A COMPARATIVE STUDY OF REGIONAL AND COVER TYPE INFLUENCES ON CARBON CONTENT IN ABOVE-GROUND WOODY LIVE BIOMASS

By

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An undergraduate thesis submitted in the partial fulfillment of the requirements for the degree of Bachelor of Science in Forestry

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Second Reader

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ABSTRACT

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Key words: Carbon storage, Boreal Forest, Great Lakes-St. Lawrence, Species diversity, Forest management, Climate change mitigation, Above-ground woody biomass, regional differences, Ecological stand characteristics, Species composition,

This thesis provides an analysis of the influence of forest region, cover type, and species composition on carbon storage in above-ground woody biomass across boreal and Great Lakes-St. Lawrence (GLSL) regions. The plot data was gathered for Perimeter Forest Ltd., which specialises in providing high-integrity carbon credits resulting from its forest management and biodiversity conservation efforts in Canada. The study unveils significant regional differences in carbon storage capabilities, with the GLSL region's hardwood ecosystems exhibiting superior carbon storage potential compared to the boreal region. The study also found that the type of cover type had an influence on the amount of carbon present. Tolerant hardwoods showed higher levels of carbon in the Great Lakes-St. Lawrence region, while mixed woods showed higher levels in the boreal region. These differences are attributed to the distinct ecological adaptations, growth rates, and sizes of species within each region. The findings highlight the necessity of sophisticated, dynamic management approaches that consider regional differences, species diversity, and stand ecological characteristics to maximize carbon storage and contribute significantly to climate change mitigation efforts.

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INTRODUCTION

The pressing challenge of climate change emphasizes the importance of forest ecosystems in storing carbon, a critical process for mitigating the effects of global warming. The Pan-Canadian Framework on Clean Growth and Climate Change was adopted by the federal government as well as the majority of provinces and territories. The PCF is an ambitious plan to reduce greenhouse gas (GHG) emissions, create clean jobs and growth, and increase Canada's resilience to the effects of climate change (Canadian Council of Forest Ministers, 2021). The Boreal Forest and the Great Lakes—St. Lawrence Forest regions are the two largest forest regions in Canada, and they are notable not only for their economic value, but also for their critical contributions to climate regulation and carbon storage. These ecosystems are central to efforts to mitigate the accelerating effects of climate change. Understanding how regional variations and forest cover types affect carbon storage capabilities is crucial for developing adaptive forest management practices that enhance ecosystems' role in carbon storage (Triviño et al., 2015; Dalmonech et al., 2022).

There are many moving parts in dynamics of carbon storage within ecosystems, including stand age, species composition, natural disturbances, and climate variability. The amount of carbon that forests can store and sequester is greatly impacted by these factors. Significant effects of climate change on forest ecosystems over the next centuries have been predicted by several studies (Miquelajauregui et al. 2019; Dunn et al., 2007; Yu et al., 2019). Harvested wood volume and forests' capacity to act as carbon sinks are predicted to be impacted by changes in forest productivity and composition as well as natural disturbance regimes like fire, insect outbreaks, and climate extremes (Moreau et al., 2022). Comprehending the relationship among variables is imperative in formulating strategies for forest management that facilitate the storage of carbon and tackle climate change.

The Boreal Forest, which spans high latitudes across Asia, Europe, and North America, and the GL-SL Forest are characterized by a rich diversity of coniferous and deciduous trees, provide unique settings for studying the impact of regional and cover type variations on carbon storage. This thesis combines quantitative and qualitative analysis to investigate the hypothesis that regional differences and variations in forest cover types have a significant impact on carbon storage capacities, using DBH-based biomass models developed by Ter-Mikaelian and Korzukhin (1997).

The insights gained from this study could help inform and refine global climate change mitigation efforts through improved conservation and forest management strategies. Furthermore, by advancing our scientific understanding of forest carbon dynamics, this thesis contributes to the development of targeted, effective strategies for maximizing forest ecosystems' carbon storage potential, which plays an important role in global climate change mitigation initiatives.

LITERATURE REVIEW

MEASURING BIOMASS

Babst et al.'s 2014 study focuses on measuring forest biomass, a key factor in carbon storage, and how it affects forest ecosystems. The study emphasizes the significance of accurate and consistent measurement techniques in assessing forest carbon storage potential. The study emphasizes the variability in growth and carbon accumulation patterns across Europe's forests. The study also focuses on the relationship between biomass accumulation and basal area increment as key indicators of forest growth and carbon accumulation. The study advocates for standardized measurement techniques to improve scientific understanding of forest carbon dynamics and to develop strategies for maximizing climate change mitigation opportunities. The study emphasizes the importance of precision and standardization in measuring forest biomass for accurate carbon storage assessments. It also emphasizes the complexity of forest ecosystems and the need for nuanced management strategies to improve their carbon storage capacities.

The study conducted by Chojnacky, Heath, and Jenkins (2014), as described in the article, highlights the importance and efficiency of using allometric biomass equations to estimate tree biomass on a large scale. The researchers improved the accuracy of biomass assessments for various tree species in North America by revising and improving allometric equations. They created a new set of 35 generalized equations derived from allometric scaling theory (Chojnacky et al., 2013). This method not only confirms the importance of using taxonomic and wood specific gravity parameters as biomass estimators, but it also adheres to previous methodologies while improving their usefulness and precision for different forest types. Their research findings provide strong support for the continued use of allometric equations as a standardized approach in forest biomass studies, emphasizing their importance in both scientific research and practical forest management.

In examining how regional factors influence carbon storage in forest ecosystems, several studies highlight the impact of management practices tailored to specific forest types and conditions. Newton (2022) explores how targeted interventions can enhance tree growth and carbon storage, emphasizing the importance of considering the varying effects of different cover types on carbon storage capacities. Similarly, Park (2015) addresses the benefits of thinning practices within pine stands, showing that such interventions not only improve forest health but also enhance climatic resilience and contribute to greater carbon storage. Furthermore, Chen et al. (2010) delves into the role of fire management in boreal forests, underlining the necessity of integrating natural disturbance regimes into management strategies to optimize carbon storage. Together, these studies suggest that region-specific management practices are crucial in maximizing the carbon storage potential of forest ecosystems, thereby contributing to broader climate change mitigation efforts.

Babst et al.,'s 2014 study on above-ground woody carbon absorption across five sites illuminates how regional variations and cover types affect forest carbon storage. The study finds a correlation between tree-ring-derived storage of carbon and net ecosystem productivity, but also significant site variability. This variability shows how regional environmental conditions and forest management affect carbon storage and ecosystem productivity. The study suggests that regional climate, soil conditions, forest cover type, and management interventions can significantly affect forest carbon storage. The study emphasizes the complexity of forest ecosystems and the need for sophisticated forest carbon accounting by considering a wide range of ecological and management factors when assessing forest carbon storage potential.

According to Moreau et al., (2022), carbon balance and ecosystem capacity to act as carbon sinks determine the benefits of forest conservation and intensification. When talking about the carbon balance and ecosystems' ability to act as carbon sinks, generalizations should be avoided. According to the study, mitigation strategies for climate change should be customized to the initial characteristics and ecosystem dynamics of forest ecosystems. Forest management should stimulate net growth ecosystems and limit carbon loss to increase and stabilize carbon storage. Carbon can be stored steadily in forests using living biomass, dead biomass, and wood products stocks. This can lead to big benefits for climate change mitigation after alternative forest management. Management and wood products basket can be optimised for specific forest stands based on forest ecosystem initial characteristics (Moreau et al., 2022).

Understanding regional characteristics and carbon storage dynamics in boreal forests is essential for mitigating climate change. Recent research highlights the complex interplay between forest composition and carbon storage. Pappas et al. (2020) argue that while traditionally thought to be stored predominantly in aboveground live woody biomass, boreal ecosystems actually store a minor fraction of their carbon there, pointing instead to the significant roles of soil and belowground biomass. This insight calls for broader research and nuanced management strategies that consider all carbon pools to effectively assess and enhance the carbon storage capacity of boreal forests.

Payne et al. (2019) investigate carbon storage across different boreal forest cover types in Canada, finding that mixed wood stands not only hold larger carbon stocks but also exhibit higher aboveground net primary productivity compared to monoculture coniferous stands. This underscores the value of species diversity within these ecosystems for both carbon storage and forest management aimed at climate change mitigation. Together, these studies by Pappas et al. (2020) and Payne et al. (2019) suggest that a comprehensive approach to forest management, acknowledging the variety of carbon reservoirs and the benefits of species diversity, is crucial for optimizing carbon absorption in boreal forests.

AGE EFFECTS

Understanding the relationship between forest age, regional variations, and cover types is crucial in order to comprehend the intricacies of carbon storage in forest ecosystems. This literature review consolidates significant findings from multiple studies, providing a comprehensive understanding of the various factors that influence carbon storage in forests, with a specific focus on the impact of forest age.

Besnard et al. (2018) demonstrated the substantial impact of forest age on the spatial and temporal fluctuations of Net Ecosystem Productivity (NEP) in 126 forest eddy-covariance flux sites. Their analysis identifies forest age as a crucial factor, explaining up to 62% of the variation in space and time, and 71% of the variation between different locations, highlighting its impact on NEP. This discovery is crucial for our investigation because it not only emphasizes the intricate nature of forest carbon dynamics but also confirms the importance of forest age, as well as regional and cover type differences, as significant factors that influence carbon storage capacities.

In addition to this viewpoint, Coursolle et al. (2012) examined the changes in carbon storage over time in various age groups of forest stands. They found that Net Ecosystem Productivity (NEP) reaches its highest point between the ages of 35 and 55 years for most types of forests. However, afforested white pine stands stand out with an exceptionally high NEP value of 6.9 Mg C ha^(-1) year^(-1) between the ages of 15 and 20 years. The differences in carbon uptake rates among various forest types highlight the complexities of carbon sequestration processes and the significant impact of stand age on carbon storage dynamics. Furthermore, the study explains that climate factors primarily influence the Gross Ecosystem Productivity (GEP) and ecosystem respiration (ER) of mature stands, while younger stands are affected by both leaf area index (LAI) and climate. This emphasizes the complex relationship between stand development, environmental factors, and carbon storage.

By incorporating these observations into our research framework, with forest age as a crucial independent variable, we enhance our comprehension of the carbon storage patterns in forest ecosystems. The evidence presented by Besnard et al. (2018) and Coursolle et al. (2012) supports the idea that forest age plays a crucial role in determining the potential for carbon storage. Furthermore, it emphasizes the importance of taking a comprehensive approach when modelling the dynamics of carbon in forests. This approach necessitates the integration of forest age in conjunction with regional and cover type differentiations, thus providing a comprehensive perspective to comprehend the complexities of forest carbon storage.

MANAGEMENT IMPLICATIONS

The need to increase carbon storage in forests as a response to climate change is closely connected to the effectiveness of forest management techniques. This literature review examines influential works that explore the possibilities and necessary conditions for improving the storage of carbon through forest management.

In their research, Birdsey, Pregitzer, and Lucier (2006) propose a strategic approach to forest management that has the potential to enhance forest carbon storage by an extra 100 to 200 Tg C/year. This projection aligns perfectly with the central theme of our research and clearly illustrates the crucial role that management practices play in achieving significant improvements in carbon capture and storage rates. The study highlights the importance of making significant investments in inventory, monitoring, and the spread of new technologies and practices that are specifically designed for forest management. Strategic interventions are seen as necessary to fully utilize the capacity of forests to absorb carbon dioxide, supporting our argument that effective forest management strategies should be adopted and implemented to improve carbon storage capabilities.

In addition to the previous discussion, Dalmonech et al. (2022) explore the uncertainties surrounding the future dynamics of carbon sinks in the context of forest management. The study emphasizes the influence of management intensity on carbon storage, warning about the possibility of heightened management intensity compromising the carbon storage and stocking abilities of forests. This observation is crucial for understanding the importance of maintaining a balance in forest management techniques in order to maximize carbon storage, especially considering the differences in regions and types of forest cover. The discovery that forest management practices have an equal impact as climate change on the size of carbon sinks and stocks emphasizes the need for customized management strategies that consider the unique ecological and geographical characteristics of forest ecosystems.

Portier et al. (2018) emphasized the significance of forest management in maintaining a balance between carbon storage, fire patterns, and different types of vegetation in boreal ecosystems. The Romaine River region, renowned for its capacity to store carbon and produce timber, serves as a prime example of the necessity for meticulous management. Low-intensity forests have the potential to accumulate economically valuable live aboveground biomass, which peaks 150 years after a fire. This underscores the capacity for conserving the environment and promoting economic growth. Portier et al. (2018) proposed the practice of selectively removing trees while preserving vegetation levels as a means to safeguard ecosystem integrity and improve carbon storage. This approach offers a vital viewpoint on the management of boreal forests with complex and uneven stand structures, especially in areas with infrequent fire events.

Babst et al. (2014) and Black et al. (2000) present broader implications for vegetation diversity and forest composition on carbon storage capacities, supporting the idea that diverse forest ecosystems can store more carbon than less diverse or monoculture forests. These studies emphasize the need for management strategies that are aware of regional and cover type distinctions and designed to capitalize on these differences to increase carbon storage

The literature review emphasizes the importance of strategic forest management in increasing carbon storage, highlighting the link between scientific advancements, policy implementation, and practical methods. It underscores the need for well-informed and sophisticated strategies to combat climate change on a global scale.

CLIMATE CHANGE EFFECTS

Dunn et al., (2007) investigate the complex relationship between climate change and carbon dynamics in boreal ecosystems, as observed in the field of forest ecology. The study, which was conducted in a black spruce forest/veneer bog complex in Manitoba, Canada, shows how the ecosystem transitions from emitting to absorbing carbon, with a focus on how variations in air temperature, moisture, evapotranspiration, and summertime solar radiation affect carbon exchange. This study emphasizes the importance of incorporating climate variability into assessments of carbon storage and sequestration capacity in terrestrial ecosystems. Furthermore, it emphasizes the importance of recognizing and dealing with the various effects of climate change when developing strategies to improve forests' ability to store carbon.

According to Miquelajauregui et al. (2019), climate change will have a negative impact on boreal forests. Boreal forest ecosystems are critical to the global carbon cycle, but they are expected to see significant temperature increases in the coming century. Climate change is expected to affect boreal carbon storage by altering fire regimes, tree growth, and decomposition rates. The study used a diameter-size structured model to analyze 1.0-ha patches of monospecific black spruce stands across four climatic periods. The results revealed amplified growth reductions and increased temperature-sensitive decomposition rates of soil carbon pools. Climate change has a negative short-term impact on black spruce forest productivity and carbon storage, reducing ecosystem carbon storage by 10% by the end of 2100. This suggests that northern Quebec's black spruce forests may lose their ability to sequester and store organic carbon in the coming decades.

The prediction of future wood supply, along with aboveground biomass is one area in which climate change presents a substantial peril to long-term sustainable forest management. There has been limited research that has examined the cumulative effects of climate change on forest productivity and natural disturbances, with a specific focus on the consequences of drought. In three areas of Canada's boreal forest, the effects of disturbance- and drought-induced tree mortality on the availability of wood were modelled over a 200-year period by Brecka et al. (2020). Strong drops in aboveground biomass were discovered by the study as a result of an increase in wildfire and drought deaths, especially in drier western regions. Depending on the degree of anthropogenic climate forcing, it may be difficult to maintain current sustainable harvesting levels. According to the study (Brecka et al., 2020), implementation of adaptation measures is imperative due to the significant susceptibility of Canada's future wood supply and sustainable forest management practices to climate change.

MATERIALS AND METHODS

NorthWinds Environmental Services carried out data collection at the Kapuskasing and Algoma properties following the 2022 Standard Operating Procedure (SOP) created by Perimeter Forest. Kapuskasing forest, situated in the Boreal Region, and the Algoma Forest situated in Great Lakes–St. Lawrence Forest region served as the main study areas. Data collection spanned across these regions, covering a total of 309 plots—134 in the Algoma property and 175 in the Kapuskasing property.

The information was gathered for Perimeter Forest Ltd., which specialises in providing high-integrity carbon credits resulting from its forest management and biodiversity conservation efforts in Canada. The company's projects aimed at reducing greenhouse gas emissions are verified by independent entities and monitored on a regular basis to ensure that their claims are supported (Perimeter Forest, 2023).

STUDY AREAS

The Kapuskasing property, located in the Clay Belt region stretching from west of Hearst, Ontario to northwestern Quebec with a width of 25 to 150 kilometers as noted by Perimeter Forest (2023), and the Algoma Property in the Great Lakes–St. Lawrence (GLSL) area, have both experienced selective logging practices historically. In these practices, known as high-grading, only trees regarded of the highest value were chosen for harvest, emphasizing the selective removal of specific trees based on their value (Government of Ontario, n.d.).

SAMPLING APPROACH

In the study, a systematic random sampling approach was employed, where sample locations were determined by a predefined grid system. This method ensured an unbiased selection of sites across the study areas, allowing for a representative sampling of the population. GPS was used to pinpoint plot centers. The design included a larger circular plot with an 11.29-meter radius and a smaller one with a 3.99-meter radius. Larger plots measured trees with a DBH of 9 cm or more, while smaller plots focused on trees with a DBH of 5 to 8.9 cm. Tree heights were measured with a clinometer, using the angle of elevation and trigonometric formulas to calculate height from a fixed distance or with Vertex (Ostrom Climate 2022).

QUALITY ASSURANCE

Compliance assessment involved hot checks, and blind checks. Hot checks involved direct observation of field crews during data collection. Blind checks allowed auditors to re-measure plots independently, identifying and quantifying measurement variations (Ostrom Climate 2022). 10% of all plots were audited internally and 10% of all plots were additionally audited by the carbon crediting verification body.

BIOMASS CALCULATIONS

In this study, the individual biomass of each tree was determined using the key physical characteristic Diameter at Breast Height (DBH) and equations developed by Ter-Mikaelian and Korzukhin (1997) from "Biomass equations for sixty-five North American tree species" shown in figure 1. M is the oven dry weight of the biomass component of a tree (kg). D is DBH (cm), and a and b are parameters.

$$M = aD^b$$

Figure 1. Ter-Mikaelian and Korzukhin (1997) Biomass Equations.

Both study areas utilized the equation, with a and b parameters selected based on the closest region to each area, with a focus on above-ground biomass parameters found in appendix A of Ter-Mikaelian and Korzukhin's (1997) study. Table 1 and Table 2 display the precise values of the a and b parameters utilized in the biomass calculations for each region.

Table 1 Summary of above ground biomass parameters for each species in Kapuskasing.

Species (Kapuskasing)	a	b	Region
Aspen, Trembling	0.0527	2.5084	Upper GLSL
Birch, White	0.1182	2.4287	Upper GLSL
Spruce, Black	0.0963	2.4289	Quebec
Spruce, White	0.1643	2.248	Upper GLSL
Cedar, Eastern white	0.0910	2.234	Upper GLSL
Fir, Balsam	0.2575	2.0543	Ontario
Pine, Jack	0.0919	2.4206	Ontario
Larch, Eastern	0.0946	2.3572	Nova Scotia
Poplar, Balsam	0.0527	2.5084	Upper GLSL

Table 2 Summary of above ground biomass parameters for each species in Algoma.

Species (Algoma)	a	b	Region
Aspen, Trembling	0.0527	2.5084	Upper GLSL
Birch, White	0.1182	2.4287	Upper GLSL
Birch, Yellow	0.0872	2.587	Upper GLSL
Cedar, Eastern white	0.0910	2.234	Upper GLSL
Fir, Balsam	0.0705	2.497	Upper GLSL
Maple, Red	0.1618	2.3095	Upper GLSL
Maple, Sugar	0.1676	2.3646	Upper GLSL
Pine, White Eastern	0.0755	2.3833	Upper GLSL
Spruce, Black	0.1137	2.316	Upper GLSL
Spruce, White	0.1643	2.248	Upper GLSL

CARBON CALCULATION

According to the guidelines provided by Vashum & Jayakumar (2012) for estimating forest carbon stocks, it is suggested that 50% of a tree's dry biomass consists of carbon. The initial measurements of biomass are converted to metric tonnes in order to standardize and facilitate comparison. The carbon content is multiplied by a factor of 25 to enable a more comprehensive analysis at the per hectare level, facilitating standardized comparisons across various regions. This approach is in accordance with global reporting standards and enables a more thorough comprehension of carbon stocks in forests.

COVER TYPE DETERMINATION

The categorization of forest cover types is a crucial element of this study, serving as a structure for examining differences in carbon storage capacities among various forest ecosystems. In order to conduct our analysis, we have classified cover types into four separate groups, based on the dominant tree species, which is measured as a percentage of the basal area. The initial classification is Intolerant Hardwoods, which includes areas where poplars and white birch make up 70% or more of the basal area. Tolerant Hardwoods are classified as the second category, characterized by a composition consisting of 70% or more yellow birch and maple species. The Softwoods category encompasses forests that are primarily composed of spruce and fir species, with these species accounting for 70% or more of the basal area. The Mixed cover type is designated for forest stands that do not fit into the previous categories, and it represents a varied collection of tree species.

AGE DETERMINATION

The categorization of stand age is an aspect of this study, enabling a thorough investigation of the changes in carbon storage that occur as forests mature. The age classification for the Algoma region is determined based on a FRI cruising data-based inventory that was carried out in 2011, which could likely skew the results as they were likely photo-interpreted. This inventory provided a thorough and dependable evaluation of the composition and structure of the forest at that specific time. The historical data is crucial for establishing a reference point to comprehend the growth patterns and carbon storage capacity of various forest age categories in the area.

In the Kapuskasing region, a method that involved direct involvement and action was employed, where the dominant species in each group were sampled to ascertain their age. This technique guarantees an exact age determination, which is crucial for precise categorization and comparison.

The forest stands were divided into distinct groups based on their age, with each group representing a 20-year period. This stratification allows for the comparison of carbon storage between different stages of succession.

STATISTICAL ANALYSIS

In-depth statistical analysis was executed utilizing SPSS software. The initial phase of data scrutiny involved Chi-Square Tests of Independence, which serve to detect any association between pairs of variables. Our preliminary investigations focused on ascertaining the independence of various factors that potentially influence carbon storage, such as stand density and stand age. This step is crucial as the assumption of independence underpins the validity of many statistical tests. The Chi-Square tests revealed a statistically significant association between stand density and stand age, indicating that these variables do not operate independently within our dataset. Given this interdependence, stand density was excluded from subsequent models to avoid confounding effects. Consequently, stand age was retained as the sole factor of temporal analysis in our model, ensuring that the results are attributable to age-related effects without the confounding influence of stand density.

EXPERIMENTAL DESIGN

The data was analyzed using a univariate General Linear Model (GLM). The GLM was chosen for its adaptability and reliability in analyzing continuous dependent variables affected by categorical independent variables. The variable 'region' was included as a blocked factor to effectively account for regional differences that could potentially bias the analysis. The blocking factor is crucial in our design as it helps us separate the variability caused by regional differences. This allows us to obtain a more accurate understanding of how cover type and stand age affect carbon biomass.

RESULTS

Table 3 below displays a comparison of the cover type, number of plots, average above-ground biomass carbon (AGB-C), average age, and average stand density for each region. The table highlights the variations in forest composition and carbon storage capacity among different regions. By employing a comparative approach, one can analyze how various types of forests with similar traits can vary in ecological attributes based on their particular locations.

Table 3. Comparative Summary of Forest Cover Type Parameters Between Boreal and Great Lakes-St. Lawrence Regions

	Great Lakes St. Lawerance Region				Boreal Region			
Cover type	**Number of plots**	**Mean AGB C (t/ha) and range**	**Mean age (yrs) and range**	**Mean stand density (trees/ha) and range**	**Number of plots**	**Mean AGB C (t/ha) and range**	**Mean age (yrs) and range**	**Mean stand density (trees/ha) and range**
INTOL HRD	5	63 (18-97)	72 (24-114)	1245 (1000-1650)	23	44 (2-123)	57 (14-87)	472 (25-1151)
MIX	47	74 (5-469)	83 (3-139)	866 (325-1825)	28	60 (0.2-141)	54 (13-123)	781 (75-1550)
SFT	24	65 (19-180)	100 (3-169)	1043 (325-1675)	112	34 (0.2-118)	76 (14-211)	775 (25-2027)
TOL HRD	48	98 (24-274)	88 (3-149)	624 (300-1250)	NA	NA	NA	NA

The first model tested the impact of ecoregion (boreal and GLSL) on above ground woody biomass carbon content. As trees get bigger as they grow, age was included in the model to eliminate the possibility that statistical difference in carbon amount was due to an average older forest in Algoma region. The model's findings, indicating a p-value of <0.001, demonstrate a statistically significant difference between boreal and GLSL regions in terms of carbon storage in live above-ground tree biomass. This low p-value strongly suggests that the region is a critical factor in determining the carbon content of forests, beyond random chance.

This result implies that despite accounting for variations in tree age across the study areas, regional characteristics such as climate, soil type, topography, and other ecological factors potentially play a pivotal role in the carbon storage abilities of trees. The high statistical significance marked by the p-value indicates that these regional differences are consistent and robust across the sampled forests.

Table 4 presents a comparative analysis of carbon storage between two distinct ecological regions. The Great Lakes-St. Lawrence Forest region, exemplified by Algoma, demonstrates a notably higher mean carbon storage value of 80.9 tonnes per hectare. In contrast, the Boreal Forest region, as represented by Kapuskasing, exhibits a significantly lower mean carbon storage, registering at 39.9 tonnes per hectare.

Table 4. Mean Carbon Storage by Region

Region	Mean C (t/ha)
Algoma	80.9
Kapuskasing	39.9

Figure 2 presents a visual comparison of the amount of carbon stored in above-ground live woody biomass in different age groups in two regions: Algoma and Kapuskasing. Based on the trend lines, Algoma consistently exhibits higher carbon storage than Kapuskasing across all age classes assessed, with the exception of age class 40. Age class 40 experienced previous harvesting, leading to a reduced carbon content compared to other age classes. This is the reason why it deviates from the trend of accumulating more carbon. The visual comparison highlights the significant regional variations in carbon storage abilities, with Algoma demonstrating a clear advantage over Kapuskasing in terms of its capacity to store carbon within the studied age ranges.

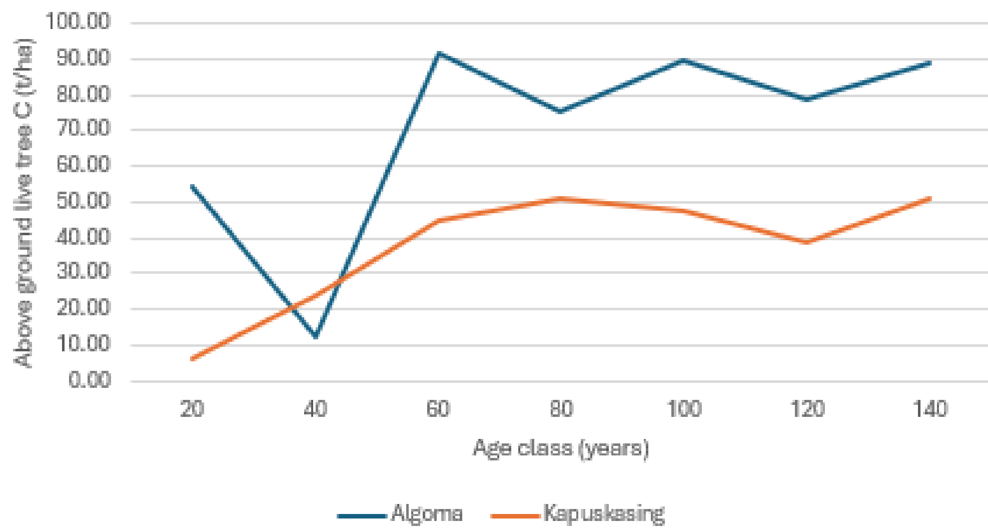

Figure 2. Trends in Aboveground Carbon Storage by Age Class

Next, cover type impact on carbon content in above ground woody biomass was examined for each region separately. The statistical model revealed that in the Algoma area, the type of forest cover exerts a considerable influence on the carbon content of live above-ground woody biomass. This was evidenced by a p-value of 0.004, indicating a statistically significant relationship between the forest cover types and the amount of carbon stored.

The results depicted in Figure 3 highlight significant disparities in carbon storage among forest cover types within the Algoma region. Tolerant Hardwoods (TOL HRD) emerge as having notably higher carbon storage capacity compared to Mixed woods (MIX) and Softwoods (SFT). Conversely, Intolerant Hardwoods (INTOL HRD) exhibit carbon storage levels that are statistically indistinguishable from those of Tolerant Hardwoods. However, it's important to note that due to the limited sample size of only five stands for Intolerant Hardwoods, further sampling is necessary to validate any potential differences between Tolerant and Intolerant Hardwoods conclusively.

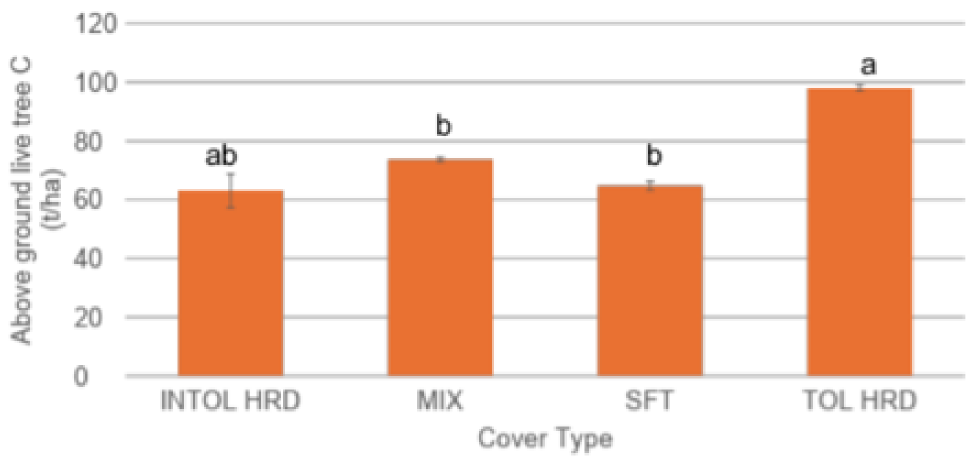

Figure 3. Aboveground Live Carbon Storage by Forest Cover Type in Algoma.

In Kapuskasing, the detailed analysis uncovers significant effects of both the age of forests and their cover type on the storage of carbon, quantitatively assessed in terms of carbon biomass per hectare. Rigorous statistical testing confirmed the substantial influence of these factors, with each showing a highly significant p-value of < 0.001. These findings underscore the critical role that both the age of the forest and its cover type play in the carbon storage process.

Upon examining the differences across various forest cover types, mixed wood stands emerged as the most effective carbon sinks. The analysis revealed that mixed woods store significantly more carbon than softwood forests. This distinction is clearly visualized in the bar chart associated with Figure 4, the results of Tukey test are denoted with the labels 'a', ‘b’ and ‘ab’. The visual representation emphasizes the marked disparity in carbon storage capabilities, with mixed wood forests showing a pronounced advantage in carbon storage.

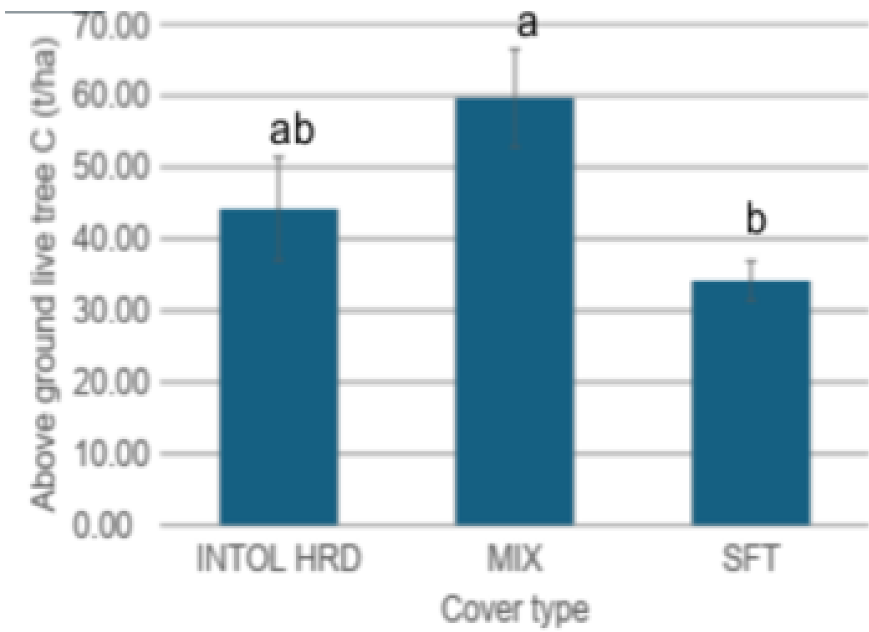

Figure 4. Aboveground Live Carbon Storage by Forest Cover Type in Kapuskasing. Differences between cover types were examined with Tukey test.

DISCUSSION

When discussing the findings of our study on the carbon storage capabilities of tolerant hardwoods on the Algoma property, it is critical to consider the ability of alternative species such as eastern white pines and red pines to sequester carbon more effectively. Leverett, Masino, and Moomaw (2021) provide compelling evidence that older eastern white pine trees and stands accumulate significant amounts of carbon over many decades while also maximizing cumulative carbon storage. Their findings show that 80-year-old white pine stands contained 117.15 t/ha of aboveground carbon, whereas 160-year-old stands contained up to 365 t/ha. This rate of accumulation far exceeds that seen in tolerant hardwoods, which averaged less than 100 t/ha in this study.

This insight is especially important because it emphasizes the need to re-evaluate forest management and conservation strategies on the Algoma property in order to maximize carbon storage. This property, like much of the Great Lakes-St. Lawrence (GLSL) region, has lost more than 80% of its white and red pines due to past harvesting practices. While the current tolerant hardwoods contribute significantly to the property's carbon storage, Leverett et al. (2021) found that eastern white pines and red pines have the potential to sequester even more carbon due to their prolonged accumulation capabilities and the high carbon amounts in older stands.

In boreal forest where early successional trees start to decline already around 60-70 years of age, Paré and Bergeron (1995) also emphasize the importance of forest age in carbon dynamics. Their study, which traced a 230-year chrono sequence post-fire in the southern portion of the Canadian boreal forest, discovered that biomass accumulation peaked around 75 years before declining in older stands due to natural and disturbance-driven processes. This supports the idea that forest management should prioritize interventions that keep forests in this ‘sweet spot' of carbon storage, maximizing their role as carbon sinks based on the regional characteristics.

CONCLUSION

This study investigates how the carbon storage capacity of woody biomass is affected by factors such as forest region and cover type. The analysis highlights notable disparities between the boreal and Great Lakes-St. Lawrence (GLSL) regions, with the GLSL region's varied, hardwood ecosystems demonstrating superior abilities to capture and store carbon. The variation in growth rates, sizes, and ecological adaptations of different species, along with the ecological characteristics of stands, accounts for this disparity. The study highlights the significance of species diversity and environmental adaptation in the dynamics of carbon storage in forests, offering valuable insights for the development of adaptive strategies for forest management. The study highlights the importance of forest management strategies being adaptable and based on detailed ecological understanding, in order to improve carbon storage and enhance the resilience of ecosystems. The research establishes a basis for future endeavours in forest management and conservation, highlighting the importance of a comprehensive approach that considers ecological attributes and the capacity for carbon storage.

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