Beech Bark Disease in Ontario: Implications to Forest Structure and Composition

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Introduction

American beech (*Fagus grandifolia*) mortality by beech bark disease (*Neonectria faginata*) may cause major changes to forest structure and composition in southern Ontario. American beech is a major component of southern Ontario’s hardwood forest, often occurring with Sugar maple (*Acer saccharum*), Yellow birch (*Betula alleghaniensis*), and Eastern hemlock (*Tsuga canadensis*) (McLaughlin and Greifenhagen 2012). Historically, American beech dominated southern Ontario’s forests from 7000 to 500 years ago, prior to a partial replacement from 500 to 200 years ago by Sugar maple, Oak (*Quercus spp.*), and Eastern white pine (*Pinus strobus*) due to land clearings, and forest fires (Suffling *et al.* 2003; Williams *et al.* 2004). In the 19th century, European settlers extensively and indiscriminately cleared southern Ontario’s forests, and American beech, Sugar maple, Eastern hemlock, and Oak were almost eliminated from the landscape (Suffling *et al.* 2003). As a result American beech, a slow-growing species, has not nearly recovered towards its pre-settlement abundance (Suffling *et al.* 2003). Moreover, American beech is threatened by the beech bark disease across its range in Ontario (Forrester *et al.* 2003). Extirpation of large American beech by beech bark disease may cause major changes to the structure, composition and functions of forests in southern Ontario.

Beech bark disease is caused by the co-infection of American beech by an invasive beech bark scale (*Cryptococcus fagisuga*), and a Nectria fungi (*Nectria coccinea var. faginata*) (Latty *et al.* 2003). The beech scale feeds on American beech bark causing small fissures in the bark which allows the Nectria fungi to invade into the bark (Mason *et al.* 2013). The Nectria fungus proliferates inside the parenchyma of the bark killing the living tissue of the bark, resulting in cankers (Mason *et al.* 2013). The cankers may aggregate around the bole of the tree effectively girdling the tree, or they can reduce the structural integrity of the tree making it more susceptible to other disturbances like wind-throw (Papaik *et al.* 2005). The beech scale was introduced to North America in 1890 from Europe, and has now spread throughout southern Ontario (McLaughlin and Greifenhagen 2012). Beech bark disease has been in Ontario since 1990, and has spread throughout most of the range of American beech in southern Ontario (McLaughlin and Greifenhagen 2012).

The progression of beech bark disease in forest stands occurs in three stages: the advancing front, the killing front, and the after-math zone (Shigo 1972). In the advancing front
the beech bark scale invades the stand and feeds on American beech bark; but at this stage the incidence of the Nectria fungi is low (Houston 1983). In the advancing front only baseline mortality from natural small scale disturbances is observed (Cale et al. 2017). In the killing front the scale population and the Nectria fungi have reached high levels, and widespread aboveground mortality in American beech is observed (Shigo 1972). Mortality is most pronounced in larger American Beech trees due to their larger trunk size which provides increased surface area for colonization of the scale, and increased amino nitrogen in the bark (Witter 1983). Amino nitrogen is a precursor to an important nutrient for the growth of the scale, and therefore the increased concentration of amino nitrogen in larger trees allows for greater colonization success of the beech scale (Wargo 1988). Following the killing front, the stand transitions into the aftermath forest (Shigo 1972). In the aftermath zone often there is replacement of large American beech trees by a younger cohort, and the forest structure and composition have changed (Cale et al. 2017).

There is however variation in the pattern of spread of beech bark disease depending on stand age and density, tree sizes, species composition, soil conditions, genetics, and the history of logging (Houston 1983). Typically, beech bark disease causes mortality in 6 to 7 years, however there are American beech trees that show higher tolerance to beech bark disease, and can survive a longer-time (Houston 2000). Furthermore, there are American beech trees that show genetic resistance to both the beech bark scale, and the Nectria fungi (Koch et al. 2010). Also, some forests show strong resilience to beech bark disease; the size classes, tree composition, and native biodiversity remain stable in resilient forests despite the loss of large American beech trees to beech bark disease (Morin 2007). Furthermore, some forests show differences in the susceptibility to developing dense beech thickets in the understory (Giencke et al. 2014). Beech thickets form when American beech sprouts, and saplings prolifically recruit into the canopy gaps created by the elimination of large American beech from beech bark disease (Farrar and Ostrofsky 2006). Beech thickets form in stands with high beech basal area, and heavy beech mortality from beech bark disease (Jones and Raynal 1987). Therefore, the tendency to develop thickets is mainly determined by the beech basal area prior to beech bark disease, and competition to beech recruits (saplings and sprouts) from other shade-tolerant species (Giencke et al. 2014).
Determining the impact of beech bark disease on forest structure and composition in different conditions is important for identifying the areas that are most vulnerable to undesirable ecological change (Evans et al. 2005). American beech’s impact on the ecosystem is complex, and varied depending on the forest cover type (Tubbs and Houston 1990). American beech is an important species in the nitrogen cycle in North America, its leaves have the highest nitrogen concentrations of all canopy trees in eastern North America (Latty 2003). In upland beech – sugar maple forest American beech has a strong impact on the biogeochemistry of the forest, and beech mortality can result in homogenous Sugar maple forest (Lovett et al. 2010). Lovett et al. 2010 found beech bark disease can shift mixed beech-maple forests into maple dominated forests, and the shift to maple dominated forests resulted in increased carbon turnover and nitrogen cycling in soils. In lowlands hemlock- beech- oak- pine forest American beech sprouts can outcompete and reduce the growth and regeneration of the other less shade-tolerant species, potentially reducing forest heterogeneity (Twery and Patterson 1984). Studies show that beech bark disease can benefit the growth and establishment of Eastern hemlock, Yellow birch, and other shade-intolerant species by reducing the strong competitive ability of American beech (Papaik et al. 2005).

Impacts of beech bark disease on wildlife are complex, and may positively or negatively impact different species. Wildlife that depend on beech mast may be adversely impacted by the loss of large beech trees from beech bark disease (Strorer et al. 2004). In northern hardwood forest American beech nuts are the primary hard mast for 40 species of mammals, and birds; including black bears, foxes, bluejays and martens (Strorer et al. 2004). American beech can start producing abundant nut crop at 40 years, ~ 10-12 cm diameter at breast-height (Tubbs and Houston 1990). The beech bark disease targets trees greater than 10 cm diameter at breast-height, and therefore the beech bark disease may negatively impact mast availability (Tubbs and Houston 1990). Although, studies show that the beech bark disease increases the availability of cavities, and coarse woody debris for wildlife; and therefore may benefit species that are cavity nesting, and depend on coarse woody debris (Kearney et al. 2004). American beech mortality from beech bark disease is expected to cause major ecological, and economic consequences to Ontario’s hardwood forest (Forrester et al. 2003).
The purpose of this study is to determine the impact of beech bark disease on forest structure, and composition in the Lake Simcoe Watershed. The specific objectives of the study are the following:

i) Quantify the abundance and the size (DBH) distribution of American beech in the Lake Simcoe sub-watersheds.
ii) Quantify the number of American beech with Beech Bark Disease (BBD).
iii) Map the distribution of Beech Bark Disease and American beech in the Lake Simcoe sub-watersheds.
iv) Identify plots that have high proportion of BBD for management.
v) Identify plots that have low proportion of BBD to American beech trees to identify potential genetically resistant individuals.
vi) Identify the difference in key variables (eg. slope position, interspecific competition, woody-debris load) in plots with BBD, and plots without BBD.
vii) Identify the species associated with American beech to determine the potential changes to forest composition from American beech mortality.

Methods

Study Site & Species Description

The Lake Simcoe watershed covers 3400 sq. km. of area in the southern part of the Great-Lakes – St. Lawrence Forest Region (Rowe 1972). The study was mainly conducted in two sub-watersheds: East Holland sub-watershed, and Uxbridge Brook sub-watershed. The mean annual temperate in the region ranges from 4.9 °C to 7.8 °C, and the mean annual precipitation is 759mm to 1087mm (Mackey et al. 1996). The Lake Simcoe watershed is 34% forest cover, and common tree species in the region include Sugar maple, Eastern hemlock, Yellow birch (Betula alleghaniensis), White ash (Fraxinus americana), American basswood (Tilia americana), Eastern white pine (Pinus strobus L), and American beech (Day and Puric-Mladenovic 2012).

American beech occurs in mean annual temperatures ranging from 4°C to 21 °C, and mean annual precipitation from 580mm to 1270mm (Tubbs and Houston 1990). American beech is commonly found on soils that are well-drained, and loamy soils derived from glacial till (Latty et al. 2004). American beech is generally associated with upland forest, and is associated with
high over-story basal area (Bose et al. 2017). Its strong shade tolerance allows it to outcompete other species and dominate stands (Tubbs and Houston 1990).

**Sampling Design**

Vegetative Sampling Protocol (VSP) sampling, a fixed area method, was used to sample the Lake Simcoe watershed (Mladenovic and Kenney 2015). In VSP sampling random plots, 400m², are selected across the landscape, and all vegetation within each plot is inventoried (Mladenovic and Kenney 2015). Furthermore, the percentage cover of each species within each vertical strata of a plot is estimated; the vertical strata are the following: ground vegetation (<0.5m), shrubs (0.5-2m), sub-canopy (2-10m), and canopy (>10m). The diameter at breast height for all trees (>5cm) in the plot is recorded, and the presence of disease is recorded. Beech bark disease (BBD) was identified by the presence of cankers on the bark of American beech (Mclaughlin and Greifenhagen 2012).

**Density and Frequency**

Frequency, or abundance of American beech per plot was measured as the numbers of stems of American beech per plot (Wenger 1984). Density per plot was estimated as frequency of American beech per unit of area (Wenger 1984). Total frequency was measured as the number of American beech in all plots (Wenger 1984).

**Diameter Class & Vertical Distribution**

Diameter class distribution per plot was calculated as the total number of stems of American beech in the following classes: 5-10 cm, 10 to 20 cm, 20 to 30 cm, 30 to 40 cm, 40 to 50 cm, >50 cm (Marks and Canhan 2015). Vertical distribution of American beech was calculated as the average relative cover in the four vertical layers across all VSP plots (Mladenovic and Kenney 2015).

**Mapping**

American beech was mapped in the Lake Simcoe Watershed (LSW) using ESRI ArcGIS 10.2. Shapefiles of the LWS boundary, and LWS eco-districts were provided by the OMNRF. Plots were symbolized as circles, where the size of circles corresponded to the percent relative
cover of American beech per plot. Plots with BBD were mapped as red circles, and plots without BBD were mapped as green circles.

**Basal Area & Importance Value**

Basal area (BA) of a American beech tree was calculated as \( \pi \times (\text{DBH})^2/4 \) (Mackenzie 2004). Total BA was calculated as the summation of the BA all American beech trees per a plot (Mackenzie 2004). Relative BA was calculated as total BA of a species divided by the total BA of all species. Importance value was used to determine the dominance of a species in a given area (Suffling et al. 2003). Importance value of American beech per plot was calculated as (Relative BA x Relative Frequency)/2 (Suffling et al. 2003).

**Statistical Analysis**

One-way analysis of variance (ANOVA) in SAS (SAS Institute Inc., Cary, NC) was used to analyze statistical differences in the distribution of American beech in different vertical layers, and different diameter size classes (Figure 3, 4, 5). Linear Regression in SAS (SAS Institute Inc., Cary, NC) was used to determine the variables (see Appendix) that predict the intensity of beech bark disease, relative BA of American beech, and the importance value of American beech in a plot (Table 1, 2, 3).

**Results**

**Age- Class**

The results show that American beech in the Lake Simcoe Watershed (LSW) has shifted to a younger age class. The relative cover of American beech across all plots is significantly concentrated in the shrub, and the sub-canopy layer (Figure 3; \( p= 3.01 \times 10^{-7} \)). Furthermore, American beech trees across all plots are more abundant in the 5 to 10 DBH size class (Figure 4). In all plots there are no American beech trees with a DBH of 20 to 40 cm (Figure 4). All American beech trees with a DBH of above 40 have beech bark disease (Figure 4). The results show that beech bark disease (BBD) can occur in both young, and old American beech trees (Figure 4). Although, beech bark disease on average occurs more frequently in large diameter American beech trees than small diameter American beech trees (Figure 5).

**Frequency**
The total frequency of American beech trees (>5cm DBH) across all plots in the LSW was 43 trees. Most plots had a frequency of 2 to 1 American beech, and the highest frequency was 7 American beech in a plot (Figure 6). The total frequency of American beech trees with BBD across all plots was 7. The proportion of trees with BBD per a plot ranged from 100 % to 86% of American beech trees (Figure 6). The total number of VSP plots with American beech was 34, and BBD was found in 2 plots.

**Location**

The majority of plots with American beech were located within the Oak Ridges Moraine area (Figure 1). Plots with American beech were mostly found on mid-slopes, and upper-slopes (Figure 9). Linear regression on importance value of American beech per plot showed that the importance of American beech in a plot was impacted by the slope position of the plot (Table 3). Higher slope positions resulted in a higher importance value of American beech in a plot (Table 3). Relative cover of American beech is generally higher in plots located within the Oak Ridges Moraine (Figure 2).

**BBD Intensity**

The intensity of beech bark disease in a plot was determined by the relative cover of American beech in the sub-canopy (Table 1). Higher relative cover of American beech in the sub-canopy results in a greater frequency of American beech with beech bark disease in a plot (Table 1). Contrarily, higher relative cover of American beech in the shrub layer results in a lower frequency of American beech with beech bark disease in a plot (Table 1).

**Importance**

In the majority of plots the relative over-story basal area of American beech was drastically low, often American beech compromised less than 5% of the total basal area of a plot (Figure 7). Linear regression of relative basal area of American beech per plot showed that the relative basal area of American beech is determined by the amount of sub-canopy cover, and the total basal area in the plot (Table 2). The results show that an increase in sub-canopy cover results in an increase in the relative basal area of American beech (Table 2). A increase in the total basal area of a plot results in a decrease in the relative basal area of American beech (Table 2).
Similarly, the importance value of American beech in a plot was drastically low, often American beech compromised less than 5% of the plot (Figure 8). Linear regression of importance value of American beech per plot showed that the importance value of American beech is determined by the slope position, total canopy cover, and coarse woody debris (Table 3). The results show that an increase in slope position of a plot results in an increase in the importance value of American beech (Table 3). Higher amount of total canopy cover results in a decrease in the importance value of American beech (Table 3). The results show higher coarse woody debris results in a decrease in the importance value of American beech (Table 3).

**Forest Structure**

Linear regression of the percent coarse woody debris per a plot showed that the percent coarse woody debris is determined by the importance value of American beech, and canopy cover in the plot center (Table 5). Plots with high canopy cover in the plot center have a low percentage of coarse woody debris (Table 5). Plot with a high importance value of American beech have a low percentage of coarse woody debris (Table 5). Linear regression of the percent leaf litter per a plot shows the percent leaf litter is determined by the canopy cover in the plot center (Table 6). Plots with high canopy cover in the plot center have a high percentage of leaf litter (Table 6).

**Forest Composition**

Plots with American beech were dominated by Sugar maple in all DBH size classes (Figure 10). Although, Sugar maples dominance was most pronounced in the largest size class (Figure 13). Canopy Sugar maple occurred in ~ 80% of American beech plots (Figure 11). American beech plots were also commonly associated with canopy White ash (*Fraxinus Americana*), Eastern white pine (*Pinus strobus*), American basswood (*Tilia americana*) (Figure 11). In the mid-sized diameter size class (20 to 40 cm) species other than American beech, and Sugar maple constituted most of the basal area (Figure 10). A significant proportion of the basal area was constituted in the mid-sized diameter size class (20 to 40 cm) by Red pine (*Pinus resinosa*) (Figure 13). Red oak constituted a significant proportion of the basal area in the largest diameter size class (>50 cm) (Figure 13).

In the ground cover American beech plots were commonly associated with Sugar maple, Alternative-leaf dogwood (*Cornus alternifolia*), White ash, Choke cherry (*Prunus virginiana*),
and Black cherry (*Prunus serotina*) (Figure 12). Sugar maple dominated the ground cover, where Sugar maple saplings occurred in ~ 80% of American beech plots (Figure 12). Sugar maple determined the relative cover of American beech saplings in a plot (Table 4). The amount of American beech saplings in a plot decreases with an increase in the relative cover of Sugar maple in the shrub layer (Table 4).

**Discussion & Management**

The current age structure of American beech in the LSW sub-watersheds is consistent with the age structure of forests after beech bark disease (Cale *et al.* 2017). In aftermath forests large American beech trees are often replaced by a younger cohort (Forrester *et al.* 2003; Cale *et al.* 2017; Latty *et al.* 2003). In the LSW sub-watersheds there appears to be a complete elimination of large American beech trees from the landscape, and a shift towards a younger age class (Figure 4). The elimination of large American beech trees may have occurred in the early 2000’s, since BBD arrived in the LSW in 1990’s and typically causes mortality in 7-10 years (Mclaughlin and Greifenhagen 2012). Currently, most of American beech stems in LSW sub-watersheds are in the 5 to 10 cm DBH size class, and are 2m to 8.5m in height; this diameter and height are consistent of American beech that are 20 to 40 years of age. The current population of American beech in the LSW sub-watersheds is likely the progeny of large American beech trees eliminated in the early 2000’s by beech bark disease.

The current age structure of American beech in the LSW sub-watersheds may explain the low frequency of American beech with BBD across all plots. Studies show that young American beech stands have reduced levels of BBD because the colonization of the beech bark scale is significantly reduced on smaller sized American beech trees (Twery and Patterson 1984; Forrester *et al.* 2003; Hane 2003, Houston 1994). Linear regression on the intensity of BBD in a plot showed that plots with higher amounts of American beech shrub cover had a lower incidence of beech bark disease (Table 1). Furthermore, the results show that the intensity of BBD in a stand increases when the stand is shifting towards a larger American beech size class (Table 1). Forest managers in LSW should reduce the relative cover of over-story American beech in stands to limit the spread of the disease (Mclaughlin and Greifenhagen 2012).

Thinning sub-canopy American beech is recommended as a management strategy to prevent a secondary killing front in aftermath forests (Mclaughlin and Greifenhagen 2012).
There is evidence that a high proportion of sub-canopy beech can result in a secondary outbreak of the beech bark disease (Houston 1975). Houston (1975) found similar results to this study, beech bark disease resulted in a shift of beech to a younger age-class; and as the younger beech grow Houston (1975) showed that it resulted in a secondary outbreak of the beech bark disease. There is evidence that in the LSW sub-watersheds a secondary outbreak may be imminent; the results shows that about 15 % of beech in the younger age-class has the beech bark disease.

Monitoring of young beech for signs of beech scale infestation is essential for stopping the spread of the beech bark disease (Mclaughlin and Greifenhagen 2012). An education campaign towards private landowners on how to detect the presence of the beech scale is also essential for preventing a secondary outbreak in the LSE sub-watersheds. The beech scales presence is easily detectable, the scale produces a wax that appears as a noticeable white-waxy substance on beech bark (Mclaughlin and Greifenhagen 2012). Most of the plots sampled are on private land, and therefore private landowners should be educated on how to detect the presence of the beech scale, and should be encouraged to thin sub-canopy American beech. Although, harvesting sub-canopy American beech should be discouraged; cutting beech can result in prolific re-sprouting of beech and can result in the formation of beech thickets (Farrar and Ostrofsky 2006). The beech scale depends on the live tissue of American beech bark, and therefore thinning is sufficient to stop the spread of the disease (Mclaughlin and Greifenhagen 2012).

Figure 2 can be used to identify areas that potentially have high amounts of over-story American beech. Furthermore, to limit the spread of BBD Figure 1 can be used to identify areas where the disease is present, and identify areas that are vulnerable. BBD spreads at a rate of 20km/year (Morin et al. 2007), areas that are within 20km of a plot with BBD should be prioritized (Figure 1).

Thinning over-story American beech and creating canopy gaps would also promote the establishment of shade-intolerant species. The understory of American beech plots commonly contains important mast-producing species like Red oak (*Quercus rubra*), Bitternut hickory *Carya cordiformis*, Choke cherry (*Prunus virginiana*), Black cherry (*Prunus serotine*), and White ash (*Fraxinus americana*) (Figure 12; Figure 13). Although, the over-story of American beech plots is less frequently represented by mast-producing species (Figure 11); for example
Red oak, a historically important mast species, occurs twice as more frequently in the ground layer than in the canopy in American beech plots (Figure 11; Figure 12). American beech is a strong competitor that prevents the establishment of other species in the canopy with an exception of the equally competitive Sugar maple (Tubbs and Houston 1990). Thinning over-story American beech can promote the establishment of other important mast-producing species (Heyd 2005).

However, Sugar maple could potentially benefit more than other species from the removal of over-story American beech. In LSW the elimination of large American beech trees has potentially increased the dominance of Sugar maple in the region (Figure 10). Sugar maple constitutes ~50% of the basal area of trees (> 40 cm DBH) across all plots (Figure 10). Studies show that elimination of large American beech trees from BBD may accelerate the growth of sub-canopy Sugar maple (Digregorio et al. 1999; Lovett et al. 2010). Consequently, thinning over-story American beech to promote growth of other mast producing species may inadvertently result in more homogenous Sugar maple stands. Management of BBD to promote biodiversity in LSW should reduce the over-story basal area of both American beech, and Sugar maple to allow for the establishment of other mast-producing species in the canopy.

Mast shortages from the elimination of large American beech trees may adversely impact birds and small mammals in the LSW. In northern hardwood forest beechnuts are the primary hard mast for 40 species, including chipmunks, squirrels, mice, deer, blue jays, foxes, and black bears (McCullough et al. 2000; Heyd 2005). Studies show that the basal area of American beech in a stand is significantly correlated with quantity of available beechnuts (Jakubas et al. 2004). In Ontario the abundance of American beech has drastically declined (Williams et al. 2004); often American beech compromised less than 5% of the total basal area of a plot (Figure 7). The reduction in American beech basal area in the LSW may result in a reduction in the quantity of beechnuts available to wildlife (Jakubas et al. 2004). This may adversely impact wildlife in the region; studies show a reduction in American beech basal area from BBD can result in a reduction in small mammal diversity (Storer et al. 2004). Wildlife managers in the LSW can promote mast producing species by reducing the total basal areas of stands.

Furthermore, a reduction in over-story basal area can promote American beech regeneration (Hane 2004). American beech starts producing abundant seed crop at 40 years of
age, and at about 10 to 12 cm DBH (Tubbs and Houston 1990). However, as mentioned an increase in sub-canopy American beech can promote the spread of BBD in stands. Managers need to determine the appropriate number of sub-canopy American beech trees in a stand to prevent the spread of BBD, but also produce enough beech mast for wildlife. In stands with mast-producing species, like Red oak (*Quercus rubra*), Bitternut hickory (*Carya cordiformis*), and Black cherry (*Prunus serotina*), maintaining a minimal amount of American beech trees may be counter-productive because of American beech ability to sprout and out-compete other species (Heyd 2005). Furthermore, American beech mortality is an important determinant of the amount of coarse woody debris available to cavity-nesting species in LSW (Table 5). Coarse woody debris load is significantly decreased in American beech plots with a high proportion of large trees compared to American beech plots with a low percentage of large trees (Table 5). This suggests that American beech mortality from BBD has resulted in an increase in the amount of coarse woody debris in stands (Storer *et al.* 2004). Thinning sub-canopy American beech can potentially increase the amount of coarse woody debris available for cavity-nesting species.

In conclusion, LSW managers should thin sub-canopy American beech to stop a potential secondary outbreak of the beech bark disease (Houston 1975). The following guidelines should be followed when managing a stand for the beech bark disease.

Firstly, individuals that show signs of genetic resistance against the beech bark disease should be kept in the stand, and should be monitored (Mackenzie 2004). Studies show that 1% of American beech trees show resistance to the disease (Mackenzie 2004); there is potentially a resistant beech tree in plot 402 (619781.7E, 4879243N). Potentially resistant beech trees should be monitored to determine if they are actually resistant to the disease. A few American beech trees should be kept in stands to determine potentially genetically resistant individuals (McLaughlin and Greifenhagen 2012).

Secondly, harvesting of healthy American beech should be avoided, because harvesting can potentially damage the bark triggering the prolific sprouting capabilities of beech and potentially resulting in the formation of beech sprouts (Farrar and Ostrofsky 2006). However, this study showed no evidence of the formation of beech sprouts in the LSW sub-watersheds. Other studies show that beech thickets result in high beech basal areas in stands (Giencke *et al.* 2014), however, this study showed low beech basal area per plot (Figure 7). Beech thickets
potentially did not form in the LSW sub-watersheds because of the presence of two strong shade-tolerant species: Sugar maple, and Alternate-leaved dogwood (Giencke et al. 2014). Studies show the composition of the understory is important in the formation of beech thickets; an equally competitive species to beech, like sugar maple and alternate-leaved dogwood, can prevent beech recruits (saplings and sprouts) from establishing in the canopy gaps formed by dead American beech (Giencke et al. 2014).

Thirdly, monitoring of young beech for signs of beech scale infestation is important to stopping the spread of the disease (McLaughlin and Greifenhagen 2012). Plots with healthy American beech (represented by green dots) should be prioritized for monitoring (Figure 1). Plots that show signs of infestation by the beech scale, and plots that are within 20km of plot with the beech bark disease should be prioritized for management. One of the most effective management strategies for stopping beech bark disease is thinning sub-canopy American beech to reduce the relative cover of American beech per a plot (McLaughlin and Greifenhagen 2012). Plots with high relative cover of American beech should be managed (Figure 2).

**Figures**
Figure 1 – Distribution of *Fagus grandifolia* in the Lake Simcoe Watershed 2017.
Figure 2- Relative cover of *Fagus grandifolia* and Beech Bark Disease in LSW 2017.
Figure 3. The average relative cover of *Fagus grandifolia* in different vertical strata across all VSP plots sampled. The average relative cover of *Fagus grandifolia* is statistically significant ($p = 3.01 \times 10^{-7}$).
Figure 4. The DBH distribution of *Fagus grandifolia* across all VSP plots. The DBH distribution of *Fagus grandifolia* with Beech Bark Disease across all VSP plots. The DBH distribution of *Fagus grandifolia* with BBD and normal *Fagus grandifolia* is statistically significant (p = 0.006137).
Figure 5. The average diameter at breast height (DBH) for *Fagus grandifolia* with the Beech Bark Disease versus the average diameter at breast height (DBH) for *Fagus grandifolia* without Beech Bark Disease. The difference in average diameter at breast height (DBH) for *Fagus grandifolia* was not statistically significant (p=0.0711; however the result is statistically interesting (p<0.1).
Figure 6. The number of stems of *Fagus grandifolia* per plot (Black Bars). The number of stems of *Fagus grandifolia* with beech bark disease per plot (Blue Bars).
Table 1. Linear Regression of the number of stems of *Fagus grandifolia* with beech bark disease per plot. The number of stems of *Fagus grandifolia* with beech bark disease is best predicted by the relative cover of *Fagus grandifolia* in the shrub layer, and sub-canopy layer. The number of stems of *Fagus grandifolia* with beech bark disease per plot is given by the equation \( y = 0.126(\text{Beech 2}) - 0.008(\text{Beech 3}) + 0.054 \).
Figure 7. Relative Basal Area of *Fagus grandifolia* per plot.

Table 2. Linear regression of relative basal area of *Fagus grandifolia* per plot. The equation for relative basal area is $y = 0.086 \text{(Layer 2)} - 1.4 \times 10^{-3} \text{(Total Basal Area)} + 1.369$. 

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Figure 8. Importance value of *Fagus grandifolia* per plot.

Table 3. Linear regression of importance value of *Fagus grandifolia* per plot. The importance value of *Fagus grandifolia* per plot is given by the equation $y = 1.63 \cdot \text{Slope Position} - 0.0576 \cdot \text{Full Canopy} - 0.54 \cdot \text{Woody Debris}$.
Table 4. Linear Regression of relative cover of ground cover *Fagus grandifolia* per plot. The relative cover of ground cover *Fagus grandifolia* per plot is given by the equation $y = 0.013(\text{Beech 2}) - 3E-3(\text{ACERSAS3})$.

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable Entered</th>
<th>Number Vars In</th>
<th>Partial R-Square</th>
<th>Model R-Square</th>
<th>C(p)</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rock</td>
<td>1</td>
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<td>0.6513</td>
<td></td>
<td>28.01</td>
<td>&lt;.0001</td>
</tr>
<tr>
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<td>Exposed Soil</td>
<td>2</td>
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<td>0.8852</td>
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<td>28.54</td>
<td>0.0001</td>
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<tr>
<td>3</td>
<td>Trail</td>
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<td>0.9844</td>
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<td>82.38</td>
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<tr>
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<td>0.9902</td>
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<td>7.08</td>
<td>0.0208</td>
</tr>
<tr>
<td>5</td>
<td>Beech2</td>
<td>5</td>
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<td>0.9936</td>
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<td>6.03</td>
<td>0.0319</td>
</tr>
<tr>
<td>6</td>
<td>Frequency of BBD</td>
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<td>0.0038</td>
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<tr>
<td>7</td>
<td>ACERSAS 3</td>
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<td>0.0015</td>
<td>0.9988</td>
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<td>10.97</td>
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</tbody>
</table>
Table 5. Linear Regression of the percent coarse wood debris per plot. The percent cover of woody coarse debris per plot is given by the equation $y = -0.158(\text{Importance Value}) - 0.06(\text{CentCanopy}) + 2.29(\text{Beech 4})$. 

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable Entered</th>
<th>Number Vars In</th>
<th>Partial R-Square</th>
<th>Model R-Square</th>
<th>C(p)</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
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<tbody>
<tr>
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<td>Beech 4</td>
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<tr>
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</table>
Figure 10. Basal area by size class distribution (DBH).
Figure 11. The percentage of *Fagus grandifolia* plots that a species occurred in the canopy.
Figure 12. The percentage of *Fagus grandifolia* plots that a species occurred in the ground cover.
Table 6. Linear Regression of the percent cover of leaf litter per plot. The percent cover of leaf litter is given by the equation $y = 0.78 \times \text{CentCanopy} + 4.54$. 

![Summary of Forward Selection Table](image)

![Residuals for Leaf litter](image)
Figure 13. Basal area by size class distribution (DBH).

Figure 14. The relative cover of *Fagus grandifolia* in the shrub layer per plot versus the relative cover of *Fagus grandifolia* with BBD in the shrub layer per plot. The difference in relative cover of *Fagus grandifolia* in the shrub layer is statistically significant (p=0.0207).
References


