Natural Areas Monitoring in the City of Guelph: Emerald Ash Borer impact on Ash populations in natural areas

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EXECUTIVE SUMMARY

Trees of the Ash (*Fraxinus* spp.) genus are an important component of Ontario forests. The three common Ash species, White Ash (*Fraxinus americana*), Green or Red Ash (*Fraxinus pennsylvanica*) and Black Ash (*Fraxinus nigra*) are found in a wide variety of forest types along the upland-wetland continuum and comprise a significant component of early to late successional forests. However, regardless of their different ecology and habitat preferences, all of these Ash species are susceptible to Emerald Ash Borer (EAB) (*Agrilus planipennis*). The Emerald Ash Borer is an invasive wood-boring beetle that targets and kills Ash trees (*Fraxinus* spp.) within as little as two years. Since its introduction from Asia to North America in the 1990s, forests in urban and rural areas across southern Ontario have been impacted by this insect to the point of total loss of Ash in some areas. In Guelph, EAB was first detected in 2011, where it not only directly impacts Ash species but indirectly affects forest structure and composition of a wide variety of forest types. Moreover, EAB impacts forest development and future forest composition by disrupting natural processes and known succession pathways.

In recognition of the urgency to respond to EAB impacts on woodlands, and use inventory and monitoring data as the basis of Urban Forest Management, the City of Guelph implemented a natural areas monitoring program in summer 2016. Vegetation Sampling Protocol (VSP) was selected as a quantitative, integrative, adaptable and efficient method for sampling different vegetation types in the field. It was also selected due to VSP's wide variety of practical and research applications, across different spatial scales, from plot to landscape levels. VSP site-level information can be used to inform management, planning and diverse policy needs. Site-level monitoring information is also relevant to climate change, estimates of carbon density and offsets, invasive species management, habitat conservation, natural heritage systems monitoring, estimating ecological goods and services, and others. Site-level sampling of vegetation provides data necessary to define a baseline condition of natural cover, compare vegetation quality across different landscapes and land characteristics, define reference conditions, define quality thresholds, and support adaptive management.

In southern Ontario, a network of VSP sampling plots has been established across a range of spatial scales from individual properties to broad landscape scales. The plot network also spans across a range of vegetation types: from forests, wetlands, and grasslands to disturbed and anthropogenic vegetation. Guelph, along with the City of Kitchener, is one of the municipalities in southern Ontario to be part of such an extensive vegetation monitoring network. Guelph's inventory, however, is unique as it has

provided a basis to assess EAB impacts at the woodlot scale. The City of Guelph is also one of the first municipalities in southern Ontario that has permanently marked sampled plots to ensure long-term monitoring.

Native Ash trees, found in a wide variety of forest types, are vital to Guelph's natural areas and urban forests. The focus of vegetation sampling in Guelph during summer 2016 was to gather information that would enable assessing the extent and impacts of EAB across the woodlands. Within Guelph's predominately urban matrix, VSP sampling targeted city-owned natural and parkland areas, starting by first sampling areas with a significant component of Ash. A total of 103 plots were sampled in 27 natural areas/parklands, spanning across ten different vegetation communities. The sampling was conducted from June-August 2016. VSP plot establishment, sampling and forest monitoring was a collaborative effort among the City of Guelph, OMNRF - Science and Research Branch, Natural Heritage Information Center (NHIC), and University of Toronto, Faculty of Forestry. Monitoring information, besides its use to detect changes, is envisioned to inform decision making, forest management activities, invasive species management, restoration planning, protection and recovery of species at risk and their habitats. It is also intended to support research related to urban and the rest of southern Ontario's woodlands.

The analysis conducted, using 2016 VSP field data, enabled a comprehensive assessment of Guelph's natural areas. VSP field data provided critical baseline information to measure the impacts of EAB and associated Ash tree loss in urban woodlands. Quantifying the amount of Ash helped to identify the overall magnitude of the EAB impact and define Ash-dominant areas to be most affected by EAB. Ash mortality is likely to have a significant impact on Guelph's woodlots and forest structure and composition. Studies suggest that these effects could include changes in species composition, loss of native species diversity, colonization by invasive species, inhibition of forest regeneration, reduced carbon sequestration, increased soil erosion, and stream sedimentation and warming. Identifying and mapping the amount of Ash and visible EAB impacts also resulted in information that enables informed management decisions to be made. For example, based on site-level data, quantitative and specific management targets can be set, and budgets for managing EAB impacts estimated. Known location and abundance of Ash trees and their current health can also be used to set priorities for specific management actions. Data on plant species composition in forest stands help identify areas vulnerable to post-EAB impacts and forecast what species are most likely to replace Ash. VSP data can also help to foresee and understand the implications of Ash decline on forest structure, composition, and functions.

Site level data can also be used to provide information on overall forest community composition, and to estimate floristic quality, impacts of weed plants, biomass and carbon stock.

All of this information when mapped can be used to inform both management and land use planning. As such, it can support decisions related to maintaining the integrity of the City's urban forest and natural heritage systems. Based on the analysis of 2016 field data, a variety of remediation and restoration activities are proposed for woodlands impacted by EAB. Forest regeneration could be enhanced and fast-tracked by planting replacement shade-tolerant tree species in the affected woodlands. This could be especially beneficial in areas lacking other tree species or seed sources. Preventative measures could also be taken by managing invasive plants, which threaten native species diversity and inhibit forest regeneration. Ash tree removal (standing deadwood) is recommended when there is a safety concern, but otherwise, deadwood could be left to provide nutrients to the soil, support diversity, and prevent further disturbance associated with tree removal. Erosion in hydrologically and topographically sensitive areas, where there is a significant Ash loss, could be mitigated by constructing stream barriers and restoring riparian areas. Stands identified by VSP as having significant species or species of high conservation value could be targeted for more specific conservation actions that protect these species and woodlands.

Continued monitoring of Guelph's natural areas is recommended to be completed at five-year intervals. The locations of plots established have been permanently marked to allow future monitoring and ensure sampling at the exact locations as in 2016. The plots will enable forest managers to monitor how Ash loss specifically impacts forest structure and composition over time. Continued monitoring data can also be used to inform adaptive management decisions, such as where tree regeneration or invasive species removal measures are most needed. Ongoing monitoring also helps to detect and understand the impact of Ash loss on ecological goods and services provided by woodlands, such as the change in carbon sequestration. Floristic quality indices derived from monitoring data can also be used to assess how the quality of woodlands change over time, to evaluate the efficacy of restoration efforts, and set desired floristic quality targets.

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This project and field sampling were possible as a result of work and support of the following people:

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We especially want to thank Timea Filer who has been eagerly engaged in this project since the initial discussions about VSP sampling in Guelph, until the last word of this report was written and maps made. Timea spearheaded this project, provided technical and supervising support to the field team, and ensured they had the directions, equipment, and tools to conduct field work. We are also grateful to Timea for the review of this document and valuable inputs related to the materials produced in this report.

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1 INTRODUCTION AND BACKGROUND

Natural areas such as woodlots, ravines and other open areas with self-sustained vegetation make up a significant component of an urban forest. They provide a multitude of ecological functions and social services. Some of include making the urban environment greener, ameliorating urban microclimate, improving air and water quality, reducing water run-off and erosion, and providing recreational and diverse social values to the community. In the southern Ontario context of land use planning, these natural areas are also often part of the municipal green system network (e.g. natural heritage systems, greenlands). These green systems link urban areas with the surrounding landscape, protect biodiversity and support many ecological functions and processes necessary to maintain populations of native species. Within the southern Ontario policy and designation framework, urban natural areas might also have other significance designations such as Areas of Natural and Environmental Significance, Environmentally Sensitive Areas, Significant Woodlands or Significant Wetlands.

As the growth of urban areas and developed land continues, environmental problems become even more amplified due to climate change. In light of this, green infrastructure, as a new planning and mitigation perspective, has emerged. Green infrastructure is primarily seen as a cost-effective and sustainable approach to managing storm water, ameliorating urban heat island, and reducing air pollution. Natural areas and urban woodlots are the backbones of urban green infrastructure. For example, forests, by slowing water movement across the landscape and enabling water infiltration into the soil, reduce surface water runoff during rainfall or snow-melt events. Natural areas provide vital hydrological and conservation functions, especially in wetlands, riparian areas, or areas with steep slopes. They help preventing flooding, reducing soil erosion, recharging aquifers and filtering pollutants which otherwise would have been carried directly into waterways.

However, natural areas in urban settings face a great amount of direct and indirect anthropogenic, environmental and biological pressures. These impacts range from land development, habitat fragmentation, and recreational pressures, to introduced pathogens and invasive plants and insects. These stressors, alone or in combination, impact forest structure, composition, function, and resilience. For example, invasive species such as Common Buckthorn (*Rhamnus cathartica*) and Garlic Mustard (*Alliaria petiolata*) alter forest structure and composition by outcompeting native species and suppressing forest regeneration. Natural areas are also vulnerable to introduced pests and pathogens, such as the Emerald Ash Borer (*Agrilus planipennis*) which kills Ash trees and in doing so alters native forest composition, structure, and functions.

The Emerald Ash Borer (EAB), a wood-boring beetle, targets Ash trees (*Fraxinus* spp.). Its larvae feed on the cambial tissues of Ash, which disrupts transport of water and nutrients, resulting in tree mortality within 2-5 years (Flower et al. 2013b, Poland and McCullough 2006). EAB not only has a negative impact on Ash but also on forest structure and composition as it disturbs natural processes (e.g. forest succession). Since the introduction of EAB from Asia to North America in the 1990s, forests in urban and rural areas across southern Ontario have been impacted to the point of total Ash decline in some areas. In Guelph, EAB was first detected in 2011 (Marchant 2013). Based on the recent research, it can be expected that EAB will kill Ash trees within 6-10 years from its first establishment (Marchant 2013). Ash mortality is likely to affect a significant component of Guelph's natural areas, some of which contain significant proportions of Ash. To understand the magnitude of EAB impacts and Ash loss within natural areas, an inventory and monitoring program was initiated to help quantify Ash abundance and impact of its loss on forest structure and composition.

Trees of the Ash genus are an important component of Ontario forests. The three common species, White Ash (*Fraxinus americana*), Green or Red Ash (*Fraxinus pennsylvanica*) and Black Ash (*Fraxinus nigra*) are found in a wide variety of forest types. Besides these, in the extreme southwest parts of the province, the rare Pumpkin Ash (*Fraxinus profunda*) can be found. The three common Ash species cover a wide range of sites along the upland-wetland continuum and comprise a significant component of early to late successional forests. White Ash, preferring rich, moist, moderately well-drained soils, is a component of almost all upland forest types (Schlesinger 1990). It often accompanies tree species such as White Pine (*Pinus strobus*), Northern Red Oak (*Quercus rubra*), Red Maple (*Acer rubrum*), and Sugar Maple (*Acer saccharum*). Green Ash has the largest range of all North American Ash species, tolerating a wide range of conditions from clay soils subject to flooding to soils of limited moisture (Kennedy 1990). Habitat of this species often overlaps with both White and Black Ash. Black Ash is a slow-growing wetland species commonly found in swamps from extreme southern Ontario to northern parts of the province. With the most northerly range of all three Ash, Black Ash is typically found in poorly drained areas typical of swamps, bogs or riparian areas (Wright and Rauscher 1990). Black Ash is an integral component of Black Ash-American Elm-Red Maple swamp forests. However, regardless of different ecology and habitat preferences of these Ash species, all are susceptible to EAB. EAB therefore not only directly impacts the Ash genus but indirectly a wide variety of forests and habitat types.

Urban woodlands are typically fragmented, isolated patches surrounded by various land uses and development. Such fragmented and isolated urban woodlands are also at increased risk of colonization by invasive plant species. As invasive plant have ability to colonize and thrive in disturbed environments, it is expected that they will take the advantage of conditions created by declining Ash due to EAB infestation. For example, death and removal of EAB-infested Ash trees has been shown to result in a secondary spread of invasive species like Common Buckthorn, Creeping Thistle (*Cirsium arvense*), and non-native Honeysuckles (*Lonicera japonica* and *Lonicera maackii*) in northwest Ohio (Hausman et al. 2010). In southern Ontario, Common Buckthorn, Glossy Buckthorn (*Rhamnus frangula*), Garlic Mustard, and Dog Strangling Vine (*Cynanchum rossicum*), species native to Europe, but aggressive in Ontario, jeopardize the ecological integrity of natural areas. They have the ability to form monocultures and outcompete native species by changing soil mycorrhizal and chemical properties, and thus reducing native plant diversity (Anderson 2012, Gurevitch and Padilla 2005, Hayley 2012, Klionsky et al. 2011,). They are of particular concern since they also suppress natural forest regeneration, especially important following the loss of Ash trees (Fagan and Peart 2004). As a result, the impact of EAB needs to be extended beyond the scope of a single tree, Ash species or genus, but to the entire forest community and its structure and composition.

Forest monitoring and inventory provide necessary information to define the baseline condition and assess risks caused by invasive species such as EAB. Development of Woodland Management Plans, aimed at mitigating EAB impacts and associated Ash tree loss in urban woodlands, is necessary to be based on qunataive inventory and monitoring information. Such information enables quantifying the amount of Ash, identifying the overall magnitude of the EAB impact, and defining Ash-dominant areas to be most affected. Measuring the impacts also allows the City to make informed management decisions and set quantitative and realistic management targets, as well as budgets to manage and mitigate EAB impacts. Known location and abundance of Ash trees and their current health can also be used to set priorities for specific management actions. For example, decisions about the removal of potential hazard trees in actively used parks along trails or replanting efforts with a focus on riparian areas would be better informed if based on inventory information. Data about species composition in Ash stands can help identify areas vulnerable to post-EAB impacts and forecast what species are most likely to replace Ash. It can also help to understand the implications of Ash loss on forest structure, composition, and function. In areas where Ash is abundant and large canopy gaps are expected to be formed as a result of its decline, invasive plant management actions might be necessary to reduce the risk of colonization by these opportunistic species. Inventory can also identify stands having significant species or species of high conservation value which could be targeted for more intensive management efforts. Monitoring and inventory information should form the basis of Urban Forest Management and EAB response plans, to aid in developing an effective strategy to address the environmental and financial impacts of EAB.

2 METHODS

2.1 STUDY SITE

The City of Guelph is located within the Mixedwood Plains Ecozone characterized by diverse mixed, deciduous and coniferous forests (Rowe 1972). Guelph also falls within the Manitoulin-Lake Simcoe Ecoregion and Ecodistrict 6E-1 Stratford North. This area with well-drained loam soils was once dominated by American Beech (*Fagus americana*) and Sugar Maple forests. Well-drained sands were dominated by Pines, while wet areas contained Elm, White Cedar, and Willow. The Ecodistrict has since been extensively cleared for agriculture, which has resulted in a predominately agricultural landscape doted by forest fragments (woodlands). The Stratford North (6E-1) Ecodistrict has an estimated 16% natural cover, 28 Species at Risk, and three vegetation communities targeted as priorities for conservation (Henson and Brodribb 2005). The remaining forested areas represent a mixture of natural remnants, secondary growth, and plantation forests. The City of Guelph has approximately 33% of natural cover and a population of over 120,000 people according to the most recent census in 2010 (Dougan et al. 2009, City of Guelph 2012). However, as it is expected that Guelph's population will grow and its urban areas will continue to expand, conserving natural remnants while managing the risks imposed on them (e.g. invasive species, climate change, development) will become even more important (Government of Ontario 2015).

Within Guelph's predominately urban matrix, City-owned forested natural and parkland areas were targeted for vegetation sampling in 2016. A total of 103 plots were sampled in 27 different forested areas that are also part of the City's Natural Heritage System. The sampling also captured ten different forest communities as per the Ecological Land Classification (ELC) mapping provided by the City of Guelph (Figure 1, Table 1, and Figures A6-A10). According to ELC mapping, upland forest stands were defined based on a 60% canopy cover threshold. Patch size of sampled forests ranged from 0.5 ha to 37.5 ha, with most patches being between 2 and 8 ha (Table 1). However, as 2016 sampling targeted Ash stands, the number of plots per forest patch or natural area was proportional to the size of Ash stands. Summer field sampling was conducted from June-August 2016, and spring ephemeral plants were not captured.

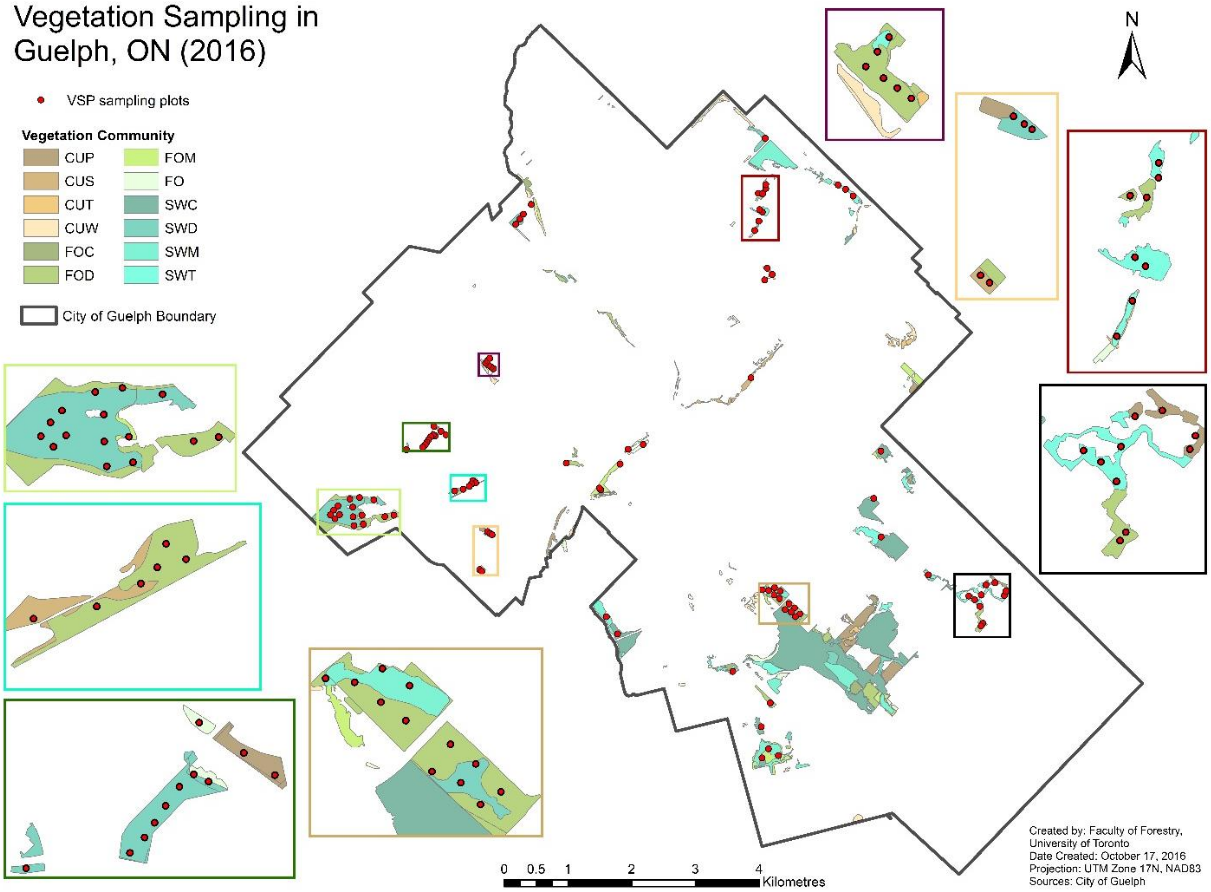

Figure 1. VSP plots sampled across public forested areas in the City of Guelph, summer 2016. Vegetation community boundaries include all natural areas in Guelph, however only those on City property were sampled.

Table 1. Number of VSP plots and ELC classes sampled across forested areas within the City of Guelph.

Location[1]	Number of Plots	Forested Area (ha)[2]	Area Sampled (ha)	ELC class(es)[3]
Ellis Creek	13	37.4	0.52	SWD(12), FOD(1)
Hadati Creek	11	22.2	0.44	SWT(6), CUT(2), FOD(2), FO(1)
Marksam Park	10	3.3	0.4	SWD(7), CUP(2), FO(1)
Westminister Woods	10	12.4	0.4	SWT(5), CUP(3), FOD(2)
Edinburgh Rd S and Kortright Rd W	6	8.1	0.24	FOD(3), SWM(3)
Margaret Green Park	6	3.8	0.24	FOC(4), SWC(1), CUS(1)
Norm Jary Park	6	4.0	0.24	FOD(5), SWT(1)
Preservation Park	6	6.9	0.24	FOD(4), SWD(2)
Hanlon Creek	4	23.0	0.16	SWC(2), FOM(2)
Riverside Park	4	4.0	0.16	SWD(3), CUS(1)
Silvercreek Park, South Side	3	5.6	0.12	FOM(3)
Stephanie Drive Park	3	1.8	0.12	SWD(3)
Watson Creek	3	5.1	0.12	SWT(3)
Crane Park	2	8.2	0.08	SWM(1), SWC(1)
Elmira Park	2	0.9	0.08	CUS(2)
Mitchell Park	2	4.1	0.08	FOD(2)
Silvercreek Park	2	2.6	0.08	FO(2)
Eastview Park	1	7.6	0.04	SWD(1)
Eramosa River Park	1	4.4	0.04	CUS(1)
Howitt Park	1	2.3	0.04	FOD(1)
Milson Crescent and Marigold Dr.	1	2.3	0.04	SWT(1)
Milson Crescent and McWilliams Rd	1	2.0	0.04	FOD(1)
North Side of Kortright East	1	4.3	0.04	SWC(1)
Holland Crescent Park (Ridgeway Ave)	1	2.1	0.04	SWT(1)
Robin Road Park	1	18.0	0.04	SWT(1)
Sugar Tree Woodlot	1	0.4	0.04	SWD(1)
Whitetail Court	1	7.8	0.04	FOD(1)
27	**103**	**204.6**	**4.12**	

[1] Location names were assigned based on park or forested area name. Intersections or road names were assigned to smaller forest patches that have no name identified.
[2] Forested Area (ha) calculated as the sum of the individual polygon areas comprising each location in the Woodland-ELC layer, identified by same name.
[3] ELC vegetation communities: CUP - Cultural Plantation, CUS - Cultural Savannah, CUT - Cultural Thicket, CUW - Cultural Woodland, FOC - Forest Coniferous, FOD - Forest Deciduous, FOM - Forest Mixed, FO - Forest Unknown, SWC - Swamp Coniferous, SWD - Swamp Deciduous, SWM - Swamp Mixed, SWT - Swamp Thicket

2.2 SAMPLING DESIGN AND FIELD METHODS

Site sampling, baseline monitoring data collection, was accomplished following Vegetation Sampling Protocol (VSP) (Puric-Mladenovic and Kenney 2015). Sampled geo-referenced fixed area plots were selected from a systematic VSP sampling grid developed for the study area (Appendix, Figure A5). Stand selection for the sampling of natural areas in 2016 included only City property and was prioritized based on the known presence or dominance of Ash. However, the method of plot selection within these areas was randomized using the VSP grid to eliminate sampling bias. Navigation to plots was accomplished using a handheld Garmin GPS. All sampled plot centers were permanently marked, and the coordinates of plot centres recorded using the GPS unit. Plot coordinates were also manually recorded on the field forms. At the end of the field season, plot coordinates were rerecorded using a high accuracy (sub-meter) GPS device – Geneq SX Blue II.

Field sampling included an inventory of all plants within the fixed area 400m² circular plots (11.28m radius) (Figure 2). Plant abundance was assessed by four vertical strata: ground vegetation (<0.5m), shrubs (0.5-2m), sub-canopy (2-10m) and canopy (>10m). Plant abundance for each species was recorded as absolute percent cover for each stratum. Diameter at breast height (DBH), a standard method of measuring the diameter of the trunk of a standing tree 1.37m above the ground, was also recorded. All trees, woody plants and snags having a DBH of 5cm or more were measured. Within each plot, heights of at least three trees representative of the canopy were measured using a clinometer.

In addition to sampling vegetation structure and composition, the health of Ash trees were assessed. This was done to capture any observable presence and intensity of EAB impact. To capture and measure these impacts, percent canopy dieback was assessed and recorded on a scale of 0, 1, 2 or 3. Canopy dieback of 0 indicates no visible signs of canopy decline and 3 indicates severe canopy decline according to the Neighbourwoods© Tree Inventory Protocol (Kenney and Puric-Mladenovic 1995, Table 2). In addition to this, symptoms indicating the presence of pests/diseases were also recorded. In the case of Ash, EAB was identified according to the appearance of D-shaped emergence holes through the bark. Trunks and branches were also inspected for the presence of abnormal characteristics, such as epicormic shoots, and if present they were recorded as indicative of EAB.

Table 1. Canopy dieback rating /crown defoliation as per the Neighbourwoods© Tree Inventory Protocol (Kenney and Puric-Mladenovic 1995).

Canopy Dieback	Description
0	Crown not defoliated (healthy): Only normal minor twig defoliation
1	Crown slightly defoliated: Trace to 25% crown without leaves
2	Crown moderately defoliated: 25% to 50% crown without leaves
3	Crown severely defoliated: more than 50% crown without leaves

Forest regeneration was sampled within five, 1m x 1m, regeneration sub-plots established within each VSP plot. Sub-plots were located at the plot centre and the four mid-points between the plot center and plot edge along the four cardinal directions north, south, east, and west (Figure 2). Herbaceous vegetation was recorded as a percent cover in each sub-plot. Woody plants were identified as either seedlings (DBH < 2.5cm) or saplings (DBH 2.5-5cm), and counted individually.

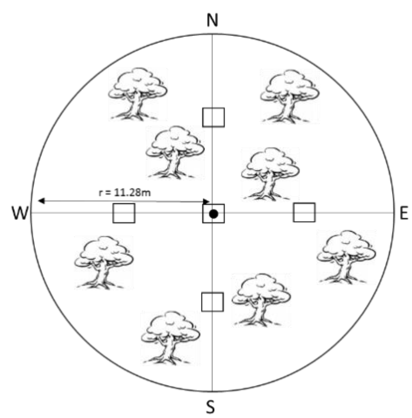

Figure 2. VSP sampling plot (400m²) with five 1m x 1m subplots

For a comprehensive site interpretation, additional environmental characteristics, anthropogenic and biological disturbances per plot were assessed and recorded. These included factors such as the presence of water, surface stone/rock, exposed soil, woody debris, leaf litter, dirt trails, and topography. Biotic, anthropogenic and environmental disturbances were noted along with their extent within the plot.

Plant identification was done to the species level, but where the exact species could not be discerned (e.g. grass with no flowering head), the plant was identified to the genus level. In total there were approximately 253 plant species recorded, including some plants that were only able to be identified to the genus level.

2.3 DATA ANALYSIS

All field data was entered in a standard database format, which enabled the derivation of some different compositional and structural measures. This helped to quantify Ash contribution and vegetation characteristics within sampled areas. Having data for georeferenced plots in a standard database enabled results to be mapped at plot and stand level.

2.3.1 Forest Composition

Forest composition refers to a stand's diversity in plant species, including all trees, shrubs, forbs and grasses. It also provides information about the type of forest community that exists in a stand. For example, compositional data show if a stand is dominated by a single tree species or mixture of tree species. Forest composition was assessed using VSP data to derive measures such as Relative Cover, Importance Value (IV), Coefficient of Conservatism (CC), Floristic Quality Index (FQI), Weed Index (WEED), and Species Richness.

2.3.1.1 Species Relative Cover

Forest vegetation is dominated by tree species, but also accompanied by understory ground and shrub vegetation. This vertical structure and multiple vegetation layers make forests unique and distinguishable from other vegetation. Trees can be found across all vertical strata (forest layers) from canopy to groundcover. The relative cover for all species within a plot was derived to assess their relative abundance, according to the equation below:

$$Relative\ Cover = \frac{(FrequLayer) + (AvgCover)}{2}$$

$$FrequLayer = \frac{n}{N}\ x\ 100$$

$$AvgCover = \frac{\sum_{i=1}^{n} C_i}{n} = \frac{C_1 + C_2 + \cdots + C_n}{n}$$

Where C_i represents a species' percent cover at layer i, i represents a layer of vertical strata, n represents the number of strata layers a species occurs in within a plot, and N refers to the total number of vertical strata recorded for a plot. This calculation considers a given species frequency of occurrence in each forest layer (vertical strata) and average percent cover for each of the layers it occurs in. Relative cover is therefore an overall representation of species abundance within forests. Since trees are generally in all vertical layers, they will typically have higher values for relative cover than ground vegetation.

2.3.1.2 Tree (Woody species) Importance Value (IV)

Importance Value (IV), a measure of the dominance of a woody species within an area, was calculated for all recorded tree and woody species (DBH ≥ 5cm). IV considers a given species' relative frequency and relative basal area (BA) within a plot, by the following equation:

$$IV = \frac{RelF_x + RelBA_x}{2}$$

$$RelF_x = \frac{\#\, X\ trees}{\#\, All\ trees}\ x\ 100$$

$$RelBA_x = \frac{Total\ BA\ of\ X\ trees}{Total\ BA\ of\ All\ trees}\ x\ 100$$

Where $RelF_x$ is the Relative Frequency of species X and $RelBA_x$ is the Relative Basal Area of species X. IV gives an overall estimate of the influence of a tree species across plots as it balances tree size and number of trees within a fixed area. IV values range from 0 to 100, wherein the larger the importance value, the more dominant a tree species is.

2.3.1.3 Coefficient of Conservatism (CC)

Coefficient of Conservatism (CC) can be used as an indicator of ecosystem quality (Francis et al. 2000). CC is a metric representing the probability that a native species will be present in a landscape relatively unaltered from its pre-settlement condition. CC values for Ontario plants range from 0 to 10. Plants that tolerate a variety of conditions and disturbance have a rank of 0-3. Plants that associate with a specific community, but tolerate moderate disturbance have a rank of 4-6. Plants that require later successional communities with minimal disturbance have a CC rank of 6-8. Plants that tolerate only a narrow range of conditions are ranked between 9-10 (Oldham et al. 1995). These higher values of CC, therefore, indicate species sensitive to disturbance (e.g. habitat specialists, later successional). These species are often associated with pre-settlement forest remnants and high quality natural cover.

Based on Oldham et al. (1995), CC values were assigned to each native species present in VSP plots. Non-native species were not included in CC calculations. Mean CC value per plot was derived as the sum of all native species' CC values divided by the total number of native species in a plot:

$$MeanCC = \frac{\sum_{i=1}^{N} CC_i}{N}$$

Where CC_i represents the coefficient of conservatism for the i^{th} native species and N represents the number of native species per plot. Mean CC is an indication of the quality of natural cover within an area, higher values being desirable.

However, besides the measure of MeanCC, additional values were derived including CC centralized and variation in CC (CC CV). CC centralized is equivalent to MeanCC per plot multiplied by 10. CC CV is equivalent to the standard deviation in CC per plot divided by MeanCC. While all are correlated with CC, each of these indices can be used as a useful description of forest composition.

2.3.1.4 Floristic Quality Index (FQI) and Adjusted Floristic Quality Index (FQAI)

Floristic Quality Index (FQI) is another measure of vegetation quality and can be used to assess the naturalness of an area (Swink and Wilhelm 1994). FQI is a weighted estimate of species richness determined from the mean CC and richness of native species within a plot, according to the equation:

$$FQI = MeanCC \; x \sqrt{N}$$

Where $MeanCC$ represents the average CC value of native species per plot and N represents the total number of native species per plot.

Adjusted Floristic Quality Index (FQAI) modifies FQI to include non-native species according to the equation (Miller and Wardrop 2006):

$$FQAI = \left(\frac{MeanCC}{10} \; x \; \frac{\sqrt{N}}{\sqrt{N+A}}\right) x \; 100$$

Where $MeanCC$ represents the mean Coefficient of Conservatism of native species, N represents the total number of native species per plot, and A represents the total number of non-native species per plot.

High quality habitats typically have higher FQI and FQAI scores, supporting species of greater conservation value that have a narrow range of habitat tolerances and a higher CC (Spyreas 2014).

2.3.1.5 WEED Index and WEEDless Index

Weedy species are those species considered invasive to an area, having undesirable qualities such as rapid reproduction, wide dispersal, aggressiveness, and hardiness. Non-native species were assigned a Weed Index (WEED) between -1 to -3 (Oldham et al. 1995), depending on their impacts on native vegetation. A WEED score of -3 indicates a species has strong potential to displace native vegetation, while a score of -1 indicates there is little evidence that a non-native can displace a native species (Oldham et al. 1995).

However, to avoid negative values of WEED index, Mean Weed Index (WEEDmean) of a plot was calculated based on the absolute value of WEED score. The average of absolute WEED index per plot was derived as:

$$WEEDmean = \left|\frac{\sum_{i=1}^{N} WEED_i}{N}\right|$$

Where $WEED_i$ represents the WEED score for the i^{th} non-native species and N represents the number of non-native species within a plot.

WEEDless Index is a weighted average derived from Mean Weed Index and number of weedy species per plot (Puric-Mladenovic 2015), determined according to the following equation:

$$WEEDless = \left(1 - \left(\frac{\frac{WEEDmean}{3} + \frac{N}{MaxN}}{2}\right)\right) \times 100$$

Where $WEEDmean$ represents the Mean Weed Index per plot, N represents the number of non-native species per plot, and $MaxN$ represents the maximum number of non-native species per plot within the sampling area. WEEDless Index ranges from 0 to 100, with low values indicating highly invaded areas with a significant proportion of weedy species. High WEEDless values are therefore desirable.

2.3.1.6 Species Richness

Species richness is a measure of plant diversity at a plot. Species richness was calculated as the total number of different plant species within the plot area, including native and non-native species.

2.3.2 Forest Structure

Forest structure refers to the organization of the physical and biological components of a woodland, including the horizontal and vertical distribution of forest layers, with an emphasis on tree attributes. It can be measured in many different ways such as tree frequency, density, basal area, canopy height and biomass.

2.3.2.1 Tree Frequency and Density

Tree frequency was recorded as the total number of trees (DBH ≥ 5cm) belonging to a given species or group per plot. Tree species density was calculated as frequency divided by plot area (0.04ha), to represent each tree species in terms of stems per hectare.

2.3.2.2 Basal Area

Tree basal area (m^2) was used as a measure of tree area coverage. Basal area (BA), the area of a trunk cross-section at breast height, was calculated using DBH according to the following equation:

$$BA = \pi \left(\frac{DBH}{2}\right)^2$$

Where π is 3.1459 and DBH is the diameter at breast height (≥5cm).

Basal area can be converted to a basal area per hectare (BA/ha) by dividing tree area by the plot area of 400m² or 0.04ha:

$$BA/unit = \sum_{i=1}^{n} BA_i \, w_i$$

$$w_i = \frac{1}{Plot\ Area} = \frac{1}{0.04ha}$$

Where BA_i represents the Basal Area of tree i in m² and w_i represents the sample expansion weight factor.

2.3.2.3 Biomass

Aboveground Tree Biomass was used to assess the above ground carbon pools in both live and standing dead biomass (snags). Aboveground biomass was calculated for each tree within a plot using species information and measured DBHs (≥5cm), according to Lambert et al. (2005) (Puric-Mladenovic et al. 2016). The Lambert method calculates dry biomass for tree components of wood, bark, branches and foliage, using species specific model parameters according to the following equation:

$$Biomass_{component} = \beta_{component\ 1}\ x\ DBH^{\beta_{component\ 2}} + e_{component}$$

Where $Biomass_{component}$ is the mass of the component in dry tonnes, DBH is the diameter at breast height (cm), $\beta_{component\ (n)}$ are model parameters, and e are the error terms.

Biomass estimates of the individual components (wood, bark, branches and foliage) were combined to calculate total aboveground biomass, as follows:

$$AGBM = BM_{wood} + BM_{bark} + BM_{branches} + BM_{foliage}$$

Where $AGBM$ is the total live aboveground biomass of a tree in tonnes and BM_x is the biomass of component x.

Live below ground (root biomass) (BGBM) was estimated from live above ground biomass (AGBM), based on the findings from the literture. The biomass of larger non-annual tree roots (>2mm diameter) was estimated as equivalent to approximately 20% of the AGBM (MacDicken 1997, Ponce-Hernandez et al. 2004, Santantonio et al. 1977):

$$BGBM = AGBM\ x\ 0.2$$

Live Forest Biomass, used in the calculation of carbon content, was calculated as the sum of both above and below ground live biomass:

$$Live\ Forest\ Biomass = AGBM + BGBM$$

2.3.2.4 Carbon Content

Carbon content in tonnes was estimated from total live forest biomass (above and below ground), according to the commonly used 0.475 conversion factor (Chen et al. 2011, IPCC 2006, Jenkins et al. 2003, McGroddy et al. 2004, Raich et al. 1991):

$$Carbon\ Content = Live\ Forest\ Biomass\ x\ 0.475$$

From carbon content, estimates of carbon dioxide (CO_2) stock in tonnes were made using the molecular weight conversion factor of 3.67 (Walker et al. 2011):

$$CO_2 = \ Carbon\ Content\ x\ 3.67$$

Carbon dioxide (CO_2) stored in forests, rather than carbon, is more relevant since it is the primary greenhouse gas emitted into the atmosphere, and is also what is traded in carbon-offset markets.

2.4 MAPPING FOREST STRUCTURE AND COMPOSITION

Derived measures of forest structure and composition per plot were used to map results at both the plot and polygon level. Mapping was accomplished using Geneq SX Blue II recorded plot centres and ESRI ArcGIS 10.2 (2013), and all maps produced are enclosed as a supplement to this report.

2.4.1 Mapping plot information

The descriptors of forest composition and structure were mapped at the plot level. Depending on the type of the variable /descriptor, they were mapped as total (e.g. basal area) or average values (e.g. MeanCC) per plot. Variable quantities per plot were displayed on the maps as graduated circles, sized according to value.

2.4.2 Mapping polygon (stand/woodland) information

Plot data were further extrapolated per stand or woodland, based on the polygon layers (spatial layers) received from the City of Guelph. The spatial data, Ecological Land Classification (ELC) and Woodlands, were combined to produce a Woodland-ELC layer which could support the analysis. Although polygon boundaries included privately owned lands, only areas owned by the City of Guelph were sampled, and therefore data is only extrapolated for City properties.

For analysis at the polygon level, statistical means from plots within a Woodland or ELC polygon were derived and assigned to the stand. This was conducted for all plots within polygons, including those areas only containing one plot. In total there were 391 ELC polygons within the Woodland-ELC layer, 14% of which contained at least one sampling plot, and 215 Woodland polygons within the Woodland-

ELC layer, 20% of which contained at least one sampling plot. Differences in the number of polygons are due to the smaller and thus more numerous ELC divisions, compared with larger Woodland polygons.

2.4.2.1 Woodland-ELC Layer

ELC and Woodland layers received from the City of Guelph were prepared and combined into one map layer, Woodland-ELC, to support the analysis. Woodland areas with vegetation community information defined individual forest stand polygon boundaries. The 27 areas sampled (Table 1) were subdivided into different polygons with corresponding ELC attributes (Table 3). A union between the Woodland and ELC layers, clipped to maintain the original Woodland outer bounds, but subdivided according to ELC class was created. The union layer was amended to eliminate non-treed ELC classes and slivers formed due to the differences between Woodland and ELC boundaries. ELC classes considered non-treed included: AGR (Agriculture), CUM (Cultural Meadow), OAO (Water), H (Humus), MAM (Marsh Meadow), MAS (Marsh), or blanks. These class slivers were eliminated by joining the sliver to the adjacent forested polygon or deleting it if it did not contain tree cover (e.g. lawn), determined using satellite imagery obtained as an ESRI base map. Where there was no ELC class defined and joining was not suitable, a code of “FO” foran unknown forest type was assigned if the area was treed, but the vegetation community was not classified in the ELC map. Four sampling plots were located outside the mapped Woodland-ELC boundaries. In these instances, boundary lines of the adjacent polygon were adjusted using the digital imagery. This imagery has also served as a guide to refine the boundaries of forest patches in which the sampling plots were located (Figures A1-A4). Woodlands containing sampling plots were further inspected to ensure correct topology. Slivers and gaps between polygons were removed via snapping boundaries. However, polygon data cleaning and standardizing were only completed for areas containing VSP sampling plots. Throughout Woodland-ELC processing, the original woodland boundaries were maintained where possible. Also, the original woodland polygon IDs (*WoodID*) were maintained to identify woodland stands, and new WOODELC polygon IDs (*WOODELCid*) were assigned to identify ELC stands.

The output Woodland-ELC polygon layer was reduced from its original 683 polygons to 391, with the overall area reduced by 3.1%. This reduction in area was primarily due to the deletion of a few large marsh and meadow polygons which were non-treed so could not be joined to the adjacent polygon.

Forested Area (ha) was also evaluated using the Woodland-ELC layer, for areas containing sampling plots (Table 1). Forested area was calculated as the sum of the individual ELC polygon areas comprising each location, identified by the same name. Where location was not defined for a polygon, Google Maps was used to identify a location to attribute a park or forested area name. A few smaller woodland polygons did not have any associated name and are referred to according to street or intersection name.

Statistical values were calculated for each polygon using the individual plots located in its boundary and attributed to the polygon in the Woodland-ELC layer (see Appendix A-E). This was completed for both the ELC polygons and larger woodland polygons, to determine mean plot values and polygon totals at both the ELC and woodland scale.

Finally, for each of the variables, summary statistical analysis was completed (Tables A1-A3) and further discussed in the results.

Table 2. ELC code and associated vegetation community description for forested areas sampled. The codes are also included in the GIS polygon layer WOODELC4.shp ELC polygon GIS file.

ELC Code	Community Description
CUP	Cultural Plantation
CUS	Cultural Savannah
CUT	Cultural Thicket
CUW	Cultural Woodland
FOC	Forest Coniferous
FOD	Forest Deciduous
FOM	Forest Mixed
FO	Forest Unknown
SWC	Swamp Coniferous
SWD	Swamp Deciduous
SWM	Swamp Mixed
SWT	Swamp Thicket

3 Results and Discussion

The Vegetation Sampling Protocol (VSP) implemented to sample Ash and other forest stands in the City of Guelph in 2016, was a proactive response to monitoring natural areas. VSP provides critical, baseline information to quantify the existing and potential loss of Ash, current and future impacts of EAB, and the effect of this on ecological goods and services. By monitoring the distribution and extent of invasive species, VSP data can also help identify areas vulnerable to invasive species colonization. VSP data can, therefore, help classify high risk areas and inform Guelph's Emerald Ash Borer Plan and Urban Forest Management Plan, to mitigate environmental and ecological impacts. VSP data also provide additional information on overall forest community composition used to estimate factors such as floristic quality, biomass, and carbon sequestration.

Field sampling and baseline data were used to derive indices that enable the detection and assessment of vegetation change over time. For example, some of these indices include Coeffiecnt of Conservatisam (CC) and Floristic Quality Index (FQI) (Brudvig et al. 2007, Foster et al. 2007, Kirk 2006, Matthews and Endress 2008, Miller et al. 2006, Oldham et al. 1995, Spyreas et al. 2012, Swink and Wilhelm 1994, Taft et al. 2006) or Floristic Quality Index Adjusted (FQAI) (Miller and Wardrop 2006, Miller et al. 2006, Rocchio 2007). Variations in how CC and FQI is calculated exist, such as whether non-native species are included or whether richness is divided rather than multiplied (Andreas et al. 2004, Cretini et al. 2011, Matthews et al. 2015, Spyreas and Matthews 2006). Vegetation characteristics can also be measured using diversity indices such as Shannon's Diversity Index or Simpson's Diversity Index (Andreas et al. 2004, Brudvig et al. 2007, Foster et al. 2007, Taft et al. 2006), or modified structural or functional diversity indices (Paquette and Messier 2011, Staudhammer and LeMay 2001). Other methods of measuring forest condition include vegetation volume (Wood et al. 2015), tree productivity (Paquette and Messier 2011) and the Index of Biological Integrity (Miller et al. 2006).

3.1 Natural Areas Overview

The City of Guelph has 2931.1ha of open and natural areas comprised of forests, open areas, and agricultural lands (33.2% of land base), determined from Guelph's ELC layer (Figure 3). However, of this, only 23% or 696.5ha (7.9% of the land base) is owned by the City (Figure 3). Woodlands comprise 454.9ha, 16% of the natural cover or 5.1% of the land base, based on estimates from the Woodland-ELC layer (Figure 3). Of the total woodland cover, 245.7ha is owned by the City of Guelph, which is equivalent to 35% of the City-owned natural cover or 2.8% of the land base (Figure 3). Based on ELC mapping, the majority (64.2%) of woodland cover in Guelph is swamp, while upland forest comprises 17.6%, cultural forests are at 14.0%, and about 4.1% are other unclassified forests (Figure 4). City owned woodlands show a similar pattern, with 58.6% identified as swamps, 23.2% upland forest, 13.3% cultural forest and 5.0% unclassified forest (Figure 4).

Figure 3. Proportion of Natural Cover and Woodland Cover in Guelph, Ontario (2016). Values are presented for the total cover within Guelph's municipal boundaries, as well as the cover within City-owned properties only.

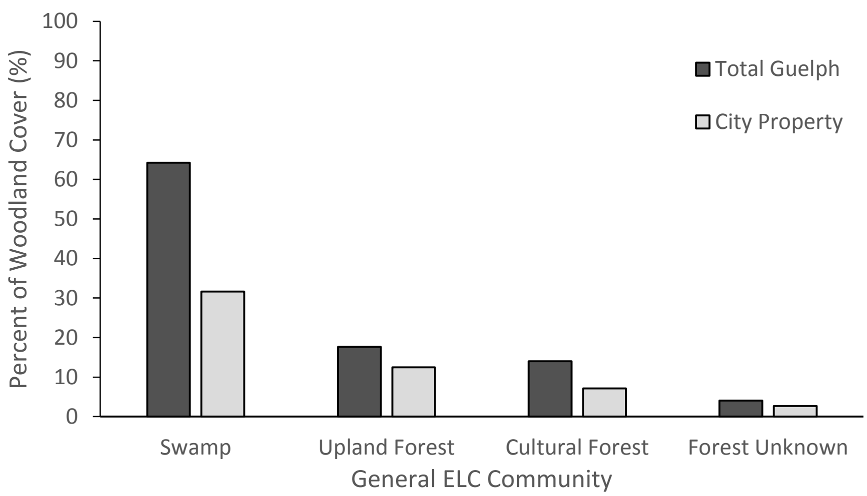

Figure 4. Composition of woodland cover by vegetation community for Guelph, Ontario (2016). Values are presented for the total woodland cover within Guelph's municipal boundaries, as well as the woodland cover within City-owned properties only.

Swamps, comprising the largest portion of total forested area, are predominately coniferous forest (35%), followed by mixed forest (11%), deciduous (11%) forest, and thicket swamp (7%) areas (Figure 5a). Swamps on City property are more evenly distributed, with 17% coniferous, 17% deciduous, 15% mixed and 10% thicket swamp (Figure 5b). Guelph's upland forests contain a large proportion of deciduous forest (11%), moderate amounts of mixed forest (5%) and fewer coniferous forests (2%) (Figure 5a). Similarly, upland forests on City property are 15% deciduous, 6% mixed and 2% coniferous forest (Figure 5b). Cultural or cultivated forests primarily consist of plantations (7%) or woodlots (4%), with small portions of cultural savannahs (2%) and thickets (2%) (Figure 5a). Cultural forests on City property are predominantly woodlots (6%), with fewer plantations (3%), savannahs (2%) and thickets (2%) (Figure 5b). Unclassified forests comprise the smallest percentage of woodland cover, at 4% for all Guelph and 5% for City property, and are likely disturbed or successional forests or forests whose structure and composition is novel, and therefore was not assigned to an ELC class (Figure 5).

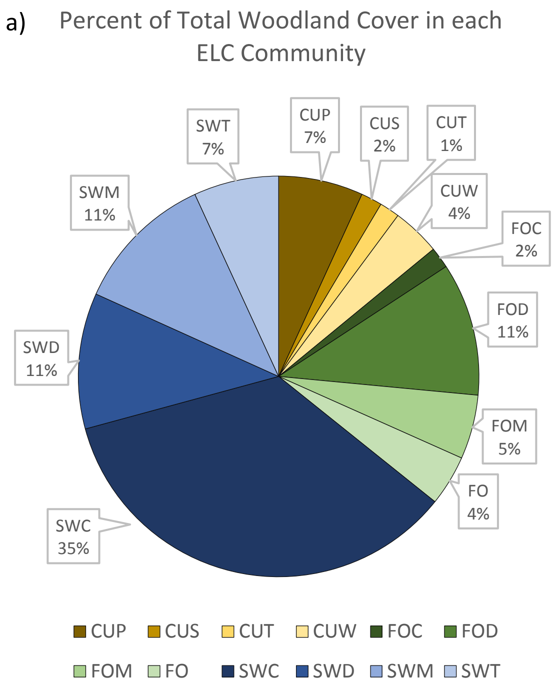

Figure 5. Percent of woodland cover in Guelph classified by ELC vegetation community (2016). Values are presented for a) the total woodland cover within Guelph's municipal boundaries, and for b) the woodland cover within City-owned properties. ELC communities recorded include: CUP - Cultural Plantation, CUS - Cultural Savannah, CUT - Cultural Thicket, CUW - Cultural Woodland, FOC - Forest Coniferous, FOD - Forest Deciduous, FOM - Forest Mixed, FO - Forest Unknown, SWC - Swamp Coniferous, SWD - Swamp Deciduous, SWM - Swamp Mixed, SWT - Swamp Thicket.

A total of 103 plots were sampled in 27 different forested areas that are part of forest cover in Guelph (Table 1). The plots were sampled across ten different ELC communities (Table 1, Figure 7). Number of sampled plots is relatively consistent with the proportion of each general ELC community found in Guelph (Figure 6). Swamps, as the most abundant forest cover type, also comprise the largest portion of areas sampled (52%) (Figure 6). Sampled swamps are diverse and include a range of types from deciduous (28%), mixed (4%) and coniferous swamps (4%) to thickets (17%) (Figure 7). The second largest portion of sampled areas (30%) is in upland forests, with plots sampled across deciduous (25%) and mixed (5%) forests (Figures 6-7). Cultural forests, covering almost the same amount of land base as upland forests (Figure 4), represent a smaller portion of sampled areas (14%), with plots comprised by cultural plantations (6%), savannahs (6%) and thickets (2%) (Figures 6-7). The fewest number of plots (4%) were sampled in novel and disturbed forest communities, which have no ELC class assigned to them (Figures 6-7).

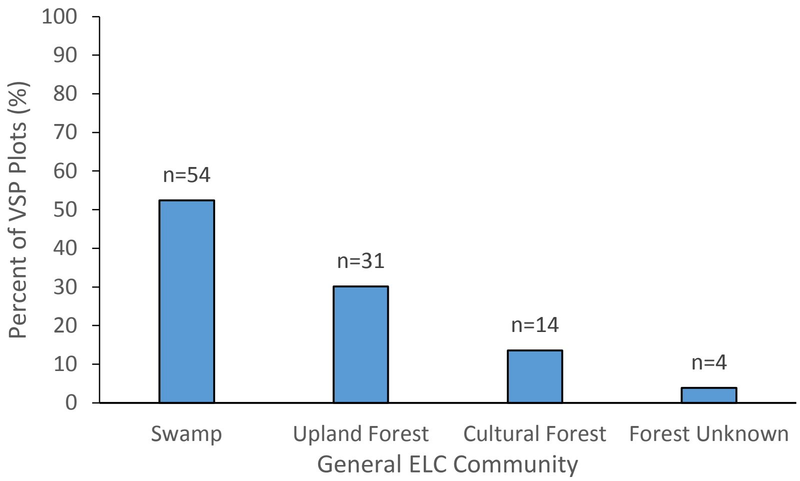

Figure 6. Composition of VSP plots sampled in Guelph by vegetation community (2016), where n refers to the number of sampling plots within each vegetation community.

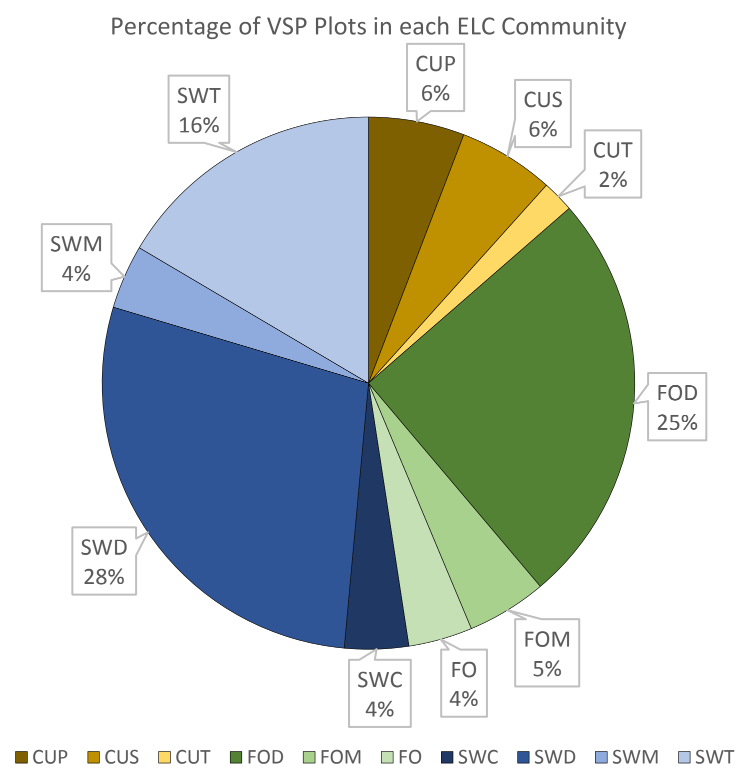

Figure 7. Percent of VSP plots sampled in Guelph classified by ELC vegetation community (2016). CUP - Cultural Plantation, CUS - Cultural Savannah, CUT - Cultural Thicket, CUW - Cultural Woodland, FOC - Forest Coniferous, FOD - Forest Deciduous, FOM - Forest Mixed, FO - Forest Unknown, SWC - Swamp Coniferous, SWD - Swamp Deciduous, SWM - Swamp Mixed, SWT - Swamp Thicket.

Of the 454.9ha area of total woodland cover in Guelph, 4.12ha (0.9%) was directly sampled by VSP (Table 4).The sampled area amounts to 1.7% of City-owned woodlands (City-owned woodlands cover 245.7ha) directly sampled by VSP (Table 4). ELC polygons with at least one plot sampled in 2016 amounts to 125.5ha (27.5%), while woodland polygons with at least one plot sampled amounts to 178.6ha (39.3%) (Table 4). Considering only City-owned property, this amounts to 120.5ha (49.0%) of ELC stands sampled or 172.4ha (70.2%) of woodlands sampled with at least one plot.

ELC stands / polygons sampled have 1 to 11 plots inventoried within them, while plot density ranges from 0.2 to 15.2 plots per ha, with a mean of 2.4 plots per ha (Table 5). When forests are assessed as a woodland polygon/forest patch, number of plots per polygon ranges from 1 to 13 plots, with plot density being from 0.06 to 15.1 plots per ha, with a mean of 1.9 plots per ha (Table 6).

Table 3. Sampled area via ELC and Woodland polygon extrapolation of the Woodland-ELC layer. Values are presented for total woodland cover in Guelph and woodland cover within City-owned properties only. Total woodland cover in Guelph is 454.9ha, while City-owned woodland cover is 245.7ha.

	Total area sampled (ha)	**Percent of total woodland cover sampled (%)**	**City area sampled (ha)**	**Percent of City woodland cover sampled (%)**
VSP Plots	4.12	0.9	4.12	1.7
ELC polygons	125.5	27.6	120.5	49.0
Woodland polygons	178.6	39.3	172.4	70.1

*Polygons with ≥ one plot are considered. Slight differences in the area (ha) sampled between the total vs. City woodland area sampled are due to the effects of City property boundaries, which do not follow vegetation community or Woodland boundaries.

Table 4. Sampling plot distribution for ELC areas in the Woodland-ELC layer. Average (Mean), minimum (Min) and maximum (Max) values are displayed for plots per polygon, plots per hectare, and hectares per plot.

ELC Measurement	**Mean**	**Min**	**Max**
Plots per polygon	1.9	1	11
Plots per ha	2.4	0.2	15.2
Ha per plot	1.3	0.07	5.2

Table 5. Sampling plot distribution for Woodland areas in the Woodland-ELC layer. Average (Mean), minimum (Min) and maximum (Max) values are displayed for plots per polygon, plots per hectare, and hectares per plot.

Woodland Measurement	Mean	Min	Max
Plots per polygon	2.5	1	13
Plots per ha	1.9	0.06	15.1
Ha per plot	2.1	0.07	18

3.2 Ash Distribution and Abundance

VSP sampling during 2016, started by targeting Ash stands. Ash trees (DBH ≥ 5cm) were found in 83.5% of the plots sampled in Guelph (Table 7). Of the sampled woodlands 81.0% or 42 stands contained Ash (Table 7). When plot information is extrapolated across stands, 81.1% of the 53 stands sampled (as per the ELC mapping) contain Ash (Table 7). By area this equates to 80.8% of the ELC stands sampled containing Ash and 72.9% of the woodlands sampled containing Ash (Table 7).

The size distribution of Ash ranges from a minimum of 5cm to maximum of 62.5cm, with the majority of trees (71%) having a diameter less than 20cm and mean DBH of 16.0cm (Figure 8). Ash trees (DBH ≥ 5cm) have an average density of 217 trees per hectare, while larger Ash trees (DBH ≥ 10cm) are less abundant at a density of 141 trees per ha (Figure 9). In total, 893 Ash trees were recorded across VSP plots (Figure 8), whose summed plot area covers approximately one percent of the total forested area in Guelph (Table 4).

Table 6. Number and proportion of sampled plots containing Ash. Number of hectares and proportion of ELC stands and woodland cover containing Ash.

	Total number	***Number with Ash***	***Percent with Ash (%)***
# of VSP Plots sampled 2016	103	86	83.5
ELC Stands (polygons)	53	43	81.1
ELC Area (ha)	125.5	101.4	80.8
Woodland Stands (polygons)	42	34	81.0
Woodland Area (ha)	178.6	130.1	72.9

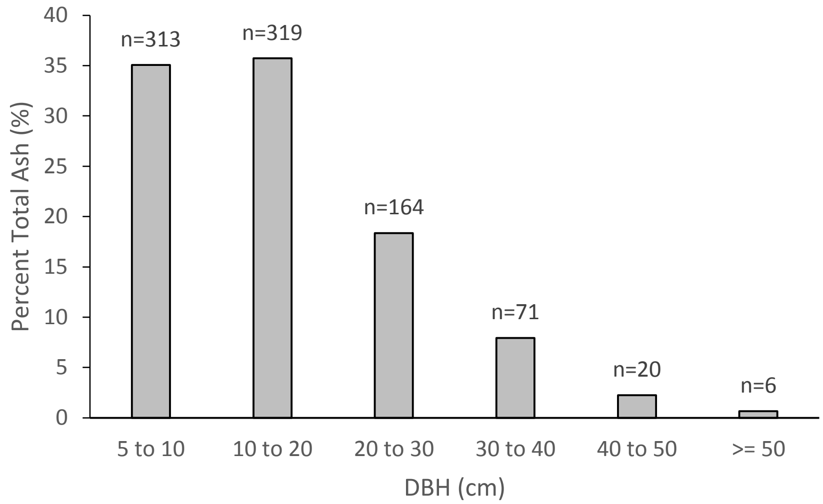

Figure 8. DBH distribution of Ash trees (DBH ≥ 5cm) in VSP plots in Guelph (2016), where n refers to the number of trees measured within a specified diameter range.

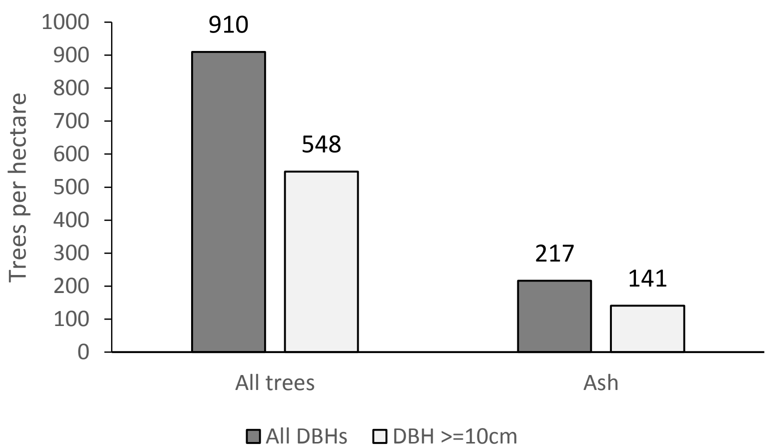

Figure 9. Density of all sampled trees and Ash trees in VSP plots sampled in Guelph (2016).

Ash frequency or the number of Ash (DBH ≥ 5cm) per plot ranges from 0 to 39, with mean of 8.7 trees per plot (Appendix, Figure B1). When Ash frequency is extrapolated across the ELC stands, some stands might contain as many as 5,194 Ash trees. Ash frequency extrapolated across woodlands bring the number of trees to a higher value of 8,349 Ash trees (Table A2-A3). The overall number of Ash trees in sampled ELC polygons (stands) is estimated to be 22,507, while the overall estimate of Ash trees in sampled woodlands is 28,131. The estimates of Ash based on VSP sampling are higher (more than double) than the 10,000 city owned Ash tree estimate calculated for Guelph (Marchant 2013). The higher numbers obtained through this study could be due to VSP sampling that includes all trees in canopy and sub-canopy (5cm and above). Percent of Ash per sampled plot ranges from 0-100%, with a mean of 25.3% of Ash per plot (Appendix, Figure B6). When plot information is extrapolated to the polygons, Ash comprises a significant component of sampled stands and woodlands, with some areas having as much as 71.5% of trees per polygon being Ash (Figures B7-B10). Mean percent of Ash per forest (ELC) stands is 22.3% and mean Ash component for sampled woodlands is estimated to be 24.3% (Figures B7-B10).

Relative abundance of Ash per plot ranges from 0-56.9%, with a mean of 33% (Appendix, Figure B11). Extrapolated across the sampled polygons (stands and woodlands), relative cover of Ash ranges from 0-52.8%, with mean of about 31% for both forest (ELC) stands and woodlands (Figures B12-B15).

Importance Value (IV) is associated with relative frequency and basal area. However, IV represents a more objective measure of Ash component as it is accounts for both tree size and frequency. Ash IV per plot ranges from 0-100% (Appendix, Figure B16), showing that some sample plots do not have any Ash, while other plots are dominated by Ash. However, a mean IV of 25.7% (Appendix, Figure B16) indicates that Ash comprise about one forth of the sampled stands/woodlands. When plot information is averaged by forest (ELC) stands, Ash IV ranges between 0-73.6% with a slightly lower mean of 22.8% (Figures B17-B18). When plot information is averaged by woodland polygons, Ash IV ranges from 0-73.6% with a slightly higher mean of 24.5% (Figures B19-B20). These estimates indicate that Ash component in the sampled woodlands is significant and comprises about one quarter of tree species. Thus the findings indicate that Ash decline due to EAB impacts will likely result in significant canopy loss of about 18% overall (mean 25%) for sampled woodland (Table A3, Figures B34-B35). However, other changes in forest composition and structure of these woodlands are expected to occur as a result of Ash decline.

Another estimate of the Ash component within the woodlands and stands was based on aboveground live biomass. Ash Aboveground Live Biomass per plot ranges from 0 to 194.5 T/ha, with a mean of 35.4 T/ha (Appendix, Figure B21). Averaged and extrapolated to the forest stand (ELC), Ash biomass ranges from 0 to 179.3 T/ha with mean 29.5 T/ha (Figures B22-B23). Ash biomass, when extrapolated to the woodland area, ranges from 0 to 130.5 T/ha with mean 30.9 T/ha (Figures B24-B25). Estimates of Ash biomass across sampled areas reach up to a total of 1242.5 tonnes for a single ELC stand and up to 1651.7 tonnes for a single woodland. The total estimate of Ash Biomass across sampled stands is estimated to be 4067.6 tonnes (Figure 10). When biomass estimate was done by woodland polygons, the results show that the total biomass is higher as it reaches 4853.7 tonnes (Figure 10). Ash biomass was also assessed as a percentage of total plot biomass which resulted in a mean value of 27.3% of Ash biomass per plot. When this value was extrapolated across sampled polygons (stands and woodlands), Ash biomass ranges from 0-89.9% per sampled polygons, with a mean 24.5% for ELC stands and a mean of 26% for woodland polygons. However, percent Ash biomass as a proportion of the total tree biomass is 19.3% for ELC stands and 15.9% for woodland polygons.

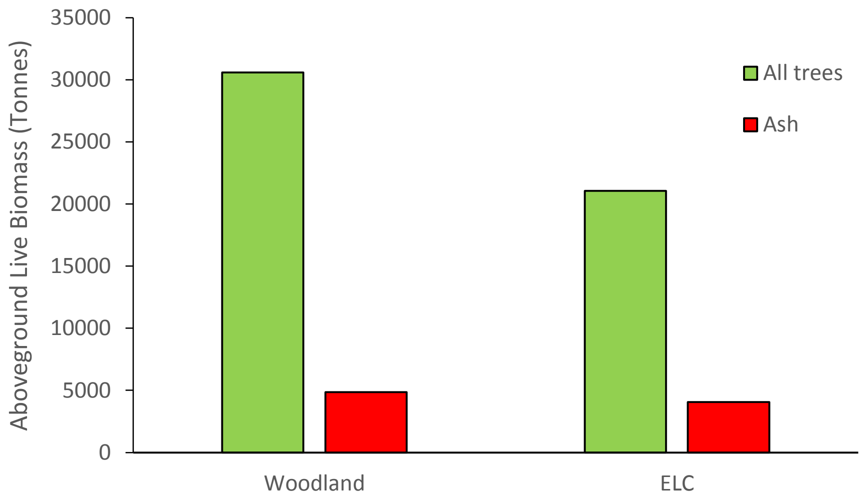

Figure 10. Total Aboveground Live Biomass (AGB) for all trees and Ash determined by extrapolation of plot information to the woodland and stand polygons. The extrapolation was done for polygons (ELC stands or woodlands) having at least one VSP plot. This includes 27.5% of ELC polygons or 39.3% of woodland polygons, by total woodland cover in Guelph.

Considering that sampling targeted Ash stands, it is reasonable to expect that Ash frequency and biomass are likely to be different (lower) in unsampled forests. However, because Ash forests were targeted, values obtained from 2016 sampling cannot be extrapolated for unsampled areas.

Regardless of this, results show that a significant amount of Guelph's natural areas have a minor or major component of Ash. Plots, where Ash trees were present, often have a significant abundunce of Ash trees. Ash abudunce, eiather if it was as expressed as percent Ash, percent Ash biomass or Ash importance, is often high (over 50%) at some locations. Ash is not only present in the canopy and sub-canopy layer but is also often present across all vertical stratawhich is refelected by higher values of relative Ash abundance. All of these different values indicate that Ash comprises about ¼ of woody vegetation in the City of Guelph's woodlands.

Plots with the greatest dominance of Ash (IV ≥ 65%) are located in Stephanie Drive Park deciduous swamp, Westminister Woods thicket swamp, Mitchell Park deciduous forest, Hadati Creek thicket swamp, Marksam Park deciduous swamp, Holland Crescent Park thicket swamp, and Ellis Creek deciduous swamp (Appendix, Figure B16). Woodlands predicted to be most significantly impacted by EAB due to high importance value of Ash (IV ≥ 50%) include areas of Mitchell Park, Holland Crescent Park, Hadati Creek, Sugar Tree Woodlot at Imperial Rd N and Westwood Rd, Marksam Park, and Stephanie Drive Park (Appendix, Figure B19-B20). The areas where Ash comprises a significant component of forest will be heavily impacted by EAB as their structure and composition will change. These sites will likely require remediation and restoration to prevent ecological collapse and maintain the integrity of the City's green (natural heritage) systems. It is expected that Ash loss in these woodlands, will have an impact on vegetation composition and diversity, as well as ecological goods and services. For example, this may include riparian areas losing a majority of their trees and in turn facing the additional risk of erosion, sedimentation, and stream warming (Marchant 2011), making restoration initiatives in these areas a priority.

3.3 EAB Presence and Intensity

Ash trees in the City of Guelph are currently experiencing significant impact from EAB, with 82.8% of all sampled trees showing signs of infestation (Figure 11). EAB was detected, on average, in 69% of Ash trees per plot (Figure C6). When plot estimates are extrapolated across polygons (stands/woodlands), the range remains the same (0-100%) (Tables A2-A3). ELC stands are estimated to have about 63.9% of trees per stand with EAB (Table A2), while the overall percent of Ash estimates with EAB is 80.9% (Table A3).

When EAB impacts are extrapolated across woodlands, it is expected that 66.9% of trees per woodland have EAB and that the overall percent of Ash with EAB is 79.7%. In addition to this, sampling shows that 4% of all sampled Ash trees (DBH ≥ 5cm) also had epicormic shoots, which are indications of EAB stress (de Groot et al. 2006).

Ash infected with EAB experience water and nutrient stress contributing to canopy dieback or crown defoliation (Flower et al. 2013b). Of all Ash trees sampled, 17.9% show no crown defoliation, 29.3% show minor crown defoliation, 29.5% show moderate crown defoliation and 23.2% show severe crown defoliation (Table 2, Figure 12). Thus about 50% of trees already have significant canopy decline (defoliation ≥ 25%). At some plots, it was observed that as much as 100% of Ash trees have severe defoliation (Figure C1).

Extrapolated by stands, it can be expected that the overall percent of Ash trees with a given degree of defoliation is as follows: 18.3% no defoliation, 29.2% minor defoliation, 29.7% moderate defoliation, and 25.5% severe defoliation (Figures C2-C3). Extrapolated by woodland polygons, the overall percent of Ash trees with a given degree of defoliation is as follows: 19.5% no defoliation, 28.5% minor defoliation, 25.8% moderate defoliation, and 26.3% severe defoliation (Figures C4-C5).

The majority of sampled Ash trees (82.1%) have at least some crown defoliation (Figure 11), suggesting that management of the Ash trees will need to be addressed in the short-term. For example, 207 sampled Ash trees already show severe crown defoliation, amounting to an estimated 7,388 Ash trees in woodland areas sampled (which is about 39% of the total woodland area, or 70% of the City-owned woodland area). Considering a plan to remove dead or dying Ash trees and average cost of removal/replacement at $1,500 per tree (Marchant 2013), the cost for the 207 sampled trees with severe defoliation could be as high as $310,500. However, this dollar value is just an illustration, as total costs are likely lower since many trees have small DBHs and only hazard trees near paths need be removed.

Plots with the most significant Ash dieback (severe dieback ≥ ten trees) are located in Holland Crescent Park thicket swamp, Hadati Creek thicket swamp, Westminister Woods thicket swamp, Mitchell Park deciduous forest, and Ellis Creek deciduous swamp (Figure C1). Woodlands with the greatest EAB impact (severe dieback ≥ 500 trees) are Ellis Creek, Hanlon Creek, Holland Crescent Park and Hadati Creek (Figures C4-C5). These areas could be targeted for the most immediate tree removal and replacement.

All sampled plots with Ash show signs of EAB infestation in trees, making it unlikely that there are any Ash stands in these areas free from infestation. Ash trees which appear healthy can also be infested with EAB, although to a lesser degree (Flower et al. 2013b). Any Ash tree in Guelph not already injected with TreeAzin™ might likely not be suitable for treatment with TreeAzin™, which must be injected into the tree before attack by EAB (Marchant 2013).

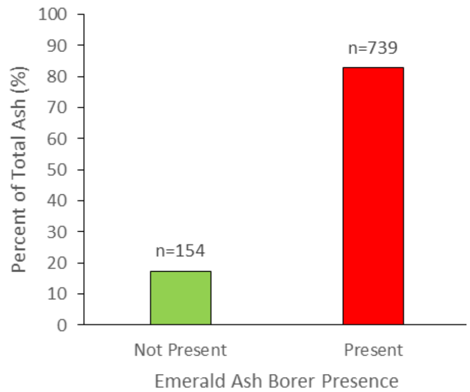

Figure 11. Prevalence of Emerald Ash Borer infestation in Guelph's Ash trees sampled with VSP (2016). n refers to the number of Ash recorded with or without EAB.

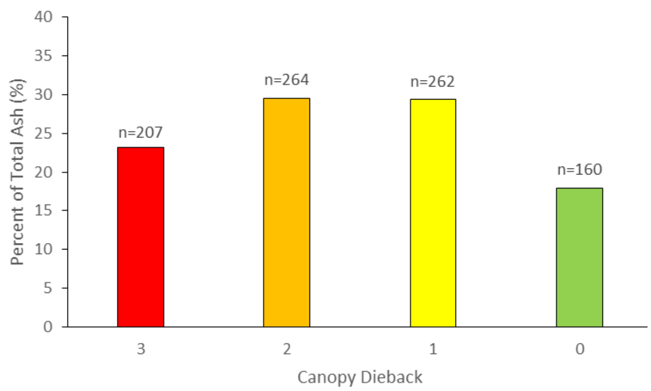

Figure 12. Canopy dieback of Ash trees sampled with VSP in Guelph (2016). Dieback is a measure of percent of canopy that is defoliated, as described in Table 2. n refers to the number that is defoliated, as described in Table 2. n refers to the number of Ash recorded with the specified degree of canopy loss.

TreeAzin™ has typically been used to treat trees greater than 20cm DBH in many municipalities, due to the increased ecological value associated with larger trees and cost trade-off of removal vs. treatment (Marchant 2013). Guelph's Ash trees without detected EAB have DBHs which range from 5cm to 57.5cm. There are 21 trees which might be of interest in treating with TreeAzin™, ranging in DBH from 21.1cm to 57.5cm, with no visible signs of EAB and no canopy dieback recorded. These trees are located in 11 different plots (plot autoID: 98, 107, 134, 136, 105, 152, 162, 157, 194, 116, 203), in the following five woodlands: Ellis Creek, Preservation Park, Marksam Park, Mitchell Park, and Margaret Green Park. These woodlands are located towards the western edge of Guelph's municipal boundary in deciduous forest and deciduous swamp.

3.4 WEEDS AND INVASIVE SPECIES

Composition of woodlands was also assessed to understand the abundance and impact of non-native and invasive species. Non-native species are found at 99% of sampled plots, or all ELC stands and woodlands sampled. The most prominent invasive species found are Buckthorn and Garlic Mustard, found at 92.2% and 51.5% of plots respectively (Tables 8-9). When extrapolated across stands, 94.3% of the 53 sampled stands contained Buckthorn, while 95.2% of the 42 sampled woodlands contained Buckthorn (Table 8). By area, this equates to about 93.3% of both the stands and woodland areas having Buckthorn (Table 8). Garlic Mustard, while not as prominent as Buckthorn, still comprises about 52.8% of the 53 sampled stands, or 57.1% of the 42 sampled woodlands, when plot information is extrapolated (Table 9). It can be expected that 66.3% of the sampled stand area and 59.6% of the woodland area contains Garlic Mustard (Table 9).

Table 7. Proportion of plots, stands and areas sampled containing Buckthorn.

	Total number	With Buckthorn	Percent with Buckthorn
VSP Plots	103	95	92.2
ELC Stands	53	50	94.3
ELC Area (ha)	125.5	117.1	93.3
Woodlands	42	40	95.2
Woodland Area (ha)	178.6	166.6	93.3

Table 8. Proportion of plots, stands and areas sampled containing Garlic Mustard.

	Total number	With Garlic Mustard	Percent with Garlic Mustard
VSP Plots	103	53	51.5
ELC Stands	53	28	52.8
ELC Area (ha)	125.5	83.2	66.3
Woodlands	42	24	57.1
Woodland Area (ha)	178.6	106.5	59.6

Dog strangling vine (*Cynanchum rossicum*), another aggressive invader to natural areas in southern Ontario, was not recorded in any of the VSP plots sampled summer 2016 in Guelph. This however does not mean that dog strangling vine is absent from Guelph, but that the species is at a lower abundance not captured by the random plots.

Relative cover of Buckthorn per plot is on average 32.3%, with maximum of 61.6% (Figure D1). Extrapolated across the sampled areas, relative cover of Buckthorn per sampled area is about 32.7% for both stands and woodlands (Figure D2-D5). Garlic Mustard's relative cover per plot on average is 10.8% (Figure D6) with a maximum of about 67%. Extrapolated across sampled areas, relative cover of Garlic Mustard on average is about 10% per stand or woodland (Figures D7-D10).

Buckthorn is also found to reach substantial DBH, and in some plots was included in DBH measurements as it had diameter greater than 5cm. The size distribution of Buckthorn is on average 8.6cm, with a maximum DBH of 33cm for a clumped multi-stem Buckthorn that could not be measured individually (Table A1). Buckthorn frequency or the number of Buckthorn per plot ranges from 0 to 83, with a mean of 9 stems per plot (Table A1). When estimated per hectare, Buckthorn on average has a density of 225 trees per hectare (Table A1). When Buckthorn frequency is extrapolated across sampled stands, numbers indicate there could be as many as over 10,000 Buckthorns larger than 5 cm DBH (Table A2), while when extrapolated across woodlands that number is just under 8,500 Buckthorns with DBH more than 5cm(Table A3). The overall estimate of Buckthorn in sampled stands is 27,251 and in sampled woodlands is 29,689 (Tables A2-A3). This is equivalent to an average of 19.8% of Buckthorn ≥5cm DBH per plot, or average of 20.9% per stand and 21.6% per woodland (Figures D11-D15).

Buckthorn average Importance Value (IV) per plot is 13.8% with maximum of 71.6% (Table A1). When averaged by stands and woodlands, Buckthorn IV is about 15% for both (Tables A2-A3).

Average Buckthorn Aboveground Live Biomass per plot is 6.2 T/ha (Figure D16). Based on plot data, estimated Buckthorn biomass across sampled areas could be as high as 318.0 tonnes for a single ELC stand or 266.2 tonnes for single woodland (Figures D17-20). The overall Buckthorn Biomass across sampled areas is estimated at 791.5 tonnes for stands and 873.3 tonnes for woodlands (Tables A2-A3). Converted to a percentage of total plot biomass, percent Buckthorn biomass on average is 6.8% (Table A1). Extrapolated to the polygon, percent Buckthorn biomass on average is 7% for stands and woodlands (Tables A2-A3).

Plots with the greatest amount of Buckthorn (relative cover > 50%) are located in Riverside Park savannah and deciduous forest, Westminister Woods plantation, Hadati Creek deciduous forest and disturbed / novel (unknown ELC) forest, Norm Jary Park deciduous forest, Margaret Green Park deciduous forest, Holland Crescent Park thicket swamp, Crane Park mixed swamp, and Marksam Park deciduous swamp (Figure D1). Woodlands with the greatest component of Buckthorn (relative cover >

50%) are Riverside Park, Hadati Creek, and Holland Crescent Park (Figures D4-D5). Plots with the greatest impact of Garlic Mustard (relative cover > 40%) are located in Elmira Park savannah, Stephanie Drive Park deciduous swamp, Mitchell Park deciduous forest, and Margaret Green Park deciduous forest (Figure D6). Woodlands with the greatest component of Garlic Mustard (relative cover > 40%) are Elmira Park, Stephanie Drive Park and Mitchell Park (Figure D7-D10).

However besides Buckthorn and Garlic Mustard, sampling data shows presence of other weedy and invasive plants. Number of weedy species per plot can be as high as 16 plants, with a mean of 5.3 weedy plants per plot (Figure D21). In total, there were 55 different weedy species recorded for all VSP plots sampled (Table A1). Mean Weed Index (WEEDmean) per plot, a measure of non-native species aggressiveness, ranges from 0 to 3 with a mean of 2.2 (Figure D26). Extrapolated by stands, WEEDmean ranges from 1.25 to 3 with mean 2.1 (Figures D27-D28). Extrapolated by woodlands, WEEDmean ranges from 1.25 to 2.6 with mean 2.1 (Figures D29-D30). The WEEDless Index per plot ranges from 21.9-100%, with a mean of 47% (Figure D31), which is similar when extrapolated to stands and woodlands (Figures D32-D35).

Plots least impacted by non-native species with the highest WEEDless index (WEEDless > 60) are located in Preservation Park deciduous swamp and deciduous forest, Ellis Creek deciduous swamp, Eastview Park deciduous swamp, Hanlon Creek coniferous swamp, and Norm Jary Park deciduous forest (Figure D31). One plot sampled (plot 203) in particular, had no non-native species recorded and was located in Preservation Park deciduous swamp (Figure D31). Woodlands least impacted by non-native species (WEEDless > 52) include Eastview Park, Preservation Park, Hadati Creek, Holland Crescent Park, Norm Jary Park, and Milson Cres and McWilliams Rd (Figures D34-D35). Areas with the least invasive species impact are those that have natural, rather than cultivated vegetation, suggesting anthropogenic communities (e.g. plantations) or those maintained by human activity, are more vulnerable to colonization by introduced species, likely due to greater historical and present day disturbances.

Relative abundance of Buckthorn was also compared with the relative abundance of Ash for the 86 VSP plots containing Ash (Figure 13). Results show that there is a fair amount of plots with a large relative abundance of both Ash and Buckthorn. Abundance of Buckthorn in Ash plots, along with other weeds and invasive species, is of concern since they suppress forest regeneration. High Buckthorn cover has been shown to reduce sapling densities in the understory, as well as the growth of shade-intolerant (e.g. White Pine) and shade-intermediate (e.g. Red Maple) seedlings in gaps (Fagan and Peart 2004). If tree seedlings are sufficiently inhibited by Buckthorn, recruitment of canopy trees in gaps could be delayed indefinitely (Abe et al. 2002, Beckage et al. 2000, Wardman and Schmidt 1998).

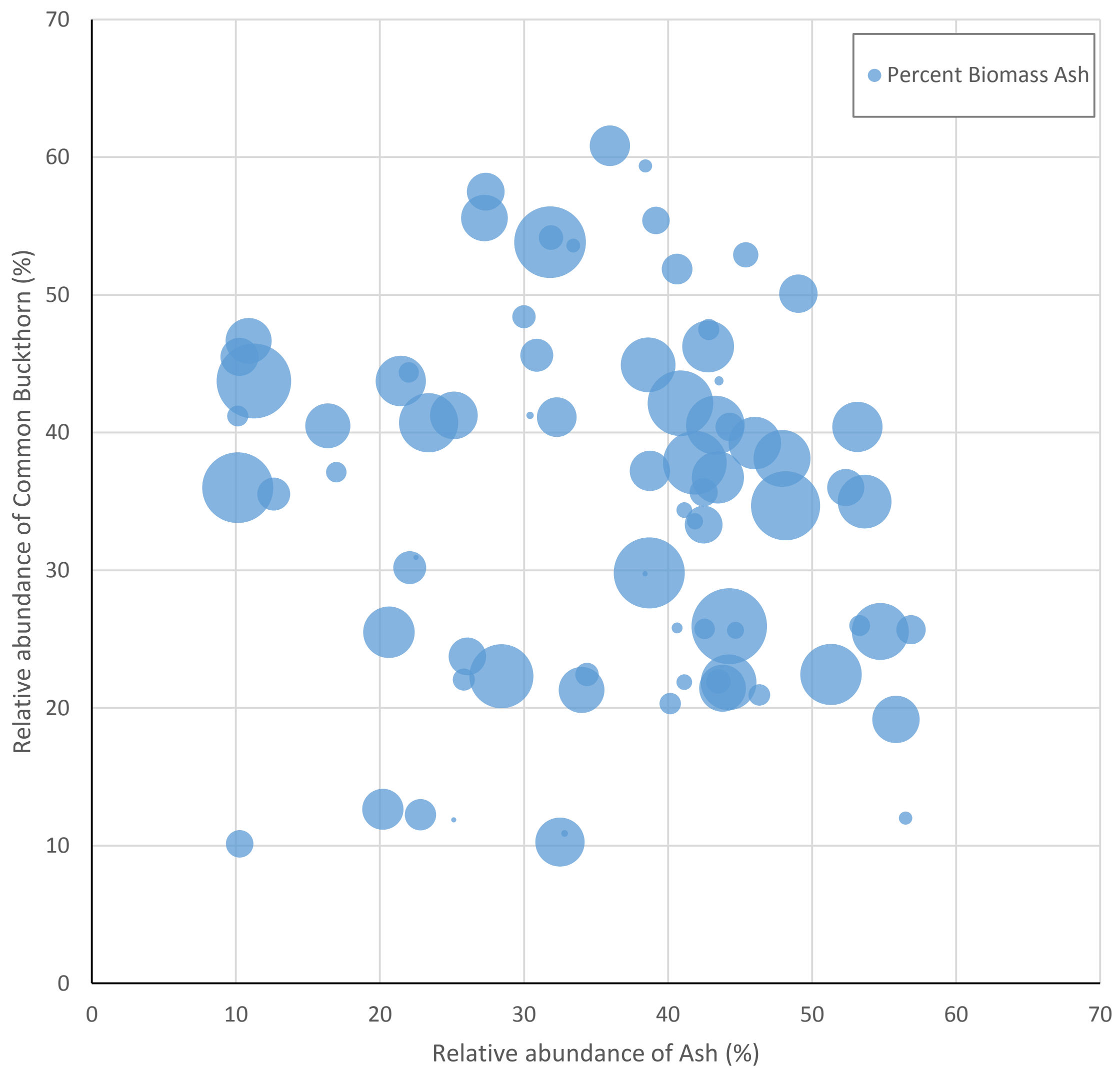

Figure 13. Relationship between the relative abundance of Ash and relative abundance of Common Buckthorn in VSP plots sampled in Guelph (2016). Circles scaled according to the percent of aboveground biomass per plot that is Ash.

The negative impacts of invasive species on regeneration and native species are expected to be magnified by the impacts of EAB and Ash decline as invasives thrive in disturbed habitats, including forests. The removal of EAB-infested Ash trees and canopy opening has been shown to result in a secondary spread of invasive species like Common Buckthorn, Creeping Thistle, and non-native Honeysuckles in northwest Ohio, USA (Hausman et al. 2010). Other studies also suggest that alien insects have potential to facilitate the colonization of invasive plants by altering native plant species competition and resource availability (Eschtruth and Battles 2009, Eschtruth et al. 2006, Knight et al.

2010, Simberloff and Von Holle 1999). Areas considered most at risk of invasive species establishment in Guelph include those woodlands with significant percent canopy loss due to Ash dieback (>25%) and with moderate and higher Buckthorn or Garlic Mustard relative covers (>10%). These include the locations of Ellis Creek, Mitchell Park, Hadati Creek, Riverside Park, Holland Crescent Park, Margaret Green Park, Stephanie Drive Park and Westminster Woods.

3.5 Forest Regeneration

Percent Ash canopy cover per plot, expected to be lost in the upcoming years, is on average 27.2% but in some areas can be as high as 100% (Appendix, Figure B31). Extrapolated to the sampled areas, percent canopy lost due to EAB is on average 25% for stands and woodlands (Figures B32-B35). Normalized by polygon area, however, overall percent canopy loss in sampled areas is 22.1% for ELC stands and 18.2% for woodlands. Plots with the most significant canopy loss (Percent Canopy Ash > 75%) are located in: Hadati Creek thicket swamp and thicket, Holland Crescent Park thicket swamp, Marksam Park deciduous swamp, Westminister Woods thicket swamp and plantation, Mitchell Park deciduous forest, Margaret Green Park deciduous forest, and Stephanie Drive Park deciduous swamp (Appendix, Figure B31). Woodlands projected to experience the greatest canopy loss (Percent Canopy Ash > 50%) are Holland Crescent Park, Mitchell Park, Hadati Creek, Marksam Park, and Margaret Green Park (Figures B32-B35).

The loss of mature Ash trees will result in the formation of large canopy gaps in some of Guelph's natural areas. Although gap formation is a natural forest process, sudden, large canopy gaps caused by alien insects like EAB differ from those caused by normal tree decline. Natural canopy decline forms more slowly, while those caused by disturbances such as storms do not selectively eliminate specific taxa (Gandhi et al. 2007) as EAB does. These rapid and species-specific openings in the canopy alter the light regimes of forests, affecting temperature and moisture (Twery 1990, Stadler et al. 2006). Increase in understory light is likely to shift composition towards species which are most capable of taking advantage of the increased light availability and resetting forest succession.

The identity of canopy replacements in gaps created by EAB depends on species co-occurrence with Ash, their growth rate when exposed to increased light availability in gaps, and the extent of invasive species cover. Tree and shrub species (DBH ≥ 5cm) which co-occur most frequently with Ash in VSP plots include: Common Buckthorn, American Elm (*Ulmus americana*), Sugar Maple, Red Maple, Ironwood (*Ostrya virginiana*), Silver Maple (*Acer saccharinum*), Basswood (*Tilia americana*), Eastern White Cedar (*Thuja occidentalis*), Trembling Aspen (*Populus tremuloides*), Black Cherry (*Prunus serotina*) and

Manitoba Maple (*Acer negundo*), listed in order of decreasing percentage of Ash plots (Figure 14). Species from Maple genera are well-suited as Ash replacements due to their wide range in ecological tolerance, along with their properties of shade tolerance, abundant seed production and good seed dispersal (Abrams 1998, Godman et al. 1990, Kobe et al. 1995). Basswood's large size, rapid growth, and tolerance for shade and moisture (Ashby 1960, Crow 1990), make it another potential Ash replacement. American Elm, although common in many sampled sites, may have less potential as a replacement species of Ash due to the impact of Dutch Elm Disease and competition against more shade-tolerant species (Barnes 1976, Bey 1990). Trembling Aspen, is a fast-growing pioneer species and highly shade-intolerant (Perala 1977, Perala 1990), making it a less suitable canopy replacement, however, increased sunlight associated with EAB-induced gap formation may enable Aspen growth, if it is not outcompeted by Buckthorn. Black Cherry, as an early successional and shade-intolerant species, could also take advantage of the gaps formed, as it has a growth rate faster than most other tree species when exposed to sunlight (Auchmoody 1982, Marquis 1990), which potentially could be facilitated by large canopy gap formation. Ironwood, Eastern White Cedar, Buckthorn and Manitoba Maple are less likely to reach the canopy due to their smaller heights (Johnson 1990, Metzger 1990, Missouri Department of Conservation 2011, Overton 1990), but may play an important role in the understory and impact regeneration of shade-intolerant species. Buckthorn and Manitoba Maple pose additional threat due to their ability to quickly invade sites and divert community composition and succession, which could cause forest communities to diverge into those (novel communities) that have not been seen before.

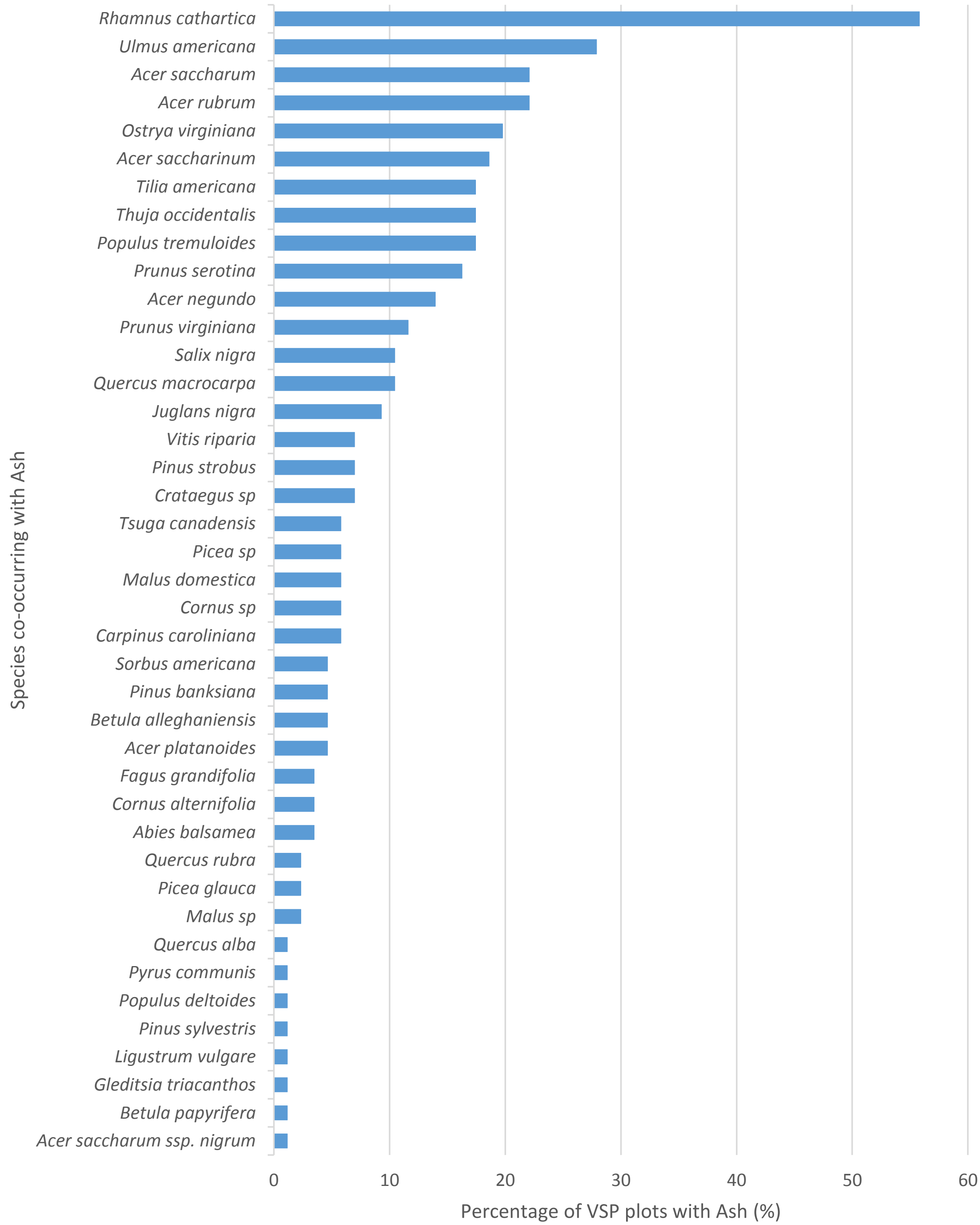

Figure 14. Frequency of species co-occurring with Ash according to VSP data for Guelph (2016) for 41 woody species (DBH ≥ 5 cm) co-occurring in the 86 out of 103 plots sampled which contained Ash.

Studies on the replacement of Ash canopy trees had comparable findings. Red Maple, American Elm, Basswood and Slippery Elm (*Ulmus rubra*) were found to be the most suitable replacements of Black Ash in wetland areas in Minnesota, Ohio, and Michigan (Iverson et al. 2016). In drier sites, Sugar Maple and Northern Red Oak were found to be the most likely replacements (Iverson et al. 2016). In Black Ash wetlands in northern Minnesota, it was found that plantings of American Elm and Swamp White Oak (*Quercus bicolor*) had the highest survival rates, while conifers and shade intolerant species had the least (Looney et al. 2015). A similar study by Flower et al. (2013a) in the Midwestern USA showed *Acer* and *Ulmus* species had the highest relative growth rates in EAB affected sites. Additionally, Burr and McCullough (2014) indicated that Red Maple, Sugar Maple, and Black Cherry were the most suitable species to replace Green Ash at stands sampled in Michigan due to their abundance and prevalent regeneration.

Table 9. VSP Plots with no seedling or sapling regeneration recorded for sub-plots.

VSPPLOTid	Location	Easting	Northing
171	Crane Park	560247.3491	4817531.629
152	Ellis Creek	556233.2399	4819394.992
151	Ellis Creek	556094.7076	4819369.186
202	Ellis Creek	556255.7777	4819252.677
122	Elmira Park	558081.3571	4818541.448
186	Eramosa River Park	562340.9539	4821549.186
125	Holland Crescent Park (Ridgeway Ave)	565125.3288	4818455.705
95	Margaret Green Park	557954.7298	4819884.092
133	Marksam Park	557189.9457	4820459.658
107	Marksam Park	557251.0277	4820534.853
102	Marksam Park	557551.9082	4820654.002
98	Marksam Park	557226.4502	4820498.214
158	Mitchell Park	556595.6939	4819370.911
142	Riverside Park	558892.6164	4824266.158
201	Silver Creek Park, South Side	559984.3135	4819791.822
150	Stephanie Drive Park	558204.3455	4819137.923
111	Sugar Tree Woodlot	556930.1582	4820421.065
123	Westminister Woods	565980.9991	4817699.405
126	Westminister Woods	565759.5497	4818125.932

Considers only seedlings or saplings located in sub-plots (not the whole VSP plot area).

Some VSP plots are Ash dominated as measured by a high IV of Ash (including one plot that is 100%) and lack diversity in other tree species (Figures B16-B20). These sites may not have canopy replacements readily available, due to the lack of seed sources for tree regeneration. Only 5% of VSP plots had native saplings (DBH 2.5-5cm) recorded in regeneration subplots, excluding Ash, indicating poor tree regeneration. This is compared with the Buckthorn sapling regeneration found at 12% of VSP plots. At these plots Buckthorn regeneration occuers in have higher densities than native trees. When seedlings (DBH < 2.5cm) were assessed, 81% of VSP plots had regeneration of native seedlings excluding Ash, recorded in regeneration subplots. However, 87% of VSP plots showed regeneration of Buckthorn seedlings. Plots with no native seedling regeneration are listed in Table 10. These findings indicate that there are some plots in which natural regeneration of native tree species might not be sufficient, especially in the presence of dense Buckthorn cover. These areas, therefore, could benefit from targeted restoration that can include a tree planting program to facilitate canopy regeneration. Seedling stock should prioritize robust shade tolerant species, selecting native, site appropriate species which have potential to establish and thrive on the sites.

3.6 Forest Carbon

Total Ash Biomass (above and below ground) estimates for sampled areas are as much as 4881.1 tonnes for sampled ELC stands and 5824.4 tonnes for sampled woodlands, not including the remaining unsampled areas (Table 11). Based on sampled areas, an estimate of total carbon stored in Ash trees is 2318.5 tonnes for stands and 2766.6 tonnes for woodlands (Table 11). This is equivalent to 8509.0 tonnes of stored CO_2 when estimated by stands and 10153.5 tonnes of stored CO_2 when estimated for woodlands sampled (Table 11). Considering the average passenger vehicle emits 4.7 tonnes of CO_2 in a full year (US EPA 2014), this is equivalent to adding 1,810-2,160 additional cars on the road.

Table 10. Forest carbon and sequestered CO_2 for Ash trees in stands and woodlands sampled in Guelph (2016). Values presented as a total (in tonnes) and density (in tonnes per hectare).

	Unit of Measurement	Above Ground Biomass	Below Ground Biomass	Total Biomass	Carbon Content	CO2
ELC Stands	T	4067.6	813.5	4881.1	2318.5	8509.0
	T/ha	32.4	6.5	38.9	18.5	67.8
Woodland Stands	T	4853.7	970.7	5824.4	2766.6	10153.5
	T/ha	27.2	5.4	32.6	15.5	56.9

EAB-induced Ash tree mortality represents a significant reduction in live biomass and increase in woody debris, thereby impacting the physical environment and biogeochemical cycling (Bernacki 2014, Stadler et al. 2006). This will have a considerable impact on carbon storage through the elimination of a large carbon sink (Ash), and addition of a carbon source as deadwood decomposes. EAB-induced Ash loss reduces Net Primary Productivity (NPP) to varying degrees, depending on Ash basal area, associated with tree size, density, and biomass (Flower et al. 2013a). In an Ohio study it was found that on average, EAB resulted in a 30% reduction of NPP at affected sites (Flower et al. 2013a). Loss of NPP and carbon storage is expected to be partially compensated for by enhanced growth of other tree species in the absence of Ash (Bernacki 2014, Flower et al. 2013a).

The long-term effect on NPP and thus carbon storage depends on the replacement species compared with the declining host species. In stands where Ash is replaced by slower growing species such as Maples, productivity may be permanently reduced (Burr and McCullough 2014, Lovett et al. 2013). Since Maples are abundant in stands where Ash makes a significant component (Figure 14), they could serve, to some dgree, as a replacement for Ash (Abrams 1998, Godman et al. 1990, Iverson et al. 2016, Kobe et al. 1995). However, regaldess this, a reduction in forest diversity and productivity is a likely scenario for the City of Guelph's natural areas if EAB impacted forests are not actively managed. However, in stands where Ash are replaced by a similarly fast growing species such as Black Cherry (Auchmoody 1982), loss in productivity might be less severe over the long-term. Stands which already are or that will become abundant in Buckthorn following the loss of Ash are at risk of long-term effects of reduced NPP and carbon storage. Woody biomass has been found to be significantly less for forests dominated by Buckthorn than those dominated by native tree species (Mascaro and Schnitzer 2011). Buckthorn leaf litter also has high nitrogen content, facilitating microbial decomposers and invasion of the Eurasian earthworm leading to an overall increase in decomposition rates and release of CO_2 (Heneghan 2003, Heneghan et al. 2006).

3.7 Significant Species and Floristic Quality

In total there were approximately 253 plant species recorded across all 103 plots sampled, including a few plants that were only able to be identified to the genus level due to lack of identifiable features (e.g. grass with no flowering head). Species Richness, the number of species per plot, ranges from 10 to 61, with a mean of 34.1 species (Figures 15-16, Figure E1). Extrapolated to stands plot richness range remains from 10 to 61, but with a mean slightly higher at 35.6 species (Figure E2-E3). Species richness was extrapolated to the woodland polygon, resulting in a range 15 to 61 plants per polygon, with a mean of 36.8 species (Figure E4-E5). However, as number of species is sampled area dependant (e.g. number of plots sampled) these numbers should not be used to draw any definite conclusions about species richness per polygon.

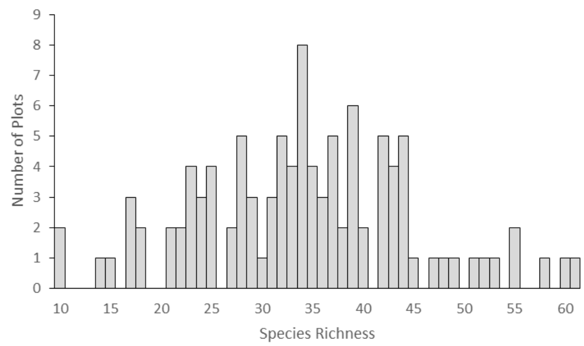

Figure 15. Species richness in VSP plots sampled in Guelph, ON (2016).

Plots with the greatest number of species (richness > 40) were located in Hadati Creek thicket, Howitt Park deciduous forest, North Side of Kortright East coniferous swamp, Watson Creek thicket swamp, Hanlon Creek coniferous swamp and mixed forest, and Edinburgh Rd S and Kortright Rd W mixed swamp (Figures E1). Woodlands with the greatest mean species richness per plot (richness > 50) include Hadati Creek, Howitt Park, North Side of Kortright East, Hanlon Creek, and Edinburgh Rd S and Kortright Rd W (Figures E4-E5). Species-rich areas such as these tend to have greater stability and productivity, thereby being more resistant to invasive species, and resilient to climate change and natural disasters (Gamfeldt et al. 2013, Peterson et al. 1998, Werner and Gallo-Orsi 2016).

Figure 16. Box plot of species richness for VSP plots sampled in Guelph, ON (2016).

Locally significant species are found in 17.5% of VSP plots sampled, with a maximum of 2 plants per plot (Figure E6). These include a total of 4 different species identified in the *Guelph Locally Significant Species List* (2012): American Mountain-Ash (*Sorbus Americana*), Philadelphia Panic Grass (*Panicum philadelphicum ssp. philadelphicumi*), Black Maple (*Acer saccharum ssp. nigrum*), and Interrupted Fern (*Osmunda claytoniana*) (Figure 16). Relative cover of significant species per plot reaches a maximum of 38%, with a mean of 2.8% (Figure E11). When extrapolated to sampled areas, this on average 3.3% for stands and 3.4% for woodlands (Figures E12-E15).

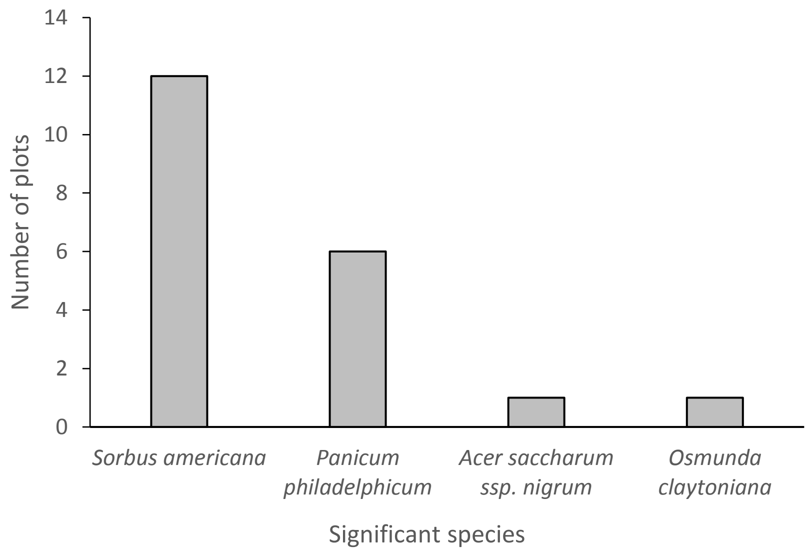

Figure 17. Significant species captured by random VSP plots in Guelph, ON (2016).

The 18 plots containing significant species are spread out across nine different parks: Marksam Park deciduous swamp, unknown forest and plantation, Hadati Creek thicket, Whitetail Court deciduous forest, Westminister Woods thicket swamp and plantation, Hanlon Creek coniferous swamp, Milson Crescent and Marigold Drive thicket swamp, Crane Park mixed swamp, Silver Creek Park South Side mixed forest, and Howitt Park deciduous forest (Figure E6). Woodlands with more than two significant species per plot include Marksam Park, Milson Crescent and Marigold Drive, Howitt Park, Whitetail Court, and Hadati Creek (Figures E3-E5). Woodlands in order of the greatest average relative cover of significant species (Relative Cover > 10%) are Marksam Park, Milson Crescent and Marigold Dr., Howitt Park, Hadati Creek, and Whitetail Court (Figures E14-E15).

Ash-dominated stands (>25% of canopy) containing significant species include Marksam Park, Hadati Creek, Westminister Woods and Silvercreek Park South Side (Figures B31). Significant species in these areas are at risk due to changing understory light regimes, temperature and moisture predicted with the loss of a large portion of the canopy (Stadler et al. 2006, Twery 1990). These species, however, are expected to be affected differently based on their ecological tolerance. Black Maple is very shade tolerant and prefers rich mesic forests (Gabriel 2004). Philadelphia Panic Grass prefers full sun and seasonally flooded sands typically bordering acidic streams, lakes, and wetlands (Barkworth at al. 2007). American Mountain-Ash is typically found at moist sites with full sun (Steiner 2011). Interrupted Fern prefers shaded woods with medium to moist soil (Steiner 2011). However, Interrupted Fern was not found at any of the random sites sampled nor any plots with significant Ash canopy cover. Black Ash wetlands and associated species are likely to be further impacted due to changing hydrology, rising water table and shift to an altered ecosystem state following Ash mortality (Slesak 2016). Significant impacts Ash loss on hydrology have been shown for areas with 75-100% Black Ash and basal areas ranging between 23.0-39.2 m^2 / ha in Minnesota (Slesak 2016). This is comparable to some of Guelph plots which have significant component of a Black. For example, a plot (184) in Hadati Creek thicket swamp has Black Ash basal area of 24.5 m^2 / ha. Although other wetlands sampled in Guelph have lower basal areas of Black Ash, effects of Ash loss on hydrology may still be substantial. Colonization of invasive species such as Buckthorn following Ash dieback (Hausman et al. 2010) could have a compounding effect on significant species.

Coefficient of Conservatism (CC) of species recorded in sampled plots ranges from 0 to 10. Mean Coefficient of Conservatism (MeanCC) per plot ranges from 2.6 to 4.9, with an average of 3.7 (Figure E16). Extrapolated to the sampled stand, MeanCC ranges from 2.7 to 4.8 with an average of 3.7 for stands (Figures E17-E18), while MeanCC ranges from 2.9 to 4.8 with an average of 3.7 for woodland polygons (Figures E19-E20). A MeanCC of 3.7 indicates species in sampled plots have a low overall CC showing that the majority of taxa are tolerant of moderate to high disturbance (Oldham et al. 1995). Remnant habitats with intact flora, however, generally have a MeanCC of 5-6, indicating higher conservation value (Swink and Wilhelm 2004). Comparisons of MeanCC can be made between datasets since CC has been found to be unaffected by sample plot size, species richness or seasonality (Francis et al. 2000, Matthews 2003, Rooney and Rogers 2002).

Plots with the greatest conservation value for Guelph (MeanCC > 4.5) are located in Preservation Park deciduous forest and deciduous swamp, Hadati Creek thicket swamp, Marksam Park deciduous swamp, Westminister Woods plantation, and Hanlon Creek mixed forest (Figure E16). Woodlands with the greatest conservation value (MeanCC > 4.2) are Hadati Creek, Hanlon Creek, Whitetail Court, Preservation Park, and Marksam Park (Figures E19-E20).

Another measure similar to CC, but more standardized to a percent scale is MeanCC Centralized. MeanCC Centralized per plot ranges from 26.2-49.3%, with an average of 37.4% (Figure E21). When calculated as an average per stand, MeanCC Centralized ranges from 27.1-47.6% with mean 37.2% for stands and ranges from 29.0-47.5% with a mean of 37.0% for woodlands (Figures E22-E25).

Floristic Quality Index (FQI) per plot ranges from 7.4 to 24.6, with a mean FQI of 14.7 (Figure E26). Extrapolated to stands, mean FQI ranges from 7.5 to 24.6, with a mean of 14.6 (Figures E27-E28).

Extrapolated to woodlands, mean FQI ranges from 7.5 to 23.7, with a mean of 14.7 (Figures E29-E30). A mean FQI of 14.7 indicates many plots have lower vegetation quality with combined effects of low native species richness and presence of species tolerant to disturbance, indicating a disturbed habitat (Milburn et al. 2007). FQI values from 1-19 indicate poor vegetative quality, 20-35 moderate to high vegetative quality, and above 35 "Natural Area" quality (Swink and Wilhelm 1994). Intact remnant habitats, however, can have an FQI between 45-55 (Swink and Wilhelm 1994).

Adjusted floristic quality index (FQAI) has been shown to have a stronger correlation with the degree of site disturbance compared to FQI (Miller and Wardrop 2006, Miller et al. 2006, Rocchio 2007). In a Pennsylvania study investigating the relationship between FQAI and disturbance, mean FQAI was 46 for low disturbance, 33 for moderate disturbance and 22 for high disturbance sites (Miller and Wardrop 2006). Undisturbed reference sites had a FQAI from ~54-87 and disturbed sites a FQAI from ~41-67 in a similar study in Colorado, however, mean values were not presented (Rocchio 2007). The FQAI per plot determined for Guelph ranges from 22.4-47.8, with a mean of 32.2 (Figure E31). Extrapolated to the stand, FQAI ranges from 23-47 with mean 32 (Figures E32-E33). Extrapolated to the woodlands, FQAI ranges from 23-46 with mean 31 (Figures E34-E35). These values suggest that Guelph's natural areas range from low to high disturbance, with the mean FQAI in the moderate to high disturbance region.

Plots with the greatest floristic quality (FQI > 19) are located in: Hanlon Creek coniferous swamp and mixed forest, North Side of Kortright East coniferous swamp, Hadati Creek thicket and thicket swamp, Preservation Park deciduous forest, Ellis Creek deciduous swamp, Stephanie Drive Park deciduous swamp, Howitt Park deciduous forest, Watson Creek thicket swamp, and Whitetail Court deciduous forest (Figure E26). Woodlands with the greatest floristic quality (FQI > 19) are North Side of Kortright East, Hanlon Creek, Hadati Creek, Howitt Park and Whitetail Court (Figures E29-E30). Plots with the greatest adjusted floristic quality (FQAI > 40) are located in Preservation Park deciduous forest and deciduous swamp, Hadati Creek thicket swamp, Hanlon Creek coniferous swamp and mixed forest, Whitetail Court deciduous forest, Westminister Woods plantation, and Marksam Park deciduous swamp (Figure E31). Woodlands with the greatest adjusted floristic quality (FQAI > 40) are Hadati Creek, Whitetail Court, Hanlon Creek and Preservation Park (Figures E34-E35).

FQAI and WEEDless were also compared to identify areas with the highest vegetation quality, with the least impact from invasive species (FQAI>35, WEEDless>55). These included plots located in Ellis Creek deciduous swamp, Preservation Park deciduous forest, Hanlon Creek coniferous swamp and Hadati Creek thicket swamp (Figure 18). These areas would be of greatest conservation value due to their high floristic quality and minimal impact of invasive species, which ideally should be maintained.

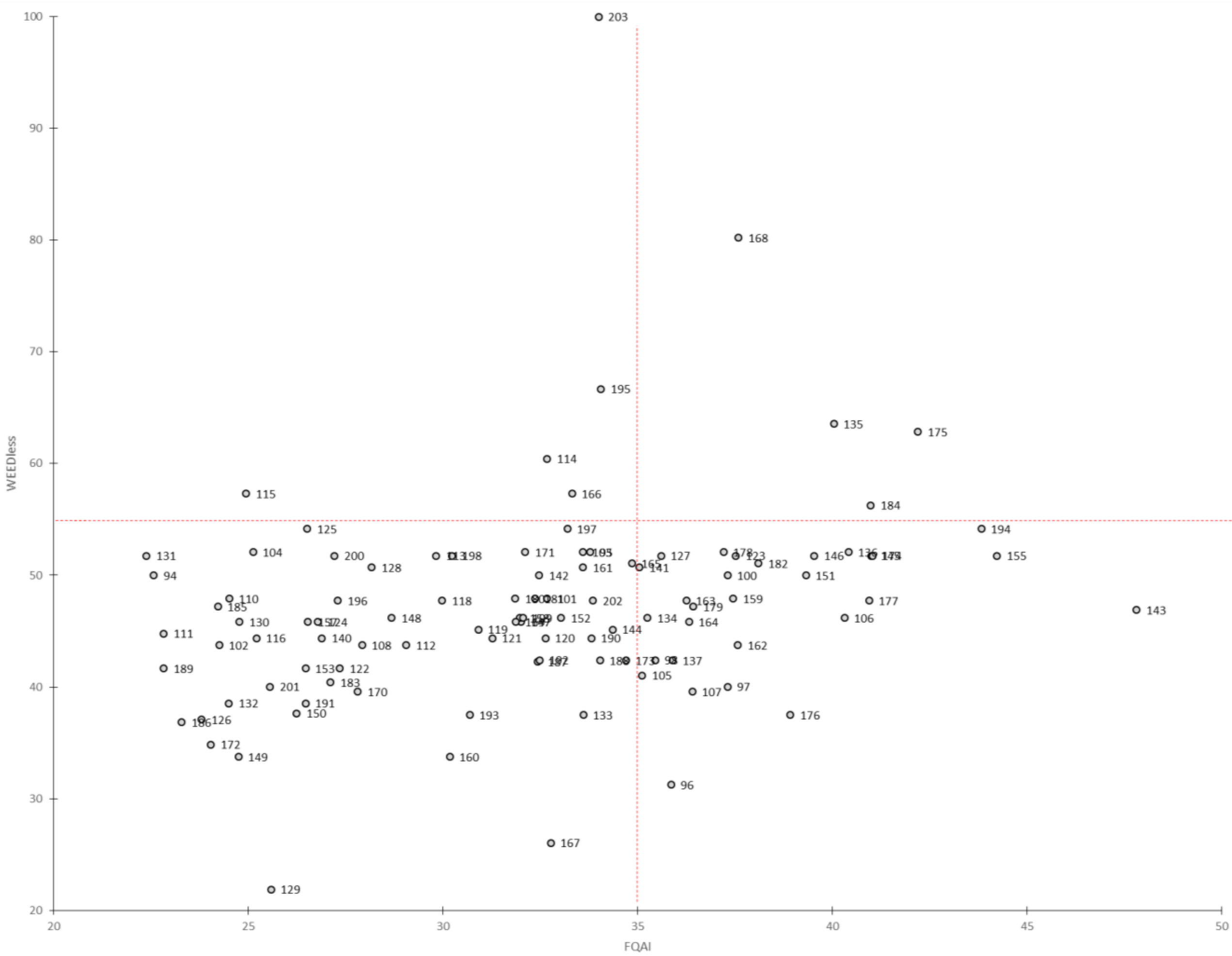

Figure 18. Adjusted Floristic Quality Index (FQAI) and WEEDless value per plot. Plots with high FQAI and WEEDless are labelled according to their VSPplotID.

FQAI and Importance Value of Ash (IVash) were also compared to identify areas with the highest vegetation quality that will most significantly be impacted by Ash loss (FQAI>35, IVash>50). These included plots located in Westminister Woods thicket swamp, Hadati Creek thicket swamp, Marksam Park deciduous swamp, and Preservation Park deciduous swamp (Figure 19). These sites would be of greatest priority for EAB mitigation activities, so as to preserve their high floristic quality, despite the projected loss of a dominant tree species.

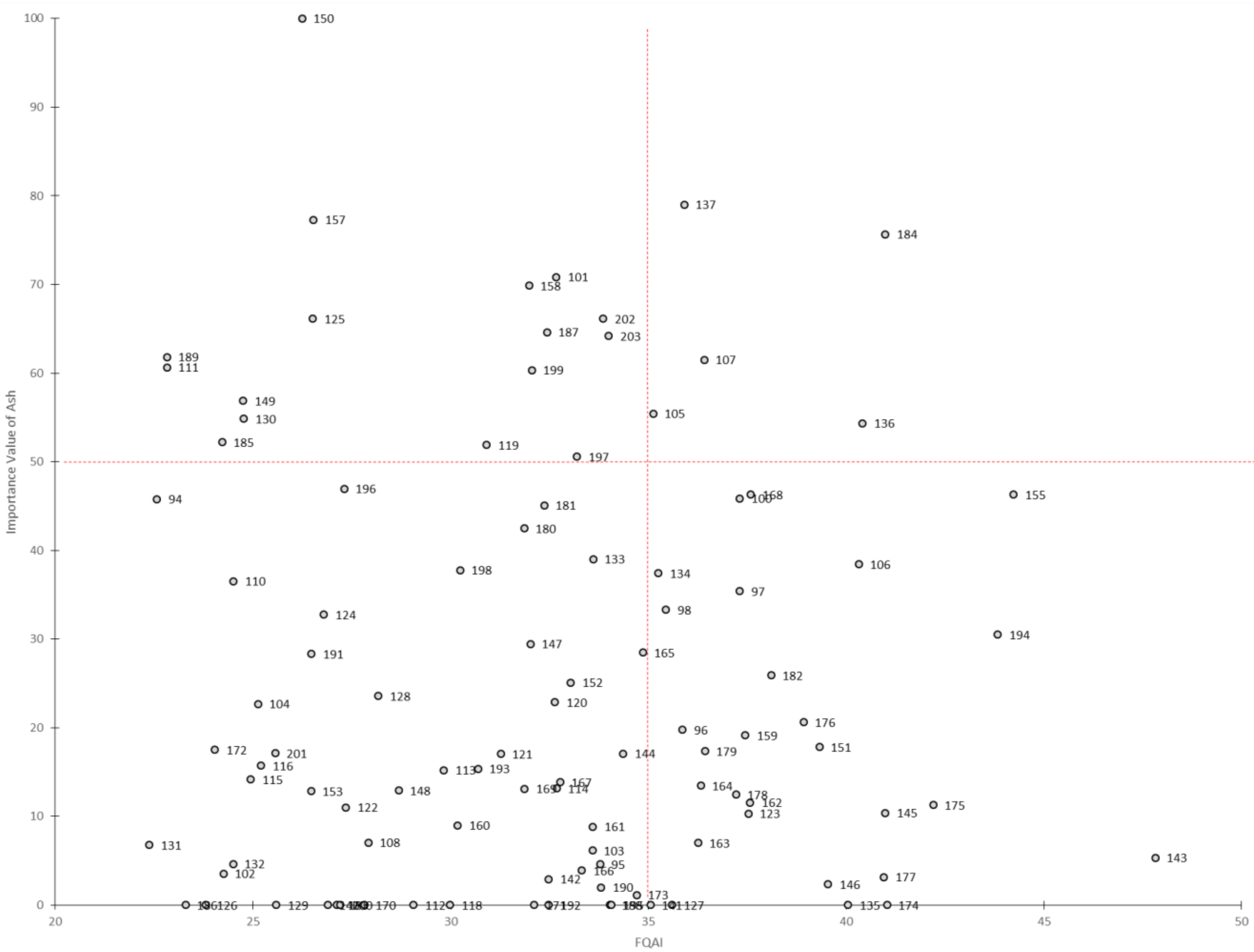

Figure 19. Adjusted Floristic Quality Index (FQAI) and Importance Value of Ash (IVash) per plot. Plots with high FQAI and IVash are labelled according to their VSPplotID.

4 CONCLUSIONS

Woodland cover, comprised of native and planted forests, makes up 5% of Guelph's land base, with there being a total of 33% of open and natural areas in Guelph. Guelph's properties targeted for sampling in 2016 however, has just 8% open and natural cover, and 3% woodland cover. Guelph's woodlands are predominantly composed of swamp forests at 64.2%, followed by upland forest at 17.6%, cultural forest at 14.0%, and about 4.1% is made up of other unclassified forests. Woodlands on City property show a similar pattern, with 58.6% swamp, 23.2% upland forest, 13.3% cultural forest and 5.0% unclassified forest.

Native Ash trees, found in a wide variety of forest and habitat types, are vital to Guelph's natural areas and urban forests. VSP sampling in summer 2016 targeted Ash stands on City property, with 70% of Guelph's City-owned woodland cover having at least one VSP plot (39% total woodland cover in Guelph). Three native Ash species (Black, White, and Green Ash) were found at 83.5% of the VSP plots sampled. In these plots, Ash species often comprise a significant component of the total tree count, biomass, and canopy cover. In total, 893 Ash trees (DBH ≥ 5cm) were recorded across the 103 VSP plots (covering a sampling area of 4.12ha). Based on the plot data and extrapolated across sampled woodlands (39% of total woodland cover, 70% City-owned woodland cover), it is estimated that there are about 28,000 Ash trees in the City of Guelph that are 5cm and more in DBH. This estimate gives a higher number than the previous 10,000 Ash tree estimates for Guelph's owned Ash areas (Marchant 2013). The higher numbers obtained through this study could be due to VSP sampling that includes all trees in canopy and sub-canopy (5cm and above). Regardless, it can be expected that potential Ash loss will have a substantial and lasting impact on many of Guelph's woodlands.

The majority of sampled Ash trees (82.1%) have shown signs of declining health and have at least some crown defoliation. Since crown defoliation is indicative of EAB impact, this finding suggests an emergent need for management actions to mitigate Ash loss and deal with large amount of dead trees. Since 82% of trees show sign of EAB infestation, the likelihood of finding unaffected trees is low. However, if there are Ash trees that are found to be healthy and suitable for TreeAzin™ injection, they would need to be looked at immediately. For example, there are 21 Ash trees that are 20cm and above that had no visible signs of EAB recorded by VSP. As some of them (7 trees) are over 40cm DBH, they represent a potential seed source, and if deemed healthy could be good candidates for the TreeAzin™ injection. Since the VSP plots are geo-referenced and staked, these trees can be easily located and inspected in detail.

Areas most significantly impacted by EAB were measured by high importance value of Ash. These areas include Mitchell Park, Holland Crescent Park, Hadati Creek, Sugar Tree Woodlot at Imperial Rd N and Westwood Rd, Marksam Park, and Stephanie Drive Park. Vegetation communities most severely impacted by potential Ash loss are deciduous and thicket swamps. These and other woodlands affected by EAB are at risk of further degradation due to changes in species composition as well as, depending on topography, increased erosion, sedimentation and stream warming. Loss of Black Ash in swamps could threaten not only biodiversity but can impact hydrology, which may be reflected in a rising water table and shift to an altered ecosystem state following Ash mortality (Slesak 2016). Furthermore, loss of Ash trees from canopy and sub-canopy will create large canopy gaps in some stands, as 30% to 80% of the canopy could open due to Ash decline. This sudden gap formation will change light, temperature and moisture conditions on the forest floor and shrub layer, and it can be expected that understory species composition and forest regeneration will be altered (Stadler et al. 2006, Twery 1990). Moreover, these new conditions facilitate colonization by invasive plant species such as Common Buckthorn and Garlic Mustard (Eschtruth et al. 2006, Eschtruth and Battles 2009, Simberloff and Von Holle 1999). Since presence of invasive species in sampled areas is significant, it can be expected that forest regeneration would further be inhibited by the spread and increase in abundance of invasive species (Fagan and Peart 2004).

In addition to the compositional shift that can be expected in these woodlands, the loss of live Ash biomass, which are a carbon sink, and wood decomposition, could potentially release 8,500 to 10,000 tonnes of CO_2, equivalent to adding about 1,810-2,160 additional cars on the road (US EPA 2014). Although Ash loss and canopy openings are expected to enhance growth of other tree species in mixed and diverse stands, this only partially compensates for the loss of mature Ash (Flower et al. 2013a). EAB not only results in the immediate release of CO_2 but also reduces the carbon sequestration potential of Ash dominated stands whose trees would have continued to grow and store carbon in their biomass. Moreover, Ash replacement tree species could have significant impact on carbon sequestration. Net primary productivity can be reduced long-term if slower growing trees such as Maples or smaller tall shrubs such as Buckthorn become the dominant species (Flower et al. 2013a, Mascaro and Schnitzer 2011). As a result, the potential of forests after Ash loss to sequester CO_2 can be lost or reduced.

Natural Ash replacement in stands depends on the size of the gaps created, diversity of tree species in stands, their growth rate when exposed to increased light availability, availability of seed source within stands and their proximity, as well as abundance and extent of invasive species cover. Based on tree species co-occurrence in sampled plots, trees that are most likely canopy replacements in upland sites are Sugar Maple, Red Maple, and Basswood. Other potential canopy replacements include Black Cherry and Trembling Aspen, which have lower tolerance to shade. In deciduous swamps, Silver Maple and American Elm could take advantage of gaps created. However, though American Elm seeds early and profoundly, due to the impact of Dutch Elm Disease on this species, deciduous swamps might be locked in a successional stage where Elm never reach their full size.

Considering the impacts and consequences associated with Ash loss, Ash dominated woodlands (e.g. those having > 30% Ash) will likely require remediation and restoration to prevent ecological collapse and maintain the integrity of the City's natural heritage systems. If there are no seed sources in stands or around them, tree replacement might have to be done by planting native and shade tolerant trees suitable to the site. With this intervention, forest regeneration could be enhanced and fast tracked. Planting could be especially beneficial in areas lacking other tree species to support natural regeneration and / or where there are few seedlings or saplings recorded during 2016 sampling.

Besides addressing regeneration, it would be necessary also to decide what to do with the amount of dead biomass. While some dead biomass is necessary for nutrient cycling and biodiversity, too much might halt regeneration. The disturbance associated with tree removal has been shown to promote invasive species spread compared to areas left uncut (Hausman et al. 2010). While leaving some trees on the ground, Ash removal is recommend when there is a safety concern. Preventative measures could also be taken by managing invasive plants, which threaten native species diversity. Data on invasive plants can be used to prioritize areas for their removal. Moreover, Ash loss in hydrologically and topographically sensitive areas might cause erosion on slopes or along rivers. These impacts could be mitigated by constructing stream barriers or planting riparian vegetation.

Continued monitoring of Guelph's natural areas impacted by EAB is recommended to be completed at five year intervals. The locations of sampled plots have been permanently marked to allow for easy re-sampling of plots. Contioung monitoring will enable to track the effects of Ash loss on forest structure and composition over time. Monitoring outcomes can be used to support adaptive management, such as where tree regeneration or invasive species removal measures are most needed. Ongoing monitoring also helps to detect and understand the impact of Ash loss on ecological goods and services provided by these areas, such as the change in carbon sequestration. Floristic quality indices obtained from vegetation monitoring, such as MeanCC and FQAI, can also be used to assess how the quality of woodlands change over time, evaluate the efficacy of restoration efforts, and set desired floristic quality targets (Foster et al. 2007, Matthews and Endress 2008).

Ash mortality in EAB affected areas is expected to be almost 100 percent, regardless of the habitat, diversity, density or size of Ash. The future of Ash trees in forests depends on the presence and longevity of the Ash seed-bank and regeneration, however, due to continued EAB pressure and deer herbivory on saplings, the chance of Ash persistence is uncertain (Hausman et al. 2010). EAB can persist at low densities following infestation, and kill Ash saplings once they reach an adequate size of 3cm DBH (Knight et al. 2010). Considering this and the expected changes in forest structure, composition and functions due to EAB, which are magnified by climate change, invasive species and other stressors, it is necessary to continue monitoring the sites sampled in 2016. Monitoring and collecting baseline field data supports adaptive management and day to day decision making, but also provides information for future science and research to help understand how forests are changing.

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6 APPENDICES

Map figures listed below are linked to the appropriate PDF. For the links to work, ensure that the map PDFs are kept in the "Appendix" folder, which is in the same folder as this Report.

APPENDIX A: WOODLAND OVERVIEW

WOODLAND-ELC LAYER BOUNDARY

VSP PLOTS

DATA SUMMARY

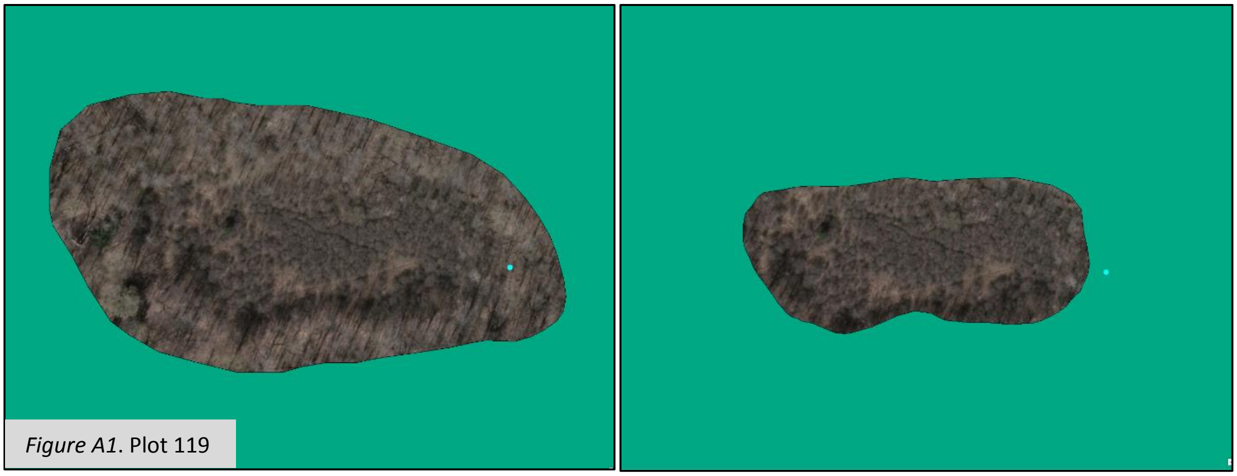

Figure A1. Plot 119

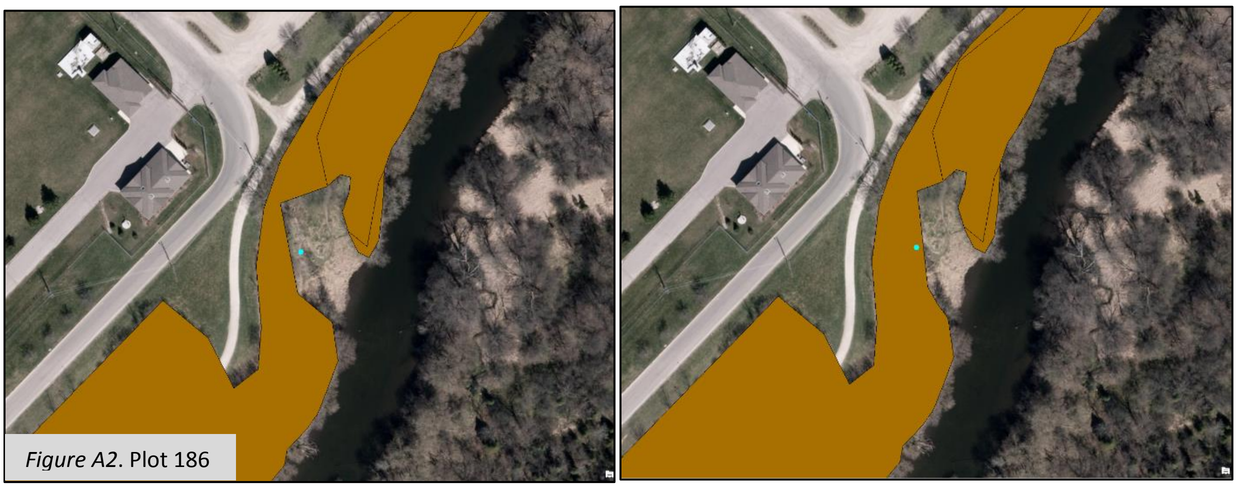

Figure A2. Plot 186

Figure A3. Plot 147

Figure A4. Plot 189

Figures A1-A4. Boundary adjustments for four plots located outside the Woodland-ELC layer. These include Ellis Creek deciduous swamp (Plot 119), Eramosa River Park savannah (Plot 186), Westminister Woods plantation (Plot 147), Margaret Green Park savannah (Plot 189).

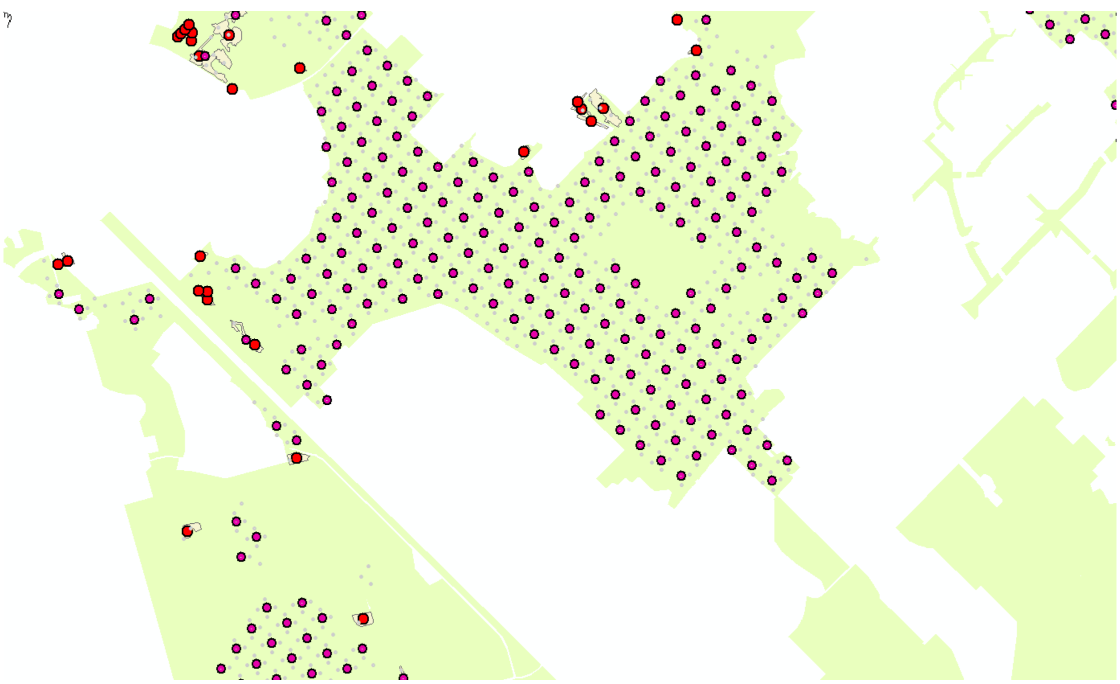

Figure A5. An example of VSP sampling grid for the City of Guelph.

Table A1. VSP plot data summary for Guelph (2016). Variables defined in methods section and statistics provided by plot data.

Attribute	Mean	Min	Max
Number of Trees (DBH≥5cm)	36.4	5	125
Number Ash Trees (DBH≥5cm)	8.7	0	39
Number Ash Trees (DBH≥10cm)	5.6	0	26
Ash Percent Tree	25.3	0	100
Average Ash DBH (cm)	18.4	5.94	37.4
Basal Area All Trees (m^2)	1.1	0.08	2.8
Basal Area Ash (m^2)	0.2	0	1.2
Basal Area per hectare Ash (m^2/ha)	6.1	0	30.7
Percent Basal Area Ash	26.2	0	100
Ash Dieback 0	1.6	0	11
Ash Dieback 1	2.5	0	20
Ash Dieback 2	2.6	0	16
Ash Dieback 3	2	0	22
Ash IV	25.7	0	100
Above Ground Live Biomass (T/ha)	149.3	8	579
Above Ground Live Biomass Ash (T/ha)	35.4	0	194.5
Percent Biomass Ash	27.3	0	100
Biomass Remaining (T/ha)	90.2	0	567.4
Number of EAB-Infected Ash	7.2	0	36
Number of Non EAB-Infected Ash	1.5	0	15
Percent Ash Trees with EAB detected	69.1	0	100
Ash Relative Cover	33	0	56.9
Percent Canopy Ash (Loss due to EAB)	27.2	0	100
Number of Buckthorn (DBH≥5cm)	9	0	83
Buckthorn Percent Tree	19.8	0	91.2
Average Buckthorn DBH (cm)	8.6	5.25	18
Basal Area Buckthorn (m^2)	0.06	0	0.6
Basal Area per hectare Buckthorn (m^2/ha)	1.5	0	15.4
Percent Basal Area Buckthorn	7.8	0	60.7
Above Ground Live Biomass Buckthorn (T/ha)	6.2	0	65.2
Percent Biomass Buckthorn	6.8	0	62.9
Buckthorn IV	13.8	0	71.6
Buckthorn Relative Cover	32.3	0	61.6
Garlic Mustard Relative Cover	10.8	0	67.5
CCmean	3.7	2.6	4.9
CCmean Centralized	37.4	26.2	49.3
CC Variation (CC CV)	56.4	17.5	97.4
MinCC	0.3	0.001	4
MaxCC	7.5	4	10
FQI	14.7	7.4	24.6
FQI Normalized (FQIPrc)	19.4	34.5	100
FQAI	32.2	22.4	47.8
Number of Significant Species	0.2	0	2
Significant Species Relative Cover	2.8	0	38
Species Richness	34.1	10	61
Number of Weedy Species	5.3	0	16
Mean Weed Index (WEEDmean)	2.2	0	3
WeedLess Index (WEEDless)	47.2	21.9	100
WEEDmean Normalized (WEEDmeanPrc)	72.6	0	100

Table A2. VSP plot data extrapolated by stand polygons (ELC). Summary statistics of the variables defined in methods section.

Attribute	Total	Mean	Min	Max
Area (ha)	125.5	2.4	0.07	25.3
Number of Plots	103	1.9	1	11
Plot Density (plots / ha)	N/A	2.4	0.2	15.2
Plot Coverage (ha / plot)	N/A	1.3	0.07	5.2
Number of Trees (DBH>5cm)	126968.6	2395.6	43.8	16766.2
Number Ash Trees (DBH>5cm)	22507	424.7	0	5914.1
Number Ash Trees (DBH>10cm)	15337.9	289.4	0	3617.4
Ash Percent Tree	N/A	22.3	0	71.5
Basal Area All Trees (M2)	3885.4	73.3	0.6	923.5
Basal Area Ash (M2)	702.2	13.2	0	206.1
Percent Basal Area Ash	N/A	23.3	0	84.9
Ash Dieback 0	4118.6	77.7	0	976.1
Ash Dieback 1	6579.7	124.1	0	2239.3
Ash Dieback 2	6076.7	114.7	0	1665.1
Ash Dieback 3	5732	108.2	0	1033.5
Ash IV	N/A	22.8	0	73.6
Above Ground Live Biomass (T)	21064.8	397.4	2.9	6350.1
Above Ground Live Biomass Ash (T)	4067.6	76.7	0	1242.5
Percent Biomass Ash	N/A	24.5	0	89.9
Biomass Remaining (T)	16997.2	320.7	2.9	5107.6
Number of EAB-Infected Ash	18199.8	343.4	0	4306.4
Number of Non EAB-Infected Ash	4135.3	78	0	1607.7
Percent Ash Trees with EAB detected	N/A	63.9	0	100
Ash Relative Cover	N/A	31	0	52.8
Percent Canopy Ash (Loss due to EAB)	N/A	24.5	0	100
Number of Buckthorn (DBH>5cm)	27250.7	514.2	0	10114.5
Buckthorn Percent Tree	N/A	20.9	0	91.2
Basal Area Buckthorn (M2)	191.4	3.6	0	75
Percent Basal Area Buckthorn	N/A	8.4	0	60.7
Above Ground Live Biomass Buckthorn (T/ha)	791.5	14.9	0	318
Percent Biomass Buckthorn	N/A	7.4	0	62.9
Buckthorn IV	N/A	14.6	0	71.6
Buckthorn Relative Cover	N/A	32.7	0	61.6
Garlic Mustard Relative Cover	N/A	9.8	0	63.3
CCmean	N/A	3.7	2.7	4.8
CCmean Centralized	N/A	37.2	27.1	47.6
CC Variation (CC CV)	N/A	58.7	21.9	88.4
MinCC	N/A	0.2	0.001	3
MaxCC	N/A	7.6	5	10
FQI	N/A	14.6	7.5	24.6
FQI Normalized (FQIPrc)	N/A	74.5	34.5	100
FQAI	N/A	31.8	22.8	42.6
Number of Significant Species	4	0.2	0	2
Significant Species Relative Cover	N/A	3.3	0	20.7
Species Richness	253	35.6	10	61
Number of Weedy Species	55	5.6	1	16
Mean Weed Index (WEEDmean)	N/A	2.1	1.25	3
WeedLess Index (WEEDless)	N/A	46.7	21.9	76
WEEDmean Normalized (WEEDmeanPrc)	N/A	71.2	41.7	100

Table A3. VSP plot data extrapolated by woodland polygons. Summary statistics of variables defined in methods section.

Attribute	Total	Mean	Min	Max
Area (ha)	178.6	4.3	0.07	37.4
Number of Plots	103	2.5	1	13
Plot Density (plots / ha)	N/A	1.9	0.06	15.1
Plot Coverage (ha / plot)	N/A	2.1	0.07	18
Number of Trees (DBH>5cm)	200911.4	4783.6	51.3	56271.4
Number Ash Trees (DBH>5cm)	28131.6	669.8	0	8348.7
Number Ash Trees (DBH>10cm)	18827.7	448.3	0	4894.1
Ash Percent Tree	N/A	24.3	0	71.5
Basal Area All Trees (M2)	5811.2	138.4	0.6	1344.5
Basal Area Ash (M2)	843.1	20.1	0	274.3
Percent Basal Area Ash	N/A	24.8	0	84.9
Ash Dieback 0	5481.1	130.5	0	1439.4
Ash Dieback 1	8008	190.7	0	3094.8
Ash Dieback 2	7254.8	172.7	0	2519
Ash Dieback 3	7387.7	175.9	0	1295.5
Ash IV	N/A	24.5	0	73.6
Above Ground Live Biomass (T)	30572.2	727.9	2.9	9244.5
Above Ground Live Biomass Ash (T)	4853.7	115.6	0	1651.7
Percent Biomass Ash	N/A	26	0	89.9
Biomass Remaining (T)	25718.4	612.3	2.9	7592.8
Number of EAB-Infected Ash	22411.4	533.6	0	5469.9
Number of Non EAB-Infected Ash	5504.3	131.1	0	2663
Percent Ash Trees with EAB detected	N/A	66.9	0	100
Ash Relative Cover	N/A	31.3	0	52.8
Percent Canopy Ash (Loss due to EAB)	N/A	26	0	100
Number of Buckthorn (DBH>5cm)	29688.7	706.9	0	8465.9
Buckthorn Percent Tree	N/A	21.6	0	73.1
Basal Area Buckthorn (M2)	210.9	5	0	62.8
Percent Basal Area Buckthorn	N/A	8.4	0	60.7
Above Ground Live Biomass Buckthorn (T/ha)	873.3	20.8	0	266.2
Percent Biomass Buckthorn	N/A	7.2	0	56.4
Buckthorn IV	N/A	15	0	65.7
Buckthorn Relative Cover	N/A	32.7	0	61.6
Garlic Mustard Relative Cover	N/A	10	0	63.3
CCmean	N/A	3.7	2.9	4.8
CCmean Centralized	N/A	37	29	47.5
CC Variation (CC CV)	N/A	59.6	33.5	82.6
MinCC	N/A	0.2	0.001	2
MaxCC	N/A	7.7	5.5	10
FQI	N/A	14.7	7.5	23.7
FQI Normalized (FQIPrc)	N/A	17	37.8	100
FQAI	N/A	31.4	22.8	42.6
Number of Significant Species	4	0.3	0	2
Significant Species Relative Cover	N/A	3.4	0	20.7
Species Richness	253	36.8	15	61
Number of Weedy Species	55	6.1	2	16
Mean Weed Index (WEEDmean)	N/A	2.1	1.25	2.6
WeedLess Index (WEEDless)	N/A	45.7	21.9	66.7
WEEDmean Normalized (WEEDmeanPrc)	N/A	70.7	41.7	86.1

APPENDIX B: ASH DISTRIBUTION AND ABUNDANCE

ASH FREQUENCY

PERCENT ASH TREES

RELATIVE ABUNDANCE OF ASH

IMPORTANCE VALUE (IV) OF ASH

Ash Biomass

Forest Regeneration

Appendix C: EAB Presence and Intensity

Ash Canopy Dieback

EAB Infestation

Appendix D: Weeds and Invasive Species

Relative Abundance of Buckthorn

Relative Abundance of Garlic Mustard

Percent Buckthorn

Buckthorn Biomass

Weedy Species

APPENDIX E: SIGNIFICANT SPECIES AND FLORISTIC QUALITY

SPECIES RICHNESS

SIGNIFICANT SPECIES

FLORISTIC QUALITY