The Distribution and Effects of Beech Bark Disease on Tree Growth.

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Beech bark disease (BBD) represents a major threat to the population of American beach (Fagus grandifolia). BBD has been shown to have over a 50% mortality in stands of mature trees. This study examines the distribution and impact on growth of BBD in a hectare stand of beach containing northern hardwood forest in northern Michigan (USA). The location, diameter, and infection severity of trees in the plot were recorded and compared with historical data on the same plot. Beech trees with a larger diameter at breast height (DBH) showed significant positive correlation with increased infection severity (p .001). Beach trees grew on average more per year before BBD was detected then after.

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Introduction

Invasive species have repeatedly devastated North America's forests functionally removing species such as the American Chestnut (*Castanea dentata)* and posing significant threats to the populations of many others including Elm (*Ulmus*), Ash (*Fraxinus*), Hemlock (*Tsuga*), and Beech (*Fagus*) (Lovett, et al., 2016). The loss or decline of various tree species due to invasive pests cause cause billions of dollars of annual economic losses and significant degradation of affected forest habitat (Lovett, et al., 2016). Beech trees trees are impacted by a condition known as Beech bark Disease

(BBD) that is caused by the combined effects of the wooly beech scale insect (*Cryptococcus fagisuga*) and several species of Ascomycete fungi (*Nectria*) (Latty et al., 2003). BBD kills infected trees by damaging the bark and ultimately girdling the tree (McCullough et al., 2005). Mortality of infected american beach (*Fagus grandifolia*) more than 50% in trees with a diameter at breast (DBH) height of 10 in (25.40 cm) or greater (Houston, 1998).

The disease complex begins with an infestation of the wooly beech scale insect which damages the bark and makes the tree vulnerable to further infection by the fungal agents (Houston, 1994). *Cryptococcus fagisuga* was first identified in North America during 1911 in Bedford, Nova Scotia (Houston, 1994). It to have been brought over in 1890 on ornamental European beech (*Fagus sylvatica*) trees imported from Europe (McCullough et al., 2005). One of the causative species of fungus *Neonectria galligena* is native and does not normally infect beach that is not scale infested, the other *Nectria coccinea* var. *faginata* is believed to be introduced (Houston, 1994). Either species of pathogenic fungus or a combination of them can cause BBD often the native species of fungus attacks first and the non native species colonizes second (Houston, 1994). By the 1930s BBD was found in the united states and has continued to spread since with it reaching michigan in 2000 (McCullough et al., 2005).

Michigan has an estimated 138 million Beech trees including 15 million with a DBH of over 9 in (22.86 cm) and 0.9 million greater than 21 in (53.34 cm) (Heyd, 2005). This study focuses on a stand of BBD infected northern hardwood forest in lower northern Michigan. The location known as the Wells plot is a square hectare of roughly

100 year old forest. All trees with a measurable DBH have had their size and location recorded previously in 1987 and 2000. BBD was not observed at that time. The previous research on this site provides a historical baseline with which to compare allowing for analysis on how BBD has impacted the forest. This study aims to determine the distribution of the BBD in the plot, whether it affects mature trees more severely, and if the presence of BBD has affects tree growth. Improved understanding of how BBD affects native forests allows for better forest management techniques.

Materials and Methods

Beech trees were surveyed at the wells plot (45°33'08"N 84°42'48"W). All Beech trees with historical records were relocated, DBH remeasured and categorized for severity of BBD. Dead trees without evidence of BBD were noted but not measured or used for analysis. Additionally Trees still living that had fallen over or where knocked over where measured but not included in growth analysis. Any trees not previously recorded were ignored. Trees were manually located by their previously cataloged grid coordinates. This was facilitated by preexisting grid marks at 10 m intervals. In cases of ambiguity historical DBH was compared to current DBH and the most probable tree reasoned out. DBH was taken at 1.3 M with a metric DBH tape. Trees infection severity was classified on a 1-4 scale (Appendix A) with 1 being none to mild, 3 being severe, and 4 being dead trees visibly infected with BBD and no other probable cause of death identified. Scale insect prevalence was utilized as as the indicator for BBD. This was selected instead of directly observing *Nectria* because the fungal fruiting bodies are rarely observed in michigan (McCullough et al., 2005).

All surveyed trees were mapped and an average nearest neighbor test was run in ArcGis. A one way anova was used to determine relationship between tree diameter and BBD severity. Average percent growth per year was calculated from a combination of historical (1987 and 2000) and new data (2018). A linear regression was run on the tree growth data to show correlation. Only trees that were present and alive between 1987 to 2018 were used to calculate growth. Trees that were bowed over due to treefall where also excluded from analysis because being bent over may have impacted their growth rate.

Results

All 286 trees previously recorded in the plot were successfully located, and with the exception of the 42 that died of non BBD related causis nearly all of them showed at least some signs of BBD infection. Beach trees on the plot tended to be young with 92 first recorded in 2000 and only about a third of the trees had a DBH over 10cm. Larger beech trees showed significantly more severe BBD infection than smaller ones ($p<0.001$). The average percent tree growth per year trended lower during 2000 to 2018 than during 1987 to 2000. Average nearest neighbor cluster analysis determined that the overall population of trees was significantly clustered ($p\approx0$) but yielded mixed results when run for infection severity and tree size class.

Table 1: Number of Beech Trees Surveyed per Category.

total # surveyed	# severity 1	# severity 2	# severity 3	# severity 4	# dead not by BBD
286	190	30	21	1	42*

*Of the 42 Beech found dead but not believed to have died from BBD only 3 had a DBH greater than 5cm and most were found snapped by treefall.

Table 2: Number of Beech Trees Surveyed by size Distribution.

0<DBH≤5	5<DBH≤10	10<DBH≤15	15<DBH≤20	20<DBH
98	89	27	16	14

Figure 1:

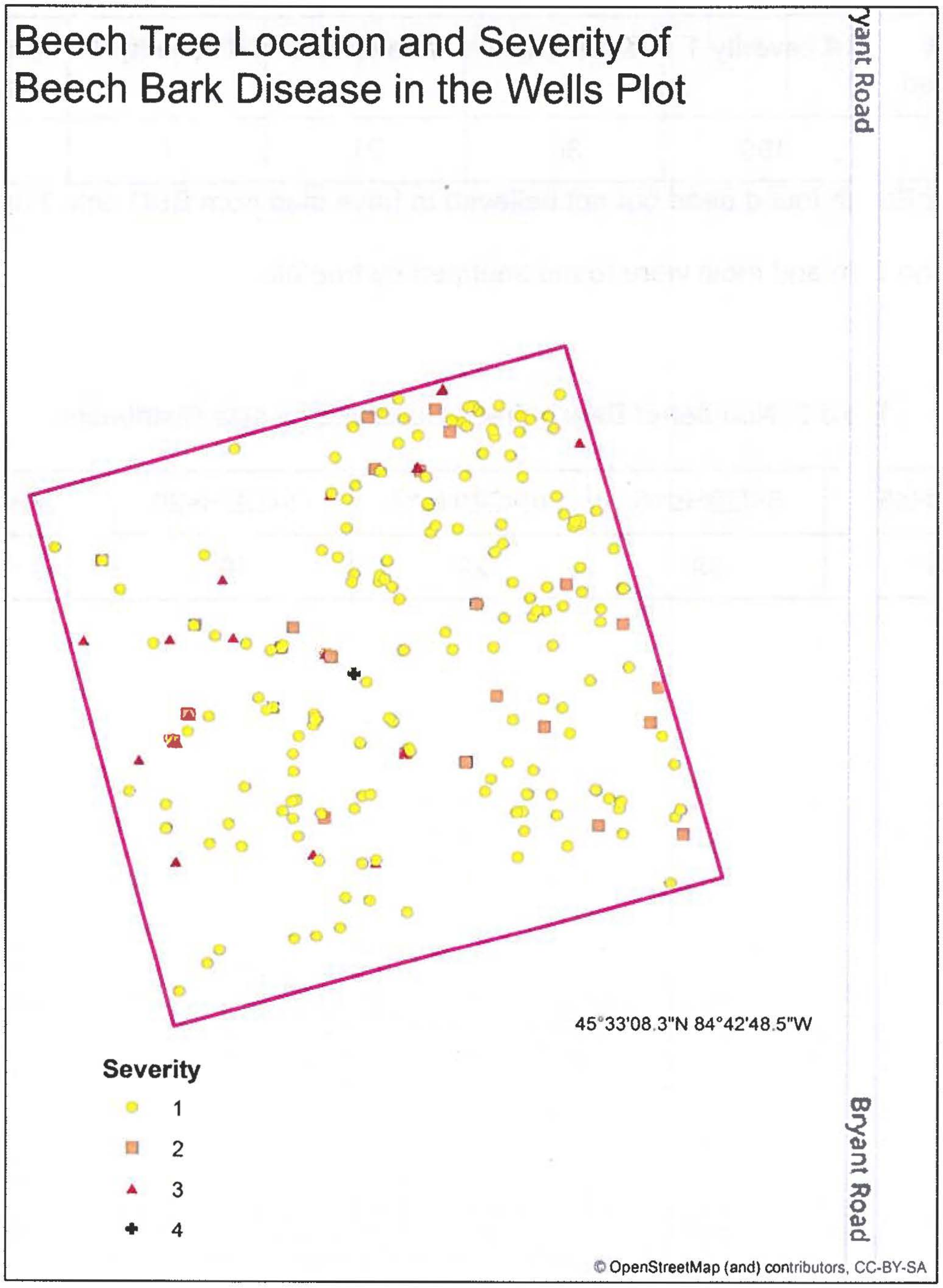
Beech Tree Location and Severity of Beech Bark Disease in the Wells Plot
yant Road
45°33'08.3"N 84°42'48.5"W
Severity
1
2
3
4
Bryant Road
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Table 3: Average Nearest Neighbor Results Summary

Subset	All	Severity 1	Severity 2	Severity 3	<4.5 cm DBH	4.5≤ to ≤8 cm DBH	>8 cm DBH
Pattern	Clustered	Clustered	Random	Random	Clustered	Random	Clustered
P value	0.000000	0.000000	0.824627	0.223206	0.000000	0.357987	0.024986
Z score	-10.2771	-5.46731	-0.22159	1.218047	-5.99355	-0.91920	-2.24162
Obsered. *M* Dist(m)	1.984217	2.823453	7.871490	10.11518	3.039892	4.684867	4.869850
Expected *M* Dist(m)	2.900903	3.561984	8.041538	8.881231	4.271985	4.931938	5.626028
Ratio	0.683995	0.792668	0.978852	1.138939	0.711589	0.949906	0.865592

Figure 2: Severity of BBD Compared to Tree Diameter ($p<0.001$).

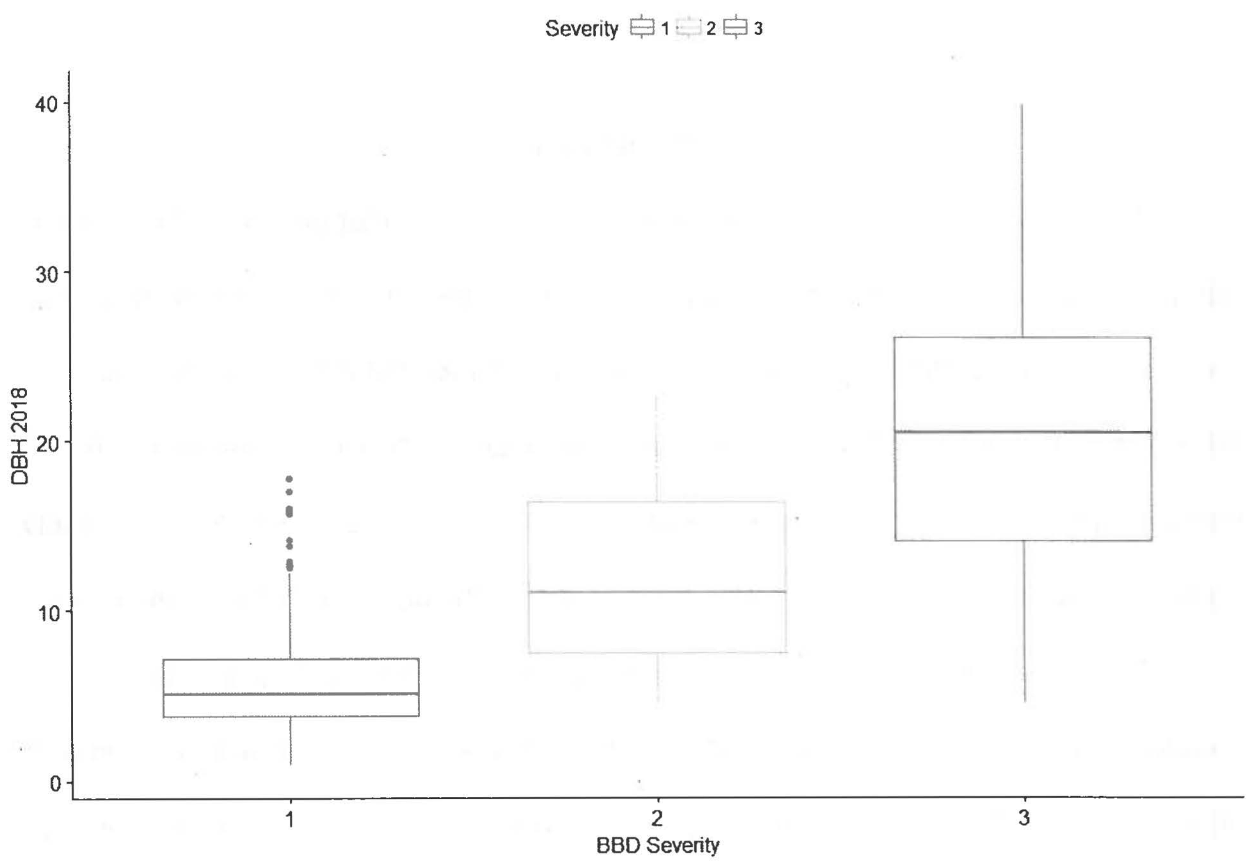
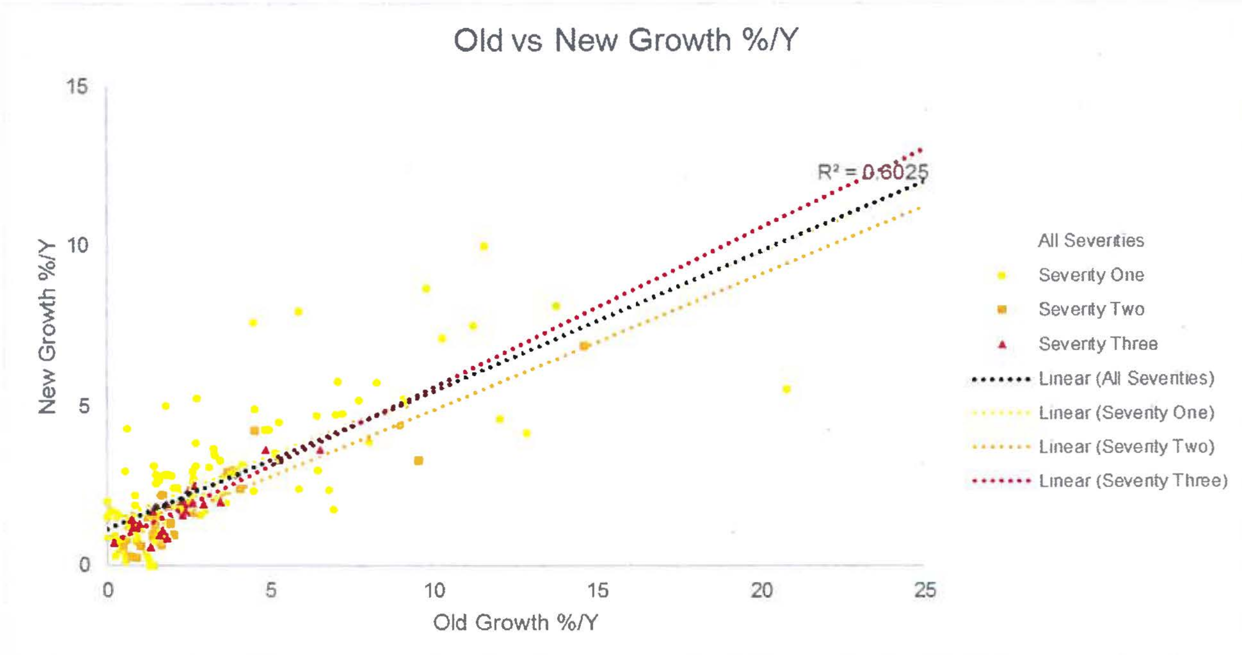


Figure 3: Average Percent Growth per Year of Surveyed Trees in 1987 to 2000 Compared to in 2000 to 2018. (n=163)



Discussion

The wooly beech scale was so pervasive in the wells plot that almost no beech tree lacked signs of it. No fruiting bodys of the fungus were directly observed however, they are often not present even at a site of significant infection (McCullough et al., 2005). This study assumed wooly beech scale prevalence strongly correlated with fungal presence. If the *Nectria* is not present in the stand then this study's results likely underestimate the true impact of BBD. Further research could clarify this relationship.

Tree size in agreement with other literature (Witter et al., 2005) was found to correlate with BBD infection (Figure 2). This trend strongly impacts analysis of the rest of of the data. In figure 1 and 3 the infection severity effectively also refers to Tree size. Beech trees were found to grow slower after the arrival of BBD in the state. Causation cannot be determined in this case but no other probable cause was observed and results agree with existing literature (Witter et al., 2005). The exact year of stand infection is unknown so the impact of BBD may in fact be greater. BBD severity did not appear to have a major impact on percent decrease in growth rate. Other research has shown that after BBD severity hits a threshold severity no longer correlates with greater stunting of growth (Witter et al., 2005).

Spatial analysis of BBD distribution (figure 1 and table 3) was Inconclusive. The entire population of surveyed beach trees was found to be strongly clustered. This makes it difficult to determine if any severity based analysis is valid or simply an artifact of the trees natural growth pattern. Additionally because tree size so strongly correlates with BBD severity the data must be looked at in subpopulation level to standardize it. However, if the data is split up by size class there is not enough variance in severity to look for a statistical trend. It is possible that this represents a real trend and BBD tends to be spread evenly at stand level but more data would be necessary to determine that. Overall no clear conclusions can be drawn from this data about how BBD is distributed in already infected forest systems. Further research could survey a larger swath of land and utilize a finer grained scale in order to better study BBD distribution.

The Wells plot contained many small beech trees and comparatively few large ones (table 2). This may impact the distribution of the disease in the stand. Only one tree in the plot was suspected of dying of BBD. It may be that the stand has not been infected long enough to kill many of the trees. Older trees are known to have a higher mortality (Houston, 1998) so therefore, comparison to a mostly old beech stand could prove fruitful. Outside the plot a recently snapped infected beech was observed. This is a described phenomenon associated with BBD where the damage caused by the fungus makes the tree more prone to breakage (McCullough et al., 2005). Twice stabbed ladybugs (*Chilocorus stigma*) a species that eats scale insects and is often found at BBD infected sites (Houston, 1998) where also observed on the plot. However, the ladybugs were only noted on the most severely infected trees and therefore probably not having much of a controlling impact on BBD.

BBD is expected to continue to expand its range in North America (Morin et al., 2007). Even in areas impacted by BBD Beech remains a component of the forest but in a reduced capacity (Cogbill, 2005). Some resistant trees have been observed but are not expected to cause a major rebound in beech populations (Houston, 2005). This reduction of Beech may have significant impacts on the local wildlife because it is a major mast producer in part of its range where oak is less common (Jakubas et al, 2005). The damage both ecological and economic of Introduced forest pests in North America will be felt for generations. Traditional forest management has long focused more on maximizing timber value or creation of habitat. Increasingly it will have to further emphasize protecting the trees from invasive diseases and pests. More data on forestry diseases and pests is vital in combating their spread and ameliorating their damage.

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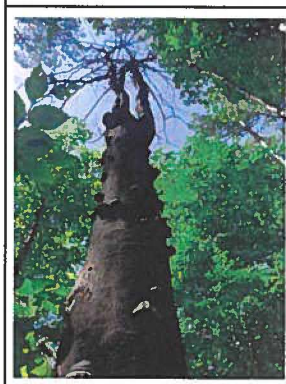
Appendix A

Beech Bark Disease Severity Rubric

	**Severity 1: none to little disease** Either no sign of disease or small, sparse spots dispersed around random areas of the tree.
	**Severity 2: moderate disease** Clustered areas or patches of disease along most of the tree. Typically in weaker areas of the tree and around bases of branches.
	**Severity 3: heavy disease** Disease has spread to the whole tree. More uniform dispersal around the tree. The scale insect is more commonly found on more heavily infected trees.
	**Severity 4: death by disease** Sign of disease is still apparent on the tree. Detritivorous fungi attach to the tree.