A Land Manager's Guide to Beech Leaf Disease in Michigan

Prepared By: Vincent Ader, Lauren Bennet, Ilse Hassler, Daniel McConnell, Jenna Nutter

SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY
UNIVERSITY OF MICHIGAN

MATTHAEI BOTANICAL GARDENS AND NICHOLS ARBORETUM
UNIVERSITY OF MICHIGAN

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Executive Summary

This report is intended to provide information that will aid in the management of beech leaf disease (BLD), a novel forest disease affecting American beech trees (Fagus grandifolia). The first section provides background information about American beech and BLD, including identification and current distribution. In this section, we summarize what is currently known about BLD while emphasizing major existing knowledge gaps. We also discuss the ecosystem services and economic value that American beech provide, demonstrating the negative consequences of their potential widespread loss. Finally, the first section presents a risk assessment for BLD in Michigan, examining the distribution of American beech habitat and BLD-suitable climatic zones. The second section provides an overview of management strategies for BLD, including prevention, detection, reporting, monitoring, treatment, and educational outreach. Because BLD is a novel disease, much remains unknown about which management practices are most effective. Therefore, we have presented a combination of practices that are 1) generally applicable for forest pest or pathogen management, 2) the current best practice given what is known about BLD, or 3) currently under development. In the third section of the report, we summarize a pilot study conducted in the summer of 2023. This was included to demonstrate the implementation and use of long-term monitoring plots, and to provide an overview of the current status of BLD in Michigan. We conclude with a discussion of stakeholder needs, identifying areas where additional work and knowledge is needed.

Image: The 2023/2024 BLD Master’s Project Team

Statement of Purpose

This report summarizes the information currently known about beech leaf disease, including its impact on human and natural systems, and provides guidance on how to manage it. It also gives an overview of the status of beech leaf disease in Michigan as of Fall 2023. It is our hope that, armed with this information, readers will take action to help minimize the threat posed by this disease to American beech and their dependent organisms. While the intended audience is primarily land managers in Michigan, much of the content is broadly applicable and of use to a variety of stakeholders.

Key Terms

Beech leaf disease.. BLD
Litylenchus crenatae mccannii... LCM
Fagus grandifolia.. American beech

Acknowledgements

Image: The BLD field crew standing near a beech tree sign in Waterloo State Recreation Area.

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Part 1. Beech Leaf Disease

1.1 INTRODUCTION

American beech (Fagus grandifolia) is a common, broadleaved, deciduous tree that is easily identified by its smooth gray bark, papery leaves, and long buds (Figure 1). It is a large, slow-growing, and long-lived species, growing 80 to 120 feet tall and 18 to 50 inches in diameter at breast height, on average, and living as long as 400 years (Carpenter, 1974). The native range of American beech includes most of the eastern United States, as well as the southeast edge of Canada (Carpenter, 1974; Tubbs & Houston, 1990) (Figure 2). American beech occurs most densely in the Appalachian Mountains, particularly in east Kentucky, West Virginia, north-central Pennsylvania, northern New York, Vermont, New Hampshire, and Maine (Selvi, 2023; Wilson et al., 2012) (Figure 3). Within Michigan, American beech is dense in the northern lower peninsula and eastern upper peninsula, sparse in the southern lower peninsula, and nonexistent in the western upper peninsula (Wilson et al., 2012) (Figures 3 & 4). It prefers mesic, nutrient-rich forests, where it typically grows in mixed stands with other northern hardwood species (Carpenter, 1974; Tubbs & Houston, 1990). American beech is the only species of beech native to North America (Tubbs & Houston, 1990), though European (F. sylvatica), Oriental (F. orientalis), and Chinese (F. engleriana) beech are widely planted as ornamentals (Martin & Volk, 2021).

Figure 1. Identification of American beech (Allison, 2022).

Figure 2. The native range of American beech (Carpenter, 1974).

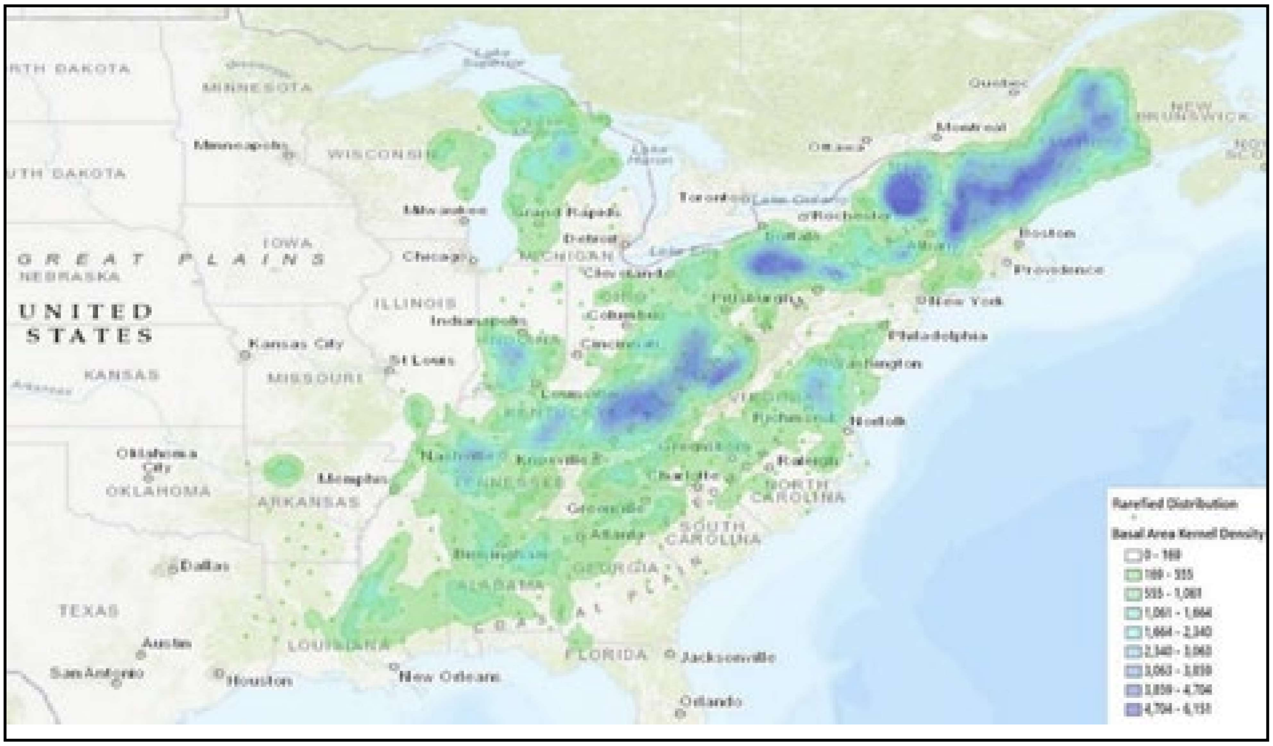


Figure 3. The distribution of American beech in the United States (Selvi, 2023; Wilson et al., 2012). A basal area kernel density estimation is shown overlaying the range of American beech (green dots). Blue areas indicate where beech is most dense. Data were acquired from the Forest Inventory and Analysis program via Wilson et al., 2013.

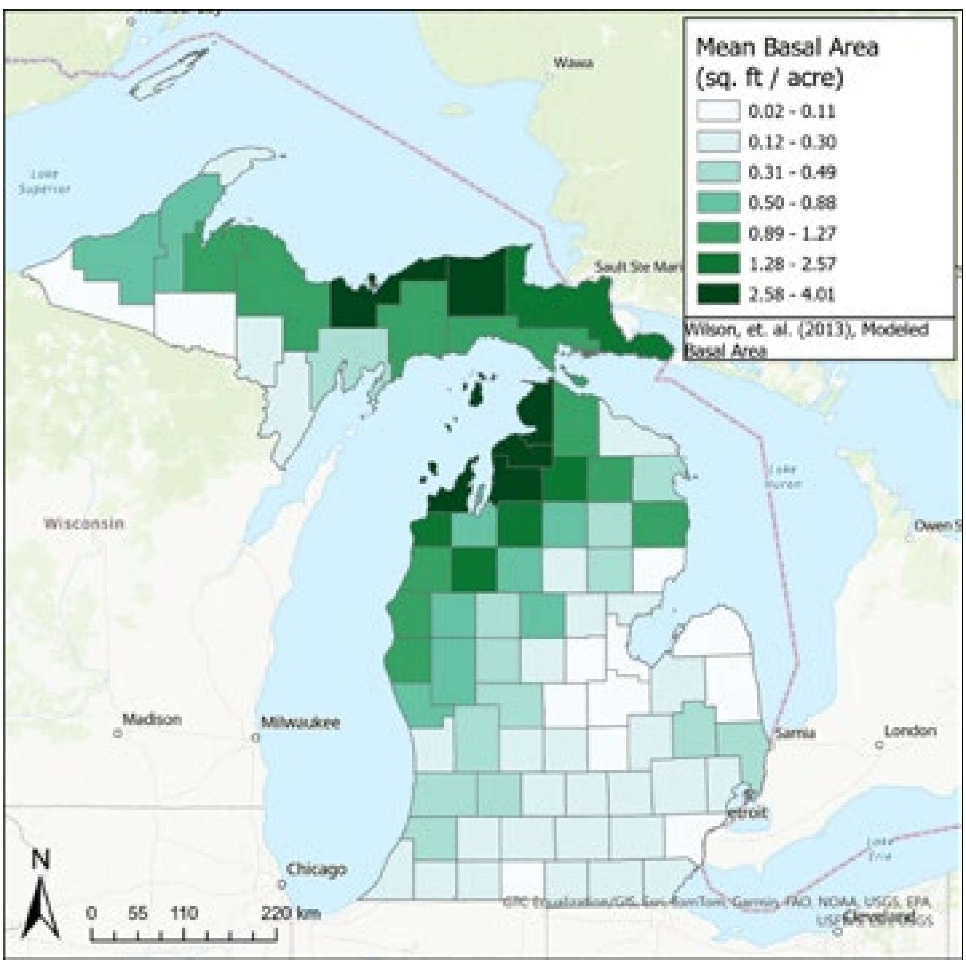


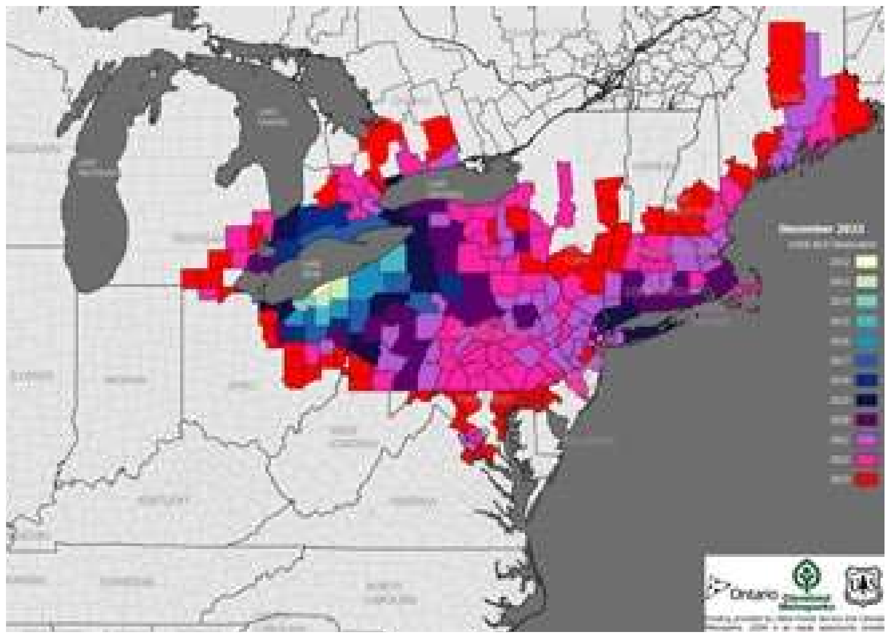
Figure 4. The mean basal area density of American beech per county in Michigan. This figure is intended to show relative densities throughout southern and northern Michigan. Basal area is skewed low due to zonal statistics by county reducing the mean. Data were acquired from the Forest Inventory and Analysis program via Wilson et al., 2013.

1.2 Beech Leaf Disease

1.21 Disease Emergence and Progression

Beech leaf disease (BLD) was first observed in Lake County, Ohio in 2012, and has since spread across much of the northeast United States. As of December 2023, the disease had been documented in fourteen states and one Canadian province, including: Connecticut, Delaware, Massachusetts, Maine, Maryland, Michigan, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Virginia, Vermont, West Virginia, and Ontario (Figure 5). In 2022, BLD was identified in St. Clair, Oakland, and Wayne counties, marking the first observations in Michigan (Michigan DNR, 2022). In 2023, BLD was confirmed at additional locations in Macomb, Washtenaw, Lenawee, and Hillsdale counties. Figure 6 shows a map of known BLD-positive sites in Michigan as of 2023.

Figure 5. BLD distribution as of December 2023. Courtesy of the Ontario Ministry of Natural Resources and Forestry, Cleveland Metroparks, and the U.S. Forest Service.



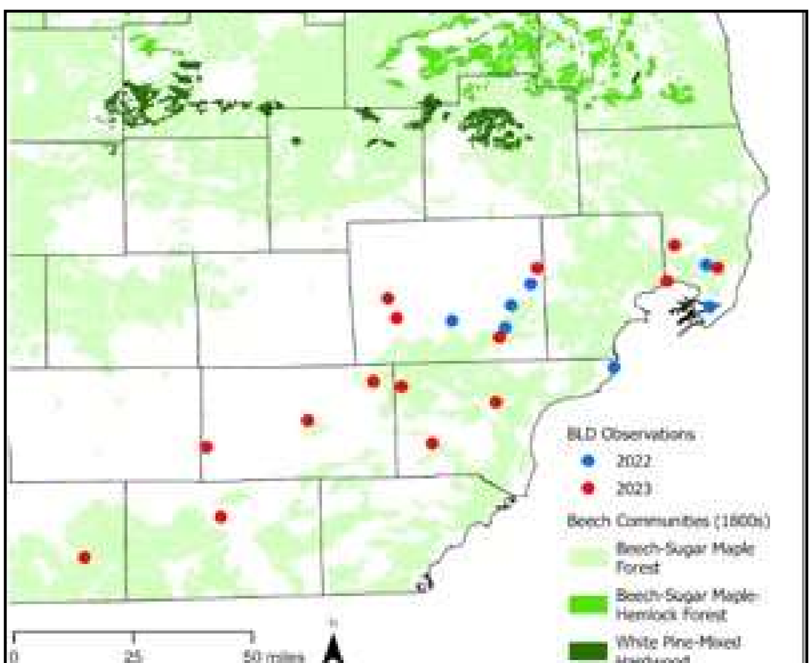


Figure 6. Known BLD-positive locations in Michigan and the year of first observation. Points are overlaid on beech-containing vegetative communities circa 1800s (Comer et al., 1995). Occurrence data for BLD were acquired by the Michigan DNR, Midwest Invasive Species Information Network, and our capstone project team.

1.22 Causal Agent

In 2019, BLD was definitively linked to Litylenchus crenatae mccannii (LCM), a microscopic foliar nematode (Carta et al., 2020). Inoculation of healthy American beech has indicated that LCM must inhabit developing buds for BLD symptoms to occur (Carta et al, 2020; Reed et al., 2020). L. crenatae is native to Japan, where it parasitizes Japanese beech (F. crenata) and causes leaf galls (Kanzaki et al., 2019). Notably, BLD symptoms have not been found on Japanese beech trees at the Holden Arboretum, which does have heavily symptomatic American beech (Carta et al., 2023). Though LCM and L. crenatae have nearly identical ribosomal DNA, differences in morphology and host range led to the decision to classify LCM as a separate subspecies (Carta et al., 2020). However, additional causal agents are suspected, particularly bacteria and fungi (Burke, 2020; Ewing, 2021). A possible bacterial connection is Wolbachia spp., a genus known to have symbiotic relationships with nematodes and arthropods (Carta et al., 2023; Ewing et al., 2021). In Michigan, LCM DNA has been identified in asymptomatic leaf tissues, an observation which could be explained by the existence of a secondary pathogen, although it could be due to an error in testing.

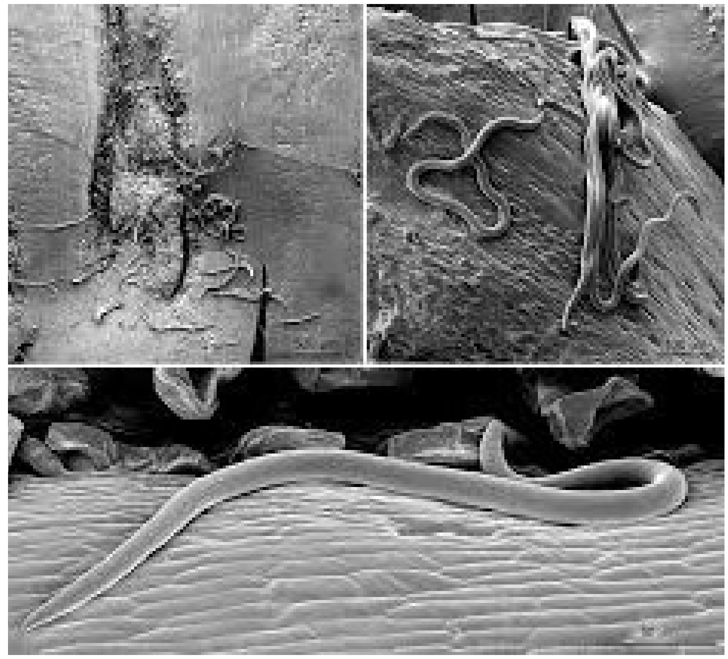


Figure 7. Electron microscope images of LCM eggs with adult females and adult females on bud sheaths (Carta et al., 2020).

Figure 8. Electron micrscope image of LCM (Carta et al., 2020).

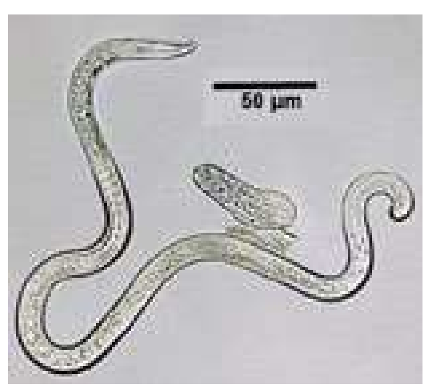


Figure 9. Litylenchus crenatae mccannii under a microscope (Carta et al., 2020).

1.23 BLD Pathway

The mechanism by which BLD moves from tree to tree and region to region is still unknown, though a few theories have been proposed. One theory under investigation is that moisture facilitates nematode movement. Previous studies have shown that moisture is necessary for the movement and survival of many plant pathogens. Carta et al. (2023) demonstrated that if LCM nematodes are placed in a moist chamber, they will move readily between symptomatic and asymptomatic leaves. Therefore, it has been proposed that rain, or even humidity, are contributing to the spread of BLD. Another suggestion is that nematodes are being transported by birds. A handful of bird species are known to feed on beech buds, including the tufted titmouse, black-capped chickadee, downy woodpecker, and purple finch (Carta et al., 2023). These birds could be picking up nematodes when they feed and then depositing them elsewhere, either in feces or directly from their mouths (Carta et al., 2023; Reed et al., 2020). The U.S. Forest Service has begun catching birds and testing their feces to see if LCM can survive being ingested. Another theory of transmission is that predatory arthropods like mites or ambrosia beetles are moving nematodes or their eggs (Carta et al., 2023; Ewing et al., 2021). Predatory oribatid mites with nematodes attached to them have been found on beech leaves, demonstrating that arthropods have the capacity to move nematodes (Carta et al., 2023). If Wolbachia is not a secondary cause of BLD, its symbiotic relationship with feather mites could explain its presence on symptomatic beech (Carta et al., 2023). Finally, wind and human activity are also possible modes of BLD transmission.

Figure 10. A life cycle diagram of the development of BLD from LCM nematode to symptomatic trees.

1.24 Symptoms

The most prominent BLD symptoms are dark green bands of thickened tissue between the leaf veins. In more severe cases, extreme leaf shrinkage and curling also occur (Ewing et al., 2019; Martin & Volk, 2021) (Figures 12 & 13). BLD also causes bud suspension (i.e. buds form but do not leaf out), reduced bud production, and premature leaf drop, leading to canopy thinning and eventual mortality (Martin & Volk, 2021; Ewing et al., 2019). It is common to see a mix of affected and unaffected branches in the same tree, and for symptoms to initially appear in the lower portion of the canopy (Ewing et al., 2019). Damage occurs within developing buds, so leaf banding and distortion are visible at leaf out and do not spread within a growing season (Ewing et al., 2021). However, damaged leaf tissue may turn chlorotic or necrotic throughout the growing season, shifting from dark green to yellow or brown (Reed et al., 2020) (Figure 14). BLD disproportionately affects saplings, killing them within 2-5 years, though occasional mortality of mature beech has occurred within 7 years (Martin & Volk, 2021; Reed et al., 2022). In addition to American beech, BLD symptoms have been observed on European, Oriental, and Chinese beech (Martin & Volk, 2021).

Figure 11. A beech leaf with extensive interveinal banding.

Figure 12. Beech leaves with moderate to severe BLD symptoms.

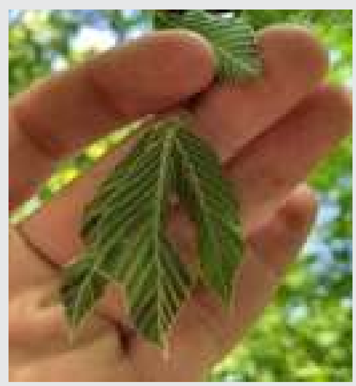
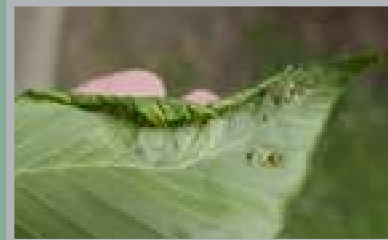


Figure 13. Curled beech leaves of an infected BLD tree.

Figure 14. This picture shows symptomatic leaves with interveinal bands that have turned chlorotic (yellow) or necrotic (brown). Photo credit: Sabrina Tirpak, Rutgers Plant Diagnostic Laboratory.

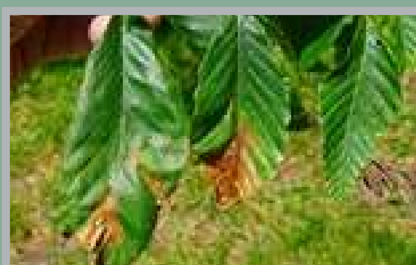
Beech Leaf Disease Lookalikes

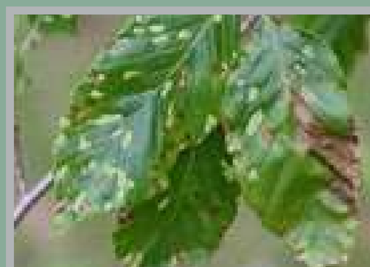
Beech Leaf Curl Aphid
-causes leaf curling and can cause yellowing (yellow banding as opposed to dark green)

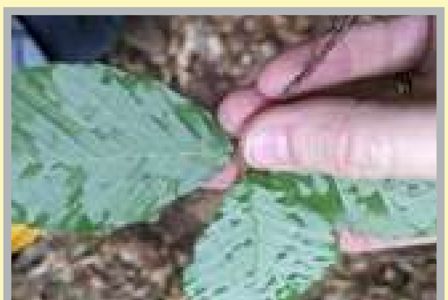


Erineum patch - caused by erophyid mites that create galls. These patches present as light green in the spring, and cycle through yellow, dark red, and brown in the fall. (NC State, 2019)

Anthracnose - a fungal disease that results in dark sunken spots on leaves and/or leaf curling or cupping.







Powdery Mildew - common in many plant species. This is a fungus that resembles talcum-powder in white or light grey.

1.3 IMPORTANCE OF AMERICAN BEECH

To fully grasp the threat that BLD poses, it is necessary to understand the value that American beech trees provide. American beech is one of the most abundant hardwood species in North America. Michigan alone has approximately 37 million beech trees greater than five inches in diameter (Michigan DNR, 2023). Across its range, American beech is a major component of three forest types (Sugar Maple-Beech-Yellow Birch, Red Spruce-Sugar Maple-Beech, and Beech-Sugar Maple), and a minor component of 17 others (Tubbs & Houston, 1990). Maple-beech-birch forests comprise nearly 30% (6.3 million acres) of Michigan's 20 million acres of forested land (Michigan DNR, 2022). Like all trees, American beech provide a plethora of ecosystem services, including supporting, regulating, cultural, and provisioning services (Figure 15). Many of these services have an associated economic value. Given this, it is easy to see how a loss of beech due to BLD would have tragic consequences for both human and natural systems.

1.31 Ecosystem Services

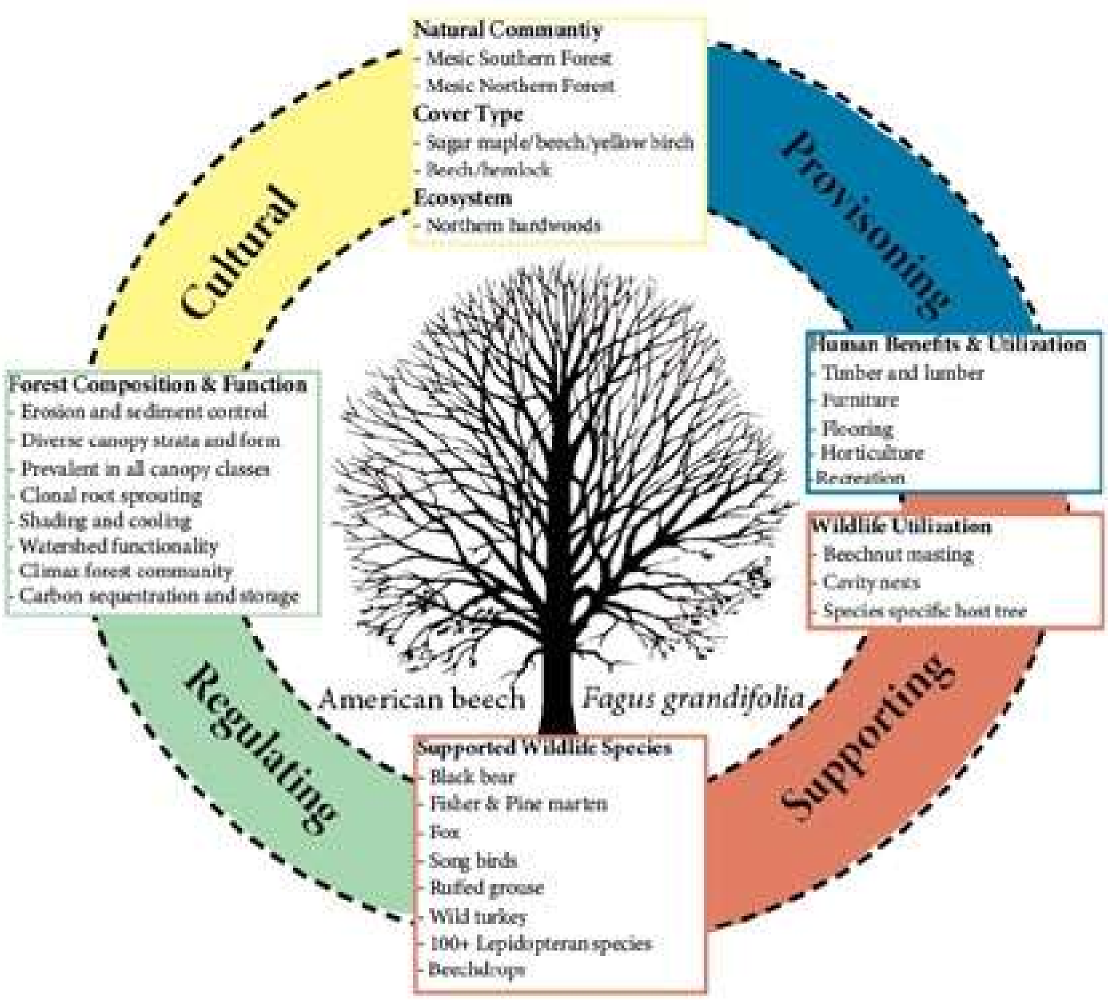


Figure 15. American beech through the lens of ecosystem services.

1.311 Supporting

Figure 16. Beech drops (Epifagus virginiana) a host-specific parasitic plant of American beech.

Beech trees provide food and shelter for a wide variety of wildlife. Over 40 species are known to feed on their nuts, which are a great source of protein and fat (Jakubas et al., 2004). They also support an array of arthropods and lepidoptera, which in turn provide food for birds. As previously discussed, some birds feed directly on beech buds. Additionally, the clonal sprouting nature of beech contributes to a diverse canopy structure, providing a range of perches and nesting sites for birds and mammals. Meanwhile, beech snags provide habitat for cavity nesters. Lastly, American beech supports a parasitic plant called beechdrops (Epifagus virginiana), which is host-specific and only grows in beech forests.

Beech trees also play a role in nutrient cycling. In the Catskill Mountains, the replacement of beech by sugar maple due to the effects of BBD caused a decrease in litter composition, decrease in soil C:N ratio, and increased nitrate and nitrite in soil solution (Lovett et al., 2010).

It has been observed that the replacement of beech by sugar maple results in less forest floor mass, increased nitrification, increased leaching of nitrate into streams, and decreased retention of atmospherically deposited nitrogen because soil organic matter formed by sugar maple has a higher tendency for nitrification than that of beech (Lovett et al., 2010).

1.312 Regulating

American beech trees regulate the surrounding ecosystem in a variety of ways. By limiting erosion and controlling sedimentation, beech trees support streams, rivers, and overall watershed function. They also contribute to water filtration. The generous canopies of beech have a shading and cooling effect on the forest floor, regulating understory plant growth and limiting invasive species colonization. This can also be observed in urban settings, where beech provides shade to stave off the urban heat island effect. As with all tree species, beech contributes to carbon sequestration and storage, and therefore has a regulating effect on climate.

Figure 17. Beech tree with full canopy cover.

Figure 18. Beech tree with decreased canopy cover and open gaps.

Figure 19. Michael Kost observing the canopy of a large beech tree.

1.313 Provisioning

The American beech is a facet of both the timber and horticulture industries and provides economic value to both (see the Economic Value section).While American beech is not highly sought after for timber compared to other species, its wood is used for furniture, flooring, veneer, and other products (Tubbs & Houston, 1990). Additionally, American, European, and Asian beech varieties, all prized for their beauty, have been widely planted for ornamental purposes. Due to the high cultivation of European beech and its many cultivars they can be found as statement pieces across the urban landscape in parks, cemeteries, and yards (Holden

Figure 20. An informational sign on beech trees located in Waterloo State Recreational Area.

1.314 Cultural

The cultural services of American beech are found in its relation to human identity, recreation, learning, and health. Beech trees contribute to a sense of place for many people, including those that inhabit the Northern hardwoods or beech-maple forests of Michigan. Their smooth gray bark, spreading canopies, and distinct bronze fall foliage make them both highly recognizable and well-loved. Beech trees are notoriously carved with names and love notes, sometimes remaining visible on the bark for generations. Although we discourage this behavior, we recognize it as an important part of how people connect to beech trees. Beech forests provide abundant opportunities for recreation and learning, contributing to physical and mental well-being.

Figure 21. A beech tree with names and initials carved into the trunk.

1.32 Economic Value

The timber industry in Michigan will be the primary industry directly affected by a loss of American beech (F. grandifolia). Much of Michigan's timber comes from the northern parts of the state on federal land such as the Huron-Manistee, Hiawatha, and Ottawa National Forests. The State of Michigan itself manages 21% of the forested lands across the state (MIDNR, 2010). State forest lands provided 20% of all the timber utilized by the state (MIDNR, 2010). American beech accounts for 523 million cubic feet of timber volume in the state, or otherwise 15,701 thousand tons of aboveground biomass (Pugh, 2017, Table 1). In past years, however, American beech has experienced negative net growth trends observed at -4,260 thousand cubic feet per year (Pugh, 2017). Annually, 10,284 thousand cubic feet of beech is harvested from Michigan forests (Pugh, 2017). While beech timber is currently of lower economic value than other hardwoods, it is still widely used. Applications of beech include veneer logs, pallets, pulp, flooring, plywood, railroad ties, fuelwood, baskets, rough lumber, and furniture (Tubbs and Houston, 1990).

Table 1. Forest resource inventory volumes based on Forest Inventory and Analysis (FIA) data from 2011 to 2017 in Michigan (Pugh, 2017).

Species	Trees[a] (million trees)	Net volume[a] (million ft^3)	Aboveground biomass[b] (thousand tons)	Net growth[a] (thousand ft^3/yr)	Mortality[a] (thousand ft^3/yr)	Harvest removals[a] (thousand ft^3/yr)
Sugar maple	439	5,144	158,591	104,484	18,434	69,961
Red maple	475	4,859	130,664	125,900	23,232	54,829
Northern white-cedar	470	3,006	48,292	46,638	13,306	12,382
Red pine	220	2,484	44,702	69,830	7,136	31,240
Eastern white pine	109	1,867	31,912	64,402	7,675	7,900
Northern red oak	95	1,766	53,915	55,578	3,090	14,536
Quaking aspen	185	1,647	37,200	38,548	43,058	36,801
Bigtooth aspen	121	1,315	28,683	38,947	19,846	14,625
Black cherry	94	1,141	29,054	35,329	9,907	14,992
Eastern hemlock	76	1,128	21,737	22,401	4,186	7,059
Balsam fir	184	727	19,915	19,538	28,424	9,846
White spruce	70	646	11,817	9,697	15,146	10,309
Yellow birch	56	644	18,975	2,171	10,960	5,352
American beech	37	523	15,701	-4,260	16,465	10,284
Green ash	47	393	12,193	-57,411	79,144	4,695
White ash	26	331	10,037	-20,917	33,882	12,009
Black ash	55	292	9,660	-10,464	21,366	655

[a] At least 5-inch diameter trees. [b] At least 1-inch diameter trees.

1.32 Economic Value cont.

If BLD was to follow a similar trajectory to that of BBD, it would have impacts to forest economics through secondary effects on desirable species (e.g. sugar maple) by inhibiting regeneration under the heavy beech thicket understory that is formed after abundant overstory mortality (Cale et al., 2017). This is, however, speculation of how BLD might convey a change in forest structure as observed with BBD, where post BLD forest changes are still largely unknown. Additional value losses attributable to BBD, and potentially BLD, include decreased primary productivity, biodiversity, structural sustainability, and mast production (Cale et al., 2017). American beech has also been historically managed for mast and timber in forests with few other mast-producing trees (Reed et al., 2022). The masting component of beechnut production influences a variety of game species such as American black bear, white-tailed deer, and eastern wild turkey. A decrease in this vital source of nutrition could potentially impact Michigan's hunting economy, an $8.9 billion industry statewide (Calatone & Vickery, 2019). Forests that were once productive for hunters could potentially lose their species richness, precipitating a decline in wild game hunters.

BLD also poses a risk to the landscape and horticulture industry. Michigan has the fourth largest tree nursery industry in the U.S. (Michigan Department of Agriculture and Rural Development, 2018). It is likely that many tree nurseries will stop carrying any beech tree varieties due to the presence of BLD in the state. The economic impact is challenging to quantify; businesses are likely to sell more non-native tree stock. Additionally, since the urban forestry and ornamental tree market relies heavily on local tree nurseries to supply them with stock to plant, urban forests will be indirectly affected by this shift away from ornamental beech trees like European beech, likely leading to more homogenized urban canopies of maple and other common street tree varieties (i.e. honey locust, elm, oak). A loss of diversity and value of urban forests can be expected by the overarching decline and mortality of American beech within its range.

Lastly, it's important to recognize that the non-provisioning ecosystem services provided by American beech also have an economic value. There is a financial cost associated with losses in watershed function, carbon storage, and shading/cooling. Researchers at Ohio State University have estimated that a loss of just half of Ohio's beech would result in environmental costs of around $225 million dollars (Ohio State News, 2019).

Figure 22. A beech sapling with BLD symptoms.

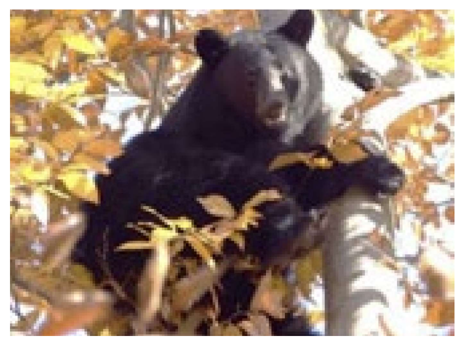


Figure 23. An American black bear in a tree curtesy of Vermont Fish and Wildlife 2017.

1.4 FOREST ECOLOGY

1.41 Wildlife

Beechnuts constitute an important food source in beech-maple forests, supporting over 40 species of wildlife (Jakubas et al., 2004). Mammals that feed on beechnuts include black bear, pine marten, fisher, chipmunk, raccoon, Virginia opossum, fox, gray squirrel, and white-tailed deer (Cale et al., 2017; McCullough et al., 2005; Tubbs & Houston 1990). Beech is sometimes browsed by deer, but it is rarely severe, and only when other, more desirable species are not available (Tubbs & Houston, 1990). The American beech canopy is an ideal perch for birds of prey such as red-tailed hawks and great horned owls. Old branch scars provide habitat for cavity nesting animals, such as black-capped chickadees and white-breasted nuthatches. Additionally, beech trees have been observed to support 120 species of lepidopterans in Michigan (National Wildlife Federation, n.d.) and serve as a host tree for the early hairstreak butterfly, which is listed as vulnerable on the International Union for Conservation of Nature (IUCN) red list. It is widely understood as an ecological principle that Lepidoptera caterpillars in turn support many species of passerines (Tallamy & Shriver, 2021).

Figure 24. Bird nests found in trees with BLD symptoms while creating survey plots.

Figure 25. Bear claw marks on an adult beech tree (Brad Pelzek, 2023).

Figure 26. Beech nuts on a European beech tree (*Fagus sylvatica*).

1.42 Effect on Forest Communities

As BLD is a novel forest pathogen, we are just beginning to understand the effects that it will have on forest communities. However, we can make predictions by combining observations made thus far with what we know about beech communities and how other pests and pathogens affect them. At this point, we know BLD causes extensive canopy thinning and mortality of understory beech. In addition, as the health of mature beech decline, their canopies will become predisposed to snap-off and windthrow. Our capstone project team saw several examples of this in a month of sampling throughout southeast Michigan (Figure 27). While occasional disturbance events are conducive to a healthy functioning mesic forest community, extensive decline and mortality will cause significant shifts in forest composition, structure, and function (Ewing et al., 2019; Reed et al., 2022). The cross-sectional sketch in Figure 28 illustrates some of these effects.

Gap phase dynamics resulting from canopy thinning and mortality of mature beech will allow the competitive release of surrounding canopy associates (e.g. sugar maple, red oak, and basswood). In particular, sugar maple in close association with these canopy gaps will experience increased radial and secondary growth (Cale et al., 2017). Additionally, canopy gaps may facilitate the colonization of common mesic forest invasive species. Many of these invasives have vegetative propagules that allow them to capitalize on canopy gaps and outcompete native species. In combination, these two processes are likely to decrease forest compositional diversity. Moreover, abundant mortality of understory beech could cause stand homogenization and a decrease in forest structural diversity. Finally, canopy thinning and mortality of beech of all sizes is likely to lead to changes in forest function by altering the ability of beech to provide ecosystem services like water filtration, carbon sequestration, nutrient cycling, and supply of food and habitat to wildlife.

Figure 27. Wind-throw (left) and snap-off (center and right) of symptomatic beech trees taken by the UM BLD capstone team.

1.43 Forest Structure and Function

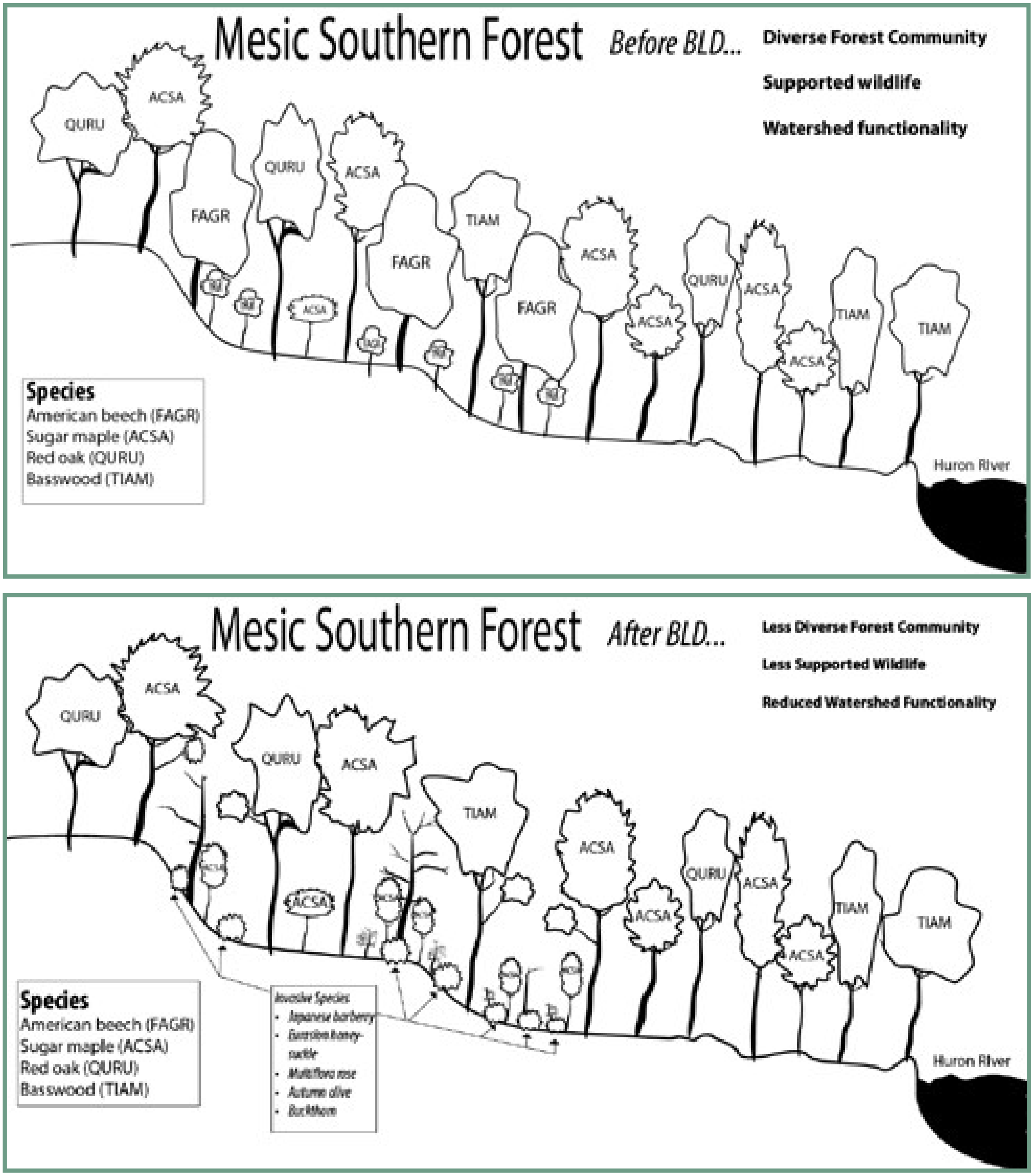


Figure 28. Mesic southern forest cross sectional sketch before and after the introduction of BLD. Note the subsequent canopy gaps filled with sugar maple and invasive species. Gap phase dynamics resulting from a loss of American beech allow for the competitive release of surrounding canopy associates (i.e. sugar maple, red oak, and basswood). Additionally, these canopy gaps allow for the colonization of common invasive species observed in mesic southern forests. These invasive species vegetative propagules capitalize on canopy gaps and out compete other native species.

Table 2. Summary of symptoms, mortality, and forest community effects from BLD.

Symptoms	Mortality/Decline	Forest Community Effects
• Interveinal banding • Leaf thickening • Leaf distortion and curling • Bud suspension • (i.e. buds form but do not leaf out) • Reduced bud production • Canopy dieback	• Sapling decline and mortality in 2-5 years (Martin & Volk, 2021; Reed et al., 2022) • Mature tree decline and occasional mortality within 7 years (Reed et al., 2022)	• Less diverse composition • Promotion of maple, invasive species • Less support of wildlife • Loss of food • Altered habitat • Reduced forest structure complexity

1.44 Beech Bark Disease & Additive Morbidity

As novel forest pests and pathogens become established, they present new opportunities for infection by other pests and pathogens. The American beech tree is no stranger to the unwarranted advances of introduced pathogens, having endured beech bark disease (BBD) since 2000 (McCullough et al., 2010; O'Brien et al, 2001). However, BBD has been present elsewhere for much longer. BBD is a disease complex that occurs when beech are simultaneously infected by a scale insect (Cryptococcus fagisuga) and fungus (Neonectria spp.). During the last 23 years in Michigan, BBD has been observed shifting beech forests into dense, even-aged stands of understory trees, typically referred to as beech thickets. Many of these trees are stems that have resprouted from the overstory beech killed by BBD. This is because BBD exhibits a consistent pattern of damage by disproportionately killing older, larger, overstory trees that fosters this resprouting of understory thickets. This is significant because BLD disproportionately affects understory beech. Therefore, where both diseases co-occur there is potential for compounding effects. Additionally, any BBD resistant genotypes of American beech planted or culturally promoted into canopies remain at risk from BLD.

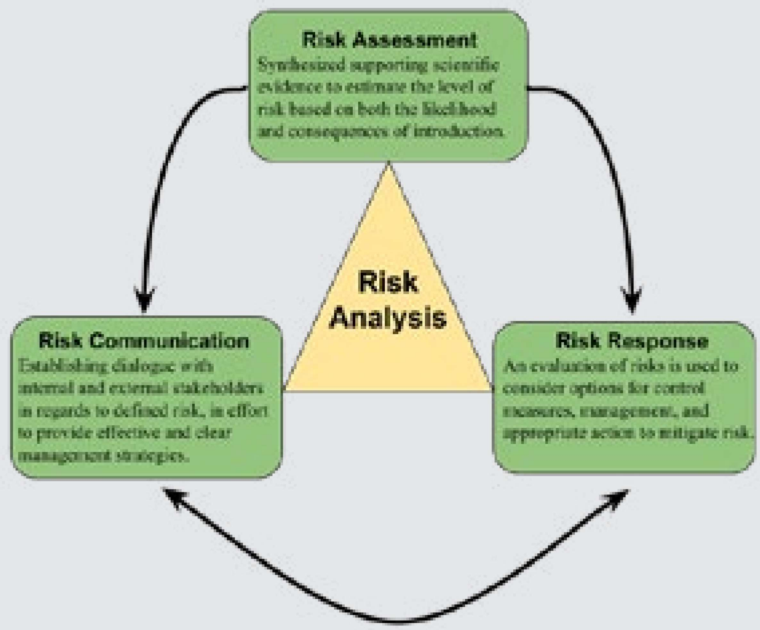
Figure 29. Examples of beech bark disease courtesy of UMass Extension, 2023.

1.5 Risk to American Beech

Risk Assessment Summary

Risk Analysis Objectives:

- Gain a better understanding of the potential timing of BLD arrival to new areas in Michigan by reviewing the current knowledge, literature, management, and research results pertaining to BLD.
- Identify a combination of preventative measures in coordination with early detection and rapid response strategies to monitor and mitigate potential risk associated with BLD.



1.51 Potential Geographic Distribution

BLD has high potential to find a suitable host in the estimated 37 million beech trees in Michigan. Currently BLD occurs across two USDA plant hardiness zones within the distribution range of American beech in Michigan (Figure 30). The American beech (F. grandifolia) tree is found in 67 counties across both peninsulas of Michigan, where it inhabits mesic northern and southern forest natural communities. Both natural communities typically occur on medium- or fine-textured ground and end moraines, in addition to those of silty-clayey glacial lake plains (Kost et al., 2007). Dominant tree species of these community types include American beech and sugar maple (Acer saccharum), which together often comprise more than 80 percent of the canopy composition (Kost et al., 2007). Mesic northern and southern forests are State listed as vulnerable (S3) (Kost et al., 2007). Lastly, American beech trees occur at some of the highest densities north of the climatic tension zone in the northwestern portion of the lower peninsula of Michigan (Figure 4).

- 32 million American beech (F. grandifolia) across 67 counties in Michigan (MIDNR, 2008).
- Mesic northern and southern forests are State listed as vulnerable (S3) (Kost et al., 2007).
- American beech trees occur at some of the highest densities north of the climatic tension zone in northwestern Lower Michigan (Appendix: 2) (Wilson et al., 2012).

- LCM overwinters in detached leaves and buds, enduring cold temperatures below 10 °C, with no effect on nematode populations (Reed et al., 2022),
- Currently BLD can be found in the 6a (-10 to -5 °F) and 5b (-15 to -10 °F) plant hardiness zones of Michigan.
- LCM has been observed to survive in developing beech buds in temperatures as low as -26 °C / -14 °F in Ontario (Reed et al., 2020).

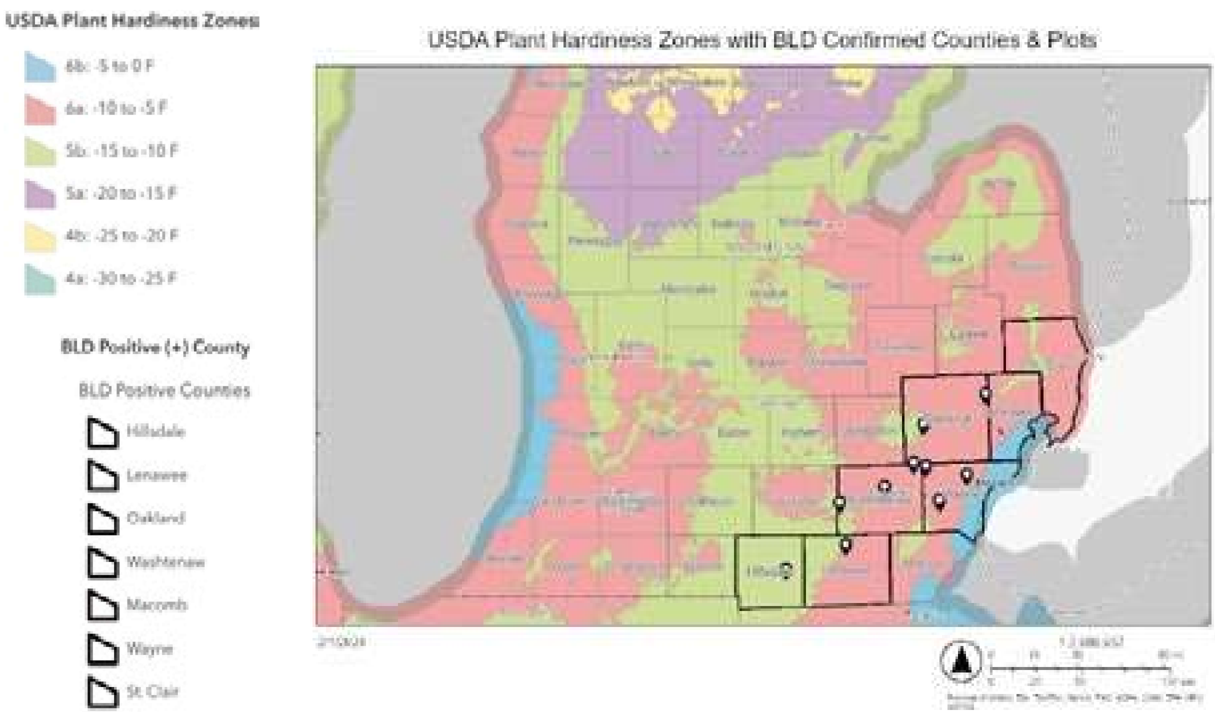


Figure 30. USDA plant hardiness zones with BLD positive (+) plots and counties in southern Lower Michigan. Nine positive plots are located in the 6a zone and one positive plot in the 5b zone.

1.52 Climate Suitability

BLD was first observed in 2012 within the Cleveland Metroparks system of Ohio, located in USDA Plant Hardiness Zone 6a (-10 to -5 °F [-23.3 to -20.6°C]). In 2021, BLD was detected in Penobscot County, Maine in a plant hardiness zone of 4b (-25 to -20 °F [-31.7 to -28.9 °C]). Michigan has the following plant hardiness zones 4a, 4b, 5a, 5b, 6a, and 6b; (Appendix 1), with most of them likely to provide suitable climatic conditions for BLD establishment. Currently BLD can be found in the 6a and 5b plant hardiness zones of Michigan. Specifically, areas with less seasonal temperature variation will be conducive for BLD spread and establishment (Zhao et al., 2023).
BLD poses a high risk to the state's estimated 37 million beech trees (MIDNR, 2008). Most risk can be attributed to the high potential BLD has for spreading throughout the distribution of American beech in Michigan. The consequences of invasion will be most heavily felt in the environmental impacts on mesic northern and southern forest structure and complexity. With the loss of mature mast-bearing beech in the northern hardwoods, and the thinning out of beech thickets in BBD-aftermath forests, wildlife populations will likely experience a drastic change from the absence of beech in these areas. This shift in canopy composition will continue to be a concern for land managers intending to steward forests for conservation, sustainability, and mast production for wildlife (Reed et al., 2022).

No effective eradication or control measures of BLD have been documented in the primary literature (Zhao et al., 2023). The prevention of forest tree diseases, such as BLD, remains the most cost-effective approach to managing forest pathogens and diseases (Zhao et al., 2023). In areas where BLD has already infected a population, priority should be placed on finding disease resistant trees to later promote breeding programs for BLD-resistant genotypes. Additionally, this focus on promoting resistant or resilient individuals will be vital to the conservation of landscape scale management. In stands where overstory beech mortality or canopy thinning is likely to result in large canopy gaps, active management may be needed to promote BLD resistant trees (Reed et al., 2022). Large scale land management of BLD will continue to be a concern. Stakeholders should implement proactive monitoring and detection programs to formulate prompt response strategies.

Ultimately, Michigan will continue to face the threat of BLD, with the hope that the harsher climates of certain regions (e.g. plant hardiness zones: 4a & 4b) (Appendix 1) can limit the advances and establishment of BLD.

Part 2. Management Strategies

2.1 Prevention

Prevention and prompt eradication of forest pests and pathogens is the most cost-effective approach to their management (Zhao et al., 2023). However, much is still unknown about how BLD is transmitted, making it difficult to identify effective preventative measures. Current best practices entail preventing the movement of disease agents on clothing, equipment, and plant material. Practitioners should take care to wash clothing and disinfect equipment before moving between sites, especially if BLD is known to be present. Particular care should be paid to any material that came into direct contact with bark, leaves, or leaf litter. Boots should be scrubbed with soapy water to dislodge debris and then sprayed with disinfectant. For greater detail on preventative measures to take when conducting field work, see Appendix.

While it is impractical to expect the public to adhere to these same preventative measures, steps should be taken to encourage individuals to do what they can to contribute. This includes facilitating the use of boot brushes before and after park visits, discouraging visitors from venturing off-trail, and advising against the movement of firewood or nursery stock.

For some pests and pathogens, thinning forest stands by removing healthy trees is an effective means of reducing transmission. However, an initial study by the New York Department of Environmental Conservation (2022) indicates that thinning is not an effective method for preventing the spread of BLD. At this time, we do not recommend removal of declining or healthy beech because this practice risks killing trees that may be genetically resistant to BLD.

Figure 31. Post-exposure boot cleaning after leaving a BLD impact plot.

2.2 Detection and Reporting

Detection and reporting of forest pests and pathogens provides information about their geographic distribution that is required for other forms of management, particularly monitoring and control, and is especially crucial at the beginning of an invasion. As such, the Michigan DNR has added BLD to its invasive species watch list. Be on the lookout for BLD symptoms, particularly interveinal banding and leaf distortion, whenever you find yourself around beech. To ensure accurate identification of BLD, familiarize yourself with other beech pests and pathogens. In particular, damage caused by beech leaf rolling aphids, eriophyid mites, beech anthracnose, and powdery mildew may be confused with that of BLD (pg 7). Among these, BLD is unique for causing leaf discoloration that is darker than the surrounding healthy tissue. Note that it is not uncommon for an individual beech tree to show signs of damage from more than one pest or pathogen. For more information about BLD look-alikes, see the Buckeye Yard & Garden onLine articles written by Joe Boggs (2016, 2020) and Boggs and Chatfield (2018).

Once identified, BLD should be reported to an appropriate organization. The Michigan DNR recommends that sightings in Michigan be reported to either the DNR's Forest Health Division or the Midwest Invasive Species Information Network (MISIN). To report to the Forest Health Division, email DNR-FRD-Forest-Health@Michigan.gov or call 517-284-5895.
To report to MISIN, visit https://www.misin.msu.edu/ and use the online reporting tool, or use the MISIN smartphone app. In addition to one of the above, BLD sightings may also be reported to the local Cooperative Invasive Species Management Area (CISMA) by calling or emailing the local CISMA coordinator. A map and contact list for the Michigan CISMAs can be found at https://www.michiganinvasives.org/managementareas/. All of these organizations will want the date and location of the sighting, as well as pictures with clearly visible symptoms so they can confirm the diagnosis. If you spot BLD in a county where the disease has yet to be identified, the DNR may ask you to collect a symptomatic leaf sample to send for DNA verification of LCM presence.

Outside of Michigan, reporting recommendations vary by state. In addition to contacting your local forest health specialist, the U.S. Forest Service recommends reporting BLD sightings to the Tree Health Survey app (Martin & Volk, 2021). This app was developed to track impacts to forest health by a variety of forest pests and pathogens, though the BLD project is currently the only one. The app employs a citizen-science approach to data collection, training users to identify beech trees, BLD, and other beech pests and pathogens (including BLD look-alikes and beech bark disease). After completing a training module, users can then input data on location, tree size, crown dieback, BLD symptom severity, and the presence of other beech pests and pathogens. Importantly, the app encourages users to record data for asymptomatic beech trees, providing data on where BLD is not. A user manual written by Volk et al. (2020) can be found on the Cleveland Metroparks website.

In addition to symptomatic trees, be on the lookout for beech trees that are suspiciously asymptomatic. For example, a healthy tree in a forest that is otherwise heavily infected. This tree may be genetically resistant to BLD, in which case it should be reported and protected so it can be used in a resistance breeding program. Efforts to identify BBD-resistant beech trees are already underway (Koch et al., 2012), and a similar effort for BLD may not be far behind.

BLD Response & Reporting

What should I do if I see beech leaf disease?

Confirm the presence of some of the following symptoms:

- Interveinal banding
- Leaf thickening
- Leaf distortion (curling, shrinking)
- Bud suspension (i.e. buds form but do not leaf out)
- Reduced bud production
- Canopy dieback

Confirm the damage is not actually due to:

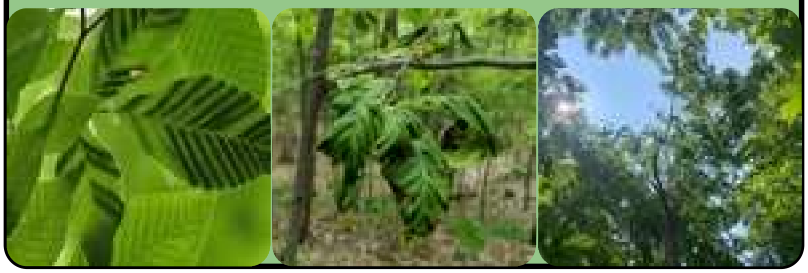
- Beech leaf curling aphid
- Beech eriophyid mites (erineum patches)
- Beech anthracnose

**Note that multiple pests and pathogens can co-occur on an individual tree.*

Identify

Interveinal Banding
Leaf Curling
Thick Leaf Texture

Thinning Canopy
Bud Suspension
Premature Leaf Drop



Document

Take photos of disease symptoms and record location of tree

Report

Call or Email Michigan DNR Forest Health Division

In Michigan, report positive BLD diagnoses to:

Michigan DNR Forest Health Division
- Email: DNR-FRD-Forest-Health@Michigan.gov
- Call: 517-284-5895

Midwest Invasive Species Information Network
-MISIN Online Reporting Tool or
-MISIN Smartphone App

In addition to the above, you may also report to:
-The local Cooperative Invasive Species Management Area (CISMA)
-Information on Michigan CISMAs

Tree Health Survey
- via Smartphone App

2.3 Monitoring

Monitoring forest pathogens involves tracking changes in disease extent and severity, as well as changes in the composition, structure, and function of infected forest communities. This information may be used to better understand the disease and its impacts, to model future changes, or to inform decisions related to prevention, control, and additional monitoring. There are a number of methods being used to monitor BLD, with the appropriateness of each method depending on the aspect of the disease being monitored (i.e. extent, severity, ecosystem effects), resource availability, and the size of the area to be monitored.

2.31 Walking Surveys

At the local level, monitoring the extent of BLD is most completely accomplished through annual walking surveys. Surveys do not need to be conducted more than once a year because BLD symptoms do not spread within a growing season. Start by identifying the extent of beech itself, if not already known. This task is easier in winter when there is reduced understory foliage, allowing the persistent pale brown leaves of young beech and smooth gray trunk of mature beech to be spotted from a distance. BLD walking surveys should be conducted in late spring or early summer, when beech have fully leafed out but before heavily symptomatic leaves fall to the ground or turn necrotic (necrotic leaves are more easily confused with BLD look-alikes). Systematically walk the area containing beech and look for BLD symptoms, particularly interveinal banding and distorted leaves. Use binoculars to scan the canopy of large trees. Focus attention on saplings and lower branches of mature trees, as symptoms usually appear there first. Interveinal bands are easiest to spot when backlit, so it may be advantageous to wait for sunny weather. Depending on the number and distribution of infected trees, map their location as either points or polygons. Consider incorporating information about disease severity or other relevant phenomena. Figure 33 shows the results of a walking survey conducted by our capstone project team. It demonstrates the use of color-coded polygons to communicate both the extent and severity of BLD. Once mapped, survey results can be compared from year to year to determine how the disease has spread. If data on severity were collected, it may also be possible to determine where and how badly the disease has gotten worse, though not in an easily quantifiable way.

Figure 32. Daniel McConnell uses binoculars to investigate the tree canopy for signs of beech leaf disease.

While a useful tool, walking surveys are labor intensive and therefore not always feasible to conduct. In particular, land managers with limited resources or who are responsible for stewarding a large area of land may have to rely on less exhaustive or less accurate alternatives. This could mean performing less extensive or less frequent walking surveys, or relying on data obtained from other sources.

Figure 33. The results of a walking survey conducted by our capstone project team in Scio Woods Preserve (Ann Arbor, MI) in June 2023. We surveyed all areas containing beech and noted where BLD symptoms were absent (green), mild (yellow), or moderate (orange).

2.32 Community-derived Data

BLD can also be monitored using data obtained from public reporting and/or communication with other monitoring organizations. Leverage the many eyes of the public by educating visitors about BLD, including how to identify and report the disease (see the Education & Outreach section). Encourage visitors to report BLD sightings to your organization, in addition to the Forest Health Division or MISIN. In case sightings are reported elsewhere but not to you, periodically reach out to the Forest Health Division, MISIN, and local CISMAs for information on BLD occurrence, and check for new observations on the Tree Health Survey app. Data can be requested from MISIN at https://www.misin.msu.edu/request/. Conversely, if sightings are reported only to you, be sure to pass this information along to other monitoring organizations. While data obtained in this way are unlikely to paint a complete picture of the state of BLD in any given area, having incomplete information is better than none, and may be enough to inform certain decisions. For example, deciding where to focus walking survey efforts if you only have the resources to survey a limited area.

The incompleteness of community-derived data can be mitigated by assessing it at a coarse spatial scale. For example, the extent of BLD across the entire range of American beech is determined on an annual basis using county-level data on disease presence (Figure 5). The data are acquired through the combined efforts of many organizations, with help from the public in initial detection and reporting. Conversion of the data from a local to regional scale allows the production of a more complete and accurate map, though not a precise one.

2.33 Long-term Impact Plots

Monitoring BLD severity and the effect of BLD on beech communities is primarily achieved through repeated measurement of long-term impact plots. These are small plots in which detailed data are collected for both individual trees and the plot as a whole. If examined in isolation, the data from any given plot are only able to provide information about that plot. They cannot be extrapolated to make predictions about other forests, or even other areas within the same forest. However, by analyzing data obtained from many plots, it is possible to identify patterns that can be used to infer information about BLD in other areas. This analysis requires that the same data be collected in every plot, using the same methodology. Recognizing this, and wanting to give strength to future statistical analyses by maximizing available data, researchers from a variety of organizations have worked together to develop a shared protocol, used throughout the US and Canada (Martin et al., 2018). This protocol provides instructions for establishing 1/10th-acre plots and recording data on a variety of site and tree attributes, including species and size, which can be used to assess changes in forest structure and function. Additionally, the protocol provides instructions for quantifying the severity of both BLD and BBD on individual beech trees. The entire protocol can be found in Appendix, and its use is demonstrated in the Pilot Study section of this report.

Because so much is still unknown about BLD, perhaps the most significant way for land managers to contribute to disease mitigation is to aid ongoing research efforts. The hope for these long-term impact plots is that they will provide data that contribute to understanding the disease and its impacts, building predictive models, or testing new control methods. Once surveyors are trained and equipment gathered, it takes less than four hours to establish and survey a single plot. If your organization has the bandwidth, please consider installing or hosting one or more plots. Even if BLD has not been detected in your area, impact plots are needed in asymptomatic sites to establish a record of baseline healthy conditions, and in BBD-positive sites to separate the effects of BLD and BBD where the diseases co-occur. If your organization is in Michigan and interested in installing or hosting plots, email Dr. Stella Cousins at scousins@umich.edu. Elsewhere in the United States, Danielle Martin, who is leading the U.S. Forest Service’s response to BLD, may be able to suggest potential research partners.

2.34 Potential Future Options

DNA testing has revealed the presence of LCM, the foliar nematode primarily responsible for causing BLD, in the leaves of asymptomatic beech trees. This suggests the possibility of a latency period during which LCM is present but BLD symptoms have not yet developed (Martin & Volk, 2021). If this is true, testing asymptomatic beech for LCM DNA could provide an early warning sign of BLD development. However, it is not yet clear whether LCM presence alone is sufficient for BLD symptoms to develop. Therefore, until more is understood about the pathogen(s) responsible for BLD, DNA testing is not a viable monitoring option.

2.4 Treatment

Several methods for preventing or slowing damage from BLD have been proposed, and their efficacy is currently under study. To date, treatments being investigated fall into two categories: phosphite products and nematicides. Phosphite products are known to stimulate plant defenses and have been shown to disrupt nematode activity (Gómez-Merino & Trejo-Téllez, 2016; Havlin & Schlegel, 2021). They are sold as fertilizers (PolyPhosphite 30) and as fungicides (Agri-Fos, Fosphite, Fungi-Phite, Reliant, Lexx-a-phos, Prophyt) (Cowles et al., 2023). Nematicides under investigation include fluopyram, abamectin, emamectin benzoate, oxamyl, acephate, spirotetramat, azadirachtin, and thiabendazole (Borden & Loyd, 2022). Of these, the treatments that have shown some success are the application of phosphite products to soil and fluopyram to foliage.

In 2017, researchers associated with Davey Tree Expert Co., Cleveland Metroparks, and ACRT services started treating the soil around small beech trees (2-4 in DBH) with PolyPhosphite 30 (Cowles et al., 20203). They chose trees with initially mild symptoms and injected phosphite solution into the soil at the base of the trees twice per year for five years, at a rate of 2 oz of PolyPhosphite 30 in 14 oz of water per inch DBH (e.g. a 4-inch tree was administered 8 oz of PolyPhosphite 30 diluted in 56 oz of water). After only the first year, encouraging differences were visible between the treatment and control trees. After five years, treated trees were significantly healthier than control trees, with reduced symptoms of interveinal banding, defoliation, and dieback of twigs and branches. The treated trees also had fewer nematodes.

In 2022, a similar study was performed by researchers associated with the Connecticut Agricultural Experiment Station and the University of Rhode Island (Cowles et al., 2023). They treated larger trees and administered the PolyPhosphite 30 solution as a soil drench around the tree base in lieu of soil injection, but at the same dosage. While they did see a slight reduction in nematode abundance in the treatment group compared to the control, this difference was not statistically significant. Cowles et al. (2023) attribute the disparity in results to tree size, suggesting the phosphite may have been overly diluted in the foliage of large trees because they have a higher ratio of foliage to trunk biomass. To compensate, they propose increasing the dosage amount or frequency for large trees. If dosage amount is increased, they suggest administering phosphite over a larger area to avoid oversalting the soil.

More testing is needed to work out the best application method (i.e. timing, frequency, dosage, delivery method, etc.) for phosphite treatment, and to determine whether it is even a viable treatment option for mature beech. In addition, there is a concern that phosphite products, including those sold as fertilizer, may have a negative effect on the symbiotic relationships between plants and mycorrhizal fungi (Havlin & Schlegel, 2021). Therefore, additional research is also needed to ascertain whether their application causes any unintended negative effects.

If you choose to move forward with phosphite application, you may find it easier to work with products sold as fertilizer because their use does not require pesticide applicator certification. However, there have been reports of PolyPhosphite 30 being hard to find. Phosphite products sold as fungicides should have the same effect, though their use does require pesticide applicator certification. If using a product labeled as fungicide, be sure not to exceed the dosage allowed by the label for soil drenching.

Another treatment that has had some success is the foliar application of fluopyram (Broadform, Indemnify). Cowles et al. (2023) found that applying Broadform to infected beech resulted in consistent, high nematode mortality, and Borden and Loyd (2022) saw similar results using Indemnify. Unfortunately, there are several limitations to the use of fluopyram, as listed below:

Limitations of Fluopyram

- Fluopyram applied as a foliar spray does not enter buds, so if there are untreated beech nearby, nematodes may migrate from untreated trees to the buds of treated trees, rendering the treatment ineffective. Therefore, fluopyram should only be used on beech that are isolated from untreated beech.
- Fluopyram is toxic to aquatic organisms, and so should not be used near water or hardscape whose runoff flows into storm drains.
- It may not be possible to spray the foliage of large trees. While Cowles et al. tried applying fluopyram as a basal trunk paint, which would have allowed easy application to trees of all sizes, it was ineffective.
- Nematodes may develop resistance to fluopyram if it is overused.

If these limitations are not a concern, fluopyram may be applied sometime between late May and late August. At this time, it is unknown whether multiple applications are needed. Cowles et al. (2023) recommend monitoring treatment effectiveness by estimating nematode abundance (procedure in Cowles et al 2023).. If live nematodes are found, additional application(s) may be necessary.

Figure 34. Polyphosphite being applied to the base of a beech tree (URI, 2023)

2.5 Education and Outreach

Education is a crucial component of the management of all diseases, but especially of novel diseases. Prevention, detection, reporting, monitoring, and control all require that people be aware of both the problem and how to mitigate it. Providing people with information empowers them to take action, and the more people who take action, the greater the potential to reduce harm. This is the central reason behind the writing of this report, and why we encourage you to share it as widely as possible. That being said, less technical materials are better suited for communicating this information to the general public. They include the following:

- Pamphlets, cards, or other materials that can be kept on hand and easily distributed.
- Posters and interpretive signage. Place these in high-traffic areas (trailheads, visitor centers, etc.) or near symptomatic trees, if you have any.
- Newsletters or social media posts.
- Workshops/educational hikes. Perhaps partner with local community organizations like schools or environmental clubs.

At minimum, public-facing educational materials should cover how to identify beech and BLD, including symptoms and look-alikes, and how to report sightings. It is also good to communicate why BLD is a problem (i.e. why people should care) and what can be done about it. Explain that effective treatment options are currently being investigated, encourage people to be on the lookout for infected beech, and discourage people from participating in behaviors that generally contribute to the spread of forest pests and pathogens.

Figure 35. The UM BLD team leads an educational walk on how to identify and report signs of BLD.

Part 3. Current Conditions and Future Considerations

3.1 Pilot Study

3.11 Introduction

With the arrival of BLD to Michigan, action was needed in order to determine the extent of the disease and establish a system for monitoring it. Both the Matthaei Botanical Gardens & Nichols Arboretum (MBGNA) and the University of Michigan School for Environment & Sustainability (SEAS), as environmental stewards, decided to respond. As part of this response, our capstone project surveyed 16 beech forests in June of 2023. Within these 16 sites, we established and surveyed 21 long-term impact plots. In the following sections, we provide our methods for site selection and data collection and present a summary of our results. We hope this will serve as an example of how to use long-term impact plots, while also providing information about the current status of BLD in Michigan.

Figure 36. (Above) Two groups of UM BLD team members measure the DBH of beech trees in survey plots.

Figure 37. (Left) UM BLD team members install a humidity sensor in a BLD impact plot.

3.12 Methods

To begin, we gathered information on potentially suitable beech forests in and around the three counties that were known to have BLD in 2022 (St. Claire, Oakland, and Wayne). We then narrowed the possibilities according to the following criteria:

- Proximity to existing long-term impact plots (established in 2020 by the DNR)
- Proximity to known cases of BLD
- Proximity to other possible sites
- Travel feasibility from Ann Arbor
- Permission to conduct research on property

Our final selection comprised 16 sites dispersed across southeast Michigan. Starting in June of 2023, we visited each location and conducted a thorough walking survey to gather information on beech distribution, BLD distribution, and BLD severity. We then used this information to decide on plot locations, placing them with consideration of beech and BLD distribution. We tried to place plots in areas that were representative of the forest community, but we were limited at some sites by a general scarcity of beech. All plots were placed so that they contained at least 2 overstory beech. Where possible, an asymptomatic and symptomatic plot were co-located, so some sites have two plots. In all, we established 21 plots throughout southeast Michigan (Figure 38). Plots were established and surveyed according to a USDA protocol written by Martin et al. (2018). Each plot was composed of a 37.2-ft radius (1/10th-acre) main plot to assess overstory trees, a 11.8-ft radius subplot to assess saplings, and four 3.3-ft radius subplots to assess seedlings. The sapling subplot was placed in the center of the overstory plot while the seedling subplots were placed on the four cardinal points of the overstory plot (Figure 40).

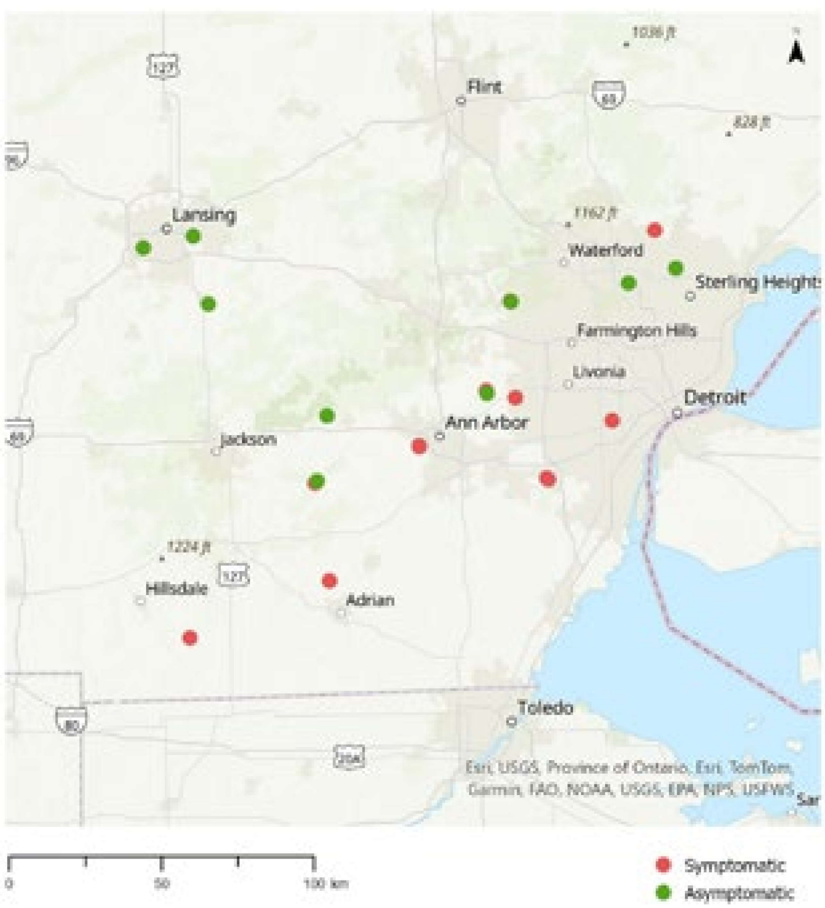


Figure 38. A map of the 21 long-term impact plots established by our capstone project team. At the time of establishment (June 2023), the green plots were asymptomatic and the red plots were symptomatic. Some plots are too close together to be distinguished clearly on the map.

For each plot, data were recorded for general information (i.e. plot ID, date, surveyors), location information (i.e. county, local place name, owner, coordinates), and site attributes (i.e. basal area, slope, aspect, slope shape, slope position). We also recorded general site remarks and drew a diagram of canopy tree locations.

In the overstory plot, we tagged all trees greater than 5 inches in diameter at breast height (DBH) and recorded the following for each:

- Species
- Tag number
- DBH
- Crown class (dominant, codominant, intermediate, suppressed)
- Crown dieback and density
- Canopy assessment (for beech only)
    - Dead main and fine branches
        - Location on tree (lower, upper, both)
        - Percent of leaves absent
    - BLD severity
        - Location on tree (lower, upper, both)
        - Percent of leaves with no symptoms
        - Percent of leaves with mild symptoms
        - Percent of leaves with severe symptoms
- Other pest remarks

Figure 39. (Left) Humidity sensor placed in a BLD impact plot. (Right) Michael Kost looks for signs of crown thinning using a densiometer.

For each sapling in the sapling subplot, data were collected on species, DBH, crown density, and BLD severity (i.e. percent of leaves affected). Saplings were defined as all trees smaller than 5 inches DBH and taller than breast height (4.5 ft). For woody species in each of the four seedling subplots, we tallied the number of individuals present and estimated the cover class. We also took a densiometer measurement from the location of each seedling subplot. Lastly, we installed environmental sensors at 11 of the sites to collect temperature and relative humidity data.

Before leaving each site, we performed the sanitation measures detailed in Appendix in an effort to prevent our research from contributing to the spread of BLD.

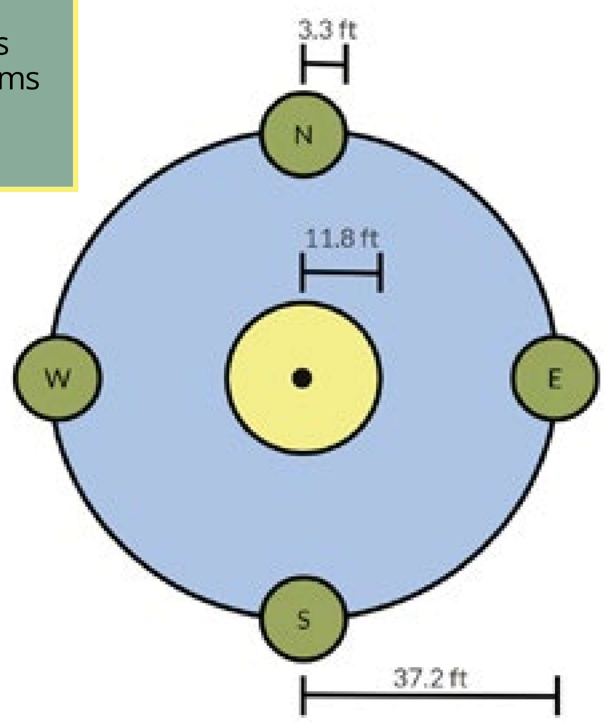


Figure 40. Layout and relative size of the overstory (blue), sapling (yellow), and seedling (green) subplots.

3.13 Results

While the purpose of our plots is for long-term impact assessment, summary statistics for the data collected so far have been provided in Table 2. These statistics were generated to provide an overview of the plots, and to develop a baseline to which future data can be compared. The metrics focus on potential indicators of BLD presence. While the seasonal variability of relative humidity and air temperature are noted as potential indicators for BLD vulnerability (Zhao et al., 2023), this table only shows the average temperature.

Table 3. Summary statistics of all of the sites that were surveyed in June 2023. The data have been averaged according to BLD presence or absence.

Metric	BLD Present	BLD Absent
Site Count	12	9
Beech DBH (cm)	34.91	41.11
Sapling Beech DBH (cm)	2.587	4.265
Basal Area (ft2/acre)	115	120
Slope (degree)	6.167	7.667
Distance to Body of Water (ft)	238.6	91.67
Relative Humidity (%, Jun. - Nov.)	80.73	80.84
Air Temperature (℃, Jun. - Nov.)	15.22	15.03

Further analysis was performed on the stem data to investigate stand composition and structure (Figure 41), as well as the relationship between beech size and BLD severity (Figure 42) Findings show that our plots are dominated by beech and sugar maple, and that the upper:lower crown-class ratio is greater in beech than in sugar maple. However, the data are likely biased towards beech because of the requirement that two overstory beech be included in each plot. Regardless, the data are within the expectations for a mesic southern forest that has only been recently infected by BLD. Lastly, the relationship between BLD severity (shown as the percentage of healthy leaves) and beech size demonstrates that our sites already show a trend in younger beech having more severe symptoms, which is consistent with previous findings about the greater vulnerability of smaller individuals.

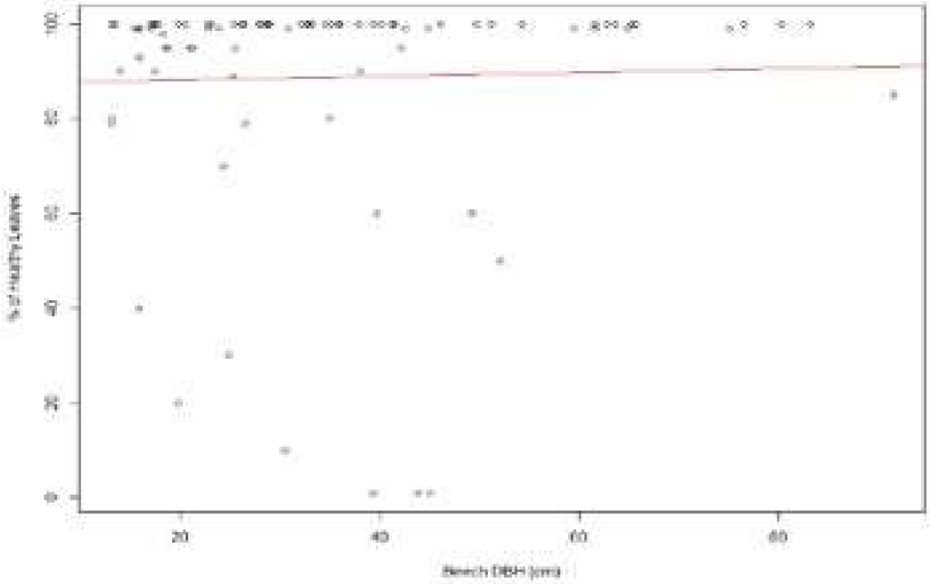


Figure 41. The relationship between the percentage of healthy leaves and DBH. Each point represents an overstory beech tree from one of the 21 plots. Percent healthy leaves is an aggregate measurement of all leaves that had BLD symptoms as opposed to visually healthy leaves. The red line shows that there is some bias toward BLD affecting younger and smaller trees.

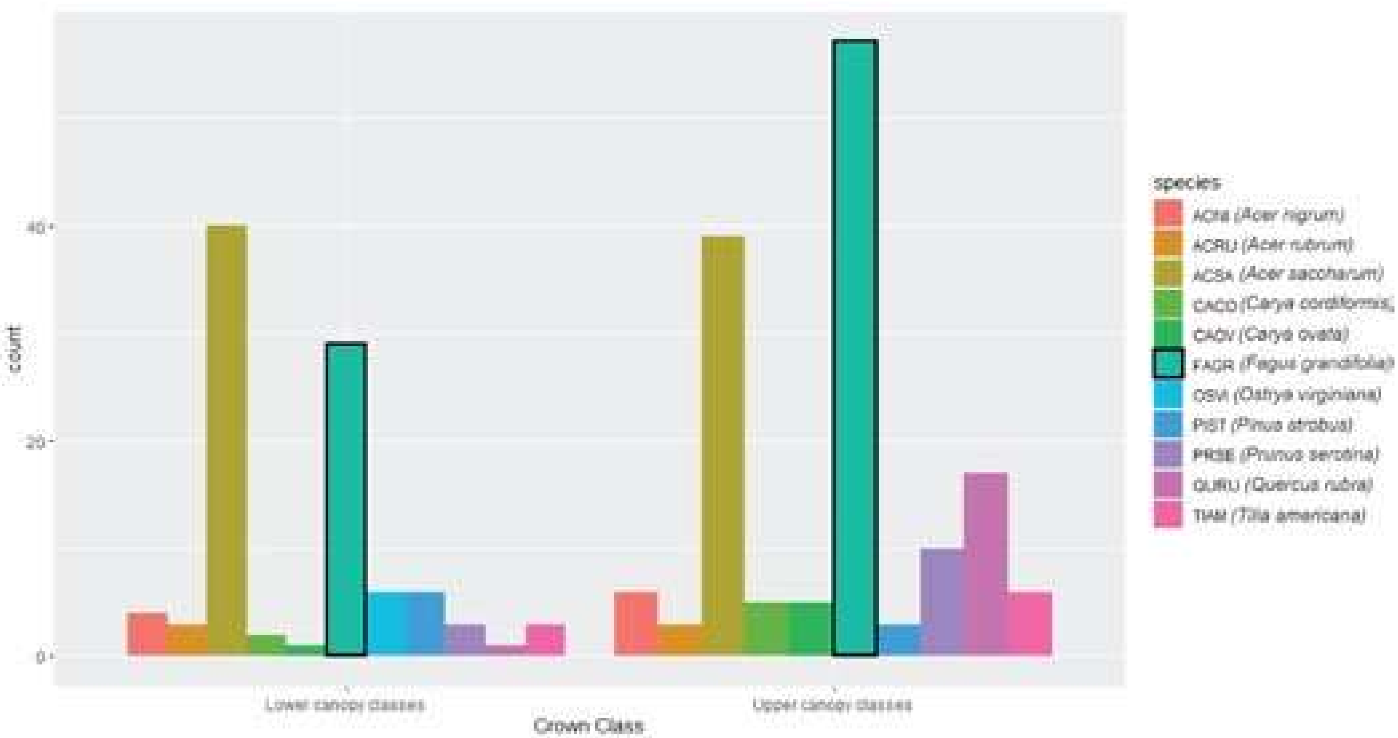


Figure 42. Counts of the ten most common overstory species in the 21 sites. Trees were split into two crown class categories: Lower, including intermediate and suppressed crown classes, and Upper, including dominant and codominant crown classes. American beech (FAGR) has been highlighted with a black outline. The data include bias towards beech due to plot selection requiring that multiple beech be included.

3.2 Stakeholder Needs

Going forward, an area of focus should be the further development and expansion of forest health assessment methods and communication networks. Better forest health assessments will aid stakeholders in monitoring the severity and spatial distribution of BLD. For example, remote sensing could be an extremely powerful tool for identifying BLD and assessing beech health. In addition, better information sharing and educational resources are needed to provide stakeholders with up-to-date information on the overall status of BLD, including advancements in treatment and management, and should not be restricted to Michigan.

More directed research within the field should focus on the causes, transmission, treatments, and effects of BLD. Greater efforts in monitoring populations of LCM are needed to further understand its mechanism of infection and means of dispersal. In addition, continued testing of treatments is needed, including to improve the effectiveness and safety of treatments that have been tested thus far, and to ensure they are viable for all beech species. Currently, information about the effects of BLD on forest composition, structure, and function is sorely lacking, especially in regards to the threats they pose to forest ecosystem services. The compounding effects of other stressors, such as BBD and climate change, also need study.

To this point, the stakeholders we have focused on include land managers, foresters, landowners, horticulturists, and researchers. However, work is needed to identify additional stakeholders and their needs.

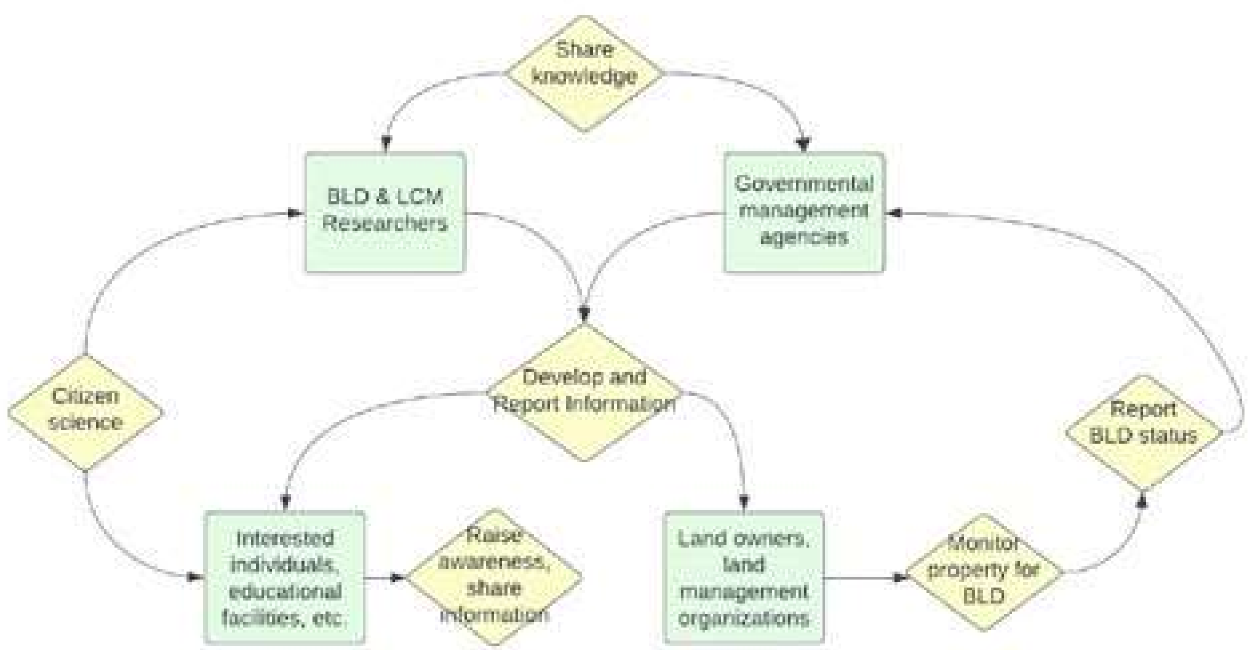


Figure 43. Potential BLD knowledge sharing framework, centered around how stakeholders in green boxes interact with each other through information, monitoring, and reporting.

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Part 5. Appendices

Appendix 1. Beech Density Map

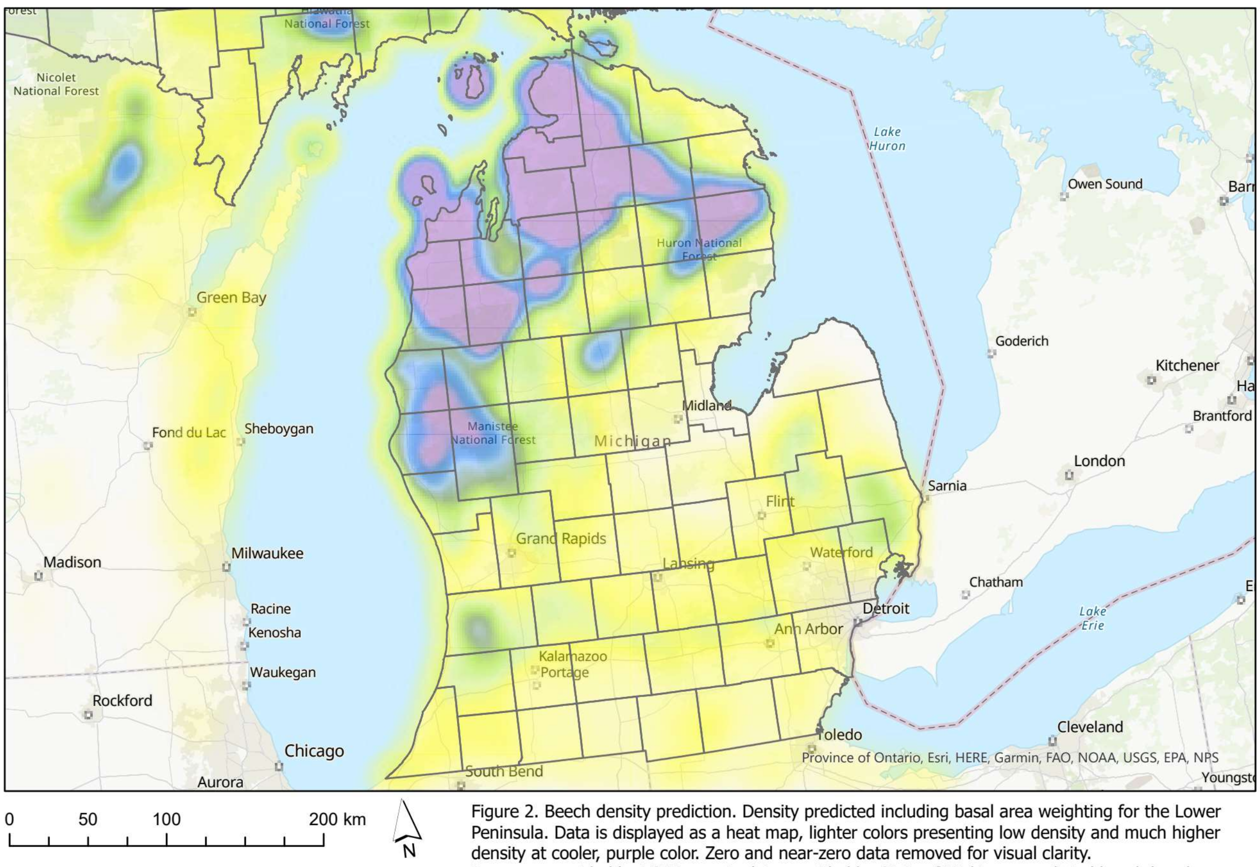
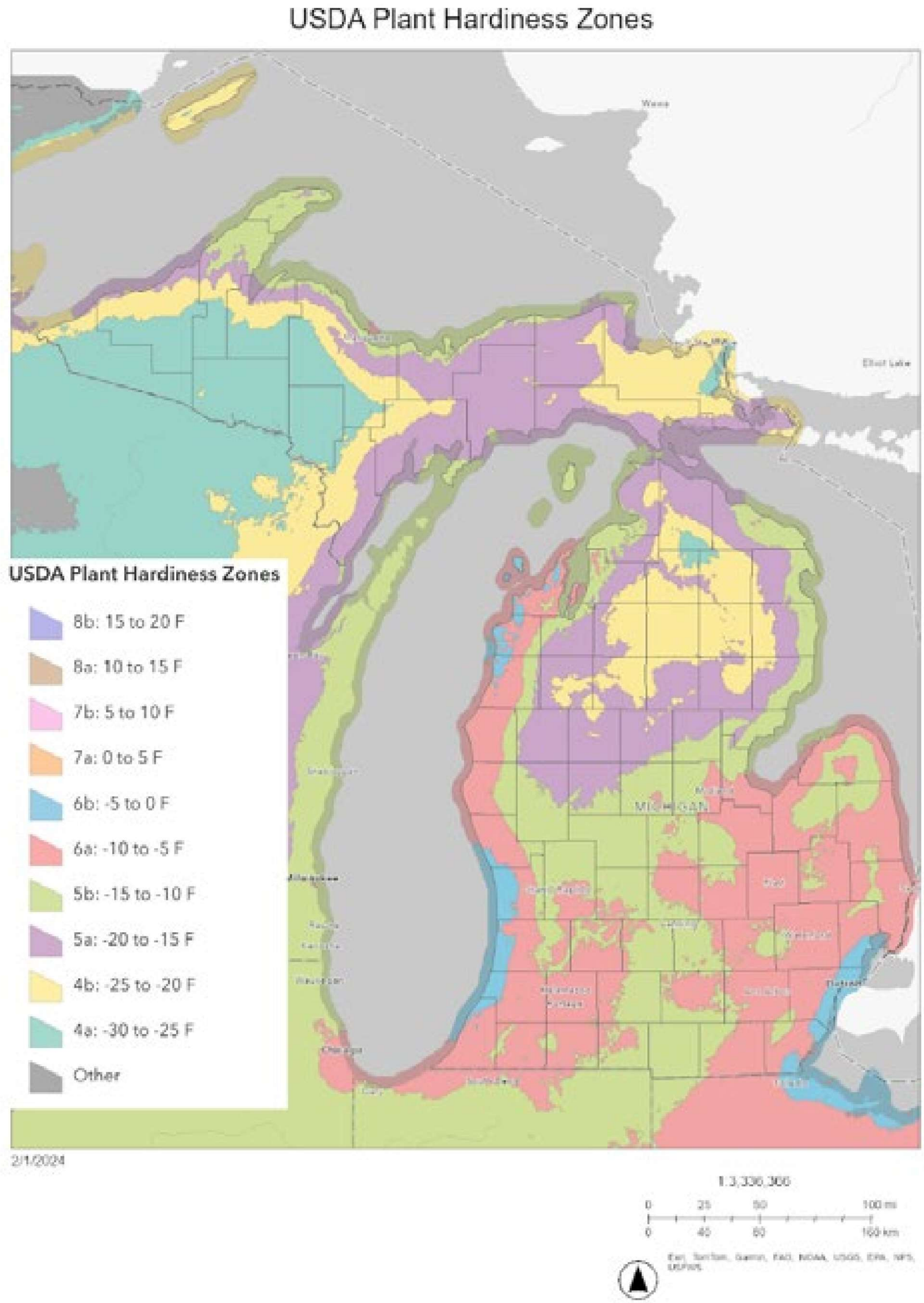


Figure 2. Beech density prediction. Density predicted including basal area weighting for the Lower Peninsula. Data is displayed as a heat map, lighter colors presenting low density and much higher density at cooler, purple color. Zero and near-zero data removed for visual clarity.
Basemap provided by ESRI, county data provided by State of Michigan, predicted beech basal area raster: Wilson, Barry Tyler; Lister, Andrew J.; Riemann, Rachel I.; Griffith, Douglas M. 2013. Live tree species basal area of the contiguous United States (2000-2009). Newtown Square, PA: USDA Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RDS-2013-0013.

Appendix 2. Plant Hardiness Map



Appendix 3. Risk Assessment Score

Table: Ratings and scores for the elements used to conduct a qualitative pest risk assessment assessment on beech leaf disease in Michigan. Host range rating and climate suitability rankings are independent of overall risk and used to identify the potential geographic distribution.

Element	Rating	Score
Consequences of Invasion		
1. Potential geographic distribution	High	3
a. Host range	High	3
b. Climate suitability	High	3
2. Dispersal potential	Medium	2
3. Potential abundance	High	3
4. Economic impact	Medium	2
5. Environmental impact	Medium	2
6. Health impact	Negligble	0
7. Social & politcal impact	Low	1
8. Management	Low	1
Sub-score		14
Likelihood of Invasion		
1. Pest history	High	3
2. Quantity of commodity imported	Low	1
3. Estimated pest density per unit imported	Low	1
4. Likelihood of surviving post harvest treatment	High	3
5. Likelihood of surviving shipment	High	3
6. Likelihood of moving to a suitable climate	Medium	2
7. Likelihood of finding a host	Medium	2
8. Potential for eradication	Low	1
Sub-score		15
Overall Risk Score		29

Appendix 4. Sanitation Protocol

Recommended steps to prevent & mitigate BLD spread

Litylenchus crenatae ssp. mccannii is a microscopic leaf-living nematode intimately linked to Beech Leaf Disease. The goal of these sanitary guidelines is to reduce (and eliminate, if possible) the pathways by which *Litylenchus* can be transported due to field visits and related activities. Widespread observations suggest that *Litylenchus* does not require assistance from human volunteers/vectors – **it moves about quite readily without our help** – but slowing the spread is worth our time and effort. The steps below are focused on a) preventing contact with *Litylenchus* b) removing organic material that hosts nematodes (soil, leaf litter) and c) killing nematodes and their eggs on surfaces where they may nevertheless remain.

In the field: Stay on trails if feasible for the purposes of your visit. Observe first with your eyes/binoculars – touch leaves, buds, and bark only when necessary. Keep backpacks on, or if needed, place on a washable tarp to reduce contact with soil/leaf litter. Do not collect samples unless necessary.

After field visits (before loading vehicles): clean and sterilize boots, equipment, and clothing that contacted organic matter

1. Wash shoes and hands and anything else carrying soil/litter in soapy water, then rinse. (Tip: change into sandals/spare shoes for this step)
2. Spray cleaned shoes etc. generously with min. 70% isopropyl alcohol and let dry
3. Spray contact areas of other non-washable equipment used during site visit (e.g. sides of binoculars, wrists of jackets, clipboards, measuring tapes) with 70% isopropyl alcohol, let dry
4. Promptly wash tarp and clothing used during visit, especially if returning to beech forests!

Useful supplies: Dish tubs, soap, scrub brush, hoof pick, water & jug, 70% isopropyl alcohol, spray bottle, bins to separate clean/dirty gear, spare shoes to change into.

Additional steps for researchers or frequent visitors:
Equipment installation: Seasonal equipment (temperature/humidity sensors, stakes) should be new or sanitized at the time of installation.
Collections: When collecting foliage samples from beech trees, tree pruners must be sterilized with 70% ethanol and flame sterilized between each shoot clipped.
Permit conditions, MI-DNR sites: See Table 1 from *Invasive Species Decontamination for Field Operations in Michigan (attached)* – follow **Medium Risk decontamination protocols and procedures** for all equipment and personnel.

Invasive Species Decontamination for Field Operations in Michigan. A guidance document for MI-DEQ, MI-DNR, and MDARD, Number: QOL-2-2014 URL: https://www.michigan.gov/-/media/Project/Websites/egle/Documents/Policies-Procedures/WRD/QOL-2-2014-invasive-species-decontamination.pdf?rev=30ebba1f42f341ae9d3b0655914cf1bf

Draft of 2023-09 - SJM Cousins, UM-SEAS scousins@umich.edu

Equipment	Low	Medium Options (pick one). Rinse after all.	High
Boats, trailers, and motors	Inspect, clean, drain, rinse, and dry	•Bleach: ½ cup [4 oz] bleach to 5 gallons of water or 120 mL bleach to 19 liters of water •Virkon Aquatic for 20 minutes (20 g/L) •Hot water pressure: 140°F/60°C for 10 second contact time	Motor flush: 140oF for 5 minutes and an exiting temperature 120°F/49°C OR ambient temperature for 10 minutes
Sampling gear (e.g., nets and other equipment that have direct contact with water)	Inspect, clean, rinse, and dry	•Bleach: ½ cup [4 oz] bleach to 5 gallons of water or 120 mL bleach to 19 liters of water •Then use 100% vinegar for 20 minutes to dissolve any veliger shells •Virkon Aquatic for 20 minutes (20 g/L) •Hot water pressure: 140°F/60°C for 10 second contact time; dry ≥5 days in sun	Use alternative gear that has not been deployed in infested water within the past 5 days
Waders, boots, and other field equipment	Inspect, clean, rinse, and dry	•Launder clothing and footwear •Disinfect other equipment •Bleach: ½ cup [4 oz] bleach to 5 gallons of water or 120 mL bleach to 19 liters of water •Virkon Aquatic for 20 minutes (20 g/L) •Formula 409 for 10 minutes for New Zealand mudsnails	Heat and dry: household steamer or pressure wash; dry â‰¥5 days
Sensitive equipment (e.g., sondes, hydrolabs, and dataloggers)	Inspect, clean, and sanitize every time it has been exposed to water; follow manufacturer's directions		
Vehicles	Inspect and clean interior and exterior	•Clean with water using pressure washer •Take vehicle through carwash with undercarriage flush	
Heavy equipment (e.g., mowers, dozers, loaders, and dump trucks)	Inspect and clean interior and exterior	Compressed air, then high pressure washer, rinse, and dry; run fans in reverse if possible to clean air intakes	
Portable pumps (any equipment that draws water from a water body)	Inspect and clean exterior surfaces	• Flush, clean, rinse, and dry •For small portable pumps, flush with either Virkon Aquatic (20 g/L) for 20 minutes or with a bleach solution (½ cup [4 oz] bleach to 5 gallons of water or 120 mL bleach to 19 liters of water for 20 minutes	
Diving equipment (e.g., wet suit, snorkel, fins, and buoyancy compensator)	Inspect, clean, drain, rinse, and dry	•Salt solution: ½ cup salt per gallon of water for 30 minutes •Hot water: >120°F/49°C for 30 minutes After treatment, completely dry if possible	

Appendix 5. Monitoring Plot Protocol

USDA
United States Department of Agriculture

Beech Leaf Disease Long-Term Monitoring Plot
Data Cheat Sheet

Authors
Danielle Martin, USDA Forest Service; Constance Hausman, Cleveland Metroparks; Dan Volk, Cleveland Metroparks; Sharon Reed, Ontario Ministry of Natural Resources and Forestry; Tom Macy, Ohio DNR Division of Forestry and John Pogacnik, Lake Metroparks

Purpose
In order to allow a thorough study of the progression of beech leaf disease (BLD), staff examined existing long-term vegetation plots and established new plots in infected and uninfected stands in 2019 across Ohio, West Virginia, New Jersey, Pennsylvania, Indiana, Michigan, Connecticut, New York, and Ontario, Canada. Long-term monitoring plot protocols were developed with the BLD Survey and Monitoring Team, a partnership between the USDA Forest Service, Cleveland Metroparks, Ohio Division of Forestry, and the Ontario Ministry of Forestry.

Plot Placement
A minimum of eight plots should be placed per state, but cooperators are encouraged to establish and monitor as many plots as they are capable of monitoring. Plots should be distributed throughout the variety of forest types or ecoregions that occur in each state where beech grows. Consideration should be given to placing plots within varying distances to water sources (rivers, streams, lakes) because nematode spread may be associated with moisture levels. Establish plots in locations with no management planned and without recent anthropogenic disturbance. Each plot should have a minimum of three beech trees (sapling or overstory) per plot.

In states with known BLD occurrences, plots should be placed within a range of BLD symptoms (i.e. distance from leading edge – high, medium, low, none) and in areas with and without beech bark disease (BBD). Plots should be representative of BLD and BBD conditions in the stand. Consideration should be given to placing a plot in locations where a positive nematode diagnosis has occurred, either asymptomatic or symptomatic. Cooperators are encouraged to place a Hobo®, ibutton®, or other humidity data logging device in their plots to capture humidity. To the best of your ability, place the device in the center of the plot, in a netted bag, 12 inches off the ground, hanging by a pole, preferably covered. Leave the device to collect data throughout the field season.

Samples are to be taken from each plot and submitted to the National Plant Diagnostic Network or state clinics for diagnoses and nematode detection.

Supplies

- DBH tape
- 10-m tape or logger's tape
- GPS
- Clinometer (or compass to measure slope)
- Binoculars (for canopy assessments)
- Tags
- Nails
- Hammer
- 1-meter stick (can be homemade)
- Data sheet
- Clipboard
- 10-factor prism
- Compass
- Densiometer, if available
- Humidity data logging device, if available
- Pole and netted bag to hang humidity device on

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Background Data Sheet Tab

General Information

- **Plot ID**: Two-letter state code, two-letter county code, two-digit sequential numbering within the county
  - All trees 5 inches in diameter are marked with aluminum tags and nails at base facing plot center.
- **Project Name:** Beech Leaf Disease Monitoring
- **Date:** (mm/dd/yyyy)
- **Surveyor Names:** Surveyor names
- **Plot Coordinates:** GPS coordinates
- **Altitude (m)**

Location

- **State and County**
- **Local Place Names** to describe the location (park, reservation, or special name)
- **Landowner**: (public or private)
- **Ecoregion**: Can be determined after GPS is taken; view ecoregions here: https://www.epa.gov/eco-research/ecoregions-north-america.
- **Photo Nos.**: Optional, not required, camera information: if images are taken of the plot, take from the north subplot facing south.

Site Attributes

Taken from plot center:

- **Basal Area:** Use a 10-factor prism from plot center to assess # of live trees (multiply by 10 to calculate basal area/acre)
- **Slope %:** Use a clinometer for % slope, assess overall landscape from plot center
- **Aspect:** Downhill reading will be averaged with (uphill rating + 180)
- **Slope Shape:**
  1. Convex
  2. Concave
  3. Flat (the entire area typically is flat)
- **Slope Position:**
  1. Bottom of slope
  2. Lower slope
  3. Mid-slope
  4. Upper slope
  5. Summit

Plot Diagram

- **Mini image:** Illustrates fixed-radius circular plots, plot center, GPS reading location, etc.
- **Large image:** Use tree number to denote location of beech > 5 inches DBH within plot; used to relocate trees if aluminum tags are lost or not able to be placed.

Site Remarks

- Provide site descriptions and general vegetation characteristics. Please add any notes about **distance to nearby bodies of water** (streams, creeks, lakes, etc.), even if they run intermittently.

Trees Data Sheet Tab

The tree plot is a 0.1-acre plot, 37.2-foot radius. Measure all trees > 5 inches DBH.

Species

For paper datasheets in the field, use the first two letters of genus and species will be used to identify species. Example: American beech = FAGR. When entering data, use the drop down menu to select species name.

If dead, write "snag" in species column and write species name in remarks column if identifiable.

Tag Number

All trees 5 inches in diameter are marked with aluminum tags and nails. Tags will be placed 1 foot from the base of the tree, facing plot center.

DBH

Diameter at breast height (in inches) will be taken for all trees 5 inches or greater in diameter.

Crown Class

Crown class measurements will be taken for all trees 5 inches or greater in diameter.

- Dominant (D): Trees with crowns extending above the general level of the forest canopy and receiving full light from above and partly from the side.
- Codominant (C): Trees with crowns forming the general level of the forest canopy and receiving full light from above but comparatively little from the sides, usually with medium-sized crowns more or less crowded on the sides.
- Intermediate (I): Trees are shorter, have smaller canopies, and are more crowded than those in the preceding classes but crowns extending into the forest canopy formed by codominant and dominant trees, receiving some direct light from above but none from the sides.
- Suppressed (S): Trees with crowns entirely below the general level of the forest canopy, receiving no direct light, either from above or the sides.

Crown dieback and density-all trees

Dieback measurements will be taken for all trees 5 inches or greater in diameter.

Crown dieback and density categories	
1	0
2	1-10
3	10-25
4	25-50
5	50-75
6	75 - 99
7	recently dead (fine twigs present)
8	dead long time

Percent of crown with dieback (1-8) and crown density (1-6 only) are separately determined for live trees and put into one of eight categories.

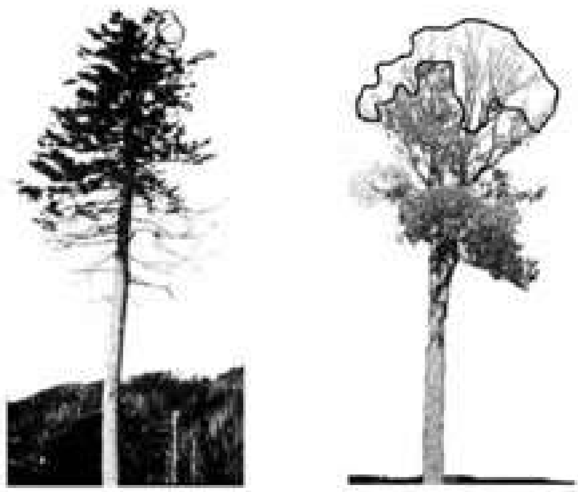
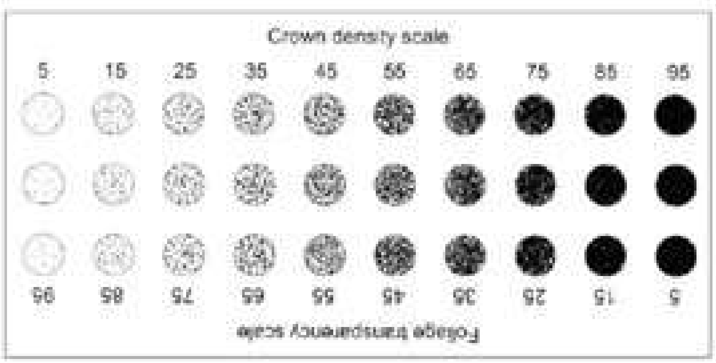


Figure 23-13. CROWN DIEBACK rating outline examples.



RECORD THE FOLLOWING FOR BEECH TREES ONLY

Canopy Assessment

A canopy assessment will be made for each individual beech tree 5 inches or greater in diameter. Leaf absence percent will be measured using 1-6 categories. Within the crown, rate the dieback present or leaf absence in that section of the crown.

Leaf absence categories	
1	0
2	1-10
3	10-25
4	25-50
5	50-75
6	75 - 99

Dead Main and Fine Branches

Record absence of foliage in both main and fine branches and their position within the canopy using 1-6 categories (for beech only). The canopy position is to be divided into two equal parts (lower and upper). Affected areas will be recorded as follows: 1 (lower section affected), 2 (upper section affected), 3 (both sections affected).

BLD Leaf Severity

For beech trees only, record the percentage of normal (leaves of typical size and shape), striped (leaves have interveinal dark striping or bubbling), and shrunken/curled leaves (leaves are smaller than typical, often thickened with curled edges) and their canopy position.

Canopy Position: Equally divide tree canopy into 2 parts	
Lower	1
Upper	2
Both	3

Leaf Severity: provide cover class for each leaf type combination	
Size	**Normal**: leaves are typical size and shape
	Shrunken or Curled: leaves are smaller than typical, often thickened with curled edges
Condition	**No Symptoms present**: typical healthy leaves
	Striped pattern: leaves have interveinal dark striping or bubbling. Striping per leaf may be variable but less than 2/3 of leaf shows pattern
	Striped/Solid: leaves are >2/3 - solid darkening, these leaves are thickened and leathery

Beech Scale, Neonectria fruiting, and BBD cankers Rating and Distribution

Presence and severity of beech scale, *Neonectria* fruiting, or BBD cankers are visually evaluated for each tagged beech tree. A clipboard (roughly 9 by 14 inches) is held against the trunk on the north and south sides of each beech tree at breast height. The area within the clipboard is assessed for both the north and south. An overall rating for scale, *Neonectria*, or BBD outside the monitoring frame (above and below) is recorded as well. The columns on the BLD Tree Data Sheet with the heading "Scale (N, S, O)" and "*Neonectria* fruiting/BBD cankers (N, S, O)" are for scale North/South/Overall and *Neonectria fruiting*/ BBD cankers North/South/Overall, for example (3, 0, 1).

The rating system for scale and *Neonectria* is as follows:

Mean Scale Intensity for Scale, *Neonectria, or BBD*	
0	**No infestation**
1	**Trace**: 1-10 single-scale colonies, Neonectria, or caniers
2	**Light**: numerous single-scale colonies, Neonectria or canker scattered over the bole
3	**Moderate**: accumulation of scale colonies, Neonectria, or cankers producing a clumping appearance
4	**Moderate-Heavy**: clumps of scale colonies, Neonectria, or cankers building to the point of beginning to appear to stream down the bole
5	**Heavy**: accumulation of scale, Neonectria, or cankers on the bole has increased to the point where portions of the bole appear white-washed or vertical accumulation lines produce the impression of scale streaming down the bole

Scale Rating

Neonectria fruiting rating

BBD canker rating

BBD canker Rating 5; Heavy BBD canker

Other Diseases

Other Pests/Remarks (Damage Codes)

Only record if pest/disease is affecting the health of the tree, for example affecting >10% of foliage, crown, stem, or root collar. For other pests, describe the type, location of damage, and percent of the tree affected using the codes below and a code similar to the dieback code. A general code is depicted by a numeral identifier. If the surveyor is familiar with the specific cause of the ailment, he or she may identify it further. For example, Eriophyid mite would be identified as 3E.

1. Abiotic (general)
   a. Ice/snow
   b. Frost
   c. Drought
   d. Flooding
   e. Fire damage
   f. Nutrient deficiency
2. Mechanical Injury/Human
   a. Pruned
   b. Blowdown
   c. Animal (general-rubbing gnawing, girdling, birdpecking, grazing)
   d. Sapsucker
   e. Porcupine
   f. Beech Snap
   g. Wound closed, scar
   h. Dry seam, frost crack
   i. Wet seam, bleeding crack
   j. Wound open, scar hole
   k. Overmaturity (only largest tree affected, hollow bole)
   l. Lightning
   m. Topped tree
3. Insect activity (general or unknown)
   a. Defoliators (general)
   b. Aphids (general)
   c. Leaf rolling aphid
   d. Mite (general)
   e. Eriophyid mite
   f. Ambrosia beetle
   g. Bark beetles
   h. Borer, other
   i. Ants
   j. Defoliators (spring)
   k. Defoliators (fall)
   l. Gypsy moth
   m. Forest tent caterpillar
   n. Hickory Tussock Moth
4. Canker (unidentified/general)
   a. Eutypella
   b. Hypoxylon canker
   c. Aftermath BBD canker
5. Leaf Chlorosis/scorch
6. Root Decay or rot (general)
   a. Armillaria
   b. Laetiporus root rot
   c. Phytophthora root rot
7. Other diseases (general or unknown)
   a. Powdery mildew
   b. Tarry Spot
   c. *Nematogonum ferrugineum*

Location Codes (*if necessary, record in "Other Pests/Remarks")

I. Stump/roots (defects visible on the buttress roots or the stump within 30 cm from the ground)
II. Bole-lower half (above the stump. 30 cm above ground, but in the lower half of the bole)
III. Bole-upper half (upper half of the bole, but below crown or branch forks)
IV. Whole bole (defects in both halves or continuous)
V. Twigs/branches
VI. Canopy/foliage
VII. Whole tree (includes bole, stump, and roots)

Damage Severity (*if necessary, record in "Other Pests/Remarks")

0= No damage, 1= 0-10 percent affected, 2= 11-50 percent affected, and 3= > 50 percent affected.

Tree Remarks: List additional comments such as excessive suckering.

Regeneration – Saplings Data Sheet Tab

The regeneration plot is an 11.8-foot radius plot, in the center of the main plot.

Measure and record all saplings <5 inches DBH, and greater than breast height. Use same ratings as described for larger tree plots.

Seedlings Data Sheet Tab

The seedling plot is a 1-m radius plot taken at each cardinal direction, 37.2 feet from main plot center. A seedling is anything <5 inches DBH, and less than breast height.

Record subplot location (N, S, E, W), as it pertains to main plot center. Record total number of seedlings within the seedling plot.

Densiometer: Optional, not required: Take four readings at each subplot (N, S, E, W).

MFO Est 2018, D. Martin