Roles of Forest Biometrics in Carbon Sequestration Strategies

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ABSTRACT

Forest biometrics is the science of forest measurement. It encompasses the quantification of biological and physical characteristics of trees and associated vegetation, insects, disease, wildlife, topography, soils and climate individually and collectively. Forest biometrics which is also the science of measuring and analyzing forest attributes such as tree growth, biomass and carbon content is essential for quantifying and optimizing the carbon sequestration potential of forests stands. Despite its potential, forest biometrics faces challenges which need to be addressed. This paper explores the roles of forest biometrics in carbon sequestration strategies, its applications in measuring carbon stock, monitoring forest growth, guiding sustainable forest management and informing climate policies. This paper also underlines the importance of forest biometrics in enabling effective carbon sequestration strategies and combating climate change and therefore recommends that there should be an investment on advanced technologies such as remote sensing to improve the accuracy and efficiency of forest carbon measurements. Strengthen capacity building and training for forest managers, researchers and policymakers in the use of biometrics tools and techniques.

INTRODUCTION

Forest biometrics may be defined by understanding this specific combination of the words – forest and biometrics. According to FAO (Food and Agriculture Organization), forest is defined as a land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent or trees able to reach these thresholds in situ. It does not include land that is predominantly under agriculture or urban land use (FAO, 2000; FAO, 2018). Biometrics can be best defined by breaking down the word: 'bio' as in biological and 'metric' as in measurement. Therefore, biometrics are biological measurements. Forest biometrics are measurements applied in forestry. Prodan (2013) described forest biometrics as the methods of mathematical statistics and biometrics that are significant to forestry. Therefore, forest biometrics is the science of forest measurement. It encompasses the quantification of biological and physical characteristics of trees and associated vegetation, insects, disease, wildlife, topography, soils and climate individually and collectively. These characteristics include all quantifiable attributes within forestry, both temporal and spatial (Arney, 2016).

Without the science of forest biometrics, forest management would be reduced to a profession limited to observation and narration. Forest inventory, site growth capacity, forest health or sustainable capacity would be unknown. Biometric measurement is a prevailing approach to appraise forest ecosystem carbon balance (Xu *et al.,* 2014). The most essential attribute of any science is the ability to quantify all attributes with some reasonable level of precision and consistency. Forest biometrics incorporates forest inventory, growth and yield modelling (Xu *et al.,* 2014), the use of Remote Sensing (RS) and Geographical Information System (GIS). These assist in the quantitative analysis of forest resources and as a guide for forest management and decision-making, which is important for understanding the value of and maintaining sustainable forests. As the adage drives "whatsoever that cannot be measured cannot be

managed", therefore estimating the forest resources such as carbon is imperative for managing forest ecosystems.

Carbon sequestration is the process of capturing and long-term storing atmospheric carbon dioxide in plants, soil, and oceans (Sedjo and Sohngen, 2012). Among the diverse forms of capturing and storing carbon dioxide is through the process of photosynthesis, which is directly associated with the amount of biomass. Forest biomass plays a critical role in carbon balance through the sequestration, resulting in biological growth or emission of carbon by deforestation (Sedjo and Sohngen, 2012). Deforestation and logging are considered the second largest source of greenhouse gas emissions in the world and will remain a major source in the near future, particularly in developing countries (Kindermann *et al*., 2008). Among some of the carbon sequestration measures are: the conservation and management of existing forests; the restoration of degraded or secondary forests; and the establishment of plantations, agroforestry systems and new forests in open areas (De Jong *et al*., 2000). Avoided deforestation was included along with afforestation, but until recently climate-policy discussions have focused on afforestation and forest management (Kindermann *et al*., 2008). This paper reviewed the roles of forest biometrics in global carbon sequestration strategies.

FOREST AS A CARBON SINK

Forests are one of the most important natural carbon sinks on earth, absorbing and storing large amounts of carbon dioxide (CO_2) from the atmosphere. Trees and other vegetation take in CO_2, for energy production and growth through the process of photosynthesis, while discharging oxygen into the atmosphere. Forest is essential in climate change mitigation because of its ability to capture and store carbon.

Generally, forests store large amounts of carbon sequestered from the atmosphere and retain them both in the living and dead biomass and soil. According to McKinley *et al*. (2011), the estimated amount of CO_2 in the atmosphere is equivalent to 810 Pg C, but 500 and 1500 Pg C are stored in terrestrial biomass and soil, respectively, of which 60% is stored in forest ecosystems. Thus, the need for the establishment and management of forests to enhance the removal and storage of CO_2 from the atmosphere. This has been documented as major ways to offset the upsurge in anthropogenic emissions of greenhouse gases and global warming reduction. Mckinley *et al*. (2011) estimated that forests and forest products currently offset 12 – 19% of fossil fuel emissions for the USA. However, in the short term, a decrease in the rate of deforestation will contribute more to mitigating CO^2 emissions than forest establishment. Globally, the rates of deforestation between 2000 and 2005 were 7.3 million ha $year^{-1}$, amounting to source of 1.4-2Pg C $year^{-1}$ to the atmosphere (Houghton, 2005; Mckinley *et al*., 2011).

Forests store carbon in three main components which are;

i. **Aboveground biomass:** this includes the trunks, branches and leaves of trees. Tropical forests, for instance, store an average of 200-300 tons of carbon per hectare in aboveground biomass (Pan *et al*., 2011)

ii. **Belowground biomass:** carbon is also stored in tree roots and soil organic matter, which can account for up to 50% of a forest carbon stock (Pan *et al*., 2011).

iii. **Dead organic matter:** fallen leaves, branches, and decomposing plant material contribute to the carbon pool by storing carbon in the forest floor.

IMPORTANCE OF CARBON SEQUESTRATION

Carbon sequestration which is the process of capturing and storing atmospheric carbon dioxide (CO_2) is a critical strategy in mitigating climate change and its related effects. It plays a dynamic role in minimizing greenhouse gas absorptions, steadying universal temperatures, and supporting the long-term sustainability of ecosystems. The following highlights its importance:

i. Carbon markets climate financing enablement

Carbon sequestration is the basis of carbon credit markets, where people can trade carbon offsets to meet their emission lessening goals. These markets provide financial incentives for conserving forests, planting trees and adopting sustainable land-use practices (World Bank, 2021).

ii. Climate change mitigation

Carbon sequestration helps in reducing the concentration of CO2, a primary greenhouse gas, in the atmosphere. Forest ecosystems, according to Boehm and Schumer (2023) absorb approximately 7.6

billion metric tons of CO2 annually through photosynthesis, thereby playing a vital role in reducing global warming to the targets set by the Paris Agreement.

iii. Ecosystem stability Support

The process of carbon sequestration enhances ecosystem resilience by promoting biodiversity and improving soil health. Forests, wetlands and grasslands not only sequester carbon but also provide essential ecosystem services, such as water filtration and habitat for wildlife by Food and Agriculture Organization (FAO, 2022).

iv. Sustainable development promotion

Carbon sequestration initiatives, such as reforestation and afforestation, contribute to sustainable development by creating green jobs and improving livelihoods, particularly in rural communities. These initiatives align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action) and SDG 15 (Life on Land) (Opoku, 2016).

v. Agricultural productivity and soil health enhancement

Soil carbon sequestration improves soil fertility and water retention, leading to increased agricultural productivity. Practices such as agroforestry and conservation agriculture enhance soil organic carbon, contributing to both food security and climate mitigation (Lal, 2005).

vi. Reduction of deforestation and land degradation effects

Deforestation and land use changes release significant amounts of stored carbon into the atmosphere. Carbon sequestration counteracts these emissions by restoring degraded ecosystems and enhancing their ability to store carbon. For instance, mangrove restoration projects have been shown to sequester up to four times more carbon than terrestrial forests (Donato *et al*., 2011).

FOREST BIOMETRICS TOOLS

According to Jirel (2024), the followings are some of biometrics tools/techniques:

1. Diameter tape (D-tape) and Caliper: diameter tape is used for measuring the diameter and the circumference of a tree by wrapping the tape around the stem of the tree at a diameter at breast height (DBH) which is 1.3 meters above ground and reading the measurement on the tape. Whereas, calipers are instruments with movable arms, in between where the tree stem is placed perpendicularly at DBH and closed tightly and reading the measurement on the scale.

2**. Clinometer:** it is an instrument used to measure the height of a tree based on the angle and geometry.

3**. Compass:** it is an instrument used to determine the aspect (the direction in which the slope of a hill is facing) to know where the vegetation will grow well.

4. **GPS Receiver:** GPS stands for Global Positioning System. It is a handheld portable instrument of the size of a mobile phone extensively used during forest inventory to obtain the latitude, longitude and elevation and the feature to mark waypoints and save the coordinate as well. It is used to mark the coordinates of forest boundaries and to verify spatial data.

5. **Spiegel relaskop:** it is an instrument used in measuring the diameter at the top and at the middle and height of a tree.

6. **Increment borer:** it is a small straw-shaped instrument that goes through the bark to the center of the cores used for determining the age of the tree by measuring the annual rings. It also helps to determine the age growth rate and soundness of the tree.

7**. Remote sensing and GIS software:** remote sensing is a process of acquiring data from a distance of an object, area or phenomenon by analyzing the data through instruments without being in direct contact with the object or area which is being examined. Remote sensing is the method of detecting and measuring the physical characteristics of the ground surface by measuring its reflected and emitted radiation whereas GIS stands for Geographic Information System. GIS uses satellite imagery to visualize spatial data and monitor the forest. It consists of several functions that help in mapping forests, knowledge on forest composition, soil health and diseases, measuring biomass, forest fire modeling and so on.

METHODS OF COLLECTING BIOMETICS DATA ON FOREST RESOURCES

1. **Forest inventory:** it is the systematic process of collecting data on various attributes of the forest such as tree DBH, height from the ground, basal area, tree grade, aspect and slope of forest which is used to analyze and interpret available forest resources such as estimation of volume, growing stock and yield.

i. This information helps to monitor the forest's condition and health. It also plays a crucial role in estimating carbon stocks and sequestration by any forest which forms a basis for carbon financing and climate change mitigation.

ii. Since it is not possible to measure every single tree in the forest, thus a sample is taken based on the accuracy needed, sample trees are measured and the result is generalized for the whole forest.

2. **Remote sensing:** remote sensing is the acquiring of data from an object or area from a distance without being in direct contact with it. Remote sensing is the method of detecting and measuring the physical characteristics of the ground surface by measuring its reflected and emitted radiation. Remote sensing technologies such as LiDAR, satellite imagery, aerial photography, drones etc can be used in combination with the ground data to determine the forest biomass, structure, health and composition.

i. **LiDAR (Light Detection and Ranging):** it is a type of active remote sensing (which emits its energy to illuminate the object). This technology is based on the use of laser signals to measure the distance to the earth's surface based on the time delay of the returned laser pulses.

The key beneficial aspect of LiDAR is that it can penetrate through the forest canopy cover which helps to collect the three-dimensional information about tree height and density. This helps in accurately estimating forest structural characteristics such as stand volume, basal area and above ground biomass.

ii. **Satellite imagery:** it is the type of passive remote sensing (that uses the natural source of energy that is sun that illuminates the earth's surface).

Satellite imagery is images captured by satellites observing the earth that provide information regarding the various ground features such as soil, temperature, elevation, vegetation, moisture etc. (Jirel, 2024).

ROLES OF FOREST BIOMETRICS IN CARBON SEQUESTRATION

As global efforts to mitigate climate change, forest biometrics has become an indispensable tool in developing and implementing carbon sequestration strategies, by providing accurate data on forest carbon stocks and sequestration potential. To maximize this potential, accurate measurement, monitoring and management of forest carbon stocks are necessary and forest biometrics provide the tools and methodologies to achieve this. Forest biometrics involves the quantitative assessment of forest attributes such as tree height, diameter, biomass and carbon content. These data are crucial for developing effective carbon sequestration strategies supporting climate policies and fostering sustainable forest management. Various studies have shown the roles of forest biometrics in carbon sequestration (e.g., Mckinley *et al*., 2011; Kondo *et al.,* 2013; Adeoti, 2023; Yavitt, 2024). Here, are some key roles of forest biometrics in carbon sequestration:

Measuring carbon stock: Forest biometrics enables the precise measurement of carbon stored in forests, including aboveground and belowground biomass. The biometric methods for measuring are:

i. Field based measurements: collecting data on tree diameter, height and species composition to estimate carbon content by carrying out calculations.

ii. Remote sensing technologies: tools like LiDAR, satellite imagery and drones provide large-scale high-resolution data on forest structure and biomass.

i. **Monitoring forest carbon dynamics**: Forests are dynamic systems that experience growth, degradation and recovery over time. Forest biometrics provide tools and techniques for monitoring changes in forest carbon stocks over time. This includes measuring tree diameter, height, and volume as well as assessing forest density and canopy cover. Forest biometrics is also essential for tracking the success of reforestation and afforestation projects, detecting deforestation and forest degradation early.

ii. Informing climate change mitigation policies: Forest biometrics contributes to the development of climate change mitigation policies by providing accurate estimates of forest carbon sequestration potential and monitoring progress towards national and international climate goals.

iii. **Identifying high carbon sequestration forests:** Forest biometrics provides helps identify forests with high carbon sequestration potential such as old growth forests or forest with high biomass density. This information can inform conservation and restoration efforts.

iv. **Supporting REDD+ and other carbon finance schemes:** Forest biometrics play a critical role in supporting REDD+ (Reducing Emissions from Deforestation and Forest Degradation) implementation and other carbon finance mechanisms by providing the data and methods needed to estimate carbon emissions reductions and removals.

v. **Biodiversity assessment:** Since forest biometrics helps to measure, assess and quantify the forest resources, this provides insights into the diversity of tree species composition, distribution patterns, wildlife etc. This information can contribute to making conservation plans and prioritizing the areas.

vi. **Supporting research and development:** Forest biometrics supports research and development in forest ecology, silviculture and forest engineering leading to innovative solutions and technologies for enhancing forest carbon sequestration.

vii. **Fostering international cooperation and knowledge sharing**: Forest biometrics promotes international cooperation and knowledge sharing by providing a common framework for measuring and monitoring forest carbon sequestration. This facilitates the exchange of best practices and lessons learned among countries and regions.

CHALLENGES AND LIMITATIONS OF FOREST BIOMETRICS

According to the reports of Yavitt (2024) in his study on quantifying forest ecosystems, forest biometrics applications strategies are faced with the following challenges and limitations which include;

i. **Cost of data collection:** collecting accurate biometric data can be labour intensive and costly. During field data collection, expertise is needed for some specialized equipment and significant time. Maintaining long-term data sets adds to the operational costs especially in large and remote forested areas.

ii. **Models Complexity:** biometric models differ in complexity from simple regression equations to complex spatial and temporal simulations. Developing, evaluating and validating these models require expertise in statistics, ecology and computer science.

iii. **Uncertainty and limitation of Data:** due to the complexity and dynamics of forest ecosystems, it faces challenges in capturing all relevant variables and interactions. The consistency of biometric predictions/forecast and management results can be affected by model assumptions, data quality uncertainties and environmental variability.

iv. **Stakeholders needs Integration:** Utilizing biometric information effectively needs partnership and communication among stakeholders, including forest managers, policy makers, and local communities. Bridging the gap between technical analyses and practical applications is crucial for ensuring that biometric insights translate into meaningful conservation and management actions.

ADVANCEMENTS IN FOREST BIOMETRICS THAT CAN ENHANCE CARBON SEQUESTRATION STRATEGIES

Advancements in forest biometrics are transforming how forests are monitored, measured and managed for carbon sequestration. These innovations improve the accuracy, efficiency and scalability of data collection enabling better implementation of global climate mitigation strategies. Below are some of the advancements:

1. Remote sensing technologies such as LiDAR (Light Detection and Ranging), satellite imagery, drones.
2. Geographic Information System (GIS).
3. Open data platforms such as Global Forest Watch (GFW), SEPAL (System for Earth Observation Data Access, Processing and Analysis for Land Monitoring).

BENEFITS OF ADVANCEMENTS IN FOREST BIOMETRICS

1. **Improved accuracy:** advanced technologies reduce uncertainties in biomass and carbon stock estimates.

2. **Scalability:** remote sensing and drones enable large scale monitoring across vast and remote forest areas.
3. **Real-time data:** innovations like satellite platforms and open-access tools allow for continuous monitoring and early detection of forest changes.
4. **Enhanced policy support:** accurate data supports evidence-based policy-making such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) and carbon credit systems.

CONCLUSION AND RECOMMENDATIONS

Forest biometrics plays a pivotal role in global carbon sequestration strategies by providing the tools and methods needed to measure, monitor and manage forest ecosystems effectively. As the urgency to mitigate climate change grows, forest biometrics offers critical data to quantify carbon stock, assess forest health and model future carbon sequestration potential. By integrating advanced technologies such as remote sensing and GIS, forest biometrics has become increasingly accurate, efficient, scalable, making it indispensable for global carbon sequestration. This study therefore recommends that there should be an investment in advanced technologies such as remote sensing to improve the accuracy and efficiency of forest carbon measurements. Strengthen capacity building and training to train forest managers, researchers, and policymakers in the use of biometric tools and methods.

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