POTENTIAL UTILIZATION OF GREEN ASH WOOD AS A RESULT OF EMERALD ASH BORER PROACTIVE MANAGEMENT IN THUNDER BAY, ONTARIO

by

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ABSTRACT

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The emerald ash borer (*Agrillus planipennis* Fairmaire) (EAB) was discovered in Thunder Bay, Ontario in June, 2016. Since that time, the city of Thunder Bay has implemented a proactive management plan of 50% treatment and 50% removal of urban green ash (*Fraxinus pennsylvanica* Marsh.) to hinder the spread of EAB to the surrounding region. As a result, hundreds of city managed green ash are scheduled for removal annually until target levels have been reached. Many of these trees were sent to landfill in 2017, primarily as a result of a quarantine on ash removal from city limits by the Canadian Food Inspection Agency (CFIA). Green ash is a high quality hardwood with many advantageous wood properties (similar to white ash (*Fraxinus americana*)) that can be used for a variety of applications. Some green ash trees cut down off of Court Street were donated by the city of Thunder Bay to the portable milling course at Lakehead University. These trees were milled using a WoodMizer LT40H portable bandsaw mill and data on wood recovery and quality was recorded. One green ash log was milled to produce 82.8 board feet (bf) of one-inch thick lumber (57% wood recovery), which was conservatively estimated to have a value of $293.11. Butt logs were found to contain a large amount of metal nails, which can be damaging to mill equipment and become a safety hazard. These logs can be milled but only after thorough scanning using a metal detector. Considering that one green ash log produced hundreds of dollars worth of high quality ash lumber, an economic opportunity exists for a small business, the city or an individual who is willing to help divert Thunder Bay’s green ash from landfill disposal.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Mathew Leitch for supervising this thesis project and being patient with its completion. I would also like to thank class mates from the Lakehead University forestry department’s portable milling course, NRMT-4276, in fall 2017 that shared data from their ash milling projects for use in this thesis paper.

INTRODUCTION

The city of Thunder Bay, Ontario is located on the northwest shore of Lake Superior, approximately 63 km and 545 km by road from the Pigeon River, U.S.A. and Manitoba borders, respectively (Google Maps 2017). The climate in Thunder Bay is relatively cold when compared to most of the urban centres in Ontario. Thunder Bay is located in plant hardiness zone 3B (Natural Resources Canada 2017), which ultimately limits the number of plant species that can survive outdoors in comparison to more southern parts of Ontario. As a consequence, many genera and species of trees that are commonly found in urban municipalities throughout many cities in Ontario do not survive the harsh and volatile winter seasons of the Thunder Bay region. As of 2011, 64 species representing 29 genera existed as municipally managed street trees, according to the Thunder Bay Urban Forest Management Plan (City of Thunder Bay, 2011).

As of 2011, green ash (*Fraxinus pennsylvanica* Marsh.) represented 26 percent of the managed tree population in Thunder Bay (City of Thunder Bay 2011). A considerable number of green ash trees are also planted on private property in Thunder Bay. Green ash is very tolerant to moisture and temperature extremes (Schoonover 1955), which allows it to survive and thrive in Thunder Bay's urban forest. Due to the tolerance of green ash to environmental extremes and other stressors, it has been planted extensively throughout the city and generally does well where planted. However, as a best management practice in urban forestry, a single genus should not represent more than 20 percent and a single species should not represent more than 10 percent of the total tree population in any given municipality (City of Thunder Bay 2011; Santamour 1990).

Urban trees are often planted in unfavorable locations for optimal growth and can experience the synergistic effects of multiple stressors including, but not limited to: air pollution, soil pollution, soil compaction, vandalism (Poland and McCullough 2006), salt deposition (Equiza et al. 2017) and construction. Compared to forest trees, the stressful conditions of urban life allow for increased susceptibility to attack from insects and pathogens (Poland and McCullough 2006).

In the summer of 2002, the emerald ash borer (*Agrillus planipennis* Fairmaire) was detected in six counties in Michigan, U.S.A. (Raupp et al. 2006) and has since been spreading across eastern North America, devastating urban and natural ash tree populations along its way. On June 30, 2016, the city of Thunder Bay issued a media release (in conjunction with the Canadian Food Inspection Agency (CFIA)) that confirmed the presence of emerald ash borer (EAB) on a municipally owned green ash tree at the intersection of 4th Avenue and Memorial Avenue (City of Thunder Bay 2016). In 2016, the CFIA and city of Thunder Bay began a monitoring program to attempt to quantify the severity of the presence of EAB in the city. A map of the EAB finds are displayed in Figure 1. As of June 30, 2016, the CFIA imposed a quarantine on the removal of ash wood from within the city limits of Thunder Bay as an attempt to delay the spread of EAB into the forests surrounding the city (CFIA 2017). Aggressive sanitation of satellite EAB populations can slow their population increase by approximately 54%, compared to doing nothing (Fahrner et al. 2017). On November 7, 2016, Thunder Bay City Council approved the recommendations of the Emerald Ash Borer Active Management Strategy to proactively treat 50 percent of the city's ash trees with an insecticide, TreeAzin®, while removing the other 50 percent (Viehbeck 2016). Rena Viehbeck (2016), of the city of Thunder Bay's forestry department, projected that at least 200 green ash trees would be removed in 2017.

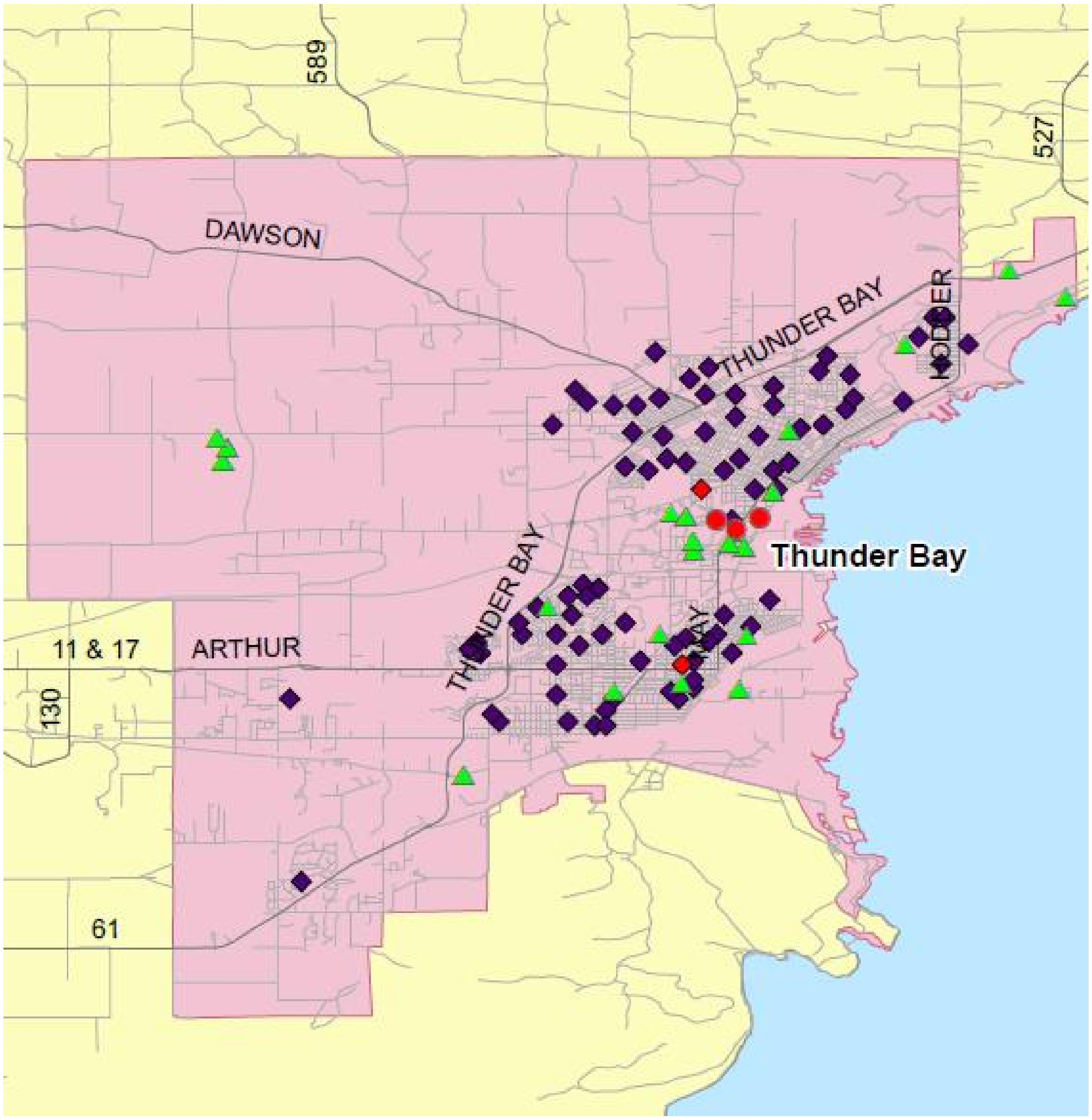

Figure 1. Results of the 2016 emerald ash borer monitoring program after the discovery of the insect within city limits. Red marks indicate positive finds, with green/purple indicating negative finds (City of Thunder Bay 2016).

As a response to the quarantine conditions imposed by the CFIA, the need to immediately limit EAB vectors, and budget constraints, the city of Thunder Bay has buried many of the ash logs removed in 2017 into a local landfill site. These ash logs cannot be used and transported as firewood due to the aforementioned CFIA restrictions, which leaves little opportunity for the municipality and general public to utilize the resource. Given that approximately 50% of Thunder Bay's green ash population is scheduled for removal in the next few years, a large quantity of potentially viable hardwood will become available as a result. This provides a prospective opportunity to produce marketable hardwood and an assortment of value added products from city grown trees that would otherwise be entombed into a nearby landfill site. If the removed green ash trees are milled so that no bark and cambium remains, the emerald ash borer cannot reproduce successfully and the wood should be exempt from the CFIA restrictions. Across North America, much of the wood that is generated as a result of street tree removals does not bring a significant rate of economic return towards municipal tree management budgets and many of these budgets operate under deficits (Cesa et al. 2003). It is doubtful that the city of Thunder Bay would prefer to dispose of these ash trees into landfill. Finding alternative uses for this resource could free up space in landfill for other wastes; provide a quality hardwood for entrepreneurial, private or public use; and potentially help offset municipal urban forest management costs.

OBJECTIVE

The objective of this project is to examine milling results of Thunder Bay grown green ash in order to enhance understanding of wood yield and wood quality from these trees. Combined with knowledge of the inherent properties of green ash, potential utility and marketability options will be explored. Diversion of hundreds of green ash trees from landfill could potentially reduce disposal costs for the city of Thunder Bay.

HYPOTHESIS

The green ash logs that are harvested from Thunder Bay streets as a result of the EAB Strategic Action Plan can be milled effectively to produce a large quantity of viable ash hardwood that could potentially be utilized by the municipality or general public at a low environmental and economic cost, with opportunities for further creation of value-added and locally sourced wood products.

LITERATURE REVIEW

EMERALD ASH BORER

Life Cycle

Adults emerge from their pupal stage in late May or early June via D-shaped exit holes (approximately 3–4 mm in diameter) and begin feeding on the leaves of *Fraxinus* trees (Poland and McCullough 2006; Timms et al. 2006). Adults feed for 5–7 days prior to mating, with the females feeding for an additional 5–7 days before laying eggs in bark crevices (Poland and McCullough 2006). After approximately two weeks, the larvae hatch and bore into the phloem and cambium tissues of the trees and feed continuously, leaving S-shaped galleries filled with frass (Timms et al. 2006).

In late October or early November pre-pupation occurs (Poland and McCullough 2006). EAB larvae develop through four instars before pre-pupation (Poland and McCullough 2006). Galleries are predominantly found under the bark on the south-west side of the tree (Timms et al. 2006), which is also the location that receives the most sunlight throughout the year (especially winter). Pupation commences in mid-April and continues into May (Poland and McCullough 2006), until the adults chew their characteristic D-shaped exit holes to perpetuate their life cycle. Occasionally, some EAB populations deviate from their normal one-year life cycle and develop over two years in colder climates (Timms et al. 2006).

<u>In North America</u>

The emerald ash borer does not cause extensive damage to ash trees in its native range in Asia because those trees have evolved alongside the insect and adapted defense mechanisms that allow for resistance to EAB larvae proliferation (DeSantis et al. 2013). Ash trees in North America have not evolved these same defense mechanisms, making them an ideal and relatively easy target for EAB. The initial introduction of EAB into the greater Detroit area likely occurred in the mid to late 1990s (Fahrner et al. 2017). Since its discovery in Michigan in 2002, EAB has spread across eastern North America and has done extensive damage to native and urban ash populations.

Without human assistance, EAB is estimated to have a natural spreading range of approximately 20 km/year (DeSantis et al. 2013) via its strongest flying adults. The actual rate of spread (>20 km/year) has been largely influenced by human-assisted long-range transport of firewood that contains overwintering or immature insects (DeSantis et al. 2013). Once the firewood had been moved to a new location, the insects emerged from under the bark and began looking for novel host trees in their new location. These satellite populations that have been introduced through human vectors have increased the rate of spread of EAB across eastern North America (DeSantis et al. 2013).

With some invasive insects, such as the Asian long-horned beetle, early detection can lead to aggressive pest management and quarantine programs using a combination of trapping surveys, insecticides, host plant removal and public outreach (Fahrner et al. 2017). With EAB, however, early detection is not feasible due to its endophytic larval lifestyle and difficulties with detection of low density infestations (Fahrner et al. 2017). Trees that are infested with EAB larvae do not usually show signs of decline until the infestation has passed the point of no return and the tree cannot be revived. The endophytic lifestyle of the larvae limits the effectiveness of monitoring and surveys that would not be invasive to individual ash trees. The best way to see if EAB larvae are present in any tree is to peel back the bark, however, in doing so the tree becomes susceptible to a large number of other pathogens that could be detrimental to individual tree health. As a result, monitoring programs typically focus on trapping adults using EAB pheromones contained within conspicuous hollow prisms (Figure 2).

Throughout its entire life cycle, the emerald ash borer experiences the coldest temperatures each year while it is overwintering as larvae underneath ash bark. Exposure to temperatures colder than -30°C has significant effects on EAB larvae mortality, however, variables such as snow cover and duration of extreme cold temperature events can reduce mortality (DeSantis et al. 2013). DeSantis et al. (2013) postulate that ash may persist in the future at the northern edge of its range due to the extreme cold temperature intolerance of EAB. These forests will still have small populations of EAB, but ash may persist indefinitely (DeSantis et al. 2013).

Figure 2. Emerald ash borer pheromone trap hanging from a green ash tree (CBC News 2016).

Symptoms of EAB infestation include: Crown dieback and thinning of foliage; epicormics branching; woodpecker damage as the birds strip away bark in search of larvae; D-shaped emergence holes approximately 3 mm in diameter; and meandering larval galleries in the cambium tissue when bark is removed (Brashaw et al. 2012).

GREEN ASH

Natural Populations

Fraxinus pennsylvanica (Marsh.) has a broad habitat tolerance, occurring naturally in swamps, riparian areas and moist uplands (Knight et al. 2013). Following an analysis of small forest stands of green ash in Michigan, Kashian (2016) hypothesized that green ash will persist in the continued presence of EAB, however, ash stand densities will not rebound to pre-EAB levels due to the ongoing presence of the beetle. Ash trees that are as small as 2.5 cm diameter at breast height (dbh) are killed by EAB, resulting in mortality before reproductive maturity is reached (Klooster et al. 2014). The result will be loss of recruitment and depletion of seed production across ash populations (Klooster et al. 2014). Permanent establishment of EAB in green ash stands should restrict ash densities, with lower ash density creating a negative feedback loop to restrict EAB populations in return (Kashian 2016).

Wood Properties

White ash (*Fraxinus Americana* L.), which is very similar to green ash, has an average green moisture content of 46% (heartwood) and 44% (sapwood) (Hoadley 2000:115). Ash wood shrinkage when drying is moderate when compared to other hardwoods (Mullins and McKnight 1981). The wood is hard, elastic, strong, brittle and straight-coarse grained (Schoonover 1955). The heartwood of green ash has a variable light-brown colour and the sapwood is light and pale (Figure 5).

Ash trees are considered valuable for their role in the manufacture of many forest derived products (Timms et al. 2006). The wood of white and green ash is used for many purposes, including multi-purpose tool handles, baseball bats, flooring, agricultural implements, furniture, woodenware, novelties (Schoonover 1955; USDA Forest Service 1999), oars, snowshoes (Mullins and McKnight 1981), decorative veneer, cabinets, millwork and crates (USDA Forest Service 1999).

Figure 3. A partially milled green ash log. Heartwood is a variable light-brown colour in contrast with the light and pale sapwood on the margins of the log.

Mechanical Properties

Green ash is just slightly lighter or less dense than white ash, which has an average density of 690 kg/m^3 (43 lb/cu ft) (Mullins and McKnight 1981). Ash wood is average in most machining characteristics and is easily bendable (Mullins and McKnight 1981), which contributes to its versatility in utilization purposes. A summary of some of important mechanical properties of three *Fraxinus* species is outlined in Table 1.

Table 1. Important mechanical properties for green ash (*Fraxinus pennsylvanica*), white ash (*Fraxinus americana*), and black ash (*Fraxinus nigra*).

Species	Specific Gravity	MOR (psi)	MOE (mil psi)	Impact Bending (inches)	Side Hardness (lb)
F. pennsylvanica	0.53	9,500	1.40	35	870
	0.56	14,100	1.66	32	1,200
F. americana	0.55	9,600	1.44	38	960
	0.60	15,400	1.74	43	1,320
F. nigra	0.45	6,000	1.04	33	520
	0.49	12,600	1.60	35	850

The specific gravity (or density) of wood largely determines many of its mechanical properties, with strength and stiffness increasing as specific gravity increases (Haygreen and Bowyer 1982). The specific gravity of green ash ranges from 0.53-0.56 (Haygreen and Bowyer 1982). For comparison, white ash has a specific gravity range of 0.55-0.60 (Haygreen and Bowyer 1982).

Modulus of elasticity (MOE) is the measure of the resistance of wood to bending (Haygreen and Bowyer 1982), or commonly referred to as stiffness (Teranishi et al. 2008). The MOE for *Fraxinus pennsylvanica* is 1.40-1.66 mil psi (Haygreen and Bowyer 1982).

Modulus of rupture (MOR) is the measure of the load that a beam can carry (Haygreen and Bowyer 1982). The MOR for *Fraxinus pennsylvanica* is 9,500-14,100 psi (Haygreen and Bowyer 1982).

The impact bending test is a measure of bending resistance when weight is dropped from standardized heights (Haygreen and Bowyer 1982). The impact bending height (causing complete failure) ranges from 35-32 in green ash.

CHARACTERISTICS OF URBAN TREES

Urban-grown trees experience many environmental and climatic differences from their forestland counterparts and they subsequently exhibit differential growth and physical patterns (City of Toronto 2016). Forest-grown shade-tolerant hardwoods typically have limited sunlight on the forest floor when they are young and their best chance at reaching maturity is allocating the majority of their resources towards height growth. The end result is a mature tree with a much straighter trunk and limited amount of defects. Urban trees are often grown in full sunlight and the trees begin lateral branching at an earlier age (Cassens and Makra 2014) to maximize overall leaf surface area and increase photosynthetic capacity. Fast growth, ring-porous species such as oak (*Quercus*), ash (*Fraxinus*), and elm (*Ulmus*) have more distinctive grain pattern when grown in open (urban) landscapes compared to forest derived trees (Cassens and Makra 2014). Urban trees are often subject to more challenges and obstacles to growth compared to forest trees and the result is greater wood irregularity (City of Toronto 2016). Some wood irregularities (e.g. frost cracks, fungal decay, included bark, mineral stain) decrease wood value while other irregularities (e.g. spalting, burlwood, crotchwood) increase wood value (Cassens and Makra 2014). The value of urban-grown trees is largely dependant on: the species of tree; presence of irregular defects on the sawlog; quality of the wood; presence and extent of decay; and growth form of any individual tree (Cesa et al. 2003).

Wood Decay

When compared to forest derived trees, which are harvested in excellent condition and health, urban trees are often harvested because they are in bad condition, poor health or become unsuitable for the planting space (Cassens and Makra 2014). Injuries to trees occur more often in the urban landscape than in forests, often resulting from collisions or interaction with machinery. Injuries to trees provide entry points for spores of saprophytic decay fungi, which colonize the tree over a period of many years. *Fraxinus* wood is characterized as only slightly or non-resistant to decay (Cassens and Makra 2014) and could be a candidate for spalting as a value added option.

Growth Features

Many growth features of urban trees add value to the wood when it is utilized for lumber or other woodworking purposes. Burls are defects in trees that appear as round swellings on branches or main stems. Burlwood is unique in its grain patterns and figurative characteristics (Figure 3), which makes it a sought after commodity for the creation of high-value wood products (Cesa et al. 2003). Wood that exists in the crotch of two diverging stems on urban trees also exhibits uncharacteristic and irregular grain pattern. Crotchwood is another highly valuable woodworking material due to its figurative characteristics, similar to burlwood (Cesa et al. 2003). Spalting is a phenomenon whereby multiple species of decay fungi colonize the same log and compete for space, creating conspicuous black lines on the margins of their territory in the log (Cassens and Makra 2014). The resulting pattern (Figure 4) is unique, visually appealing and sought after by specialist and hobby woodworkers. Spalting significantly increases the value of the wood (Figure 5., Cesa et al. 2003).

Figure 4. Burlwood surrounded by heartwood from an ash tree (The Wood Database 2018a).

Figure 5. Spalted maple, where black lines are created by fungi competing for space in the wood (The Wood Database 2018b).

Contaminants and Foreign Substances

The major reason why demand for urban-grown sawlogs is generally low is due to the presence of metal and other foreign substances that can be found included in the wood (Cesa et al. 2003). Urban trees are more likely to contain metal contaminants due to their proximity to humans. Trees are used for items such as hammocks, bird feeders, dog stakes, clotheslines (Cassens and Makra 2014), nails, wires, and spikes (Cesa et al. 2003). Metal in urban trees can be damaging to sawmill equipment and potentially become a safety hazard for millworkers due to the possibility of flying metal when sawblades come into contact (Cesa et al. 2003). New blades for thin kerf band sawmills (e.g. WoodMizer LT40H) cost around $20 to replace and resharpening is approximately $10 if the teeth are not damaged beyond repair (Cassens and Makra 2014). An effective way to mitigate sawblade damage from metal is by using metal detectors on the sawlog prior to milling (Cesa et al. 2003). Most metal is normally located within the butt log, which is the first four to six feet on a tree (Cesa et al. 2003).

METHODS

Multiple ash trees were donated by the city of Thunder Bay to the Lakehead University portable milling course in the fall of 2017 (Figure 6). The following methods and milling procedures were used by each team of two or three students that were enrolled in the course.

Figure 6. Green ash logs that were donated by the city of Thunder Bay after being removed from Court Street in 2017.

The green ash logs were milled using either the quarter-saw (canting) method or the through and through method followed by usage of the Wood-Mizer Twin Blade Edger to remove bark and defects. Logs were lifted onto a Wood-Mizer LT40H using the attached hydraulic lift system. Hydraulic toe-boards were used to level the log for even cutting, approximately parallel to the pith. The logs were secured into cutting position against the twin dogs with the hydraulic clamp system. The hydraulic clamp was secured near the centre of the log in order to ensure that the band saw blade would not contact the clamp during cutting.

With the through and through method, cuts were made at a thickness of 1 inch for each board. Once the preliminary cuts were completed, scrap wood was removed and collected for disposal. Cuts through the log were performed until we were approximately 1 inch from the pith. The hydraulic clamp was then removed and the log was flipped using the hydraulic log turners. The hydraulic clamp was then reapplied at the base of the log (no higher than 1” from the rails), which now sat flat on the rails on its open face. Toeboards were lowered at this point. Once the log was secured safely, milling resumed until all 1” boards were cut from the log. Each 1-inch-thick board was taken to the Wood-Mizer Twin Blade Edger and ran through the machine, ensuring that all bark was removed (Figure 7). Another method that was used by some groups to remove bark from boards was to use the Wood-Mizer LT40H to make multiple edge cuts at once (Figure 8). Care was taken to ensure that minimal waste wood was removed when debarking these boards. Log dimensions and final board foot (bf) recovery measurements were recorded.

Figure 7. Removal of bark from 1” boards using the Wood-Mizer Twin Blade Edger.

Figure 8. Removal of bark from 1” boards using the Wood-Mizer LT40H.

Using the canting method, each log was cut at one-inch thicknesses until bark was removed and the resulting exposed face was wide enough to approximate one side of the cant (Figure 9). The log was then rotated using the hydraulic log turners until the newly cut flat side of the log rested flush against the dogs and was re-clamped. Cutting resumed until a 90-degree angle was present on the cut edges and no bark was present throughout the cut sides. The same process repeated, as the log was turned with the previously cut flat edge resting against the twin dogs. Once the remaining excess wood was removed on the final edge of the cant, cutting of quarter sawn wood commenced until the entire cant had been milled into 1-inch boards (Figure 10). Salvageable boards from 4 outer cuts of the cant were taken to the Wood-Mizer Twin Blade Edger if they had at least 3 inches (width) of sound wood on both sides of the board.

Prices for rough sawn ash wood at 4/4 (1-inch) thickness were obtained from the website of three hardwood suppliers in southern Ontario: Peacock Lumber, Century Mill and Woodshed Lumber.

Figure 9. A green ash log being milled using the canting method. This log would need a couple more cuts at 1” thickness to finish one side of the cant.

Figure 10. Green ash log milled using the quarter saw (canting) method.

RESULTS

Results of the milling of a green ash log are displayed in Table 2. Log length and diameters from each end were used to calculate volume. The recovered boards and their dimensions are shown in Table 3.

Table 2. Volume, dimensions and recovery for a green ash log milled by the WoodMizer LT40H.

Log Length (inch)	Avg. Log Diameters (inch)	Log Volume (inch^3)	Recovery (inch^3)	Recovery (%)	Off Cut (%)	Kerf (%)
132	13.65 14.56	20,651.0	11,923.5	57.74	39.66	2.60

Table 3. Recovered board dimensions for a green ash log.

Number of Boards	Length (inch)	Width (inch)	Thickness (inch)
1	69	5	1
1	67	6	1
1	71	6	1
9	132	7	1
1	77.5	9	1
1	99.5	11	1

Recovery, trim and kerf percentages for each group and each cutting method are displayed in Table 3. There were 13 green ash logs cut in total, using both methods. Average percentages are shown at the bottom of Table 4, and presented graphically in Figure 11 and Figure 12.

The average results for each method were very similar in recovery, trim and kerf percentages. Only a slight deviation in recovery and trim percentages exist for each method in this study. The canting (quarter-saw) method saw a slight advantage in recovery percentage compared to the through and through method.

Table 4. Calculated results of recovery, kerf and trim percentages of green ash logs for each group in NRMT-4276. Through and through (T+T) cuts combined with utilization of the Wood-Mizer Twin Blade Edger and the canting (quarter-saw) techniques were used. Average percentages for each technique are presented below.

Recovery %		**Kerf %**		**Trim %**	
T+T w. Edger	Cant Method	T+T w. Edger	Cant Method	T+T w. Edger	Cant Method
63.0	65.2	3.0	2.9	34.0	31.8
68.0	68.0	3.0	3.1	29.0	28.9
76.1	77.0	3.1	3.5	20.8	19.5
81.0	57.7	3.0	2.6	16.0	39.7
43.0	62.3	2.0	2.8	55.1	34.9
70.7	75.0	2.7	3.2	26.6	28.8
	72.7		3.3		24.1
66.97	68.27	2.79	3.05	30.24	29.66

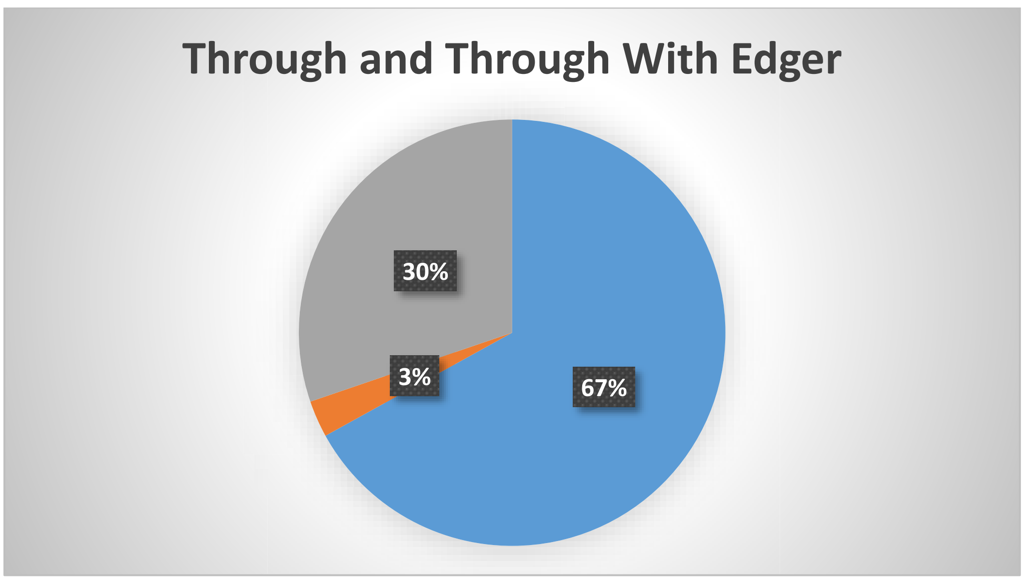

Figure 11. Average recovery % (blue), trim % (grey) and kerf % (orange) for the through and through cutting method, using the Wood-Mizer Twin Blade Edger.

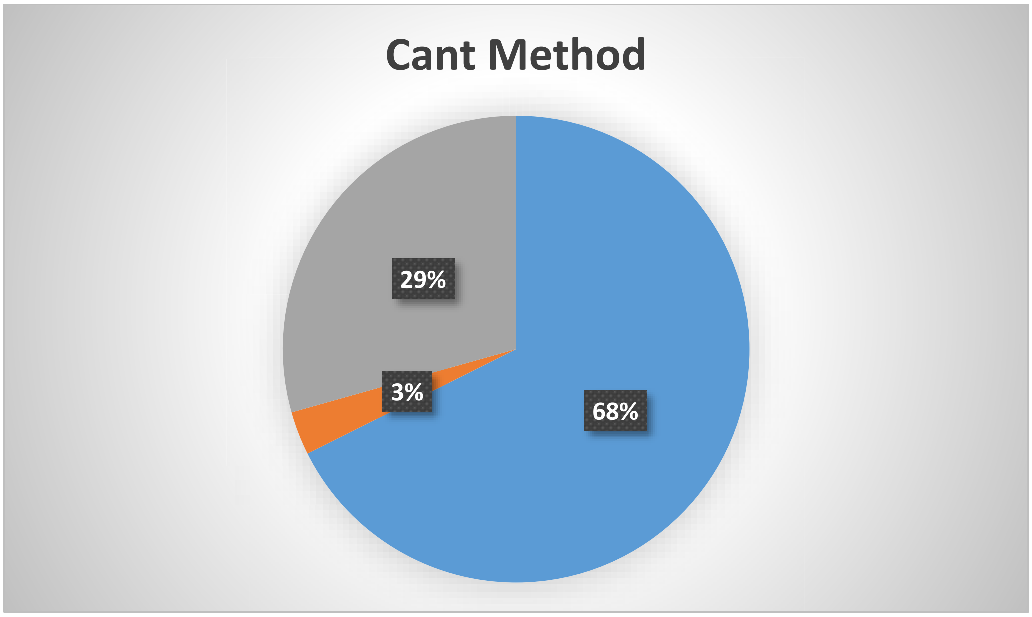

Figure 12. Average recovery % (blue), trim % (grey) and kerf % (orange) for the canting (quarter-saw) cutting method.

Green ash boards that were milled for the purposes of this thesis paper were cut at one-inch thicknesses. Prices for four commonly used tree species in Canadian dollars are listed in Table 5. For comparison, Century Mill (2018) prices one-inch thick ash at $4.10 CAD per board foot (bf) and Woodshed Lumber (2018) prices ash starting at $4.00 CAD per bf. These companies are in southern Ontario. Ash is likely in less supply in northwest Ontario, as many lumber companies that source most of their wood locally do not have it in stock in the Thunder Bay area.

Table 5. Prices ($) of ash, birch, maple and walnut boards per board foot (bf) for one and two inch thicknesses (Peacock Lumber n.d.).

Species	Board Thickness	
	4/4 (1")	8/4 (2")
Fraxinus	3.54	4.33
Betula	3.88	4.55
Acer	4.20	4.70
Juglans	11.21	11.92

DISCUSSION

Processing sawmill-sized logs from municipally derived street trees has many advantages, as outlined by Cesa et al. (2003): Potential income that can be generated from selling logs or developing bartering arrangements; reduction in labour cost by reduction in time spent by work crews in processing logs into firewood; reduction in amount of woody material to landfills; reduction in landfill costs for disposal; and conservation of forestland resources by generating saw logs from street trees that must be removed anyway. In this particular case, with the CFIA imposing a quarantine on the removal of ash wood from city limits, the city of Thunder Bay has opted to send its removed ash wood to landfill in order to limit EAB vectors in the city and mitigate potential wood processing costs. If the CFIA had not imposed a ban on ash wood transport, then the possibility of using this wood as firewood would be a viable option. Even when conversion of street trees into firewood exists as a viable option to offset municipal tree budget costs, the dollar return potential of selling the log for lumber products exceeds the return potential of selling firewood by at least two to four times (Cesa et al. 2003). In addition, the offcuts from a lumber operation could be chipped to be used and sold as mulch or biomass for wood pellets.

“Sawmills are the market and opportunity to which street tree logs can be merchandised” (Cesa et al. 2003). With the increased popularity of modern band-saw portable mills, trees no longer need to be transported to sawmills for processing. Portable mills have the advantage of having the ability to travel to wherever saw logs are located, thus reducing wood transport costs. One of the major setbacks to milling urban trees is the widespread presence of nails and other foreign metals in the wood (Figure

13), which is damaging to mill equipment. Using a metal detector can mitigate damage to band saw blades, however, it is not always effective, especially when larger logs are being cut.

Figure 13. A nail that was present inside a board. The tree grew around the nail over the years and surrounded it with wood.

Considering the results found in Table 2, the green ash log had an initial volume of 20,651 $inch^3$ and had a recovery of 11,923.5 $inch^3$ (57.7%). This log produced 82.80 bf (1 bf = 144 $inch^3$) of green ash lumber. If the most conservative price for rough sawn ash wood is used from Table 5 ($3.54 per bf (Peacock Lumber n.d.)), then the approximate value for the lumber derived from this green ash tree would be $293.11 CAD, excluding any increase in price for grain feature (e.g. burlwood, crotchwood and spalting). Considering that the city of Thunder Bay will be removing hundreds of these trees over the next few years, this could provide an economic opportunity for the city, a small business or eager individual/group.

When comparing the cutting methods in this experiment, there is no significant difference in recovery, trim and kerf percentages. Each method had similar recovery percentages. The goal of any sawyer is maximizing recovery in order to utilize as much of the log as possible. Although recovery percentage is nearly identical between each cutting method, the canting method offers an advantage over the through and through method when it comes to final production quality of the boards. The canting (quarter-saw) method typically produces higher quality wood due to the fact that the growth rings are oriented in a way that provides greater stability and reduces defects when drying. In addition to the enhanced final board quality, the canting method is advantageous because no edging is needed once the log has been milled. This could allow for a smaller work crew and less steps and movement of wood when milling these logs. The quarter sawn method in Figure 14 is not the method that was used in this study, but it illustrates the desire for grain pattern orientation. This is popular for white oak hardwoods (Cesa et al. 2003). The canting method creates a square slab while cutting off the edge wood and minimizing offcuts.

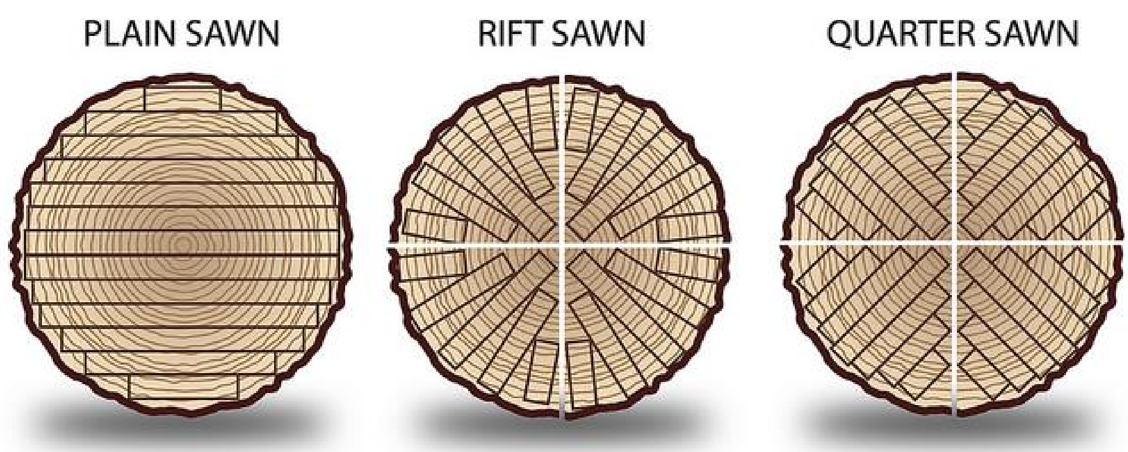

Figure 14. Milling methods: Plain (flat/through and through), rift and quarter sawn logs (Stack Exchange 2017).

One of the major limitations to increasing wood recovery in this study was the extensive presence of metal nails that were found in the butt logs of the green ash removed from Court Street. After multiple blades were broken and 13 nails were hit on the first ash log that was milled, it was determined that the butt logs all had multiple metal objects inside using a metal scanner. Each band-saw blade that is installed on the Wood-Mizer LT40H costs in excess of $30. With every blade that is damaged or ruined by striking hidden nails in a tree, the potential for profit for a sawyer is diminished. Therefore, only the crown logs or logs that were found to be clean using the metal detector were used in this recovery study after the first butt log was milled. This proved to be advantageous because it almost guaranteed that no nails would be present and that potentially less taper would be present on the logs. The downside to this problem is that the butt logs, which contain the majority of the wood in a tree, become unusable. Metal detectors can be used to identify potential nail locations, but each time a nail is struck by the band-saw blade it presents safety and economic concerns for any sawyer (Cassens and Makra 2014).

Log size is another factor that influences recovery, as larger logs have increased recovery volume compared to smaller logs (Steele 1984). The presence and potential for nails in small logs could make smaller street ash uneconomical since a sawyer would not want to risk ruining a blade for a diminishing return in lumber.

Considering the results of the recovery study, it seems that the butt logs from these particular trees are predominately unsalvageable when it comes to lumber production via milling. This could have been a particularly bad street for residents hammering nails into the trees. Court Street in Thunder Bay is one of the busier streets in the city, so an ash tree from a quitter neighborhood may have less likelihood of nails in the butt logs of those particular trees. Each tree that is milled from an urban location should be scanned with the metal detector to mitigate sawblade damages. This can be performed on site of the milling operation. These particular logs in this study that contain nails will likely be destined for landfill. However, some of the wood was provided to wood turners where the sections between nails were large enough (greater than 18 inches in this case). Even if a sawyer cannot utilize a particular log that is loaded with nails, value added opportunities can still exist for other woodworkers willing to get creative.

When wood is buried it typically becomes wetter (depending on the relative wetness of the environment), which affects wood decomposition rates (Moroni et al. 2015). Depending on a number of factors, landfills are generally considered hydraulically active and can exist in both saturated and unsaturated conditions (Fleming 2011). With increasing wood moisture levels, anaerobic conditions manifest within the wood thus affecting decomposition rates and mechanisms of decay (Moroni et al. 2015). Under anaerobic conditions, decomposition by saprophytic decay fungi (*Basidiomycetes*) is hindered, with soft-rot fungi (*Ascomycetes*) and bacteria becoming the dominant wood decay drivers (Moroni et al. 2015). Avoiding landfill can reduce the overall amount of carbon that is released through decay processes. By utilizing the wood from city grown green ash trees, carbon sequestration is increased.

Recovery of timber that has been cut down as city trees has several advantages to the community. These trees could be used as a potential source of income for the city to offset some of the costs of forestry related work in Thunder Bay, including, but not limited to: replanting, tree removal, disposal (butt logs), insecticide, and pruning. In addition, the hardwood that is obtained from these street trees could theoretically reduce the need for natural forest hardwoods, which are of relative scarcity in the Thunder Bay region compared to southern Ontario. Utility of this resource could also promote environmental awareness and conscientiousness in the city. The ash hardwood that is cut down in the next few years could potentially be used to build city infrastructure projects, park features, or be used as combinatory educational and multi-purpose structures. For example, some of the ash wood could be used to build a gazebo in a park. This gazebo would be used by locals for years to come and could offer an educational opportunity for the forestry department on the impacts that invasive species have on our urban forest. In addition, with 50% of the city's ash trees scheduled for treatment of an insecticide in perpetuity, they will remain on the urban landscape but will require a collectively large sum of money to pay for insecticide treatments every two years in order to stay alive.

CONCLUSION

The city of Thunder Bay should consider utilizing the crown logs of many of its green ash that are scheduled for removal in the next few years. There is a large cost associated with the removal and disposal of these trees, at the expense of local taxpayers. Offsetting these costs by reusing parts of some of the removed trees is environmentally and economically conscious, and should be explored as an option by the city of Thunder Bay. Utilization of these trees could provide economic opportunities, educational opportunities, raw materials for infrastructural projects, potential income to offset forestry related costs and diversion of local natural hardwood harvest.

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APPENDIX

Table 6. Recovery, kerf and trim percentages from each group in the portable milling course, NRMT-4276. Ash logs have been highlighted in green. The other logs in this table were white spruce.

Group	Saw Pattern	Recovery %	Kerf %	Trim %
Will C., Karly J., Tao L.	T & T with edger Small Log	53	3	44
	T & T with edger Large Log	58.75	2.6	38.65
	Cant edge on mill- high taper	65	3	32
	Ash T & T with edger large log w/ crack	36	2	62
Rob Glover & Cheng Xu	T & T with edger Small Log	51	2	47
	T & T with edger Large Log	81	3	16
	Cant with edger large log	67	3	30
	Ash T & T with edger	63	3	34
Wenchao Li & Zhen Zong	T & T with edger Small Log	62	3	35
	T & T with edger Large Log	65	3	32
	Cant with edger large log	61	3	36
	Ash T & T with Edger	68	3	29

James Haveman & Avery Nagora	T & T with edger Small Log	58.5	2.6	38.9
	T & T with mill edge Large Log	49.1	2.2	48.7
	T & T with edger large log	76.1	3.1	20.8
	Ash cant with Edger	65.2	2.9	31.8
Alex Emond & Felix Winkelar	T & T with edger Small Log	61	2.8	36.2
	Cant with edger Large Log	64	2.9	33.1
	T & T with mill edge large log	81	3	16
	Ash cant with Edger	68	3.1	28.9
	Cant with edger Large Log	77	3.5	19.5
Gaorun Tao & Blair Binnendyk	T & T with edger Small Log	53.46	2.41	44.14
	T & T with mill edge Large Log	72.32	3.25	24.42
	T & T mill edge large log	42.98	1.97	55.05
	Ash cant mill Edge	57.74	2.6	39.66
	Cant with edger	62.26	2.8	34.93
Lucas Klagas & Tian He	T & T with edger Small Log	50.291	2.263	47.446
	T & T with mill edge Large Log	59.362	2.671	37.966
	T & T with edger large log	70.73	2.672	26.59
	Ash cant Edger	75.006	3.18	21.815
	Cant with edger	72.678	3.271	24.052