FOREST STAND TYPE AND FOREST DIVERSITY AFFECT ON ABOVE GROUND CARBON BIOMASS IN ONTARIO'S BOREAL FOREST

by

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INTRODUCTION

Biomass is a renewable organic material that is the living and recently dead organic material synthesized by plants and other organisms (Battles 2015). Quantifying forests and determining their value is an increasingly important concept in modern forestry. Forests are often quantified by estimating their total above ground biomass in forest ecosystems (Drake et al. 2003). This is significant as in the urban United states alone, trees store approximately 700 million tonnes of carbon with an estimated value of 14.3 billion dollars. Understanding factors that increase a forest's biomass will have direct and indirect environmental and economic impacts (Nowak and Crane 2002).

Climate change is currently one of the largest threats to human health (Martens 1999). Greenhouse gases, a major cause of climate change, continue to rise. As a result, there are increasing levels of atmospheric carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, and tropospheric ozone which contributes to rising global temperatures (Novak and Crane 2002). Forests absorb atmospheric carbon and store it in plant tissues, which are approximately 50% carbon, helping to mitigate greenhouse gasses emitted by atmospheric carbon (Drake et al. 2003, Novak and Crane 2002).

Wood biomass is the oldest form of energy used by humans. In developing countries, which accounts for about 50% of the human population, biomass is relied on for fuel. In first world countries biomass has the potential to provide cost-effective and a sustainable supply of energy, while also aiding countries in meeting their greenhouse gas reduction targets (Taylor and Francis 2004).

Some of the most important factors affecting biomass potential are diversity and stand type. Diversity is now recognized as one of the three major factors controlling the functioning of ecosystems (Davis 2004), while productive ecosystems have greater biomass potential (Naeem et al. 1994). Stand type can also been seen as an important factor with regards to biomass, with mixed stands often more productive than conifer or deciduous dominated stands (Longeutaud et al. 2016). However, properties of each tree type also play a role in biomass potential. Hardwoods are dense and have properties that result in higher biomass comparatively to softwoods (Duune 2018).

The aim of this study is to determine if forest stand type and forest diversity has an affect on above ground carbon biomass.

LITERATURE REVIEW

DIVERSITY

Biodiversity is the variability of organisms found in an ecosystem, including genetic differences within species (Wilson 1988). Diversity does not just account for species richness, the number of species present, but also the proportion of each species in the stand (Poorter et al. 2015).

In forests, biodiversity correlates to forest health. According to Swangjang and Panishkan (2021), high levels of plant diversity result in a high level of ecosystem functioning. Forest health directly relates to forest productivity and in theory a higher capacity of biomass. Day et al. (2013) reported a relationship between high tree species diversity and increased biomass; while Poorter et al (2015) found biodiversity has a positive effect on above ground stand biomass (Poorter et al. 2015).

The niche complementarity hypothesis states that differences in functional traits between species will allow for greater complementarity in resource use between species. This in turn will increase the total amount of resources available to the forest community (Norman and Mouillot 2013).

Plant diversity and niche complementarity had progressively stronger effects on ecosystem functioning than monocultures, resulting in 2.7 times greater biomass than monoculture stands (Tilman et al. 2001). The study concluded that even the best-chosen monocultures cannot achieve greater productivity or carbon stores than higher-diversity sites (Tilman et al. 2001).

Ecological facilitation is a relationship where at least one organism benefits from another without harming the other individual (Brooker et al. 2021). Facilitation is a phenomenon that has beneficial interactions between species which in turn helps the entire ecosystem (Li et al. 2014). Facilitation only occurs in stressful or in harsher climates where reliance is important for survival (Michalet and Pugnaire 2014). It was determined however, that ecological facilitation is a concept that occurs in a variety of ecosystems, each to a similar extent (Michalet and Pugnaire 2014). It was also found that facilitation and species diversity had a strong relationship (Tilman et al. 2001). Higher levels of species diversity had a positive relationship on site facilitation. Michalet and Pugnaire (2014) also found that higher facilitation resulted in greater biomass potential.

While above ground biomass is strongly driven by climatic factors, tree diameter, species richness and other factors (Poorter et al. 2015), the relationship between diversity and biomass is an important relationship.

STAND TYPE

Above ground tree carbon stocks have three main determining factors: diameter at breast height, tree height, and wood density (Ray et al. 2011). While tree height and diameter are generally indicative of age, wood density can be isolated as tree density generally depends on if a tree is coniferous or deciduous (Longuetaud et al. 2016).

Hardwoods normally have a higher density and greater biomass capacity than softwoods (Longuetaud et al. 2016). Despite this, there are more significant factors that influence carbon storage. For example, it was found that increasing species richness can have a positive effect on carbon stock. It was determined that each additional tree species increases carbon stock by 6.4% (Liu et al. 2018); this was also true with plantations seeing a 6% increase in carbon storage (Dunne 2018). The same study also found that more diverse forests can store carbon “faster”. This means that forests productivity increases and their ability to store carbon and grow is at a rate “faster” than less diverse forests (Dunne 2018).

DETERMINING BIOMASS

Calculating biomass for each tree species is not a simple calculation, as such, each species requires its own equation. Each species has their own properties which dictate biomass potential. An example of this is wood density, i.e. range 160-1400kg/m^3. Other factors such as soil quality, nutrient availability, and even more complex variables such as stand diversity, density, or even richness can also affect biomass (Poorter et al. 2015). The largest influencing factor that affects biomass differences within species is climate (Chatzistathis and Therios. 2013). Climate, especially extreme weather events such as drought have important long-term effects on wood density. Climate also correlates heavily to stem height, growth rate, and stem density in immature trees (Bouriaud et al. 2005).

BATCHAWANA ECODISTRICT

The Batchawana Eco district is classified as ecodistrict 5E-13 and is associated with the Eastern Temperate Mixed Forest Vegetation Zone and the Algoma Section of the Great Lakes-St. Lawrence Forest Region (Wester et al. 2018).

Approximately 60% of the ecodistrict is deciduous dominated, with large, dense sugar maple (*Acer saccharum*) stands comprising 66% of the land base (Wester et al. 2018). Deciduous forests of sugar maple, yellow birch (*Betula alleghaniensis)*, and less commonly red oak (*Quercus rubra),* red maple (*Acer rubrum*), large toothed aspen (*Populus grandidentata*), trembling aspen *(Populus tremuloides*), and paper birch (*Betula papyrifera*) are all common (McQuay 1980).

Mixed forests are most common in the northeast in upland sites. Red pine (*Pinus banksiana*), balsam fir *(Abies balsamea*), and white spruce (*Picea glauca*) are common. In lowland areas eastern white cedar (*Thuja Occidentalis)* and black spruce (*Picea mariana*) are the dominant tree type. Coniferous species mainly reside in poorly drained sites that are associated with low-lying areas with bedrock. Soil is acidic with shallow overlying Precambrian bedrock (Wester et al. 2018).

Topography causes significant temperature, precipitation, and humidity differences across the ecodistrict due to the effect of Lake Superior (Wester et al. 2018). Wetland complexes have developed in the Batchawana ecodistrict with marshes common along the Lake Superior shoreline which also results in very different nutrient cycling. Areas in the Batchawana eco district can alter plant diversity where base-rich bedrock near the surface results in higher substrate nutrient availability (Wester et al. 2018).

METHODS AND MATERIALS

Data was collected in the Algoma property by NorthWinds Environmental Services using the 2022 Standard Operating Procedure (SOP): Field Measurements. The Algoma forest is part of the Great lakes St. Lawrence Region in Ontario. Located approximately at the coordinates N 47^0 00.200 W 84^0 23.900.

125 plots were sampled using seven different strata across the Algoma forest region. A Global Positioning System (GPS) determined plot center at random and an inventory of the plot was conducted. A nested plot design was used with a 11.28 metre fixed-radius circular plot and a smaller fixed 3.99 metre radius. In the 11.28 metre circular plot trees equal or greater than 9 cm diameter at breast height (DBH) were measured. In the 3.99 fixed radius plots, only trees from 5-8.9 cm DBH were measured. For each plot Stratum ID, Plot ID, name of worker taking measurements, date plot was measured, GPS coordinates at plot center, Maximum slope of plot, Aspect, and any other relevant notes were documented. DBH of live trees as well as dead trees were determined. Forked trees below 1.3m count as 2 separate stems, cankers, wounds, burls, bumps or branch whorls near or at DBH will require professional judgment and logic to measure. Finally, compliance is checked by hot checks, cold checks, and blind checks. In hot checks, auditors observe members of the field crew during actual data collection. These allow for the correction of errors in technique. Cold checks occur when field crews are not present for the audit. Blind checks represent the complete re-measurement of a plot by the auditors. This helps account for and calculate measurement variation (Ostrom Climate 2022).

Data was interpreted using SPSS from data documented in Microsoft Excel to determine diversity, stand type, and biomass for each of the 125 plots. Biomass was calculated using Ter-Mikaelian and Korzukhin (1997) North American tree species biomass equations.

To derive a formula determining biomass, there must be something conducive to the individual tree itself. Fortunately, there has been considerable research invested into estimating biomass of individual trees, relating to physical characteristics such as diameter at breast height (DBH), tree height or other factors. For this study Diameter at Breast Height is the physical characteristic that was used for determining each tree's individual biomass using equations developed by Ter-Mikaelian and Korzukhin (1997, Table 1).

Table 1 Summary of above ground biomass formula for each species.

Species	Region	Formula
White Birch (*Betula papyrifera*)	Great Lakes St. Lawrence	$M=0.1182(DBH)^{2.4287}$
Yellow Birch (*Betula alleghaniensis*)	Great Lakes St. Lawrence	$M=0.0872(DBH)^{2.5870}$
Speckled Alder (*Alnus incana*)	Maine	$M=0.2612(DBH)^{2.2087}$
Trembling Aspen (*Populus tremuloides*)	Great Lakes St. Lawrence	$M=0.0790(DBH)^{2.3865}$
Balsam Fir (*Abies balsamea*)	Great Lakes St. Lawrence	$M=0.0705(DBH)^{2.4920}$
Pin Cherry (*Prunus pensylvanica*)	Urban Maine	$M=0.1556(DBH)^{2.1948}$
Black Cherry (*Prunus serotina Ehrh*)	Urban West Virginia	$M=0.0716(DBH)^{2.6174}$
Red Maple (*Acer Rubrum*)	Great Lakes St. Lawrence	$M=0.1618(DBH)^{2.3095}$
Sugar Maple (*Acer saccharum*)	Great Lakes St. Lawrence	$M=0.1676(DBH)^{2.3646}$
Eastern White Pine (*Pinus strobus*)	Great Lakes St. Lawrence	$M=0.0755(DBH)^{2.3833}$
Black Spruce (*Picea mariana*)	Great Lakes St. Lawrence	$M=0.1137(DBH)^{2.3160}$
White Spruce *(Picea glauca*)	Great Lakes St. Lawrence	$M=0.1643(DBH)^{2.2480}$
Tamarack (*Larix laricina*)	Minnesota Boreal Forest	$M=0.1359(DBH)^{2.2980}$
Eastern-White Cedar (*Thuja occidentalis*)	Great Lakes St. Lawrence	$M=0.0910(DBH)^{2.2340}$

Diversity was calculated using Simpson's Diversity index (Figure 1). The variable n is the total number of organisms where n_i is the number of organisms that belong to species i.   (Fangliang and Sheng 2005):

$$1-\sum_{i=1}^{k}\frac{n_i(n_i-1)}{n(n-1)}$$

Figure 1. Measures diversity of species in a community ranging between 0 and 1 (Fangliang and Sheng 2005).

Stand type was placed in three categories, conifer, deciduous, or mixed (Table 2). Stands are categorized as mixed unless the stand is 70% or greater coniferous or deciduous trees, respectively. This is based on a study done by Dixon (1963) who created a classification system for Ontario’s Forests. In this system, if less than 75% of the stems in a stand were either coniferous or deciduous, the stand can be classified as mixedwood (Wedeles et al. 1995). In this thesis for a stand to be classified as conifer or deciduous dominated it must have 70% or greater dominance. This was decided as it satisfied the less than 75% parameter set by Wedeles et al (1995). While slightly lower, a 70% dominant requirement better encompassed the smaller number of plots looked at in this report at 125 plots.

Table 2. Between subjects factors table. One representing mixed forests two representing deciduous forests and three representing conifer dominated forests.

Stand Type	Number of Stands
1-Mixed Wood	42
2-Deciduous	69
3-Conifer	14

Biomass is often classified into above ground and below ground portions. While below ground biomass is important and can account for the majority of the species biomass such as in grasses; for the sake of this study calculating above ground biomass is more valuable for determining usable biomass (Cao et al. 2018). Biomass formulas derived from Ter-Mikaelian and Korzukhin (1997) were used for above ground biomass calculations in the Great Lakes St. Lawrence Forest region with the formula: $M=aD^b$. Where M represents biomass, D is the DBH (cm) and “a” and “b” are parameters (Ter-Mikaelian and Korzukhin 1997). Each species will have unique parameters and formula.

A linear regression analysis, a one way ANOVA, and an ANCOVA were run. In the linear regression analysis biomass and diversity were compared. The one way Anova compared stand type to total biomass.The ANCOVA compared diversity and stand type to biomass.

RESULTS

LINEAR REGRESSION

The linear regression analysis determined if there was any relationship between stand diversity and total biomass. With an R^2 of 0.008 it was determined that there is no correlation between diversity and biomass (Table 3). It was determined that with a significance value of 0.307 the regression model did not predict the dependent variable well (Table 4). An equation for the linear regression line was determined by finding the coefficient (Table 5).

Table 3: Linear Regression model summary with R values present

R	R^2	Adjusted R^2	Std. Error of the Estimate
0.092	0.008	0.000	0.49147184

The R^2 value of 0.08 and adjusted R^2 value of .000 show there is no relationship between the constant Total Biomass and Diversity.

Table 4. ANOVA for the dependent variable diversity and the constant total biomass

	Sum of Squares	Degrees of Freedom	Mean Squares	F	Significance
Regression	0.254	1	0.254	1.052	0.307
Residual	29.710	123	0.242	-	-
Total	29.964	124	-	-	-

With an F value of 1.052 and a sig. of 0.307 the regression model did not explain a statistically significant portion of the variance.

Table 5. Coefficients table for the linear regression analysis

Model	Unstandardized B	Coefficients Standard Error	Standardized Coefficients Beta	t	Sig.
Constant	-1.043	0.091		-11.447	<0.001
Total Biomass	-1.073E^{-5}	0.000	-0.92	-1.026	0.307

The coefficients table provides the values of the regression line with column "B" showing no significance. The histogram determines if the residuals are normally distributed (Figure 2). The scatter plot compares what is expected to happen to what happens for the residuals (Figure 3).

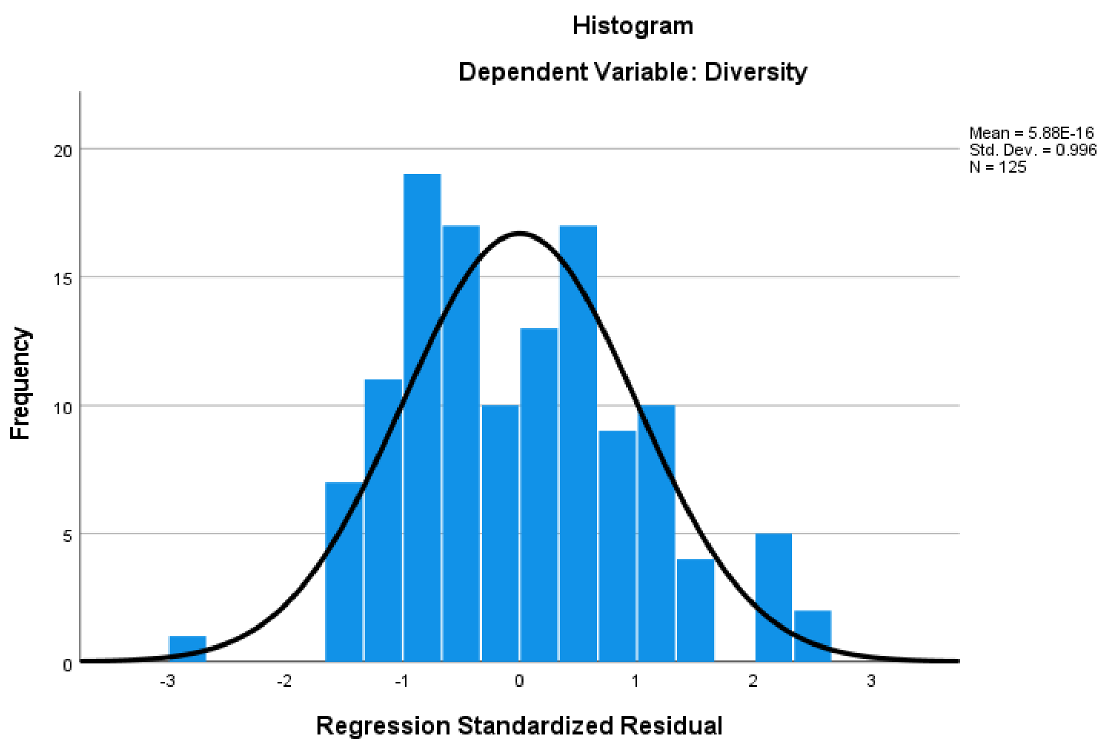

Figure 2. Histogram of residuals for simple linear regression

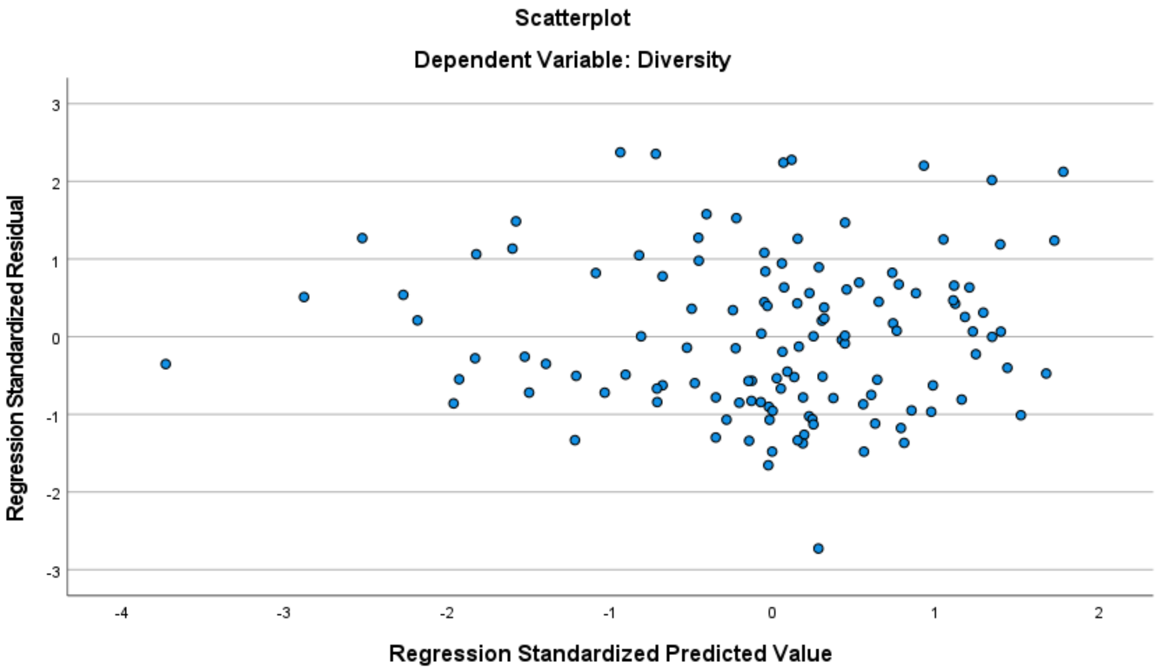

Figure 3. Scatter plot of standardized regression predicted values to regression standardized residual.

ANOVA

The one-way ANOVA compared stand type to biomass with number one representing mixed forests, two representing deciduous dominated forests, and three representing conifer dominated forests (Table 2). A mean, standard deviation and confidence interval (95%) were determined for each of the three dependent variables (Table 6). A significance level of 0.024 does not reach the desired confidence interval which means there is some level of significance in the data (Table 7). Running a Tukey HSD test it was determined that there is a significant relationship between mixed wood and deciduous stands but not to conifer stands (Table 8). To ensure equal variances between independent groups is satisfied the homoogenity of variances test was run. It was determined that there was no significance confirming equal variances between groups (Table 9).

Table 6. Means, standard deviation, and standard error descriptive statistics for stand type with confidence intervals of 95%.

	N	Mean	Standard Deviation	Standard Error	Lower Bound	Upper Bound	Minimum	Maximum
1-Mixed Wood Stand	42	7548.500	3601.783	555.767	6426.105	8670.894	1558.079	17211.100
2-Decidieious Dominated	69	8233.320	4489.425	540.463	7154.842	9311.800	339.469	23366.100
3-Conifer Dominated	14	4879.921	3654.432	976.688	2769.915	6989.927	109.773	11587.610
Total	125	7627.640	4219.110	377.369	6880.721	8374.558	109.773	23366.100

The mean total for the three stand types (7627.640) matches similarly with deciduous (8233.320) and mixed wood stands (7548.500) but not coniferous stands (4879.921).

Table 7. Sum of squares for one way ANOVA

	Sum of Squares	Degrees of Freedom	Mean Square	Frequency	Significance
Between Groups	131275035.3	2	65637517.6	3.857	0.024
Within Groups	2076035507.4	122	17016684.5	-	-
Total	2207310542.6	124	-	-	-

The significance value of 0.024 is lower than 0.05 showing there was some significance between stand types.

Table 8. Post Hoc test of Tukey HSD for one way ANOVA

Stand Type(I)	Stand Type(J)	Mean Difference (I-J)	Standard Error	Significance	Lower Bound (95% Confidence Interval)	Upper Bound (95% Confidence Interval)
1	2	-682.461	807.437	0.676	-2598.235	1233.314
	3	2668.578	1273.215	0.095	-352.329	5689.485
2	1	682.461	807.437	0.676	-1233.313	2598.235
	3	3351.039	1209.336	0.018	481.696	6220.382
3	1	-2668.578	1273.215	0.095	-5689.485	352.330
	2	-3351.039	1209.336	0.018	-6220.382	-481.696

Table 9. ANOVA homogeneity of variances test table

Total Biomass	Levene Statistic	Df1	Df2	Significance
Based on Mean	0.656	2	122	0.521
Based on Median	0.532	2	122	0.589
Based on median and with adjusted df	0.532	2	117.340	0.589
Based on trimmed mean	0.576	2	122	0.564

The lowest significance found in the homogeneity of variances test was a signficance of 0.521. This shows that there is no real difference between variances.

ANCOVA-COVARIANCE ANALYSIS

The ANCOVA was run to analysis covariance. Mixed wood, deciduous and conifer were the three groups used while controlling diversity as a covariate. For each of the stands mean, standard deviation, and number of stands were determined (Table 10). It was found that when adjusted for covariate it was not significantly significant (Table 11). Levene's test was ran to confirm equality of variances for the variable biodiversity for all stand types. With a significance value of 0.486 it is found that variance is equal and there is no covariance between stand types and biodiversity (Table 12).

Table 10. ANCOVA descriptive statistics table for dependent variable diversity

Stand Type	Mean	Standard Deviation	Number of Stands
1-Mixed Wood	7548.499	3601.783	42
2-Deciduous	8233.320	4489.425	69
3-Conifer	4879.921	3654.432	14

Descriptive statistics (mean, standard deviation, number of stands) are shown on the dependent variable, for the different levels of the independent variable. The values do not include any adjustments made using a covariate.

Table 11. Tests of between-subjects effects for ANCOVA

	Type III Sum of Squares	Degrees of Freedom	Mean Square	Frequency	Significance	Partial Eta Squared
Corrected Model	138437974.3	3	46145991.4	2.699	0.049	0.063
Intercept	681685439.4	1	681685439.4	38.869	<0.001	0.248
Diversity	7162939	1	7162939	0.419	0.519	0.003
Stand Type	119716027.4	2	59858013.7	3.501	0.033	0.055
Error	2068872568.4	121	17098120.4	-	-	-
Total	9479921425.6	125	-	-	-	-
Corrected Total	2207310542.6	124	-	-	-	-

A significance value of 0.033 does not satisfy the desired value of significance. It was concluded that there was not significant differences in diversity between stand types.

Table 12. Levene's test of equality of error variances table

Dependent: Frequency	Variable: Degrees of Freedom 1	Total Biomass: Degrees of Freedom 2	Significance
0.725	2	122	0.486

The Levene's Test of Equality of Error Variances is used when you are looking at two or more variables. It assesses the equality of variances and with a significance of 0.486 it can assume equal variances across the stands

DISCUSSION

LOGGING HISTORY

The Great Lakes-St. Lawrence Forest, particularly eastern white pine (*Pinus strobus*) and red pine forests were the center of controversy regarding the treatment of old-growth forests in Ontario in the 1980's and 1990's. The primary concern was a reduction in large red and white pine trees with small, often low-quality white birch *(Betula papyrifera*). (Pinto 2003).

In the North American Interior West twentieth-century selective harvesting of coniferous trees has halved the density of large trees within the region (Merschel et al. 2014). It was also found that recent land use change in mixed-conifer forests across the North American Interior West has increased both tree density and the dominance of shade tolerant trees while also reducing the density of large, old pine trees (Merschel et al. 2014).

The Brazilian pine tree (*Araucaria angustifolia*) is a high value coniferous species that has been the subject of over harvesting and selective logging. Studying *Araucaria angustifolia* regeneration patterns in logged, and unlogged forests determined that in unlogged forests, *Araucaria angustifolia* populations were characterized by size distributions with many large individuals and a small number of juveniles. In logged forests, logged areas predictably had fewer large individuals but many small individuals. The more recent the logging the higher number of juveniles and smaller number of large individuals there were (Souza et al. 2008).

For this study, trees that had less than 5 cm DBH or lower were not counted. Logging history in the Great Lakes St Lawrence region is poor, with some areas of the region having no logging history prior to 1975 (Lock 2021). As such it can be assumed that logging history of high value coniferous species and its time interval factors into conifer biomass. This explains why there was significance between stand type for mixed wood stands and deciduous stands but not for coniferous stands when running the one way anova (Table 8).

DIVERSITY

Diversity is now recognized as one of the three major factors controlling the functioning of ecosystems (Davis 2004). This study only accounted for diversity of overstory tree species, not accounting for animal, shrub or any other form of diversity within each plot. Species richness also plays a role in predicting biomass potential (Liu 1990). For the basis of this study, no plot had more than 8 overstory species which limits the possibility of finding significance between biomass and diversity.

Diversity is a destabilizing force on individual species, and presumably, on entire ecosystems (Li et al. 2014). Naeem et al. (1994) found diversity can have very strong impacts on the functioning of ecosystems (Naeem et al. 1994). In times of extreme weather events such as drought, productivity dropped by a factor of 10 in less diverse plots where it only dropped by a factor of two in more diverse plots (Tilman and Downing 1996).

SITE QUALITY

In the Batchawana Eco District the landscape is typically rolling with several faults and joints, resulting in complex and highly variable terrain (McQuay 1980). Precipitation, average length of growing season are all variables that fall under climate. Climate is the biggest driving factor for trees biomass (Liu 1990). Despite doing the study in the same Eco Districts it is hard to account for biomass changes when climatic variation between plots likely had an affect on biomass independent of diversity and stand type.

NUTRIENT AVAILABILITY

In Tilman's grassland studies he determined that the only limiting nutrient was nitrogen (Tilman et al. 2001). This determined that nitrogen availability greatly influences competition and species abundance (Davis 2004). Conifer sites in the Batchawana Eco District were characterized as nutrient poor, poorly drained sites (Western et al. 2018). Majority of the conifer dominated stands were low diversity cedar stands where biomass was likely limited by site quality rather than diversity or stand type.

CONCLUSION

The goal of this study was to determine if there was a relationship between forest stand type and diversity with respect to above ground overstory biomass. The results showed that there was no relationship between biomass and diversity. There was a relationship between stand type and biomass but only between deciduous and mixed wood stands not conifer dominated stands. This is likely due to the density properties of hardwoods and past logging histories hurting softwood species.

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