An Overview of Beech Leaf Disease

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The American beech, *Fagus grandifolia*, is an important hardwood of eastern North American forests, occurring from Nova Scotia and southern Ontario to northern Florida and eastern Texas. As a foundational tree species, American beech plays an important role in forest ecosystems, its cavities and canopies supporting nesting sites and shelter, and its nuts constituting a hard mast food source essential to the survival of a variety of vertebrates, from birds to black bears (Faison and Houston, 2004; Forrester et al., 2003). Dense beech foliage also plays an important role in the forest ecosystem, both in the canopy by modulating light levels in the understory, and as leaf litter, contributing to nutrient cycling on the forest floor (Lovett et al., 2010).

Beech leaf disease (BLD), first discovered in 2012 in Lake County, OH, is characterized by dark interveinal banding of leaves (Figure 1) of American, European, and oriental beech (*F. grandifolia*, *F. sylvatica*, and *F. orientalis*). By 2018, BLD had spread to stands of American beech across much of northern Ohio, northwestern Pennsylvania, western New York, and southern Ontario, Canada (Ewing et al., 2018). In 2019, BLD was found in Fairfield County, CT (Marra and LaMondia, 2020) and in NY's Westchester and Rockland Counties (just north of New York City), and Suffolk and Nassau Counties on Long Island. In 2020, more thorough surveys revealed BLD occurrences in seven of Connecticut's eight counties, and further east in central and eastern counties of PA and NY. BLD was also identified in a beech stand in Hopkinton, RI, and on European beeches in Plymouth and Lexington, MA.

The diagnostic symptom of dark interveinal banding appears in spring upon budbreak, on newly emerged leaves. These symptoms are most easily seen when viewed from below – i.e. at the lower, abaxial, surface – with light from behind

Figure 1. Mid-summer beech leaf disease symptoms on foliage of American beech (*F. grandifolia*) in Stamford, CT, viewed from below. (photo: R. Marra)

(Figure 2); viewed from above – i.e., at the upper, or adaxial, surface -- these interveinal bands exhibit noticeable hypertrophy, and this cupping increases through the season (Figure 3), occasionally turning yellow or brown later in the season (Figure 4).

In those areas where the disease has been present the longest, BLD has been observed to reappear and advance in subsequent years, with a reduction in buds and therefore foliage. Severe infestations have also been observed, affecting both understory and overstory beeches, characterized by increased canopy thinning, twig and branch dieback, followed by mortality within seven years, and sooner for saplings. In some areas, mortality rates as high as 90% have been observed among dense clusters of saplings.

In Connecticut, the distribution of the disease is sporadic and variable; at some sites, BLD is prevalent in nearly every tree (Figure 5), while at other sites the occurrence may be as rare as one or a few leaves on a single tree among a dense stand of BLD-free trees. Whether this is due to variation in resistance to the

Figure 2. Spring BLD symptoms, viewed from below, on newly emerged foliage of American beech (*F. grandifolia*) in New Haven, CT. (photo: R. Marra)

nematode, or a byproduct of the random process by which the nematode is vectored to new sites, has yet to be determined. It may also be noteworthy that most of the 2020 infestations in CT are within 10-15 miles from the shoreline, with a few exceptions. The only know infestation in Rhode Island is in the town of Hopkinton, with extensive symptoms of interveinal banding and defoliation distributed in beech stands along numerous roads in the area.

In 2019, nematodes, less than 0.1 mm in length, were extracted from symptomatic leaves of American and European beech in North America were confirmed to be most similar to *Litylenchus crenatae*, a nematode associated with leaf gall symptoms on Japanese beech (*Fagus crenata*) (Kanzaki et al., 2019). However, because North American populations differ in morphology, host-range, and DNA sequence from those in Japan, the North American nematode associated with BLD on American, European, and oriental beech has been designated subspecies *L. crenatae mccannii* (Carta et al., 2020) (*Lcm*), with the Japanese beech gall nematode designated *L. crenatae crenatae* (Carta et al., 2020), (*Lcc*). To date, there are no reports of *Lcc* in North America, nor reports of *Lcm* in Japan. However, Kanzaki et al. report finding *Lcc* only on *F. crenata* in Japanese arboreta, and not on nearby plantings of *F. grandifolia* or *F. sylvatica* (Kanzaki et al., 2019). Similarly, Carta et al. reported no symptomatic or *Lcm*-infested foliage on Japanese beech planted near symptomatic American and European beech in the Holden Arboretum (Carta et al., 2020). These observations strongly suggest host specificity, supporting the subspecies designation.

Plant parasitic nematodes belong to an animal phylum – Nematoda – whose highly diverse species, both free-living and parasitic (of both plants and animals), are found in nearly every ecosystem, from marine to terrestrial, and are considered among the most abundant animals on the planet. Most are microscopic, but there are exceptions: a nematode parasite of whales can exceed 8 meters in length (https://nematode.unl.edu/bignema.htm)!

In order to determine if *Lcm* is the cause of BLD, and not just associated with it, Carta et al. inoculated beech seedlings with freshly isolated *Lcm* nematodes, which resulted in BLD symptoms (Carta et al., 2020). While there is ongoing microbiome research investigating the role that bacteria or other symbionts of

Figure 3. Upper (adaxial) surface symptoms of BLD on *F. grandifolia* in New Haven, CT. (photo: R. Marra

the nematode might play in disease (Burke et al., 2020), the nematode is clearly playing a primary and pivotal role in BLD, either causing it directly, or possibly vectoring an as-yet unidentified pathogen.

Beech leaves emerge fully symptomatic upon bud-break; this is consistent with the observation that the *Lcm* nematode overwinters in buds (Reed et al., 2020). Infected buds collected through winter contained juveniles, adult females, and eggs, but by the time of bud-break, there is scant evidence of juveniles or adults in the newly emerged symptomatic spring leaves (Reed et al., 2020). However, evidence for the presence of the nematode, presumably only eggs, in newly emerged leaves has been confirmed using an *Lcm*-specific molecular marker (Marra, unpublished results). From that point forward, the lifecycle is completed entirely in the leaf tissue, with populations in these interveinal bands increasing through mid-autumn (Reed et al., 2020). Whereas Reed et al. found only rare instances of nematodes in dead symptomatic leaves retained on trees, they were able to find nematodes on detached dead symptomatic

Figure 4. Late season infestations result in further darkening and increased thickening of symptomatic interveinal bands. Browning, as seen in the upper right corner, is also seen, although this may also be due to anthracnose. (Photo: Robert Marra).

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leaves on the ground (Reed et al., 2020), albeit at lower frequencies than observed in buds. Perhaps the higher nematode frequency in detached leaves on the ground is due to the protection from weather extremes afforded by snow and leaf litter.

The means and timing by which nematodes transit from leaves to buds is not entirely clear. Like other foliar nematodes, *Lcm* requires water films to move, and as populations inside the leaves increase, nematodes are increasingly likely to emerge through stomates into water films created by dew or rain, from whence they can relocate to other parts of leaves and to buds. Intriguingly, Carta et al. report laboratory observations of adult female *Lcm* nematodes swarming onto beech bud tips (Carta et al., 2020).

The ability to move through water may also explain how these nematodes move within and among trees, and may underlie the perplexing evidence for long-distance dispersal, all topics of current investigation. Once they emerge from stomates into water on the surface of the leaf, current thinking is that nematodes may be carried passively in rain-splash or wind-driven rain, or picked up by mammals, birds, and/or arthropods, to as-yet uninfected leaves either on the same tree, nearby trees, or distant trees. Carta et al. (Carta et al., 2020) found *Lcm* on spider mites -- known to travel for miles on wind currents -- collected from BLD-infested trees in Ohio. Additionally, beech buds are a food source for numerous bird species, especially members of the rose finch family; whether the Lcm nematode survives passage through the bird gut is currently under investigation. Another area of research underway in my laboratory is the development and deployment of molecular forensic markers to elucidate origins of new infestations and pathways of dispersal.

Beech leaf disease is not the first major threat to the American beech. At some point in the late 1800s, an invasive exotic scale insect, *Cryptococcus fagisuga*, was inadvertently introduced into Nova Scotia from Europe, presumably on nursery stock of European beech. The scale insect feeds through the bark on the tree's phloem, and in the absence of any natural checks undergoes rapid population growth. The resulting holes and fissures in the bark render trees susceptible to entry by two native fungal species, *Neonectria ditissima* and *N. fagisuga*. This progression

Figure 5: Heavy infestation of beech leaf disease at The Preserve, Old Saybrook, CT (June 2020) (Photo: Cora Ottaviani)

gives rise to the disease complex known as beech bark disease (BBD), characterized by fungal cankers that manifest in damage to both bark and vascular system, resulting in dieback and, ultimately, mortality. BBD has moved its way southward and westward, leaving behind forests dramatically impacted and altered, comprising dense clumps of clonally propagated root-sprouted saplings. It remains unclear whether a correlation exists between BLD incidence and BBD, a topic currently under study. Systematic and uniformly undertaken surveys, such as that currently underway in multiple eastern states, which involve collecting tree and site metrics (e.g., BBD, dbh, slope, aspect, host-tree density, to name a few), will shed new light on predisposing factors that may be involved in future occurrences and outbreaks of BLD.

Injections of emamectin benzoate, which translocates through a tree's vascular system, is the subject of research in Ohio exploring treatment options for BLD. Emamectin benzoate is currently labeled for use against the pine wilt nematode (*Bursaphelenchus xylophilus*), and is effective as a preventative, not a curative, treatment. The research on BLD is ongoing, and while results so far are not promising, these efforts continue, exploring modifications to application protocols. Needless to say, this approach, while potentially efficacious on ornamental trees, would not be suitable in forests.

Given this past summer's record heat and extended drought conditions, we will have the opportunity to study the impact weather extremes such as these might have on the development and spread of BLD. For example, will the extended dry periods that have persisted in the northeast all summer and into fall curtail or minimize the nematode's ability to transit from leaf to bud, which presumably would result in an attenuation of symptoms next spring? Time will tell. Meanwhile, with funding from the USDA Forest Service, and under the supervision of USDA Forest Pathologist Danielle Martin, long-term BLD monitoring plots are being installed in CT, MI, NJ, NY, OH, PA, and WV. Multi-year data from these long-term monitoring plots will facilitate a clearer understanding of how the development and spread of BLD are impacted by weather patterns and site characteristics.

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