	58.4	High
Chippewa	179	69	7	38	Moderate
Chippewa	180	53.3	8.4	30.8	Low
Chippewa	**197**	**100**	**13.3**	**56.6**	**High**
Emmet	71	36.7	2.7	19.7	Low
Emmet	75	10	2.5	6.3	Low
Leelanau	62	3.3	5	4.2	Low
Luce	101	92.3	6.8	49.6	Moderate
Luce	102	96.7	22.6	59.6	High
Luce	104	96.7	21.4	59	High
Luce	105	100	22.3	61.2	High
Luce	106	93.3	17.9	55.6	High
Luce	107	20	22.1	27.6	Low
Luce	123	100	14.4	57.2	High
Luce	124	90	10.2	50.1	Moderate
Luce	125	63.3	8.1	35.7	Moderate
Luce	127	96.7	27.2	61.9	High
Luce	153	93.1	12.7	52.9	High
Luce	158	96.7	13.4	55.1	High
Luce	159	72.4	7.7	40	Moderate
Luce	160	100	10.4	55.2	High
Luce	161	100	14	57	High
Luce	162	100	15.9	58	High
Luce	163	93.3	17.2	55.3	High
Luce	164	93.1	12.5	52.8	High
Luce	165	100	12.8	56.4	High
Luce	181	93.3	4.8	49	Moderate
Luce	182	10.3	3.4	6.9	Low
Luce	185	96.7	8.9	52.8	High
Luce	195	90	4.5	47.3	Moderate
Luce	196	96.7	7.5	52.1	Moderate
Luce	200	93.3	5.7	53.3	High

Mackinac	130	60	5.6	32.8	low
Mackinac	135	96.7	9.3	53	High
Mackinac	136	13.3	0.2	6.8	Low
Mackinac	137	45	0.9	14	Low
Mackinac	138	75	28.1	51.6	High
Mackinac	139	3.3	0	1.7	Low
Mackinac	140	100	25.8	62.9	High
Mackinac	147	96.6	12.2	54.4	High
Mackinac	148	100	12.7	56.4	High
Mackinac	149	96.7	11.9	54.3	High
Mackinac	150	100	16	58	High
Mackinac	151	100	7	53.5	High
Mackinac	152	100	12.7	56.3	High
Mackinac	154	85.2	12.5	48.8	Moderate
Mackinac	155	100	14.2	57.1	High
Mackinac	156	90	10.1	50.1	Moderate
Mackinac	157	56.7	6.8	31.7	Low
Mackinac	198	100	23.5	61.8	High
Mackinac	199	20	0.6	10.3	Low
Manistee	29	26.7	0.5	13.6	Low
Manistee	30	3.3	0.1	1.7	Low
Manistee	52	6.7	16.9	11.8	Low
Manistee	54	10	2.9	6.5	Low
Mason	19	0.7	13	54.5	Moderate
Mason	20	83.3	9.4	46.4	Moderate
Mason	21	96.6	13	54.8	High
Mason	25	83.3	22.7	53	High
Mason	26	78.6	18.3	48.4	Moderate
Mason	27	93.1	8.7	50.9	High
Mason	46	100	17.5	58.8	High
Mason	47	96.6	24.4	60.5	High
Mason	48	100	18.9	59.5	High
Mason	49	39.3	3.9	21.6	Low
Mason	50	95.2	15.3	55.2	High
Mason	51	100	19.6	59.8	High
Mason	53	53.3	8.2	30.8	Low
Mason	82	100	6.7	53.3	High
Newaygo	45	10.3	3.8	7	Low
Oceana	24	24.5	3	12.7	Low
Oceana	39	68	23.5	47.3	Moderate
Oceana	40	86.7	9.5	48.1	Moderate
Oceana	41	44.8	6.3	25.6	Low
Oceana	42	7	2.3	5	Low
Oceana	43	73.3	7.2	40.2	Moderate
Oceana	44	43.3	3.4	23.3	Low
Schoolcraft	**108**	**96.7**	**22.6**	**59.6**	**High**
Schoolcraft	**109**	**3.3**	**16.3**	**9.8**	**Low**
Schoolcraft	**121**	**53.3**	**2.1**	**4.6**	**Low**
Schoolcraft	**186**	**100**	**31.9**	**65.9**	**High**

Schoolcraft	188	10	0.5	5.3	Low
Wexford	**10**	**48.3**	**5.6**	**27**	**Low**
Wexford	55	33.3	4.9	19.1	Low
Wexford	56	16.7	5.3	11	Low
Wexford	57	3.6	3.8	3.7	Low
Wexford	58	40	2.2	4.6	Low
Wexford	**83**	**10**	**2.5**	**6.3**	**Low**

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Table 2. A comparison of the growth and health of beech trees with and without beech scale during field sampling in 2007. In all cases, beech trees with scale exhibit lower indices of growth and health.

2007	Without Scale				With Scale			
	Mean	SD	Min	Max	Mean	SD	Min	Max
DBH (cm)	33.49	15.59	20	50.67	28.67	11.81	16.5	41.7
LCR (%)	58.77	22.84	30.65	81	51.58	24.18	44.88	79.75
Crown Density (%)	59.45	10.04	31	74.97	53.22	10.81	32.2	75.67
Dieback (%)	4.45	7.12	1.88	13.66	7.71	9.7	1.02	25.87
Transparency %	17.8	8.74	10.56	12.74	21.93	11.54	0.85	46.89
% Trees w/ Damage	46.67		20.9	77	56.42		16.98	89.58

Table 3. Changes from 2001 through 2007 in the basal area of living and dead trees in BBD monitoring plots with and without scale infestations. Note the rapid increase in dead beech basal area in plots infested with BBD.

2001	***Scale Absent***	***Scale Present***
	Mean	**Mean**
BA All Species		
Live BA	30.2	30.1
Dead BA	1.2	2.5
Live + Dead BA	31.4	32.7
% of Total BA Dead	3.7	7.2
BA Beech Only		
Beech Live BA	7	9
Beech Dead BA	0.21	0.96
Beech Live+Dead BA	7.2	9.9
% of Total Beech BA	22.8	30.6
% of Total Dead	17.1	34.3

2004	***Scale Absent***	***Scale Present***
	Mean	**Mean**
BA All Species		
Live BA	34.2	34.4
Dead BA	1.2	2.5
Live + Dead BA	35.4	36.9
% of Total BA Dead	3.2	6.7
BA Beech Only		
Beech Live BA	7.2	9.7
Beech Dead BA	0.2	1.3
Beech Live+Dead BA	7.4	11.1
% of Total Beech BA	20.1	30.8
% of Total Dead	20.2	43

Table 3, cont.

2007	***No Scale*** **Mean**	***Scale*** **Mean**
BA All Species		
Live BA	27.21	25.75
Dead BA	1.31	2.34
Live + Dead BA	28.52	28.1
%of Total BA Dead	4.26	8.23
BA Beech Only		
Beech Live BA	5.73	5.96
Beech Dead BA	0.24	1.29
Beech Live + Dead BA	5.97	7.25
% of Total Beech BA	19.61	26.82
% of Total Dead	16.75	58.96

Figure 1. Two common arrangements of the 30 sampling points per transect matrix for Extensive Sampling Plots used for beech bark disease monitoring.

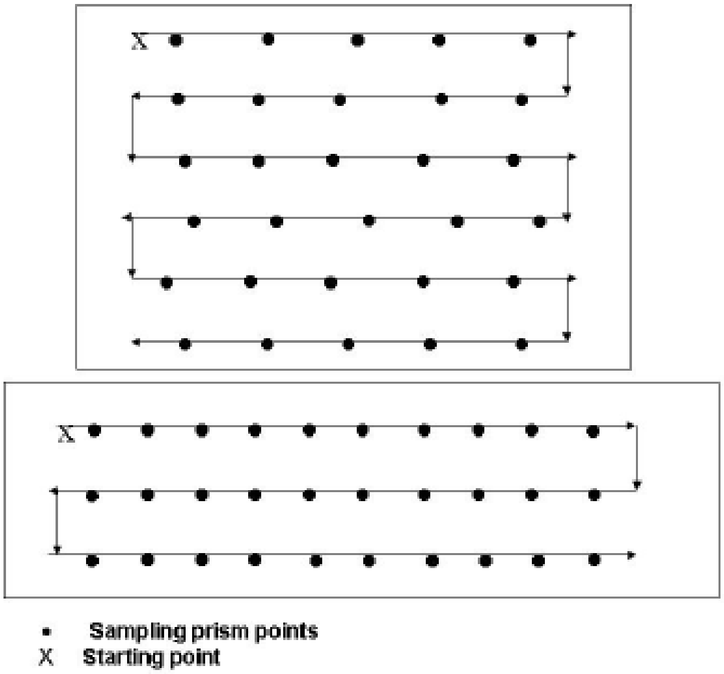

Figure 2. The subplot design for Intensive Sampling Plots used in beech bark disease monitoring.

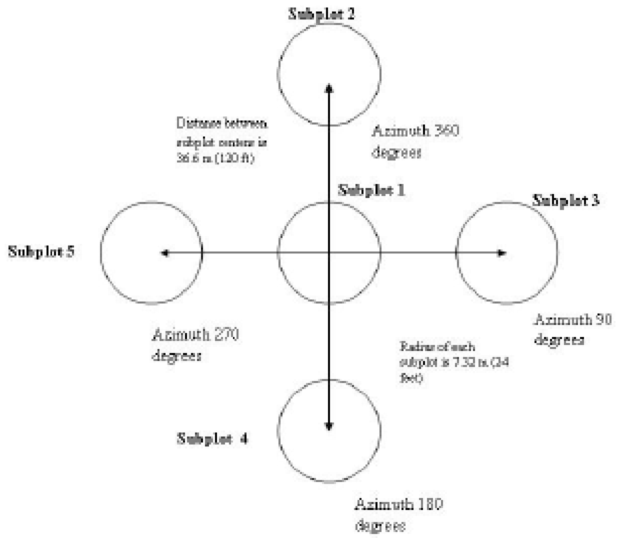

Figure 3. The distribution and severity of beech bark disease among sample plots in Michigan during 2007 surveys.

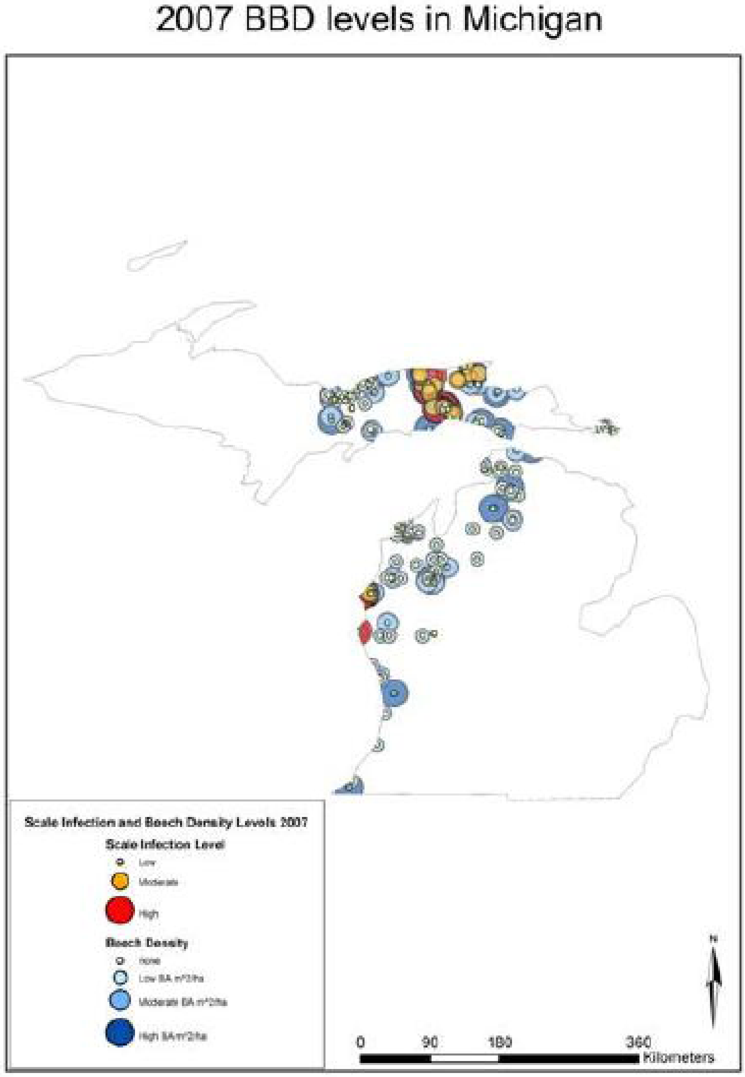

Figure 4. Change in Scale Index between 2003 and 2006 averaged across all infested sites in the Upper Peninsula (UP) and Lower Peninsula (UP). The scale index is determined by summing the measures of infection on each tree, to determine a measure of percent cover at the plot scale.

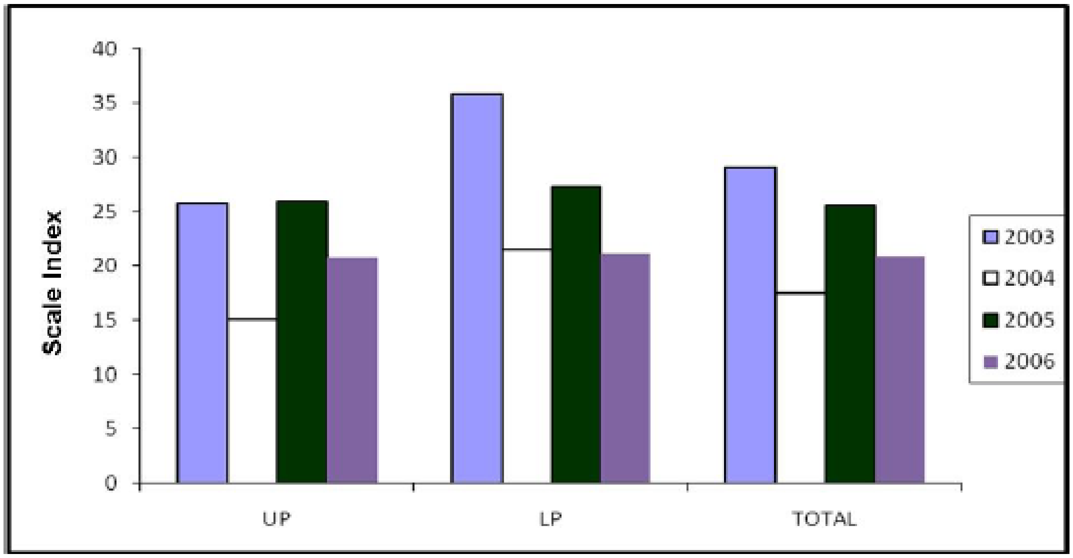

Figure 5. Changes from 2004 to 2007 in scale index and the number of dead trees in BBD sampling plots. Note that declines in scale index (negative values) are generally associated with significant tree mortality which leaves only lightly-infested trees remaining in the stand.

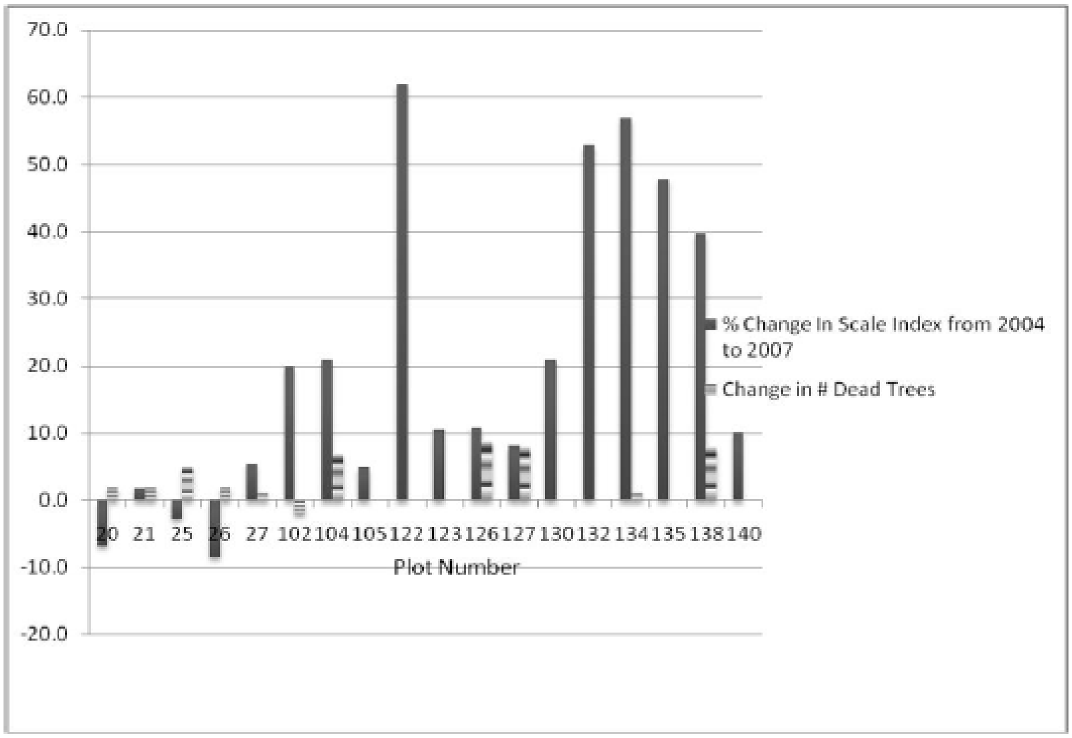

Figure 6. Damage from sources other than BBD to common trees species in northern hardwood stands in Michigan. Stands with BBD absent are represented by dark bars while stands with BBD present are represented by light bars. Note that the presence of BBD on beech appears to increase levels of other kinds of damage on some trees species that are not susceptible to the disease.

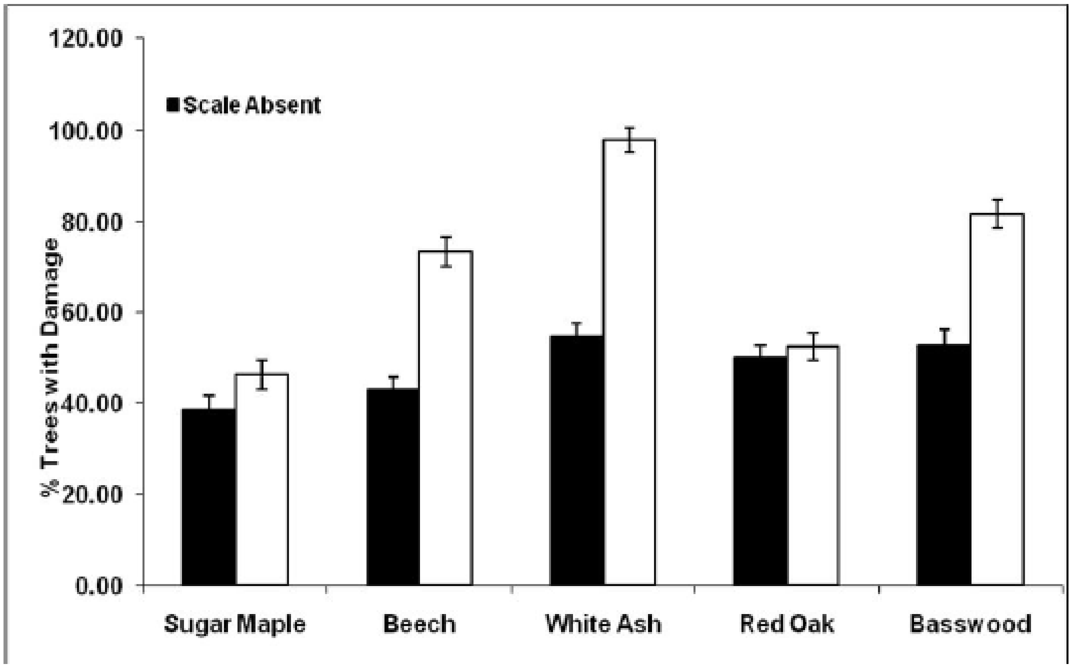

Figure 7. Indices of beech tree health in forest stands with and without infestations of beech bark disease. Data are from 2007 sampling. Notice the decline in indices of health with BBD infestation.