Comparing Carbon Sequestration and Storage in Systems of Unmanaged Timber Stands Versus Actively Managed Stands for Production

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Introduction

This publication aims to examine and present the differences in carbon sequestration in unmanaged and various types of managed forested woodlands through literature reviews. Carbon sequestration is defined as the process of capturing and storing atmospheric carbon dioxide (U.S. Geological Survey, n.d.)in soil or a physical body such as trees and plants. Carbon cycling occurs between all global systems by moving in and out of carbon sinks. In a forested system, as discussed in this publication, the carbon sinks that will be the primary focus occur in plants and within the soils. Carbon sequestration provided by the carbon sinks is essential in mitigating climate change and anthropogenic carbon input by reducing carbon dioxide concentrations in the atmosphere. Products generated by the forest also have a strong potential to mitigate climate change while providing alternative renewable energy sources (Senez-Gagnon et al., 2018).

Forests account for 92 percent of all terrestrial biomass globally, storing approximately 400 gigatons of carbon (GtC)(Metsaranta et al., 2010). The amount of stored carbon in the forest depends on the climate, type, and land use. In warmer climates, most carbon is stored in the above-ground portions of trees and plants, such as the trunk and branches. The opposite occurs for a forest in cooler temperate and boreal forests, where the majority of carbon sequestration occurs below the soil surface in the roots and soil matrix (Global Carbon | Climate Change Resource Center, n.d.).

Description

Carbon storage locations called carbon pools can differ within the ecosystem. Based on the categories of the International Panel on Climate Change, forest carbon pools consist of above-ground biomass (all living biomass above the soil), below-ground biomass (living roots), litter (non-living biomass that is not in the dead wood pool), dead wood above and below ground, and soil organic matter (Senez-Gagnon et al., 2018) Carbon pool locations and size also have a close relation to the climate the forest is located. Figure 1 shows various carbon pools, including carbon removed from the forest system as harvested wood products.

In forest systems, the locations and quantities can differ depending on the climate. Figure 2 shows warmer climates store more carbon above ground in the plant body, such as the trunk and branches. Opposite the warmer climates, temperate and cooler climates, carbon storage is primarily subsurface in the soil.

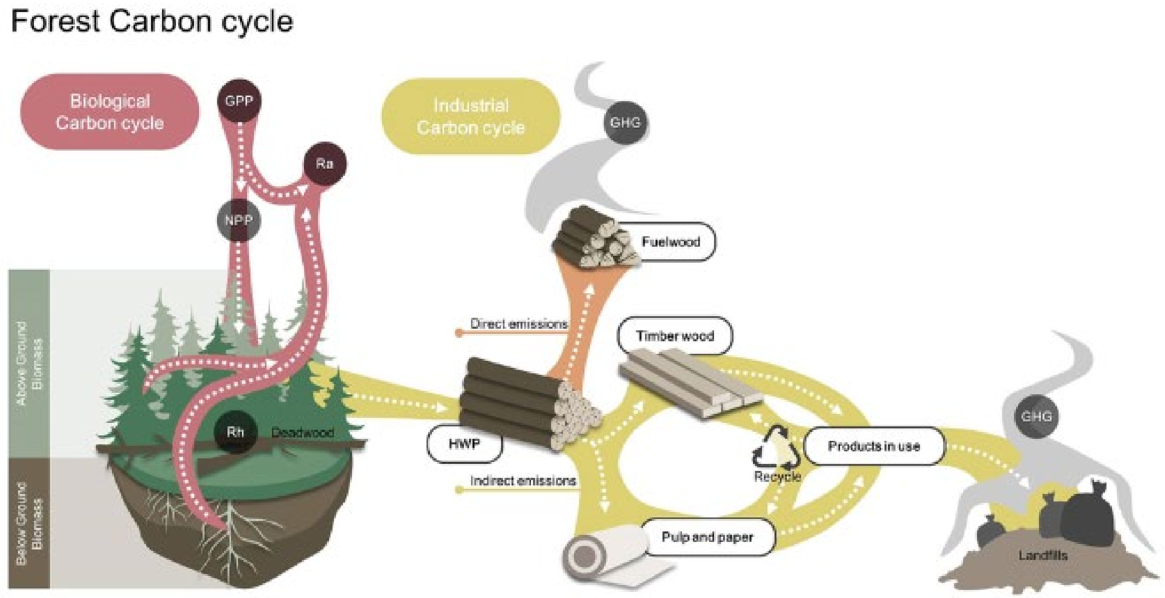

Figure 1 Source: Forest Carbon Management: A Review of Silviculture Practices and Management Strategies Across Boreal, Temperate, and Tropical Forests. Ameray et al., 2021

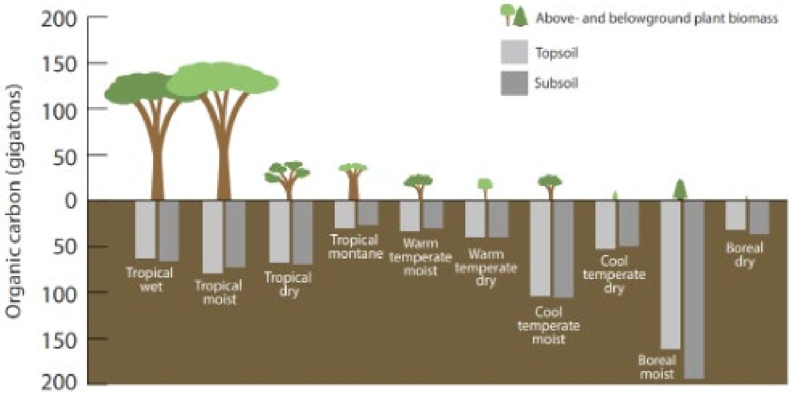

Figure 2 Shows Carbon (Gt C) stored in ecosystems. Source*:* Global Carbon | Climate Change Resource Center

Provisioning ecosystem services, such as lumber and fuel wood offered by forests, have historically and continued to be used by humans. Land management practices are becoming more common to increase the quantity and quality of goods rendered. These practices vary in intensity and purpose but share the similarity of being designed to manipulate forest product output. Generally, and for this document, the focused outcome is timber production that could be used in various ways. However, managed forested areas could include additional other services, such as animal habitats or recreational spaces.

Unmanaged forests are forests where forest management strategies are not applied or are sparsely used. These areas include old-growth forests and mature forests. Old-growth forests are described as an ecosystem distinguished by old homogenous trees and related structural attributes (*Old Growth Forests | US Forest Service*, n.d.). Old-growth forests are often considered un-timbered or untouched by timber harvest. Mature forests share similar qualities with old-growth but historically underwent some form of timber harvest. Due to the limited timber harvest rotations, other forest types aligned in the unmanaged category are afforested or reforested areas. Afforestation is the human-induced conversion of non-forested land to forested land. Reforested land is the human-induced conversion back to forested land from previously converted forested land (Ménard et al., n.d.). These areas historically may have had other land uses, such as farming or mining but are no longer used or abandoned.

Applicable Research and Techniques

Globally there has been an interest in identifying the most efficient and effective forest management practices. Recent studies have highlighted the correlation between utilizing advanced forest management techniques and carbon sequestration provided through the forest. Forest carbon pools are changed after a harvest by removing biomass from the system and adding carbon immediately to the dead wood pool through the remaining tree not taken for harvest. Deadwood debris and litter pools are changed after harvest and vary depending on the applied harvest method during the early successional forest phases.

Forest management plans are based on economic, cultural, environmental, and owner preferences. Timber harvest and management practices range in techniques and goals globally. This document will describe and review the most common practices accepted by government bodies and organizations. As expected, a "one size fits all" is not applicable in proper forest management.

One of the most common logging practices is to remove the most valuable section of the tree, the bole, which is considered the marketable trunk of the tree. Harvested wood product end use determines the minimum and maximum size for harvest. The remainder of the tree, such as the upper canopy and branches, are left in the forest system. Harvest activities change the carbon pools from the above-ground biomass and the dead wood debris pools, decreasing and increasing these pools. Recent research has indicated that in certain climates, primarily boreal and temperate, where most carbon is stored below ground, an increase of downed woody debris may increase carbon sequestration in the ecosystem before respiration from decomposition can occur. Remaining carbon moves from downed woody debris to buried carbon pools within the soil. Modeling demonstrates after harvest buried wood pools decrease until 20 years after the harvest but sharply increase until the end of the forest successional rotation (Senez-Gagnon et al., 2018).

Selective cutting and thinning of timber stands have gained popularity as a form of forest management. Selective cutting plans establish parameters of harvest within the timber plan. Parameters include the tree's diameter, seed trees, and species. Often selective cutting is presented as an option to small forest landowners as an alternative for aesthetic purposes. Select cutting has various benefits, such as leaving larger seed trees to quickly reestablish early successional systems and continue carbon sequestration through soil sequestration (Ameray et al., 2021). Due to the removal of trees from the system, however, forests that have undergone select cutting are more susceptible to wind damage and could lack future biodiversity due to already established species.

Intensive harvesting practices have also been studied to determine the quantity of carbon sequestration and storage. The most common intensive harvest technique is clearcutting. Clearcutting removes all trees of value in the system, regardless of species or diameter, for harvested wood products. Complete tree or bole-only harvest practices can be implemented with clearcutting. Clearcutting has been implemented as a management plan for other reasons in addition to timber harvest. Clearcutting can imitate major disturbance events such as wildfires or blow-downs, resetting the forest's successional cycle, providing early successional habitat, and increasing biodiversity within a stand by allowing non-shade tolerant species to grow. However, initial years following a clearcut, the decomposition rate of organic matter reduces the amount of soil organic carbon and material in the upper soil horizon (Jamroz & Jerzykiewicz, 2021). Decomposition can release carbon in the form of carbon dioxide into the atmosphere and is no longer sequestered within the system. Falsone et al., (2012) observed that after five years directly after the clearcut, the soil organic carbon content in the upper soil horizon (Oa horizon) was slightly higher than that of undisturbed study areas. This study suggests that the soil organic matter content will recover as expected but depends on the type of afforestation, forest type, and latitude.

A common practice prevalent in Nordic countries is complete tree removal. The stem, or bole, is removed and used for saw timber (lumber), pulp, or fiberboard. Logging residues, such as tops and branches, small trees, or trees with defects, are removed from the system for bioenergy or other uses. Extracting more biomass from a given site increases nutrient losses within the forest ecosystem, including carbon (Paré & Thiffault, 2016). Reduced nutrient availability and budget could decrease forest productivity, possibly decreasing future carbon sequestration. Paré & Thiffault also reported that harvest residues left on site after cut-to-length and bole logging increased soil organic carbon (SOC) by 18 percent. At the same time, total tree harvest caused a decrease of 6 percent over the long term. However, up to 89 percent of logging residues in efficient operations are utilized. The carbon is sequestered as harvested wood products, which is an important consideration when maximizing total carbon sequestration.

Unmanaged forests vary in carbon sequestration and storage capabilities based on climate and latitude. When developing management plans, forest type, dominant species, and geographic location should be considered. Figures 1 and 2 show that carbon storage locations can differ within an ecosystem. Forest systems with slower-growing, longer-living, larger trees that store the majority of above-ground carbon need to be closely monitored due to the length of years of the growing cycle and carbon sequestration compared to short-rotation forests. Fast-growing trees sequester more significant amounts of carbon at a young age and have shorter forest successional cycles. In contrast, slower-growing trees sequester more considerable amounts of carbon after many years, depending on growth rate patterns and rotational harvest length (Ameray et al., 2021). Examples of these ecosystems include the forests of the Pacific Northwest region of North America and the tropical rainforests of South America, respectively.

As a forest approaches maximum growth, total carbon sequestration remains constant until decadent begins, as seen in Figure 3 (Senez-Gagnon et al., 2018), and respiration from decomposition processes begins. A recent study conducted by Schulze et al., in 2020 identified that in fast-growing species in northern central Europe, such as spruce and beech (Picea and Fagus), unmanaged forests only mitigate 10 percent of the carbon that commercially managed forests were able to mitigate. The researchers determined that releasing carbon by decomposition through respiration is close to the sequestration rate by photosynthesis, neglecting the small amount of carbon that enters the soil in the long term (Brunet-Navarro et al., 2016; Giffen et al., 2022; Schulze et al., 2020).

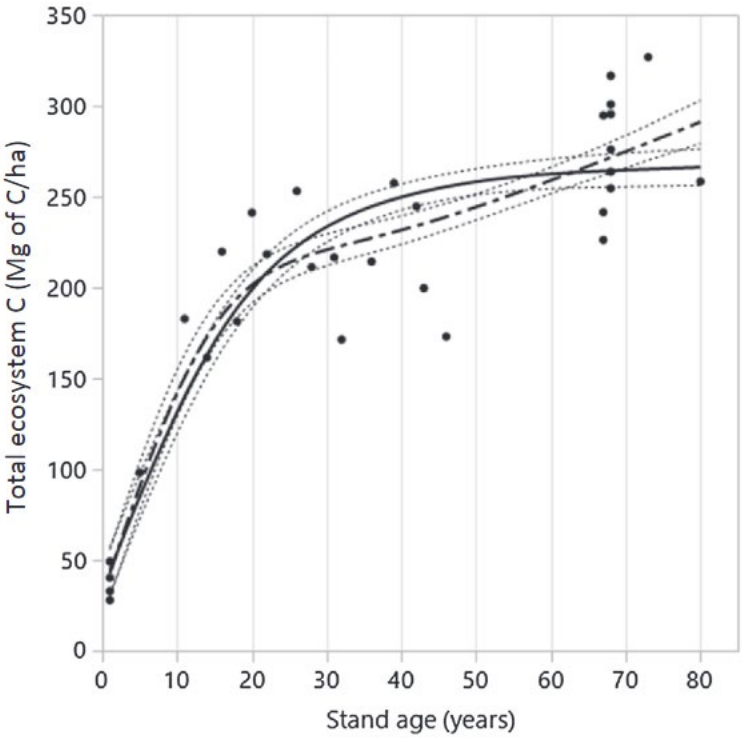

Figure 3. Predictive modeling of total carbon sequestration as forest stands age Source: Dynamics of Detrital Carbon Pools Following Harvesting of a Humid Eastern Canadian Balsam Fir Boreal Forest. Senez-Gagnon et al., 2018

As forests age through the successional life cycle, trees die, and decomposition begins. These processes transform the organic carbon stored within the tree into various other forms of carbon. Some carbon becomes fixed in the soils as dead woody debris in alternate forms by fungi and microbial processes. The remainder of the carbon is released into the atmosphere through respiration in the form of carbon dioxide. A recent study has calculated that dead trees currently store approximately 73 billion tons of carbon and release 10.9 billion tons of carbon into the atmosphere and soil yearly. The amount of carbon released through respiration can change depending on insect activity and climate conditions (Seibold et al., 2021). Figure 4 shows a model identifying the differences in gross and net primary production (GPP, NPP) and autotrophic and heterotrophic respiration (Ra, Rh).

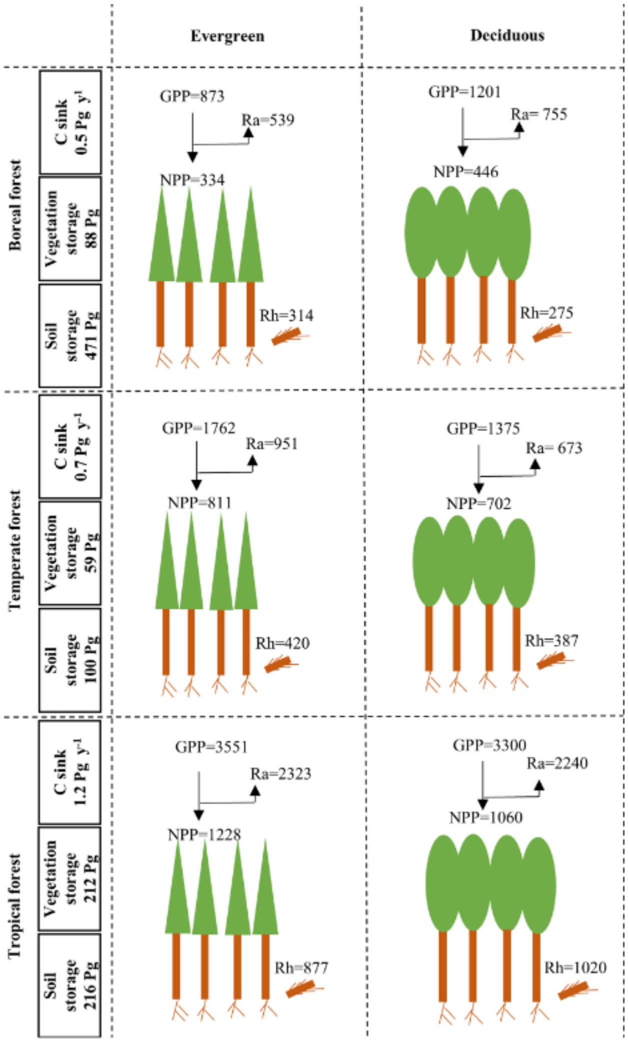

Figure 4. Comparison of storage and sequestration in temperate, boreal, and tropical forests, with modeled estimates of carbon cycling components. Source: Forest Carbon Management: A Review of Silvicultural Practices and Management Strategies Across Boreal, Temperate, and Tropical Forests (Ameray et al., 2021)

Discussion

Incorporating carbon sequestration goals into active forest management plans could reduce carbon dioxide within the atmosphere and assist in mitigating climate change. The University of Washington's Forest Carbon Study determined that the State of Washington's private forest and forestry sector, which are actively managed forests, are a Below Net Zero emitter. The study also considered the functional life of harvested wood products using half-life assessments to determine the net carbon storage benefits of wood products. However, the study did not take into consideration potentially mitigated carbon from using wood as an alternative fuel source to hydrocarbons. Even after consideration of carbon emissions from logging and harvested wood processing, these privately managed forests reduce Washington's atmospheric input by 12 percent annually (Ganguly et al., 2020). The duration of harvested wood products (lifespan) is challenging to determine due to the number of uses. The functional lifespan of harvested wood products associated with building materials varies but averages roughly 50-100 years (Ganguly et al., 2020). Continued research is being completed to determine how to include short-life carbon products, such as wood used for bioenergy, into carbon sequestration modeling.

Another factor to consider is that active forest management may reduce the frequency and intensity of wildfires within the system. Forest management deprives wildfires of readily available and easily ignitable fuel, which can correlate with wildfire intensity. Decreased fire intensity increases tree survivability since the likelihood of crown burning is reduced. Wildfires have gradually increased total global carbon emissions since 2000. From boreal forests alone, 1.76 billion tons of carbon dioxide was released from burning boreal forests in North America, Europe, and Asia, 150 percent higher than annual mean carbon dioxide emissions from 2000 to 2020 (Zheng et al., 2023).

Dead trees and snags are integrated into forest ecosystems for habitat and nutrient management. Still, they become less beneficial as excess occurs in the system due to reductions in significant natural disturbance events. Timber activities included in forest management plans can replicate the disturbance, limit the amount of natural tree die-off due to age, and provide energy and economic benefits when compared to naturally occurring wildfires (Forest Carbon Primer, n.d.). Forest wildfire management prevents continued burning to protect lives and properties, disrupting natural disturbance events.

Conclusion

Forested systems' influence and impact on carbon sequestration cannot be undervalued and have been recognized globally. During the 2015 United Nations Climate Change Conference, which established what is commonly known as the Paris Agreement, the discussion included implementing proper forest management as a critical element in mitigating climate change and achieving net zero (Harris & Stolle, 2016). Although elements of the implementation and techniques are still being evaluated, as discussed by (Schulze et al., 2020), the challenge includes the sequestration impacts of harvested wood products and the allocation of carbon credits to managed forest owners.

Consideration of forest types, geographic location, and applicable science should be applied when developing forest management plans that are considering adopting carbon sequestration as a goal. The forest types and location variables require individual analysis to determine the most effective method of management and harvest for carbon sequestration. Modification may be required in specific systems to adapt to the change in climate patterns and the system's interactions to new changing conditions (Ontl et al., 2020). It has been well documented that carbon is sequestered at higher rates and in larger quantities in systems where intense growth is abundant. Proper forest management practices promote growth at higher rates than unmanaged forests.

The applicability and importance of forest management start at the local level of individual forest owners and forest managers. While this document identifies regional carbon sequestration characteristics, individual forests are the foundational blocks that may require management techniques. As discussed, there are various techniques that can be implemented to ensure carbon sequestration is enhanced, while also providing renewable resources from the forested system. Forested systems can impact and mitigate atmospheric carbon input, as well as provide numerous ecosystem services when appropriately managed.

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