Michigan Pest Risk Assessment

USDA 2000 - Guidelines to Pathway-Initiated Pest Risk Assessments

Beech Leaf Disease

Litylenchus crenatae ssp. mccannii

(*Nematoda: Anguinidae*)

2024

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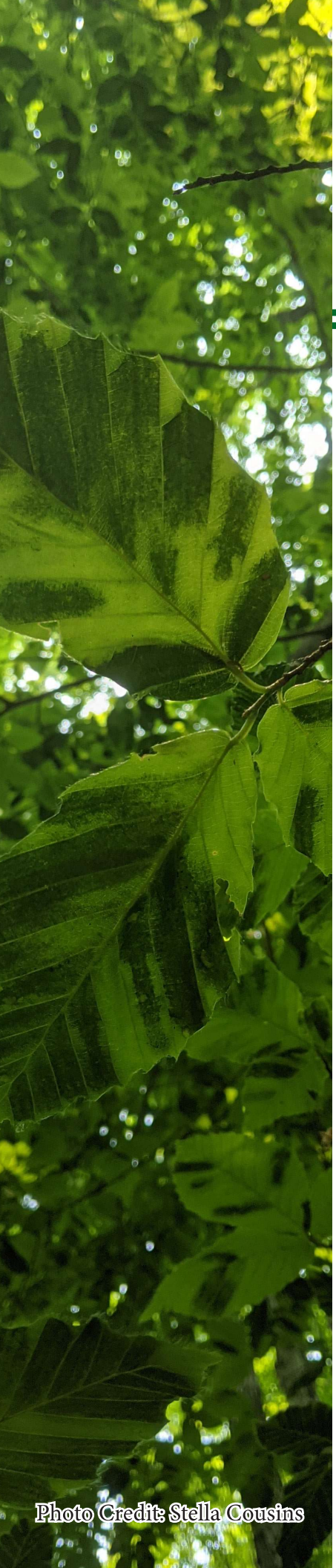


Photo Credit: Stella Cousins

Executive Summary

A risk assessment of beech leaf disease (BLD) was performed to better understand the consequences and likelihood of invasion to the state of Michigan. Methods from the USDA 2000 "Guidlines to Pathway-Initiated Pest Risk Assessments" were used to qualitativley assess BLD risk (USDA, 2000). Elements associated with risk received a ranking and subsequent score based upon the current literature, management, and research regarding BLD. BLD can be considered to have high risk based upon these findings, in particular due to its potential geographic distribution, climate suitability, and pest history as observed in other states in the region. Shifting forest community structure and composition is likely to occur across mesic northern and southern forest types. Impacts to wildlife and ecosystem services are expected to occur as a result of BLD in the northern parts of the state. Economic losses will be primarily attributed to the timber and horticultural nursery industries. A response network should be established to prepare land management organizations and land owners for the risk BLD poses upon the state. By implementing early detection and rapid response protocols, proactive management and the conservation of American beech as a natural resource can be successfully accomplished. To combat potential loss of American beech, we recommend that the state of Michigan implement biosurveillance, phytosanitary, or quarantine mitigation measures to slow the spread of BLD.

Keywords: Beech leaf disease (BLD), American beech, *Litylenchus crenatae ssp. mccannii* (LCM) nematode, mesic southern forest, mesic northern forest, pest risk.

Introduction

Background

The foliar nematode *Litylenchus crenatae ssp. mccannii* (LCM) (Figure 1A-1C) has been found to be associated with beech leaf disease (BLD) (Figure 1A) and is likely its primary causal agent of disease (Carta et al., 2020; Reed et al., 2020). While in North America our most widely distributed species of beech is American beech (*Fagus grandifolia*), the disease also represents a significant threat to both European beech (*Fagus sylvatica*) and Oriental beech (*Fagus orientalis*). The likelihood that BLD has potential to cause economic and environmental harm to a number of industries (*e.g.* timber, nursery and landscaping, horticulture, urban forestry) warrants a risk analysis.

BLD was first detected in Lake County, Ohio in 2012, and has since spread through much of the northeastern range of American beech (Ewing et al., 2019; Carta et al., 2022; Reed et al., 2022; Zhao et al., 2023). In 2022, BLD was detected in Michigan with three confirmed counties: St. Clair, Wayne, and Oakland. Since then, through the establishment of fixed radius plots, BLD has been confirmed in four additional counties: Washtenaw, Hillsdale, Macomb, and Lenawee (Figure 3). Although occurrences are currently limited to southeast Michigan, American beech is much more abundant in northern Lower Peninsula and eastern Upper Peninsula forests.

Since the introduction of LCM to the United States, much of the research regarding the disease has been aimed at understanding the natural history of LCM and the potential impacts of BLD on forest ecosystems. However, little is known about the invasion pathway of LCM. Certain modes of transmission remain speculative and still await scientific evidence to support hypothesized vectors. With BLD now in Michigan, and no invasion pathway being determined, in part because no known pathways have been described or identified elsewhere, the need for continued research is clear and necessitates the evaluation of risk that BLD poses to the state. This risk assessment is supported by a body of growing literature and awaits supporting evidence for the transmission of BLD.

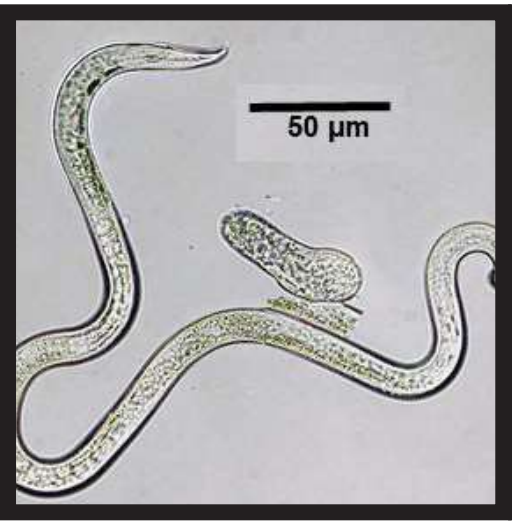


Figure 1A *Litylenchus crenatae mccannii* female. (Carta et al., 2020)

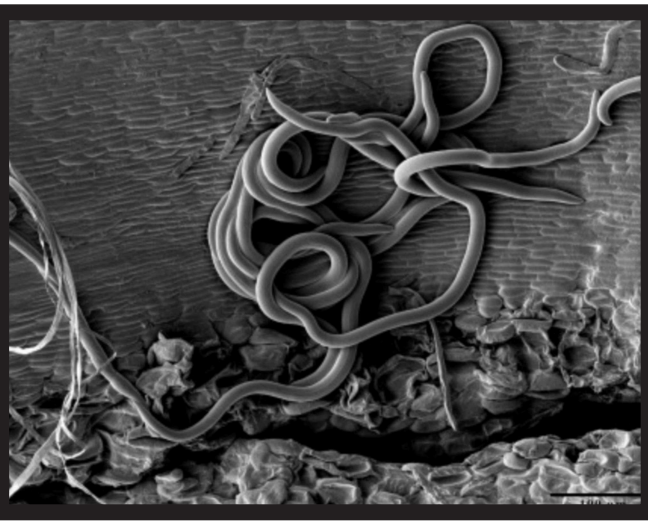


Figure 1B SEM of *Litylenchus crenatae mccannii* on beech bud scales. (Carta et al., 2020)

Figure 1C BLD symptoms on beech leaves. (Carta et al., 2020)

Risk Assessment Use

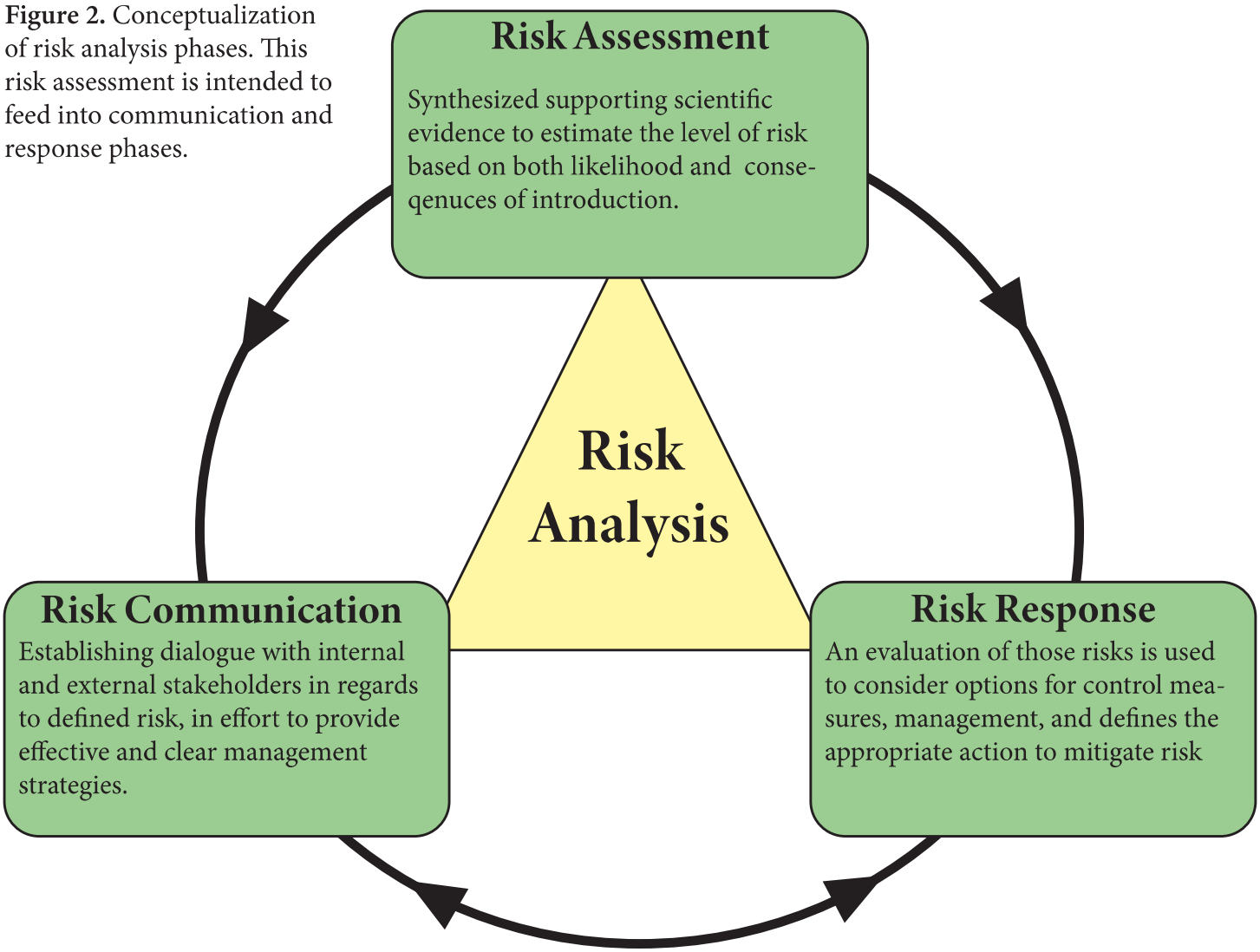
This risk assessment will be used to identify the potential invasion pathways of BLD and the likelihood of spread to new counties in Michigan. Areas of high risk are identified and recommended for monitoring. By building awareness of BLD, early detection of symptoms can prompt active management. Counties adjacent to BLD positive counties are recommended for surveying and considered to be corridors of concern.

Environmental risk mapping can be used to identify and forecast areas of likely infestation of forest pathogens so that proactive management measures can be put in place (Zhao et al., 2023). Since BLD exhibits a latency period between initial infection and symptom expression (Zhao et al., 2023), the use of environmental risk mapping and qualitative risk assessments is used to inform stakeholders on the potential spread of BLD and formulate response strategies for ecological and environmental management.

Risk Analysis Objectives:

1. 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 (Figure 2).
2. Identify a combination of preventative measures in coordination with early detection and rapid response strategies, to monitor and mitigate potential risk associated with BLD (Figure 2).

Figure 2. Conceptualization of risk analysis phases. This risk assessment is intended to feed into communication and response phases.



Similar Risk Assessments

In 2014 the U.S. Forest Service published the National Insect and Disease Forest Risk Assessment (Krist Jr. et al., 2014), wherein it provided a comprehensive approach to assessing risk for many pests and diseases that have been on the rise in the United States. The assessment of beech bark disease (*Cryptocooccus fagisuga* + *Neonectria spp*.) has certain similarities to BLD. Here, the methods and modeling procedures for beech bark disease have been used to conduct a similar risk analysis for BLD. Additionally, a qualitative pest risk assessment has been conducted by following the format from the U.S. Department of Agriculture's "Guidelines for Pathway-Initiated Pest Risk Assessments" (USDA, 2000). The USDA qualitative pest risk assessment is a standardized procedure that is typically provided by the Animal and Plant Health Inspection Service (APHIS) when deciding whether or not to implement biosurveillance, quarantine, or phytosanitary measures to mitigate the risk of pests, disease, or pathogen spread.

Through the use of environmental risk mapping, BLD infections can be modeled to forecast the potential distribution and dispersal of LCM to new host populations. In 2023, the research article "Mapping the Environmental Risk of Beech Leaf Disease in the Northeastern United States" by Zhao et al. (2023) was published and has provided a novel approach to mapping the environmental risk of BLD across the range of American beech. While the study focused on the Northeastern Ohio region, our study was derived from the methods used in the article and applied to Michigan.

Risk Assessment Methods

Overall risk can be defined as the product of the consequences and the likelihood of invasion (Selness & Venette, 2006). Furthermore, risk can be defined as the likelihood of a pest becoming established in the state and the severity of consequences after pest establishment (Selness & Venette, 2006). Risk was qualitatively assessed through a set of standardized criteria based on the 2000 U.S. Department of Agriculture "Guidelines for Pathway-Initiated Pest Risk Assessments" (USDA, 2000). Each risk element was attributed a score of high, medium, low, or negligible based upon the accumulation of information discovered from similar risk assessments, peer reviewed journal articles, and maps produced from data provided by the United States Department of Agriculture (USDA), United States Forest Service (USFS). (Wilson et al., 2012; Krist Jr et al., 2014; USDA, 2012, Pugh et al., 2017).

A numerical value was calculated by converting the ratings of each element to a score (negligible=0; low=1; medium=2; high=3). The score for unmitigated consequences of introduction was calculated using the following formula $C=(G+D+A+Ec+En+H+S)$. The variables are defined as follows, where C is the total consequence; G is the potential geographic distribution; D, dispersal potential; A, potential abundance; Ec, economic impact; En, environmental impact; H, human and vertebrate health impacts; S, social and political impacts. Additionally, a separate rating for management potential was attributed by examining the availability and effectiveness of control strategies for BLD. Furthermore, an overall score for the likelihood of invasion was calculated using the following formula $I=(Q+P+Sp+Ss+M+F)$. The variables are defined as follows, where PH is the pest history of the organism; Q, is the quantity of host material imported annually; P, estimated density of pest per unit imported; Sp, likelihood of surviving post harvest treatments (i.e. phytosanitary treatment); Ss, likelihood of surviving shipment; M, the likelihood of being transported to a suitable habitat; and F, the likelihood of finding a host. Pest history is considered through its life history within its native range and how it has adjusted into its new range. The assessment also considers the potential for eradication, however, this score is not factored into overall risk. The overall risk score formula is as follows $C+I$.

Summary of Findings

C=(G+D+A+Ec+En+H+S)
- C: total consequence
- G: potential geographic distribution
- D: dispersal potential
- A: potential abundance
- Ec: economic impact
- En: environmental impact
- H: human and vertebrate health impacts
- S: social and political impacts

I=(Ph+Q+P+Sp+Ss+M+F)
- PH: pest history of the organism
- Q: quantity of host material imported annually
- P: estimated density of pest per unit imported
- Sp: likelihood of surviving post harvest treatments (*i.e.* phytosanitary treatment)
- Ss: likelihood of surviving shipment
- M: likelihood of being transported to a suitable habitat
- F: likelihood of finding a host

Table 1. Ratings and scores for the elements used to conduct a qualitative pest risk assessment on beech leaf disease in Michigan. Host range rating and climate suitability rankings are independent of overall risk and are 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

Overall Risk Score Scale

Negligible = 0-10
(Pest risk assessment stops)

Low = 11-18
(No mitigation measures)

Medium = 19-26
(Specific mitigation measures)

High= 27-33
(Phytosanitary, biosurveillance, or quarantine mitigation measures)

Overall Risk = C+I

Pest Risk Potential

Consequences of Introduction

Photo Credit: Stella Cousins
An American beech infected with BLD displays varying symptom severity. Noticeable interveinal banding and severley shrunken leaves.

Potential Geographic Distribution: High (3)

LCM has high potential to find suitable host plants on the 37 million beech trees (MIDNR, 2008) in Michigan. Currently BLD has been found to occur across two different plant hardiness zones within the distribution range of American beech in Michigan (Appendix 2). The American beech tree is found in 67 counties across both peninsulas of Michigan, where it inhabits mesic northern and southern forest natural communities (Figure 4).

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 often comprise more than 80 percent of the canopy composition (Kost et al., 2007).

- 37 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 Michigan (Wilson et al., 2012).

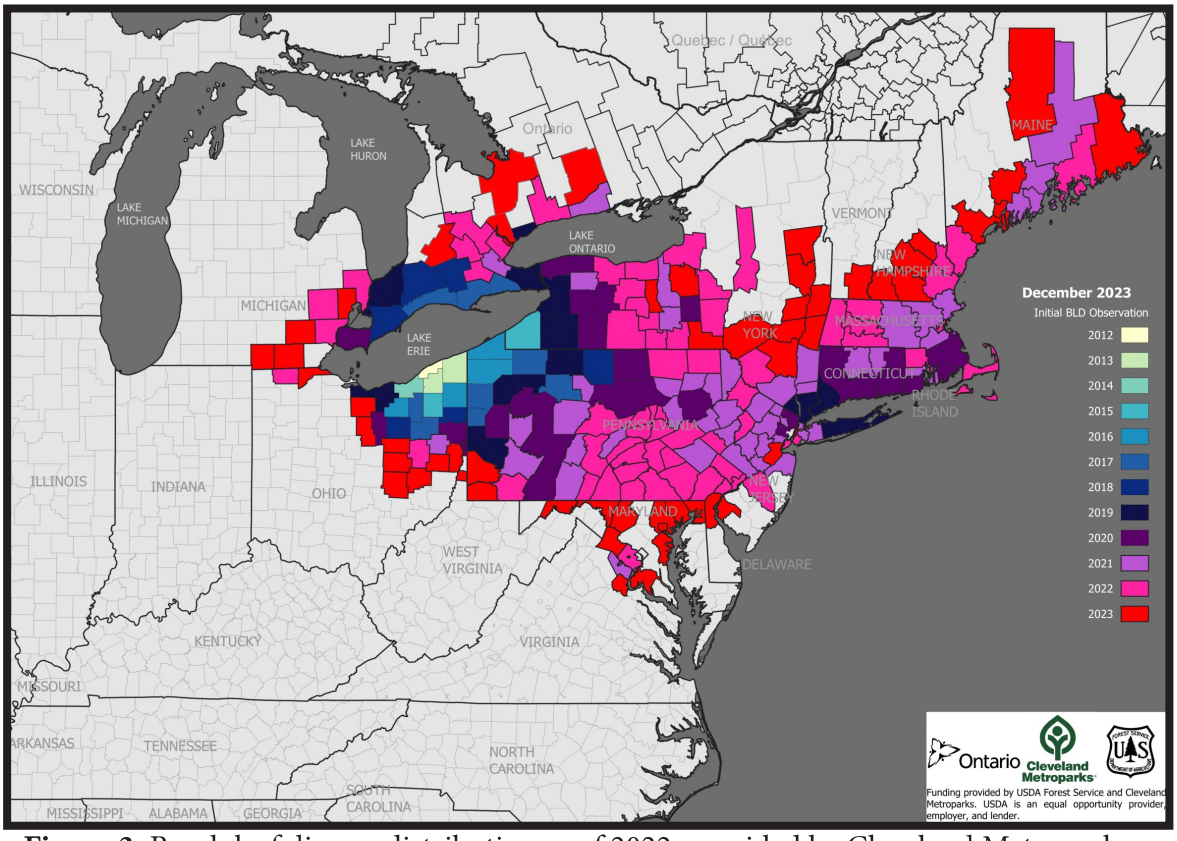


Figure 3. Beech leaf disease distribution as of 2022, provided by Cleveland Metroparks, Ontario Ministry of Natural Resources and Forestry, and United States Forest Service.

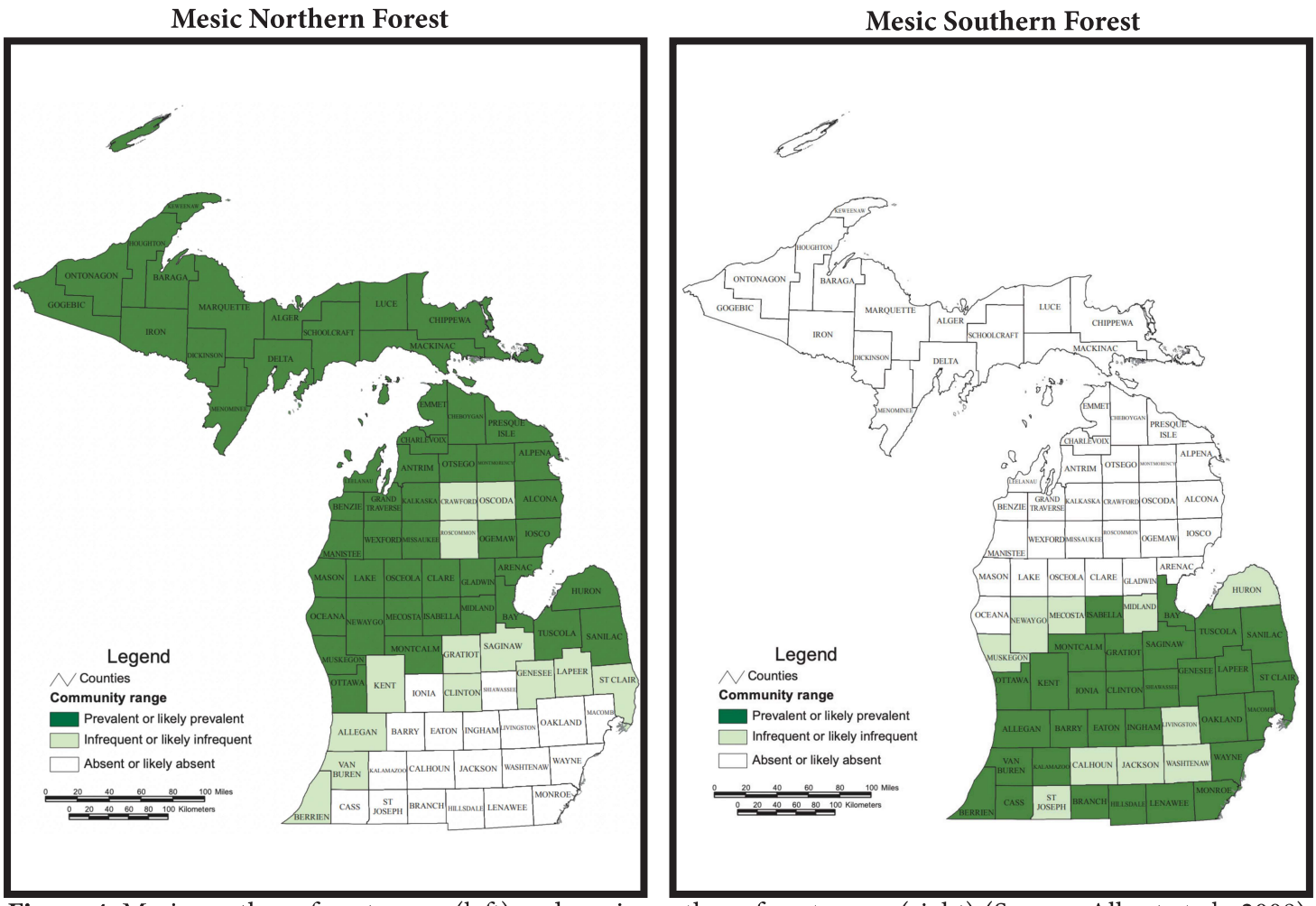


Figure 4. Mesic northern forest range (left) and mesic southern forest range (right) (Source: Albert et al., 2008)

Figure 5. Prevailing winds of the continental United States. These patterns may suggest the wind mediated dispersal of LCM, and why most of its distribution has continued along the easterun U.S. up to Maine. Additionally, this wind pattern might expalin why it took longer for LCM to reach Michigan (Source: Hagreen & Kulperger, 2004).

Host Range Rating: High (3)

LCM is considered a subspecies that exhibits differing morphology, host range, and molecular markers of a similar disease-causing nematode in Japan (L. crenata) (Carta et al., 2023; Kanzaki et al., 2019). In North America, American beech distribution spans across twenty-eight states (Figure 6) that comprise differing climatic zones and ecoregions (Kartesz & BONAP, 2015). With BLD already occupying fourteen states and Ontario, Canada (Zhao et al., 2023; Reed et al., 2022; Carta et al., 2022), it is very likely to continue its spread across the range of American beech, including new counties in Michigan. It is most likely that BLD will spread through corridors of connected landcover types of mesic northern and southern forests, where beech typically occurs in mixed stands with differing canopy structures and age classes. Counties adjacent to BLD positive counties are recommended for surveying and considered to be corridors of concern.

- American beech is a dominant canopy component in mesic northern and southern forest natural communities in Michigan (Kost et al., 2007).
- BLD has rapidly spread in forests surrounding the Great Lakes and has been observed affecting all size classes and ages of beech (Reed et al., 2022).
- Beech bark disease has been established in Michigan since 2000 (Mcullough et al., 2001).
- Common forest associates of beech include sugar maple (*A. saccharum*), black cherry (*Prunus serotina*), American basswood (*Tilia americana*), yellow birch (*Betula alleghaniensis*), and eastern hemlock (*Tsuga canadensis*) (Kost et al., 2007; Reed et al., 2022).

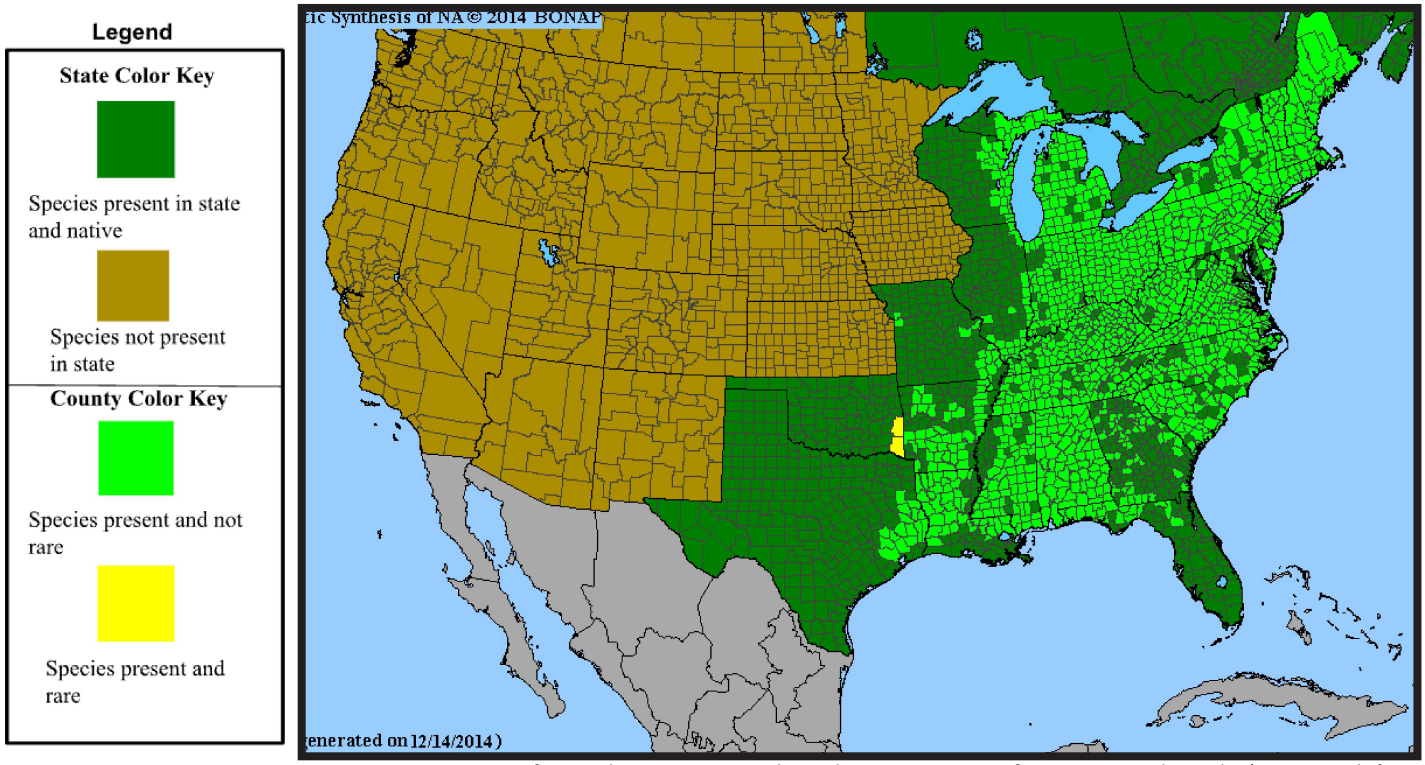


Figure 6. Biota of North American distribution map of American beech (*F. grandifolia*) where it occurs across 67 counties in Michigan (Kartesz & BONAP, 2015).

Climate Suitability Rating: High (3)

BLD had first established itself in 2012 within the Cleveland Metroparks system of Ohio, which is considered under the 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 5a (-20 to -15 °F [-28.9 to -26.1 °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 (Appendix 2). Specifically, areas with less drastic seasonal temperature variation will be conducive for BLD spread and establishment (Zhao et al., 2023).

- LCM overwinters in detached leaves and buds, enduring cold temperatures below 14 °F (10 °C), with no effect on nematode populations (Carta et al., 2020).
- Currently BLD can be found in the 6a (-10 to -5 °F [-23.3 to -20.6 °C]) and 5b (-15 to -10 °F [-26.1 to -23.3 °C]) plant hardiness zones.
- 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).

Dispersal Potential Rating: Medium (2)

The dispersal potential of LCM could be considered low due to its microscopic size. Yet, in many cases BLD has been considered a fast spreading pathogen (Carta et al., 2020 Reed et al., 2022; Zhao et al., 2023). While most modes of transmission are poorly understood, a number of vectors have been speculated. Short distance travel has been attributed to wind and rain, given that nematode motility is moisture reliant (Carta et al., 2023). The long distance movement has even more knowledge gaps. Purple finches (*Haemorhous purpureus*) have been observed eating developing beech buds; LCM is known to overwinter within the bud. Bird-assisted migration poses a likely form of long-distance transmission (Carta et al., 2020). If the nematodes can survive the gastrointestinal tract of birds they could very well be passed to new hosts through bird feces. Additionally, if LCM can persist within the mouths of these birds, it could be distributed to buds every time a bird feeds on them. LCM has also been found in leaf litter from symptomatic beech trees; it survives desiccation due to moisture from snow and ice melt (Carta et al., 2020; Reed et al., 2020). Therefore, with LCM persisting within the leaf litter it is also likely that either humans or other animals can pick up and move debris containing LCM nematodes to other locations with new hosts. Lastly, on a number of occasions LCM has been found entwined with Oribatid (*Oribatida spp.*) mites which in themselves are transmitted by a number of vectors such as wind, rain, and birds (Carta et al., 2023). With the dispersal potential for LCM relying on a number of factors, BLD has now been found in fourteen different states and Ontario, Canada (Figure 2). With seven BLD confirmed counties in Michigan since 2022, it remains likely that BLD will continue its expansion throughout the state. Corridors of land cover types have been identified that have higher densities of beech, which will be conducive to the dispersal of BLD in Michigan (Appendix 4 & 5). This main land cover type suitable for BLD identified in Zhao et al. (2023) is closed broadleaved deciduous forests, which can otherwise be considered closed canopy deciduous forest types like mesic northern and southern forest natural communities. Again though, with no modes of dispersal supported in the primary literature, it remains difficult to forecast its expansion and what types of transmission BLD might rely on.

- LCM nematodes can persist in leaf litter where they survive desiccation from snow and ice meltwaters (Reed et al., 2020; Reed et al 2022). This presence of LCM in leaf litter indicates a potential pathway for local movement, wherein detached leaves may be dispersed by wind, introducing BLD to new locations (Reed et al., 2020).
- Many parasitic nematodes complete their life cycle in a few weeks to a month, resulting in rapid increases in population (Reed et al., 2020; Kohl, 2011).
- Insects or avian vectors in addition to human-mediated movement of LCM are possible modes of dispersal for BLD (Volk & Martin, 2022).
- Mites and ambrosia beetle could possibly transport eggs of LCM between tree hosts (Burke et al., 2020).

Beech Leaf Disease
Litylenchus crenatae mccannii
Development Cycle

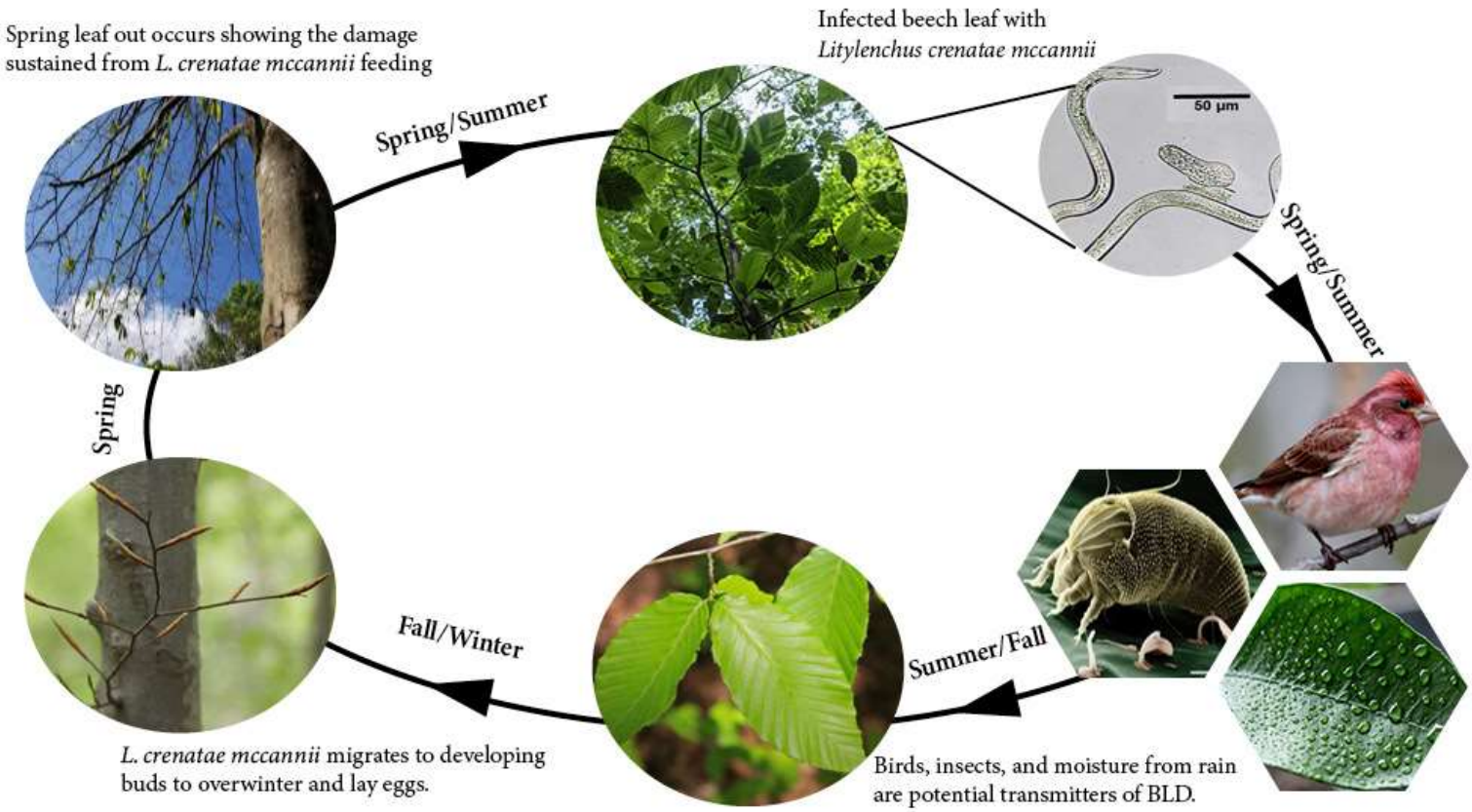


Figure 7. Disease development cycle of LCM nematodes and the speculated modes of transmission to new healthy host trees. Photo Credits: 8, 13, 16, 20, 41, 46, 50

Potential Abundance Rating: Medium (2)

The abundance of LCM is strongly dictated by the abundance of hosts available. In some cases LCM can take a number of years before trees express symptomatic leaves. Since BLD exhibits a latency period between initial infection and symptom expression (Martin & Volk, 2022; Zhao et al., 2023), a beech tree could essentially be harboring LCM until it builds up enough of an abundance for symptoms to be detected. So to some extent, under the current findings, LCM has to build up its population on a host tree before BLD is readily identifiable and diagnosable. It has been found that LCM can be in many different life stages on a given tree during the growing season (Carta et al., 2020).

With the potential for LCM to complete multiple life cycles on a tree in a year, LCM populations have been observed to undergo exponential proliferation during the growing season (Vieira et al., 2023). Once the abundance of LCM has grown to an extent that allows it to proliferate throughout a set of hosts, it reaches a carrying capacity, again dictated by the amount of viable buds and leaves available for the lifecycle to occur. Once a tree is no longer viable for LCM, nematode populations will likely collapse in a given stand unless carried to another host tree by either wind, rain/moisture, or animals. This presents a high risk to the estimated 37 million available beech trees in Michigan (MIDNR, 2017).

- Successful infection and symptom development result from the presence of the infective stage of a pathogenic nematode, like that of LCM, and the host conditions of American beech that optimize nematode growth and reproduction (Reed et al., 2022).
- LCM populations have been shown to increase over time of the growing season, and highest in late summer and early fall, with hundreds to thousands present in leaf samples (Reed et al., 2022).
- Many parasitic nematode species complete their life cycle in a few weeks to a month, resulting in rapid increases to population sizes (Reed et al., 2022).
- LCM eggs have been found in developing buds and newly emerged leaves (Carta et al., 2020).
- Infected buds collected in winter contained juveniles, adult females, and eggs of LCM (Reed et al., 2020; Marra & LaMondia, 2020).

Economic Impact Rating: Medium (2)

The timber industry in Michigan will be the primary industry directly affected by a loss/decline of American beech. 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). 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).

If BLD was to follow a similar trajectory to that of beech bark disease (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 formed after overstory mortality through the production of clonal basal sprouts (Cale et al., 2017). This is, however, speculation of how BLD might convey a change in forest structure as observed with BBD, whereas post BLD forest changes are still largely unknown. Additional value losses attributable to beech bark disease, and potentially BLD, include decreased primary productivity,

biodiversity, structural sustainability, and mast production (Cale et al., 2017).

Secondary industries affected by BLD include the landscape and horticulture industry, in which Michigan has the fourth largest tree nursery industry in the US (Michigan Department of Agriculture & Rural Development, 2018). It is likely that most tree nurseries, in Michigan and other BLD positive states, will not carry any beech tree varieties going forward due to the presence of BLD. The total economic impact of this consequence is challenging to quantify but would be rather impactful – by shifting these businesses to either sell more non-native tree stock or trees that have less value than beech. Additionally, since the urban forestry and ornamental tree market industries rely heavily on local tree nurseries to supply them with stock to plant, both will be indirectly affected by this shift away from beech trees, likely leading to more homogenized urban canopies of maple and other common street tree varieties (*e.g.* honey locust, elm, oak). A loss of diversity and value of urban forests can be expected by the overall decline and mortality of American beech.

Table 2. Forest resource inventory volumes, biomass, growth, and mortality 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.

- Common uses for beech lumber include veneer logs, pallets, pulp, flooring, plywood, railroad ties, fuelwood, baskets, rough lumber and furniture (Tubbs and Houston, 1990).
- Additional value losses attributable to beech bark disease, and likely BLD include decreased primary productivity, biodiversity, structural sustainability, and mast production (Cale et al., 2017).
- A loss of diversity and value of urban forests can be expected by the overall decline and mortality of American beech.
- Secondary industries affected by BLD include the landscape and horticulture industry, in which Michigan has the fourth largest tree nursery industry in the US (Michigan Nursery & Landscape Association, 2018).

Values of American beech

Intrinsic value - The intrinsic value of American beech can be found in the role it plays in the larger context of a natural community. Providing beech nuts in areas that lack other nut producers, homes for wildlife, and its generous canopy for birds.

- Beech nuts for wildlife
- Cavity nesting
- 120 Lepidopteran species utilize American beech (Native Wildflower Finder, n.d.)
- Forest structure and complexity

Instrumental value - The instrumental value that beech provides can be found in its wood. While not highly sought after, it can typically be seen used in furniture and flooring. Sometimes used as an agent for aging beer in barrels. Beech trees can be found across urban forest canopies adding high value and diversity to an urban forest.

- Timber harvested is converted to lumber used for furniture, flooring, and other pieces made from beech wood.
- Beech can be found in cemeteries or private properties where it serves as a statement piece adding value to a property.
- When found in an urban forest setting beech trees add much needed diversity and value to the area.

Relational values - The relational value of the American beech persists throughout much of its range. The northern hardwood forests, as a whole, have built a strong cultural identity for people that inhabit the region.

- Cultural identity for those that have formed connections with mesic northern & southern forest communities. Specifically, American beech trees and their easily carved bark attracts people (Figure 8).
- Beech trees attract wildlife that can increase human-wildlife interactions, further enforcing a bond to nature and wildlife.

A Collection of Beech Tree Carvings

Figure 8. Carvings on American beech bark, this is recognized as an important cultural service of beech trees. But we do not condone this action.

Environmental Impact Rating: Medium (2)

The reduction in density of American beech within beech-maple forests has been widely studied since the introduction of beech bark disease (BBD). The most notable change in these BBD aftermath forests has been the generation of beech thickets (Figure 9 & 10) (Cale et al., 2017; McCullough et al., 2005). Since young beech saplings tend to proliferate in understories of BBD-impacted forests, the regeneration of shade-intolerant species can become hindered by these dense beech thickets (Cale et al., 2013; Cale et al., 2017). With the establishment of these beech thickets in BBD aftermath forests, a growing concern of how BLD will now impact these beech thickets becomes apparent. Since BLD disproportionately affects understory trees (Reed et al., 2020), it is likely that these beech thickets would be thinned out through disease mortality once BLD becomes established in areas where BBD-aftermath forests occur. The potential thinning of these thickets might convey a change in the regeneration and recruitment of shade-intolerant species (*e.g. Betula papyrifera, Quercus rubra, Prunus serotina*) into the forest strata. Shade-tolerant species such as sugar maple struggle under dense beech thickets too, but already established sugar maple trees have been shown to exhibit increased radial/secondary growth from the competitive release of overstory beech mortality (Cale et al., 2013; Cale et al., 2017).

However, the resulting canopy gaps are likely to be partially shaded rather than full sun which will be favorable for more mesic species such as red maple (*A. rubrum*) or bitternut hickory (*C. cordiformis*).

Ultimately, the dense shade cast by beech thickets creates a limiting component for the recruitment and regeneration of forest associate species, leading to reduced ground cover; consequently decreasing plant richness and biodiversity in these forests.

Photo Credit CABI PlantWisePlus Knowledge Bank [4]

Figure 9. Beech thicket pictured in winter, recognized by their marcescence behavior, where leaves are retained on branches through the winter. A common behavior seen in the Fagaceae family (Source: CABI PlantWisePlus Knowledge Bank, 2019).

Photo Credit: Northern Woodlands Patrick Hackley [32]

Figure 10. A beech thicket in the summer shows a dense understory that limits the establishment of ground cover flora and other tree species. Dense beech thickets occur in BBD aftermath forests where most overstory beech trees have died and been replaced by clonal root sprouting beech that lingers in the understory until a canopy gap develops for it to extend further into the canopy (Source: Northern Woodlands, 2013).

Beech trees are one of the only nut producers, besides red oak (*Q. rubra*) in the northern hardwoods forest type (Tubbs & Houston, 1990), with that being so, a variety of mammal and bird species rely on beechnuts for sustenance (Figure 11). Since beech trees retain a masting component to their fruit production this behavior is critical to providing food to the wildlife in mesic northern forest communities. Wildlife is indirectly affected by BLD and BBD as mature, mast-bearing trees are killed. Masting isn't typically seen until individuals have reached the age of forty years old (Tubbs & Houston, 1990). Forests infected with BLD might perpetuate an even-aged stand of young beech trees that would not reach maturity and thus, could not produce beechnuts.

Some notable species of birds that feed on beechnuts include bluejay, crow, ruffed grouse, eastern wild turkey, nuthatch, and the purple finch, which has been observed eating developing beech buds during the winter. (Tubbs & Houston, 1990; Carta et al., 2022). Beech trees also account for much of the structural complexity in forest strata because of their generous canopies of low-hanging and wide-spreading limbs. These branching characteristics of beech make them attractive to raptors, and several species of hawks prefer to nest in them (McCullough et al., 2005). Beech is also known to provide quality cavity nests for wildlife, such as pileated woodpeckers, black-capped chickadees, and tufted titmice.

A variety of mammals are reliant on beechnuts in mesic northern & southern forests, such as black bear, pine marten, fisher, chipmunk, raccoon, Virginia opossum, fox, gray squirrel, and white-tailed deer (Figure 12-14) (McCullough et al., 2005; Cale et al., 2017; Tubbs & Houston 1990). Beech is browsed by deer, but not severely when other, more desirable species are available (Tubbs & Houston, 1990).

Figure 11. A healthy American beech tree bearing developing beechnuts. Observed at Lower Huron Metropark in Belleville, Michigan.

Figure 12. An eastern gray squirrel observed using a cavity nest of an American beech tree. Plenty of other species utilize these cavities for nesting.

Figure 13. A tufted titmouse observed feeding on a beechnut. A quality source of protein and fat for mammals and birds alike.

Figure 14. An American black bear observed in an American beech canopy feeding on beechnuts, likely in the fall time before denning. This observation has been widely observed of black bears before denning period. Again, beechnuts provide a quality source of fats and proteins for animals.

Ecosystem Services of American beech

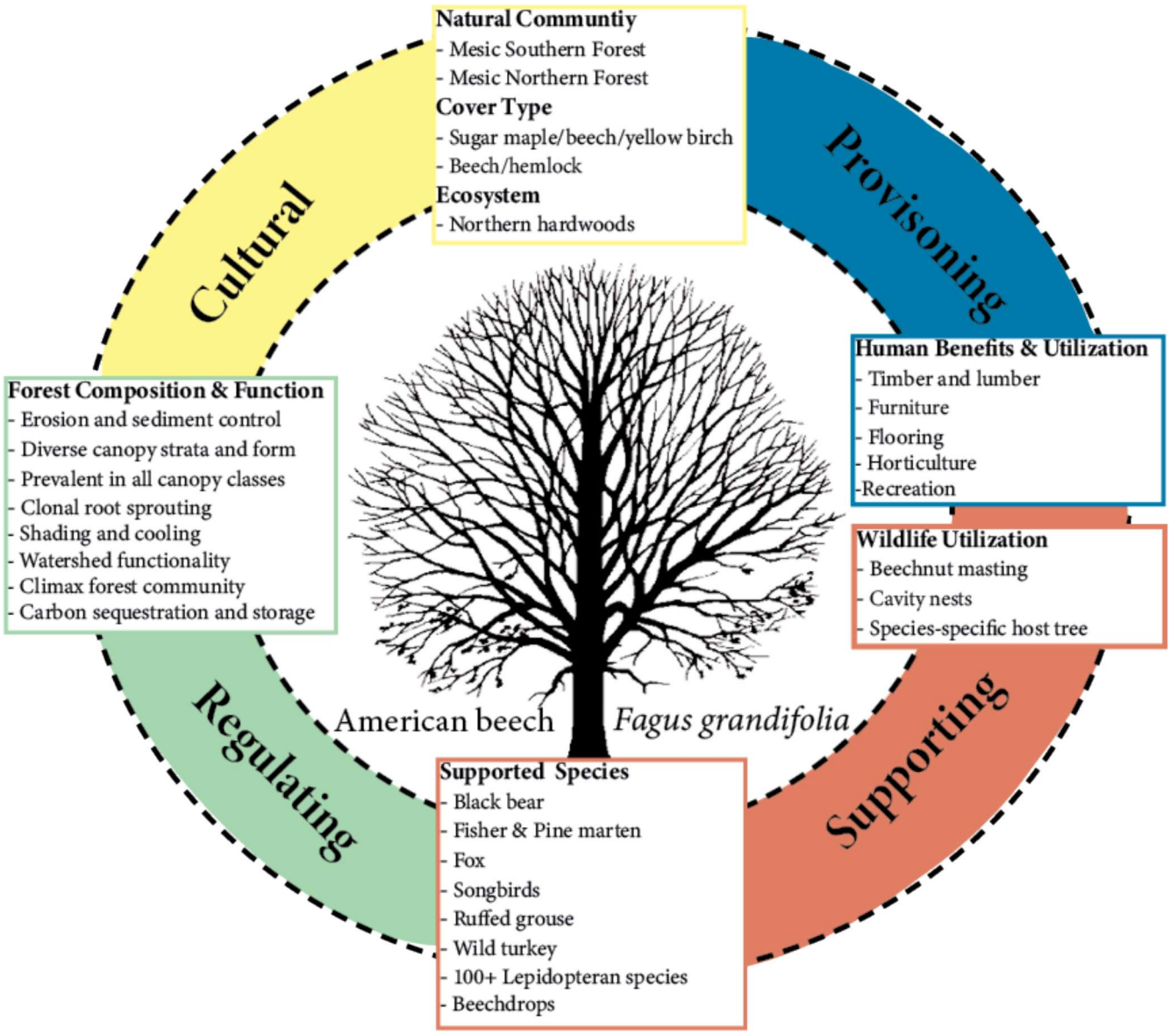


Figure 15. American beech through the lens of ecosystem services. You can begin to see the contributions that American beech has to supporting wildlife, provisioning resources for human use, regulating biodiversity and forest composition, as well as promoting cultural cohesion to natural communites and ecosystems. All services are at risk of being lost from the advances of BLD.

Photo Credit: Big Tree Seekers[2]

- Changes in forest structure may affect small mammal populations by altering habitat availability and increasing the presence of coarse woody debris on forest floors of areas impacted by BBD (Cale et al., 2017).
- Small mammal diversity is higher in healthy beech forests than in BBD aftermath forests or forests without American beech (Storer et al., 2004).
- A study showed that the replacement of beech by sugar maple in the Catskill Mountains has altered forest biogeochemistry by reducing forest floor C-N ratio, increasing nitrified mineralized N, and increasing extractable NO3- in the soil and soil solution (Lovett et al., 2010).
- Beech snags, especially those occurring from beech snap, are ideal wildlife habitat for many species. Wherein they provide dead standing wood that attracts fungi, insects and other arthropods that birds can feed on.
- Beechnuts masting years have been found to directly influence black bear size during denning season in Maine (Jakubas., 2004). The high protein and fat content of beechnuts are particularly important for black bear reproduction and survival.
- In areas where American beech is dominant in the canopy, leaf litter can have a podzolizing effect on soils by increasing the acidity. Soil pH ranges from slightly acidic to moderately alkaline in Northern & Southern mesic forests of Michigan (Kost et al., 2007).
- Historically beech was managed for mast and timber in forests with few other mast-producing trees (Reed et al., 2022)

Figure 16. American beech tree with bear claw markings (Source: Big Tree Seekers, 2024).

Vertebrate Health Impact Rating: Negligible (0)

L. crenatae mccannii is not known to cause any impact on human or animal health. Beech leaf disease remains strictly as a phytopathogen.

Social & Politcal Impact Rating: Negligible (0)

The social and cultural uses of American beech (F. grandifolia) remain sparse in modern times. The likelihood of any social or political impacts arising from BLD remains negligible across the state. At most, the loss of stately beech trees in arboretums, cemeteries or on private lands will spark concern over their loss. But no societal and political impacts will arise from this loss, and therefore can be considered negligible.

Management Rating: Low (1)

To date there have been no effective control strategies for BLD documented in the primary literature (Zhao et al., 2023). Management mainly relies on the prevention of transmitting BLD to susceptible populations. By not moving beech firewood, monitoring nursery stock, cleaning boots of leaf debris, and sanitizing gear used in infected forests, one can prevent the spread of BLD to new host trees. However, current research has revealed the use of Arbortect 20-S as an effective agent for treating symptomatic BLD trees. It is labeled as effective treatment in five states, yet remains as unlabeled treatment in Michigan. Therefore, it can't be advertised to clients as an effective treatment option.

While management of BLD in Michigan will be primarily through prevention efforts, the early detection of symptoms will be vital to building a response to BLD presence. This can be difficult since beech trees infected with LCM may not show symptoms of BLD in early stages (Fearer et al., 2022). Due to its fast spread and the latency in symptom expression after infection, the absence of BLD is difficult to determine (Zhao et al., 2023). The prevention and prompt eradication (*i.e.* early detection and rapid response) of forest tree diseases remains the most cost-effective approach to managing forest pathogens and diseases (Zhao et al., 2023).

Another long term management strategy of controlling BLD, will be through genetic breeding programs (Reed et al., 2022). Similar programs have been done for the American chestnut (*Castanea dentata*). Also, by promoting disease resistant and resilient beech trees in aftermath forests, cultural selection can improve the chances of long term success of American beech trees in mesic northern and southern natural communities.

- The Michigan DNR recommends to not move beech nursery stock and other beech materials, such as fallen leaves, from locations near infected trees (MIDNR, 2022).
- Consider using diluted isopropyl alcohol and boot burhses to clean footwear and equipment after being in contact with BLD positive trees.
- 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).
- Invasive plants have potential to fill canopy gaps left by declining beech stands (Reed et al., 2022). These anticipated losses of beech from BLD are expected to increase the abundance of invasive plants in forested areas, especially small woodlots and forests near urban areas (Reed et al., 2022).

Figure 17. Thinning canopies of an American beech stand infected with BLD. Major losses of leaves can be observed due to the shrinking, curling, and banding symptoms expressed in leaves indicating the presence of LCM nematodes. What was likely a closed canopy before, can now be considered a canopy gap for other species to capitalize on. (Source: Cowles et al., 2022)

Figure 18. Pictured on the right, an intermediate canopy American beech succumbs to infection creating a canopy gap, with tip and mound microtopograhpy occuring.

Weakened tree canopies from BLD infection predispose beech trees to windthrow and snapoff (Figure 18 & 19). Within a month of sampling throughout southern Michigan many beech trees were observed to have snap-offs and windthrows. While in moderation, these distubance events are conducive to a healthy operating mesic southern and northern forest community, extensive decline and mortality can create large shifts in canopy structure and composition (Figure 20).

Once dominant American beech trees decline in health over a five to seven year period (Reed et al., 2022), a subsequent canopy gaps leads to the competitive release of surrounding trees (Figure 17 & 19). Figure 19 clearly shows sugar maple leaves in close association to this canopy gaps, and are likely to experience increased radial and secodary growth from this

Figure 19. On the left an American beech with the top crown snapped off, extensive BLD infection observed throughout all parts of its canopy.

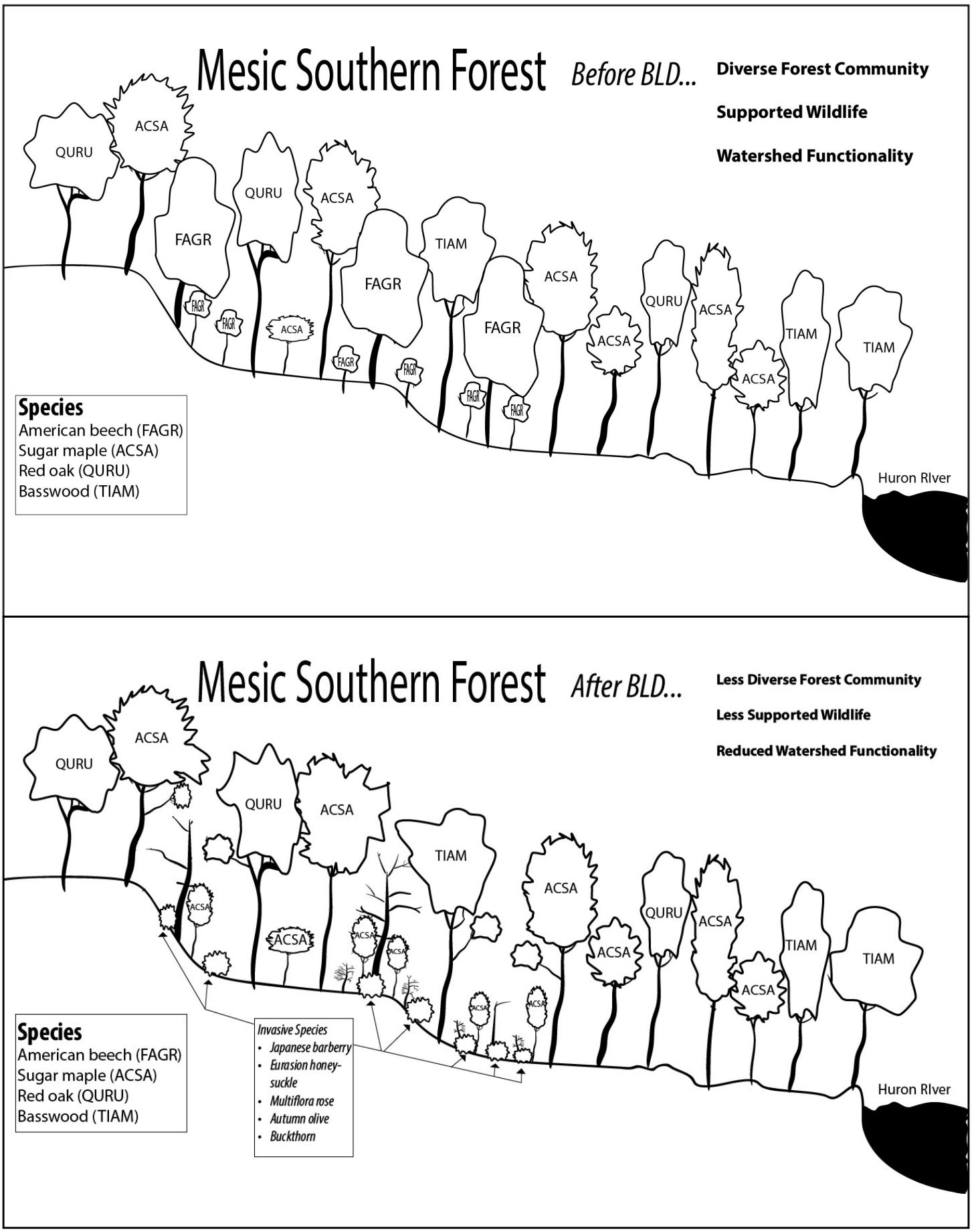


Figure 20. Mesic southern and northern forest structure before and after beech leaf disease. Note the subsequent canopy gaps filling with invasive species and sugar maple.

Pest Risk Potential

Likelihood of Introduction

Photo Credit: UMich BLD Team
A canopy dominant beech succumbs to windthrow with heavey BLD infection observed.

Pest History Rating: Low (3)

Since its introduction to the United States, LCM has been able to expand into fourteen states and one Canadian province. As the precise invasion pathway is not yet known, a few potential pathways can be considered. LCM could have been introduced through infested wood pallets or packing materials from Japan (Carta et al., 2020). Additionally, BLD could have been spread to Michigan from infected nursery stock trees that harbored LCM within leaves, buds, or dead organic matter.

In 2019, extracted nematodes from symptomatic leaves of American and European beech were found to be most similar to *Litylenchus creatae*, a nematode associated with leaf galls on Japanese beech (*F. crenata*) (Kanzaki et al., 2019). To date there have been no reports of the Japanese nematode in North America. Consequently, LCM has been designated a supspecies given its differing morphology, host-range, and identified molecular markers (Carta et al., 2020). With LCM being a newly recognized subspecies, it is unlikely to be compared to its closely related Japanese counterpart that hasnt been observed to be such a prolifi mortality causing disease like BLD. Notably, BLD has become an increasingly more invasive pest and an even faster spreading disease when compared to BBD (Reed et al., 2020).

- BLD infected understory saplings decline in health with mortality observed within two to five years, and overstory trees seeing mortality within seven years in some cases (Martin & Volk, 2022; Reed et al., 2020).
- While LCM must feed for BLD symptoms to occur, the potential role of additional pathogens, such as bacteria or fungi, in symptom development remain under investigation (Burke et al., 2020; Carta et al., 2020).

Quantity of Commodity Imported: Low (1)

It seems possible that LCM could be moved during all life stages (*i.e.* eggs, juvenile, adult) on organic matter or packing materials being shipped in transport. To assess the potential quantity of commodity being moved around Michigan, the amount of freight materials being transported across the state was evaluated (Figure 21). Michigan has a variety of commodities being transported across the state, but the primary commodity that LCM would likely be on is farm products. Such as foodstuff or organic matter that has in some way accumulated leaf debris from diseased trees. If LCM was to be moved in this manner it is likely that it would disperse when a semi-truck is being unpacked during a delivery. Or that leaf debris and organic matter could be stuck in tire treads or on vehicles where they could harbor nematodes that later become dislodged to the point where they end up on roadsides. In this case it would be suspected that BLD would be occurring on host trees immediately adjacent to some of the main trucking routes across the state. An area that should be targeted for monitoring in Michigan, due to its abundance of freight traffic, in addition to its abundance of beech trees are the counties of Wexford, Kalkaska, Antrim, Otsego, Charlevoix, and Emmet. These counties contain some of the main freeways in Michigan, especially Otsego County that has a section of I-75 and houses the town of Gaylord, which is one of the largest population centers in this part of the state.

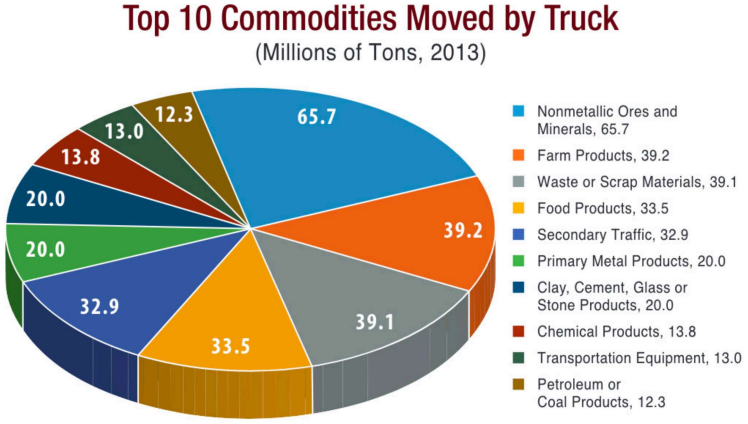


Figure 21. Pie chart depicting the distribution of commodities moved by truck in Michigan.

Estimated Pest Density of Unit Imported: Low (1)

Since the introduction of BLD there has been no measures to quantify the number at which LCM eggs or adults are being potentially transmitted by anthropogenic means. With no such commodity being targeted for monitoring, the means of this transmission remains speculative. Since LCM survival is reliant on moisture, whether that be from humidity or organic matter, it would likely be transported through nursery or landscape stock trees, as well as plants and flowers. At a smaller more localized scale, leaves from already diseased trees could be transported from lawn clippings and leaf debris being removed from properties.

The Michigan tree nursery industry is the fourth largest in the nation (MDARD, 2019). Thus, it handles a lot of organic matter that could potentially harbor BLD until moved to a new population of host trees. Since LCM doesn't necessarily require the presence of beech to persist, results do suggest that female nematodes can asexually reproduce under the right conditions (Vieira et al., 2023). If LCM was found on trees or other plants, not of genus *Fagus*, it would likely remain at low population levels. Whether LCM is primarily transmitted in these cases as eggs or adult nematodes would require more thorough monitoring and research into the case of its transmission and dispersal.

Likelihood of Surviving Post Harvest Treatment: High (3)

The use of phytosanitary measures to treat commodities being imported is recognized by the World Trade Organization as a regulated agreement enacted in 1995 (WTO, 1995). The agreement concerns itself with proper assurance that food products are safe for consumption and free of pests or disease. It recognizes that certain agricultural, animal, and plant products should undergo sanitary measures to deter the improper dispersal of pests and diseases to human, animal, and plant life. Common methods include phytosanitary irradiation that imparts ionizing radiation to inactivate pests and disease that could be harbored on products. This method is expensive and a timely procedure so has been used mostly on bulk agricultural products, such as fruits and vegetables or meat products (FDA, 2022).

Likelihood of Surviving Shipment: High (3)

The likelihood of LCM surviving shipment would be dependent on the moisture content and humidity it has while in transit. Since LCM is reliant on moisture for its motility and survival (Carta et al., 2020), it's unlikely that it would be on any sort of dry packaging without some level of moisture available. If phytosanitary or quarantine measures were to be implemented for shipments that could potentially be harboring LCM, shipments to target would include food, farm, or horticultural products that might have enough moisture or organic matter for the nematodes to survive shipment. If phytosanitary irradiation was used it would likely inactivate nematodes, whether in egg or adult forms. Also, if quarantine measures were to be implemented they should only be used in conjunction on beech wood and horticultural products such as nursery stock trees, or general landscaping plants. Additionally, an assay test could be developed to test products for the presence of LCM, but this would likely not be practical for the time being. Ultimately, without any sort of phytosanitary or quarantine measures LCM has a high likelihood of surviving shipment, the only limiting factor would be the availability of moisture to survive desiccation. To date there has been no studies examining LCM survival in shipping materials. The role of human assistance in BLD spread represents a key knowledge gap that requires further examination.

Likelihood of Moving to Suitable Climate: Medium (2)

Since the discovery of BLD in Ohio in 2012, the disease has now spread across fourteen different states in addition to Ontario, Canada (Carta et al. 2020; Reed et al. 2020; Zhao et al. 2023). To date BLD has been found in two plant hardiness zones in Michigan, zones 6a (-10 to -5 °F [-23.3 to -20.6 °C]) and 5b (-15 to -10 °F [-26.1 to -23.3 °C]) across the southeastern parts of the state (Appendix 2). These plant hardiness zones are based on the average annual low temperatures in an area.

- Less day-to-night temperatures oscillation would likely be favored by BLD (Zhao ae at., 2023). In which a suitable seasonal variation in temperature for BLD presence ranges from 48.4 to 49.2 °F (9.12 °C to 9.58 °C).
- Closed broadleaved deciduous forests is the most suitable land cover type for BLD presence (Zhao et al., 2023).
- Isothermality quantifies how large the day-to-night temperature oscillations relative to the summer-to-winter (annual) oscillations (O, Donnell and Ignazio, 2012). Roughly 16 °F (9 °C) seasonal temperatures oscillations would favor BLD establishment in regions with available host trees (Zhao et al., 2023).
- Land cover factors contribute more to the distribution of BLD (Zhao et al., 2023).

Likelihood of Finding a Host: Medium (2)

With sugar maple/beech/yellow birch forest cover types accounting for 19% of the forested lands in Michigan, and the dominant cover type across the state (Figure 22 & 23) (Pugh et al., 2017), it remains likely that BLD will have access to an abundance of hosts. However, American beech is not as common in southeast Michigan when compared to other parts of the state, which may in turn limit the dispersal of BLD to the northern parts of Michigan (MIDNR, 2022). Michigan has approximately 37 million American beech trees larger than five (5) inches in diameter at breast height (MIDNR, 2022) that span across 67 counties. The only counties that lack the presence of American beech can be found in the far western Upper Peninsula, where the climatic and soil conditions make for unsuitable habitat. Additionally, since the introduction of BBD, many beech trees are found as beech thickets, which remain in the understory, instead of dominant or intermediate canopy trees. This is concerning since BLD disproportionately affects sapling-sized trees (Reed et al., 2020), and therefore could spread throughout the entirety of these beech thickets, possibly in a matter of a few years. With American beech being such a major component to the forests of Michigan, in addition to being found at higher densities in the northern parts of the state, BLD could have catastrophic consequences to forest structure and composition in these areas.

- Sugar maple/beech/yellow birch forest cover type accounts for 19% of State forested lands in Michigan (Figure 22) (USFS, 2014; MIDNR, 2022).
- Approximately 37 million beech trees larger than 5 inch DBH in Michigan (MIDNR, 2022).
- American beech isn't as common in southern Michigan as it is in northern parts of the State. This might represent a barrier to dispersal of BLD.

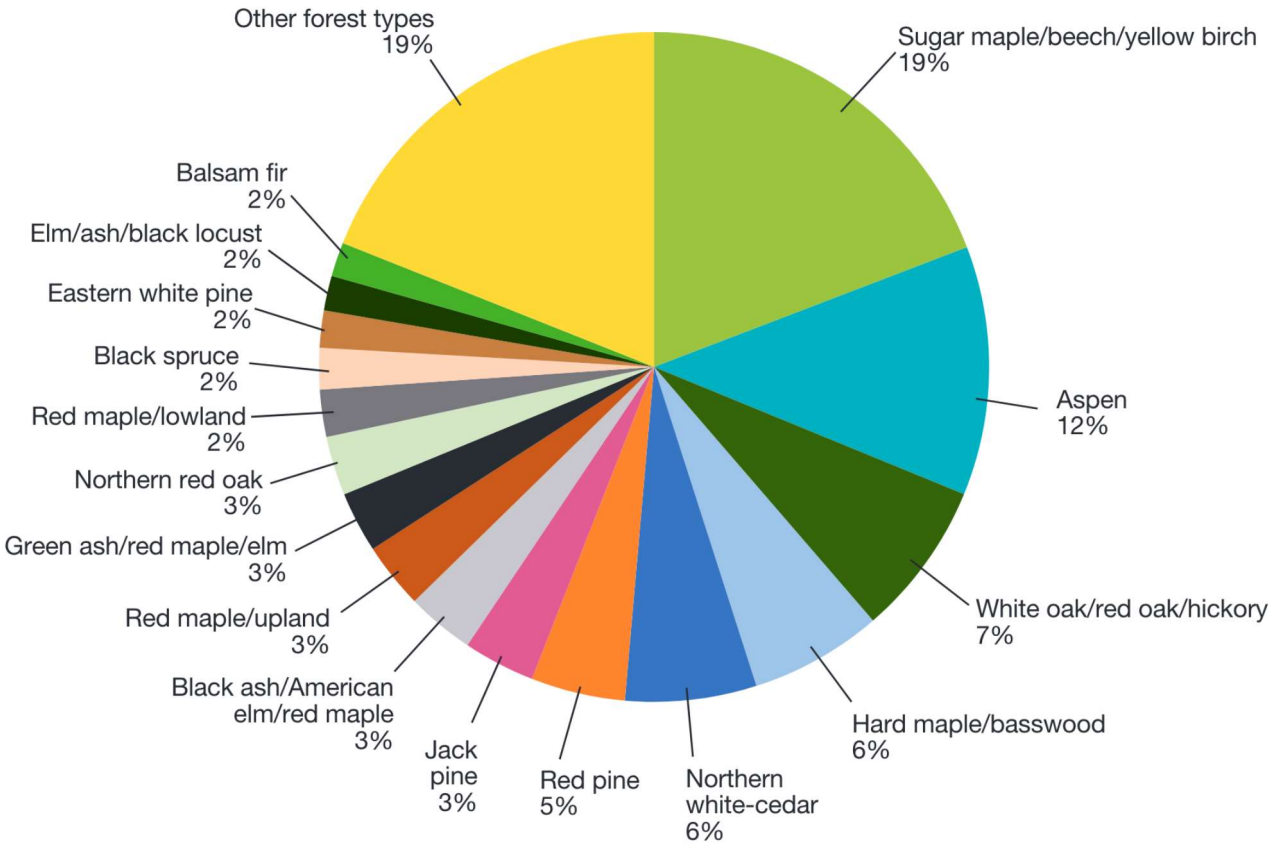


Figure 22. Pie chart displaying distribution of forest cover types in Michigan. Sugar maple/beech/birch comprises the largest percentage (19%) of cover type in the State. Followed by aspen (12%) and white oak/red oak/hickory (7%) cover types. The sugar maple/beech/birch cover type can be translated to that of mesic northern and southern forest communities where American beech is a critical component to their structure and composition (Source: Pugh et al., 2017).

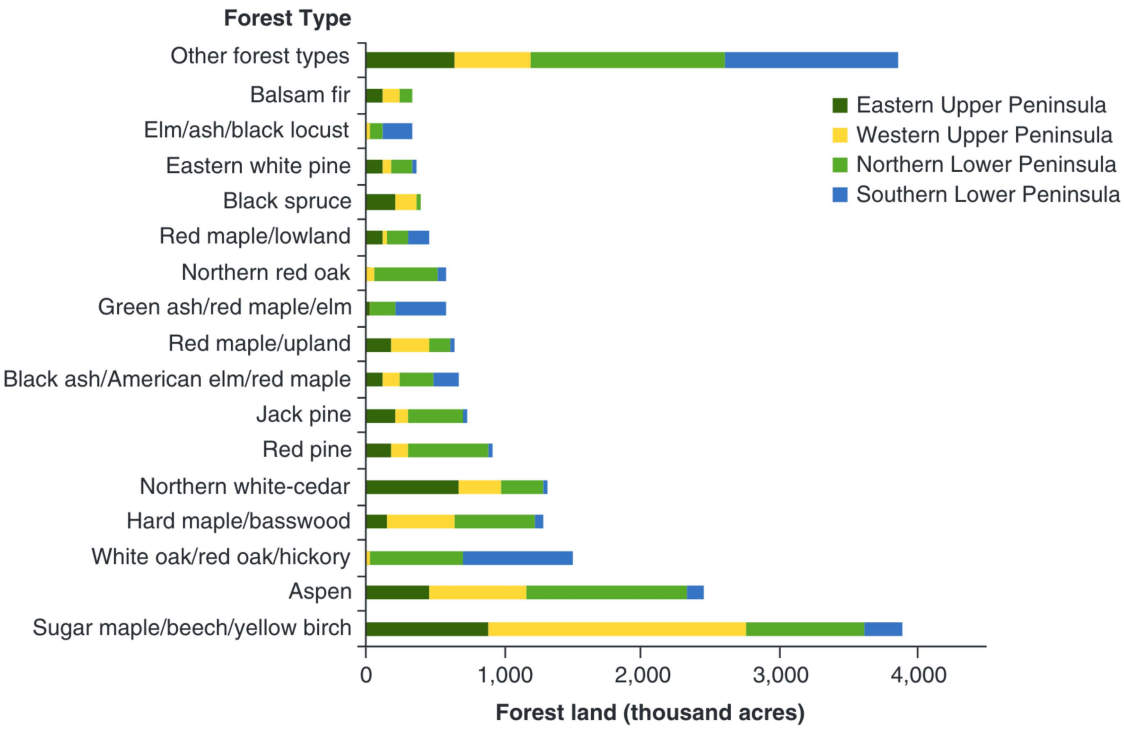


Figure 23. Bar chart displaying forest cover types per thousand acres. The Western UP has roughly 3000,000 acres of sugar maple/beech/yellow birch cover type. Followed by the Northern lower peninsula with nearly 100,000 acres (Source: Pugh et al., 2017).

Potential for Eradication: Low (1)

With no effective treatments being documented in the primary literature, the feasibility of eradicating BLD remains low. Primarily, the main management of BLD has relied on preventative measures such as cleaning and sanitizing equipment and footwear after coming into contact with infected host trees. While this can potentially slow the spread of BLD, it's not a realistic long-term management strategy. However, some experimental treatments using phosphite pesticides have been done to test their efficacy in managing BLD symptom development, or otherwise populations of LCM nematodes.

Beech trees treated with Polyphosphite-30 were observed to have less dieback on smaller branches (Cowles et al., 2022). Additionally, reductions of 83-94% of nematode populations in trial groups were observed compared to untreated groups conducted in the study (Cowles et al., 2022).

In this same study conducted by Cowles et al. (2022), spraying infested foliage with Fluopyram containing products, commonly sold as Broadform or Luna pesticides manufactured by Bayer, resulted in a consistent, high degree of mortality among LCM nematodes. These studies have produced promising results for the potential treatment of BLD on a single tree basis, but not quite as a tool to eradicate BLD from a forest setting. Ideally, these treatments could be used for ornamental trees in arboreta, cemeteries, backyards, or streets.

Lastly, current research has revelaed the use of Arbortect 20-S as an effective agent for treating symptomatic trees, which is typically applied via trunk injection (Rainbow Ecoscience, n.d.). Treatment is viable on a single tree basis given its high cost, and is not feasible for landscape scale treatments. This treatment has yet to be labeled for use in Michigan as it has been in six others.

- Fluropyram when applied as a foliar spray works as a succinate dehydrogenase inhibitor, blocking oxidative phosphorylation of specific fungi and nematodes (Cowles et al., 2022).
- Polyphosphite-30 can be applied as a soil drench at the base of trees where they boost tree defense compounds and indirectly affect nematode development through the disruption of specialized feeding structures used on plant tissues (Cowles et al., 2022).
- Arbortect 20-S can be applied via trunk injections (Rainbow Ecoscience, n.d.).

Figure 24. A treatment of Polyphosphite-30 being applied as a soil drench near the base of an American beech tree.

Conclusion - Pest Risk

BLD can be considered a high risk pest per its overall risk score of 29. Under the current findings it's recommended that the state of Michigan enacts either phytosanitary, biosurveillance, or quarantine mitigation measures (Table 1).

Currently with BLD found across seven counties in southeastern Michigan, the concern of its dispersal into areas of higher American beech density becomes apparent. In the northern Lower Peninsula and much of the Upper Peninsula, American beech is a major component of mesic northern forest structure and composition, and the sugar maple/beech/yellow birch cover type accounts for 19% of the state's forest cover (Figure 22) (Pugh et al., 2017). Counties that should be informed of a BLD watch include: Alger, Antrim, Baraga, Charlevoix, Delta, Emmett, Marquette, Otsego, and Wexford Counties. These areas should have forest pest alerts disseminated to the various stakeholder groups whose properties support stands of American beech.

Additionally, in the majority of mesic southern forests sampled across southeastern Michigan in the summer of 2023, American beech was found to be abundant in the codominant and intermediate crown class categories (Appendix 6).

The American beech adds considerable depth and complexity to canopy structure and composition in these natural communities, which in turn creates ideal habitat for many wildlife species across the state.

With the potential large-scale decline and mortality of beech stands across Michigan it remains critical to monitor these changes in forest structure and composition to inform active management.

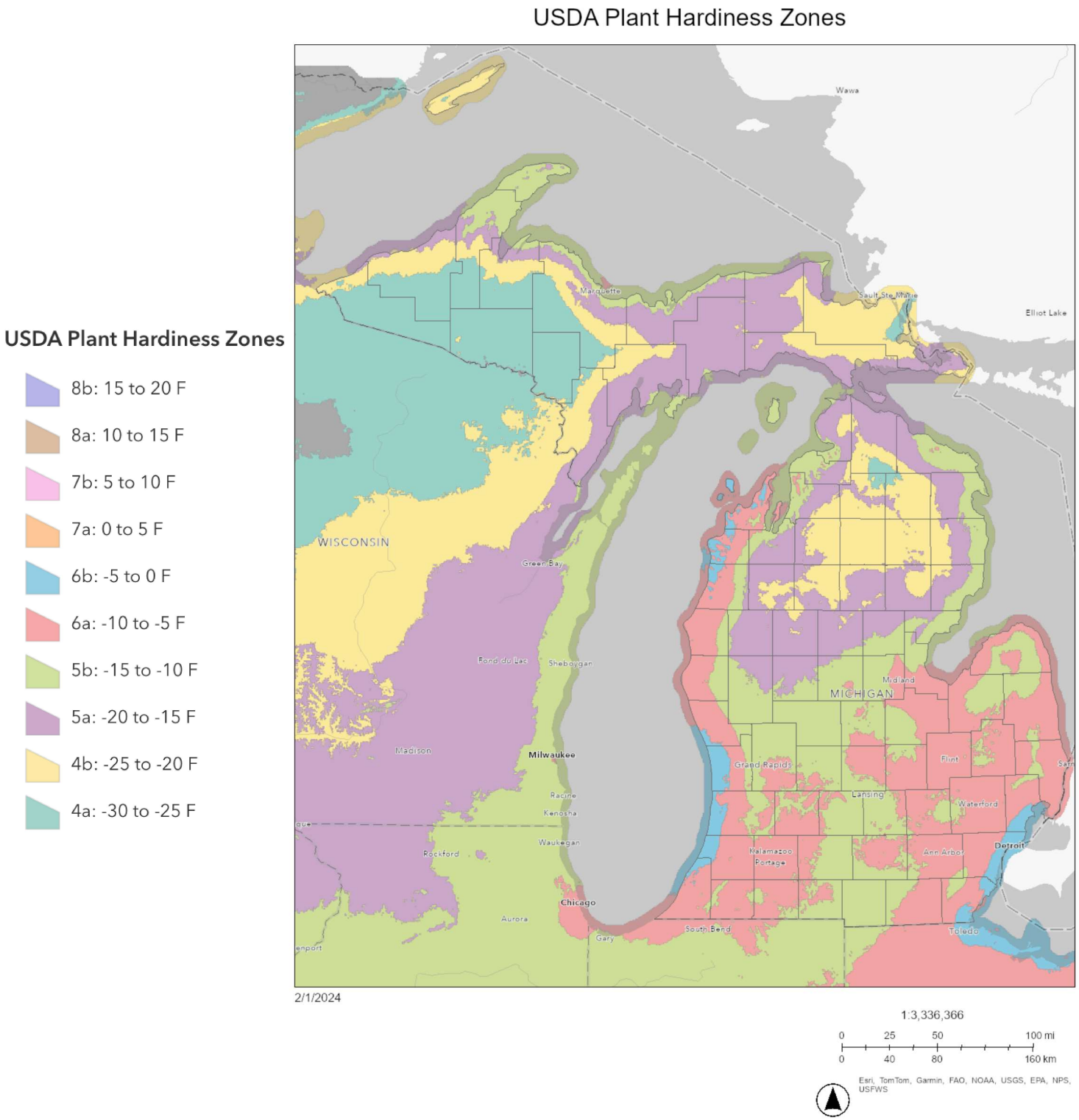
Furthermore, in areas with overstory beech tree mortality - subsequent canopy gaps should be managed to prevent the establishment of invasive species and select for trees other than sugar maple, which is likely to fill these gaps in unmanaged lands (Reed et al., 2022). However, in the northern parts of the state where BBD aftermath forests occur, heavy beech thickets could potentially disappear if BLD were to infect them, resulting in thinner, less homogenized understories and further shifting forest structure and composition.

Lastly, with no eradication measures identified in the primary literature and no modes of dispersal solidified, the management of BLD will rely mostly on prevention and early detection. On public state and federal lands with sugar maple/beech/yellow birch cover types, signs should be installed to alert guests of BLD and to encourage the use of boot brushes. On lands where beech trees are used for ornamental purposes, the use of Polyphoshpite-30 or Fluropyram could be used to prolong the decline to avoid mortality within the typically observed five to seven year window. Ultimately, the state will continue to face the threat of BLD, in hopes that the harsher climates of certain regions (e.g. plant hardiness zones: 4a & 4b) can limit the establishment of LCM nematodes and BLD (Appendix 1).

1. BLD has been rapidly spread in forests surrounding the Great Lakes and is affecting all size classes of beech (Reed et al., 2022).
2. The percent cover of sugar maple is expected to increase in BLD aftermath forests (Reed et al., 2022).
3. This composition change will remain a concern for land managers intending to steward forests for conservation, sustainability and food production for wildlife (Reed et al., 2022).

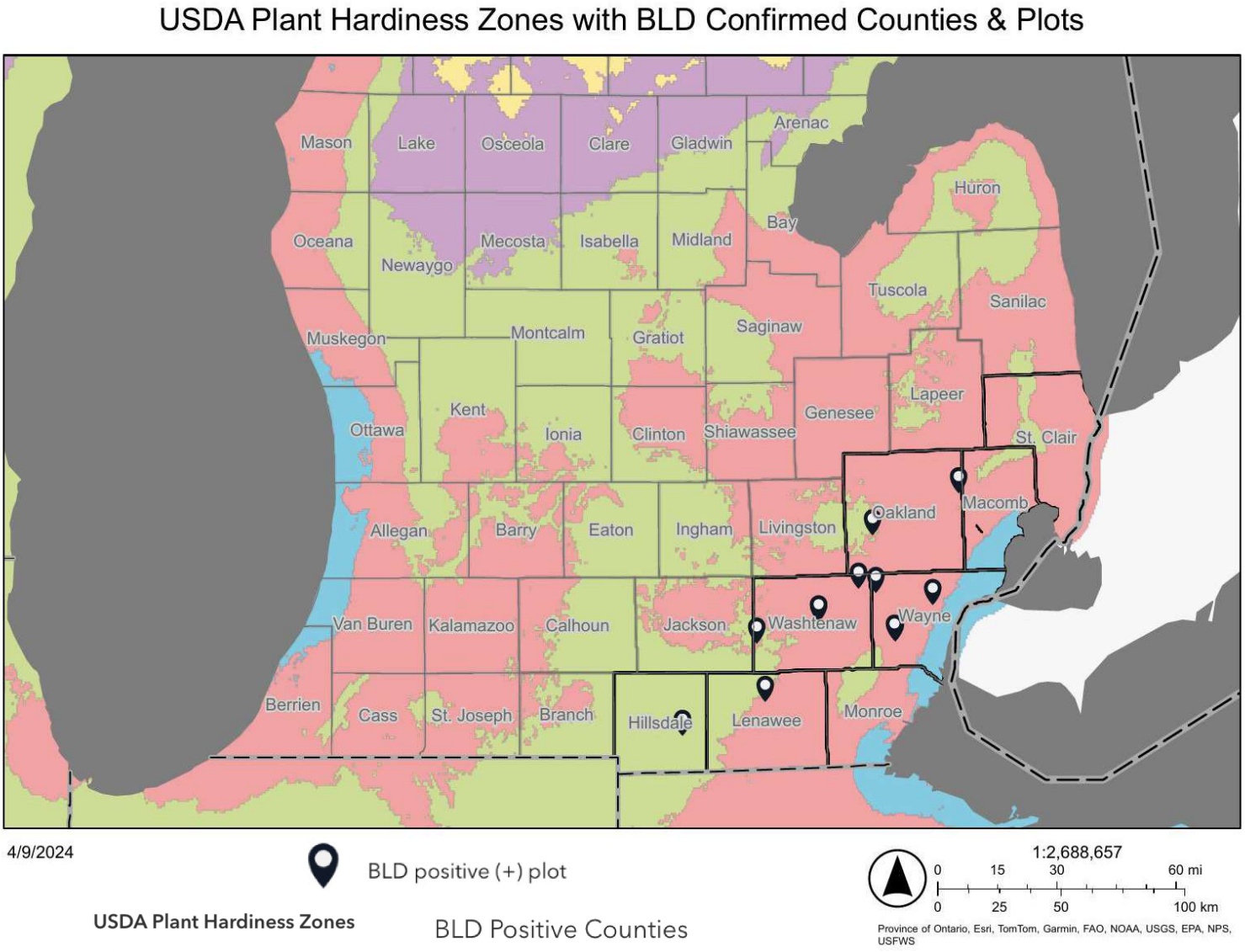
Appendices

Appendix 1



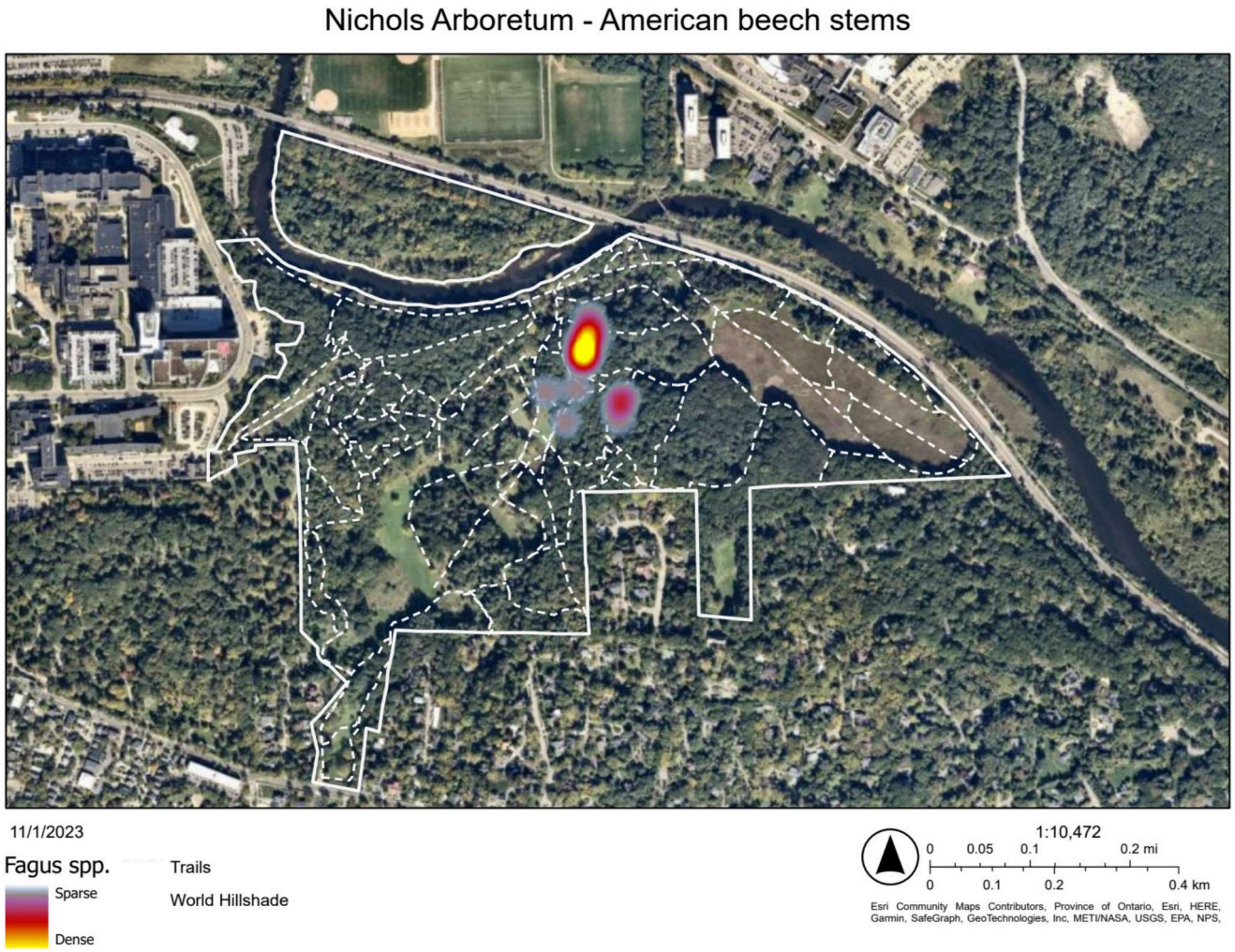
Appendix 1. USDA plant hardiness zone of Michigan (Source: Prism Climate Group & USDA, 2005).

Appendix 2



Appendix 2. USDA plant hardiness zones with BLD positive counties and plots as of 2023. Most plots occured on the 6a zones, with the exception of Hillsdale county (Source: Prism Climate Group & USDA, 2005).

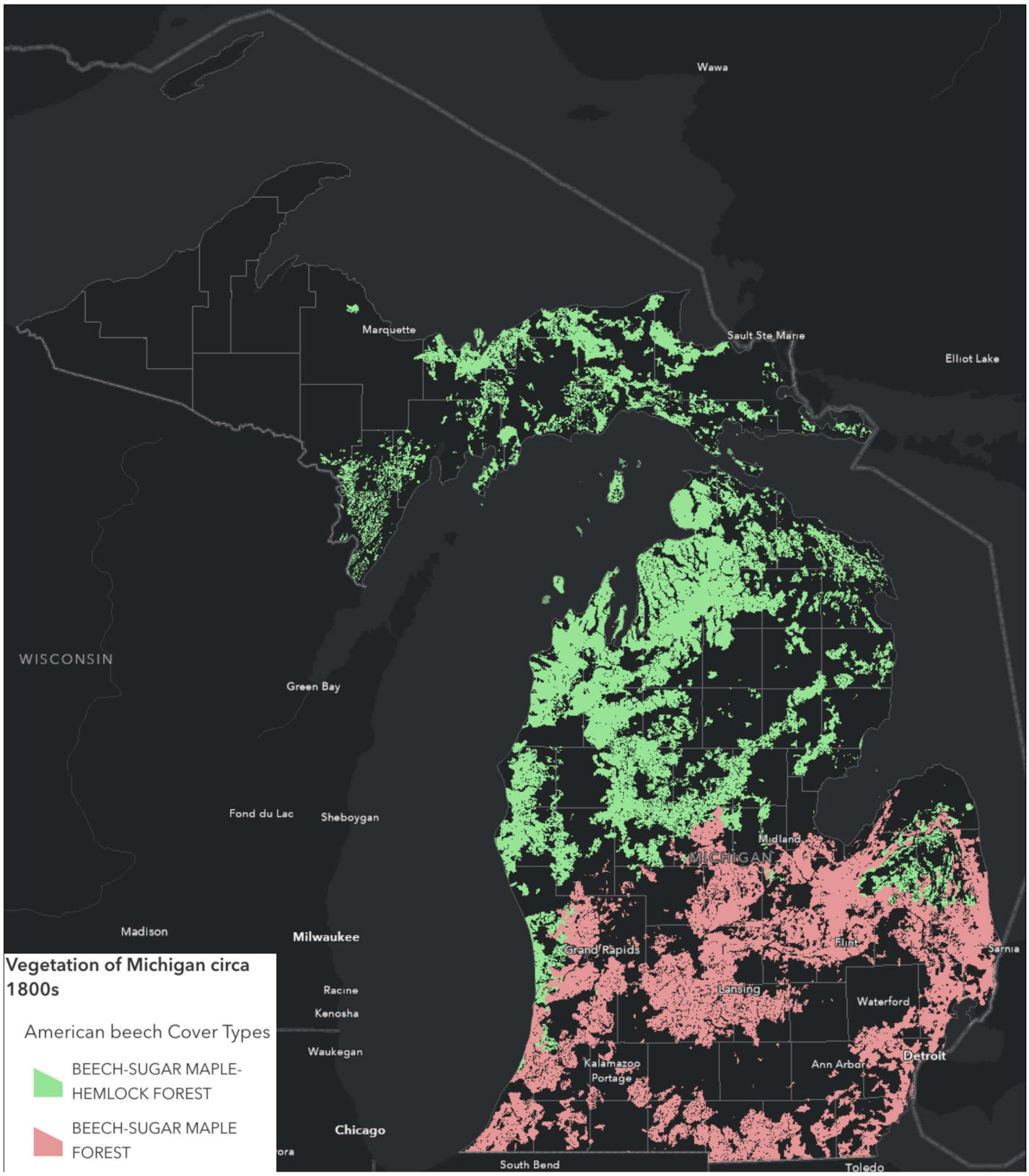
Appendix 3



Appendix 3. A heat map displaying density of beech tree varities at the Nichols Arboretum. Land management organizations should consider finding the densities of beech on their properties to understand how impactful and quickly BLD could persist in an area.

Appendix 4

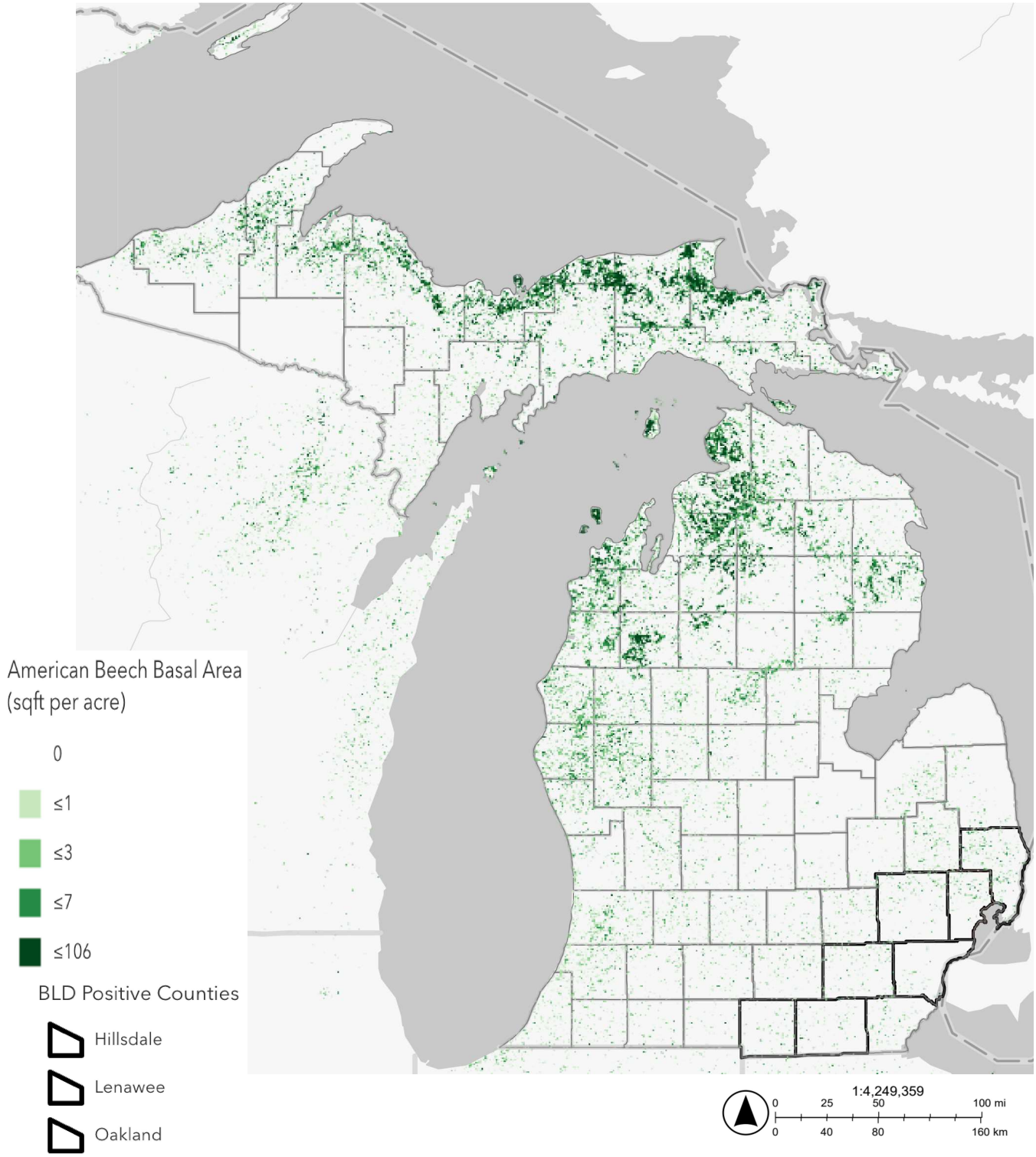
Circa 1800's Forest Cover Types with American beech



Appendix 4. Vegetaion of Michigan circa 1800's cover type classifications (Comer et al., 1995). This can be used to predict trends of where BLD might spread.

Appendix 5

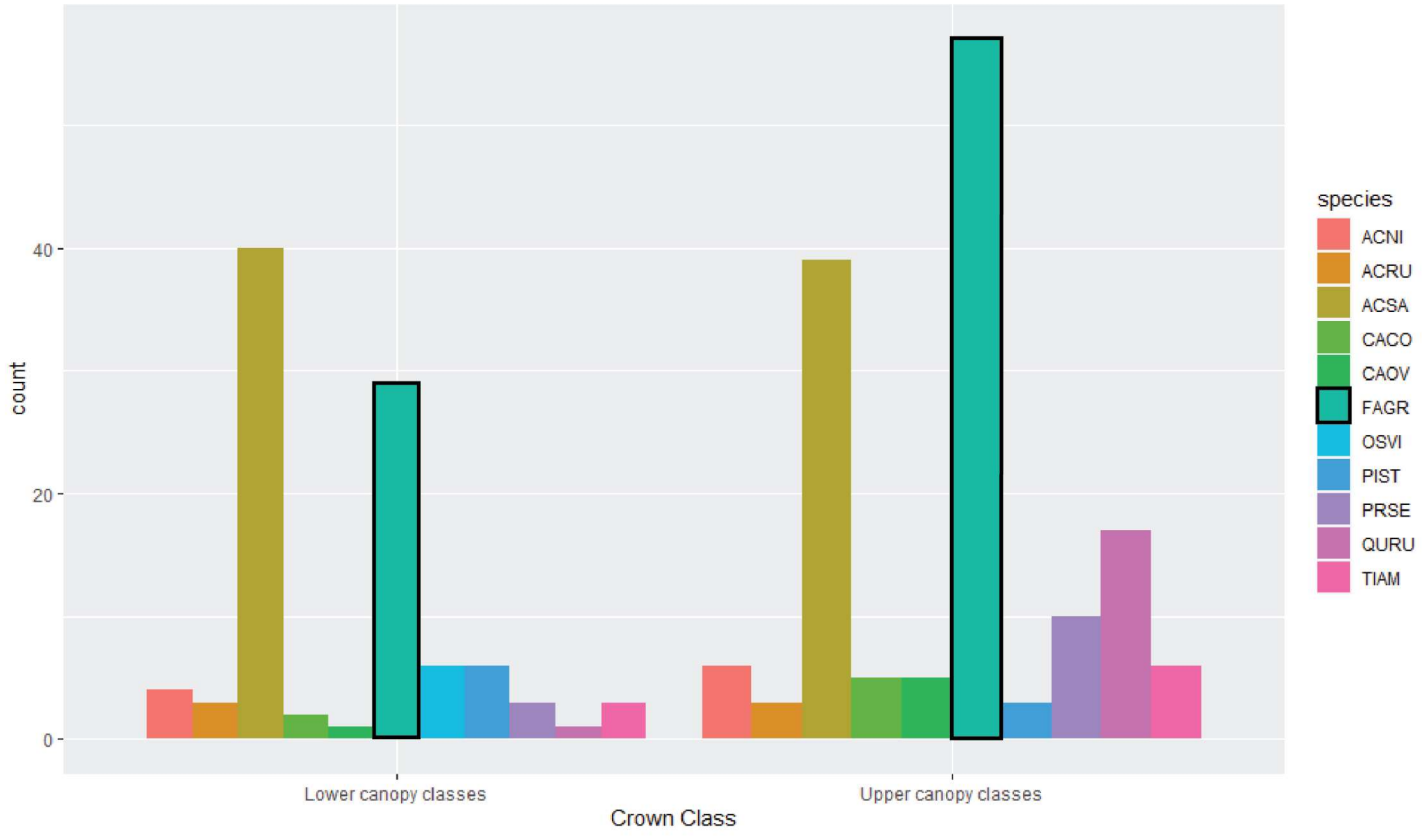
American Beech Predicted Basal Area



Appendix 5: Predicted beech basal area from FIA data represents areas of higher beech abundance and corridors of concern for BLD risk (Wilson et al., 2012).

Appendix 6

Crown Class Counts of 21 Sites in Southeast Michigan Plots



Appendix 6. 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.

Species Key

Acer nigrum (ACNI)
Acer rubrum (ACRU)
Acer saccharum (ACSA)
Carya cordiformis (CACO)
Carya ovata (CAOV)
Fagus grandifolia (FAGR)
Ostrya virginiana (OSVI)
Pinus strobus (PIST)
Prunus serotina (PRSE)
Quercus rubra (QURU)
Tilia americana (TIAM)

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