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The contribution of tropical forests to climate change mitigation. Biomass estimation techniques a necessary tool in their assessment

La contribución de los bosques tropicales a la mitigación del cambio climático. Las técnicas de estimación de la biomasa, una herramienta necesaria para su evaluación

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Abstract

Climate change is a global problem caused by human activities such as burning fossil fuels and deforestation. This leads to indicators of climate change like increased flooding, sea level rise, and water stress. Tropical forests play a crucial role in mitigating climate change through photosynthesis, storing large amounts of carbon in their biomass. Two methods, destructive and non-destructive, are commonly used to estimate the biomass of tropical forests. There are five components of biomass in these ecosystems, with most of it found aboveground. Belowground biomass is estimated based on aboveground biomass. About 50 % of the dry biomass in forest ecosystems is carbon. Allometric equations are used to estimate biomass and volume based on tree diameter and height. Different equations have been developed for different species and locations. Carbon stocks in forest ecosystems are present in both aboveground and belowground parts.

Keywords:

Aboveground biomass,
aboveground carbon,
biomass equation,
carbon pools,
destructive method,
forest ecosystem,
greenhouse gases.

Resumen

El cambio climático es un problema global provocado principalmente por la actividad humana, como la quema de combustibles fósiles y la deforestación. Este fenómeno se manifiesta a través de indicadores como inundaciones, aumento del nivel del mar y estrés hídrico. Los ecosistemas forestales tropicales juegan un papel crucial en la mitigación del cambio climático a través de la fotosíntesis, almacenando grandes cantidades de carbono en su biomasa aérea. Para estimar la biomasa aérea y subterránea en estos ecosistemas, se utilizan 2 métodos: destructivo y no destructivo. La biomasa aérea representa la mayor parte de la biomasa total, y la biomasa subterránea se estima a partir de la biomasa aérea del bosque. El carbono constituye aproximadamente el 50 % de la biomasa seca de los ecosistemas forestales. Además, se han desarrollado diferentes ecuaciones alométricas para estimar la biomasa y el volumen de los árboles en función de sus características. En resumen, las reservas de carbono de los ecosistemas forestales se encuentran tanto en su parte aérea como en la subterránea.

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Introduction

Climate change (CC) is one of our time's global issues, and forests play an important role in it. However, human activity is primarily caused by releasing greenhouse gases (GHG) into the atmosphere, reducing forests' role in CC. GHG emitted from burning fossil fuels, deforestation, and changing land use enter the atmosphere, which causes a change in the atmosphere's composition. These are the main reasons behind CC[1]. The balance between the sun's radiation and the earth's heat emission is affected by variations in the atmosphere's composition, which is the main source of changes in the global climate[2].

The effects of CC are widespread and unprecedented in magnitude, ranging from altered weather patterns that jeopardize food production to increasing sea levels that raise the possibility of catastrophic flooding. It puts a great deal of strain on the environment by disturbing ecosystems and society by reducing human well-being. For instance, it is predicted that increased water stress due to CC will affect 75 to 250 million people in Africa by (2020)[2]. Preserving natural forests and increasing the density of trees outside of them are two strategies to mitigate CC and lower GHG[3].

Forests have a significant influence on CC, one of the most pressing worldwide challenges of our day. Forests fix a lot of carbon dioxide through photosynthesis, which is then stored as carbon in various pools (soil, deadwood, litter, above- and below-ground biomass). Carbon sequestration in forest ecosystems is significantly influenced by biomass production[4].

Global forests encompass about a billion hectares and account for almost half of the world's reduction of GHG[5]. Approximately 60 % of the world's forest cover is made up of tropical forests, which store between 229 and 263 Pg of carbon[6,7] in aboveground biomass, roughly 20 times the annual emissions from land use changes and combustion[8]. Half of all existing world forests combined, or 1.2 Pg C ha^{-1}, was contributed by intact tropical forests to the global carbon sink[7].

Tropical and sub-tropical landmasses are primarily covered in dry forests. They make up 42 % of the region, by comparison, moist forests make up 33 % and wet rainforests, 25 %[9]. The majority of tropical dry forests are found in Africa, where they make up 70 to 80 % of the continent's total forested area[9].

The Paris Climate Agreement emphasized how important forests are to reducing the effects of CC. This indicates that forests play a critical role in controlling the earth's climate through the carbon cycle by absorbing carbon from the atmosphere as they develop and storing it in their leaves, woody tissue, roots, and soil[10]. The role of forest in CC mitigation is visible if reduced forest loss, improved natural forest management, and afforestation. The primary mechanism by which forests influence the climate is through the biochemical activities of trees, like photosynthesis, which have an impact on atmospheric CO_2 levels and are crucial to the carbon cycle. The world's forests absorb 2.4 billion tons of carbon dioxide each year or about one-third of the carbon dioxide released through the burning of fossil fuels[10].

Forests are the most major terrestrial carbon store in the world. Tropical forests are among the most valuable ecosystems in the world. They have a crucial role in controlling CC since biomass, necromass, and soil contain enormous amounts of carbon. They are estimated to contain 428 gigatonnes of carbon above- and below ground[11].

Our knowledge of the role that tropical forests play in the global carbon cycle is based on estimations of the biomass of various tropical forest species. Thus, it is imperative to measure tree biomass using either direct or indirect approaches[12]. This necessitated utilizing the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) program of the United Nations Framework Convention on Climate Change and successfully implementing climate mitigation policies[5]. Therefore, the objective of this work was to review the contribution of tropical forests to CC mitigation by using biomass estimation techniques as necessary tools.

Development

Today, in tropical forests, most people live in and around the forest, focusing only on the present benefits obtained from the forest regardless of their contribution to CC mitigation or the use of forest resources without considering their future. Next generations will live in an untenable environment because of this. Biomass is estimated in tropical forests using destructive and non-destructive methods. Most of the time, both destructive and non-destructive methods can be used to assess tree biomass[13]. The destructive approach entails cutting down the tree and determining the precise masses of each of its components. Although it is quite accurate, it is expensive and time-consuming to cut down trees and separate them into different components[14]. In addition, destructive methods can disturb the ecology of the forest and also disturb different biodiversity that lives in the forest.

In contrast, non-destructive methods are less expensive and take less time to estimate tree biomass since they use allometric models and biomass expansion factors that have already been developed. Under this review, the main question to be answered is: how much carbon is stored by tropical forests? Which biomass estimation method is important for tropical forests? Finally, how is belowground biomass estimated from aboveground biomass? The main created a literature review to highlight relevant theories are Gibbs et al.[2] Monitoring and estimating tropical forest carbon stocks: making REDD+ a reality, IPCC 2013 CC 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Pan et al.[7], A Large and Persistent Carbon Sink in the World's Forests and Brown[12], measuring carbon in forests: status and future challenges.

Biomass and carbon pools.

Above ground biomass. It refers to all biomass found in live plants that are above ground, including bark, seeds, foliage, stems, stumps, branches, and herbaceous plants. The main stem, or bole, stem bark, and crown, or branch wood and foliage, are the three primary parts of aboveground biomass that are typically separated out. The majority of the aboveground biomass comes from these stem forests[15].

The models of component biomass estimations are helpful in explaining the variation within the tree sections. Furthermore, distinct estimations of component biomasses are needed since different tree components are employed for various reasons. The bole is mostly utilized for the production of lumber; small branches and leaves are helpful in the production of bioenergy, and crown biomass can offer information on fuel load and wildfire evaluation[16]. The most apparent of all the carbon pools is aboveground biomass, and variations in it are a key sign of changes in the environment or the effects of interventions on benefits associated with mitigating carbon emissions. For the majority of land-based initiatives, it is a crucial pool[17]. However, a variety of site parameters, including stand density, site productivity, soil properties like texture and moisture content, and tree features like species and age, all have an impact on how much biomass a tree has.

Importance of aboveground biomass estimation to predict carbon stock. Forests are terrestrial ecosystems that are crucial in lowering atmospheric carbon. Half of the carbon stored in vegetation and half of the carbon stored in soil are found in a forest ecosystem. Forests incorporate photosynthesis, autotrophic respiration, and litter fall fluxes, estimates of forest biomass represent the ability of plants to absorb carbon over an extended period of time[18]. Estimating biomass is crucial for calculating the amount of carbon stored in forests, determining how they mitigate the effects of CC worldwide and forecasting the possible outcomes of carbon emission reduction strategies. In addition to this, national carbon monitoring programs like REDD, as well as climate and carbon cycle modeling, depend on it. Ground measurements of tree biomass are the main source of information used to estimate carbon stocks[19].

Belowground biomass. Is the biomass found in live roots or belowground? The roots are crucial to the carbon cycle for balancing CC. However, it is challenging to measure or model the stock or growth rates, belowground biomass has received the least attention in terms of research and measurement of any carbon pool. Because of the uprooting of grass and trees and the disturbance of topsoil, which is harmful under normal circumstances, the quantity is typically measured as a percentage of aboveground biomass.

Below ground biomass = 27 % above ground biomass. Below ground carbon = 50 % below ground biomass.

Methods for estimating tree/forest biomass. A variety of techniques, broadly classified as destructive and non-destructive procedures, can be used to estimate biomass and carbon[12]. The first is the estimation of tree biomass and carbon using the destructive method. The destructive technique or the harvest method is the most straightforward approach for calculating aboveground biomass and the carbon stocks contained in forest ecosystems. This approach entails harvesting every tree in the designated region, weighing the various parts of the harvested tree, such as the trunk, leaves, and branches, then weighing these parts again after they have been oven-dried[14]. This biomass estimating technique is only applicable to small areas or tree sample sizes. This method accurately calculates the biomass for a given area, but it is expensive, time- and resource-consuming, labor-intensive, damaging, and impractical for large-scale analysis. Additionally, this approach is inapplicable to degraded forests that support vulnerable species. This approach is typically used to create biomass equations that may be used to evaluate biomass on a bigger scale. For any other reason than research, these activities are therefore exceedingly costly[20].

A non-destructive technique for estimating biomass and carbon are the second method used to estimate the biomass of trees and forest stands. Since biomass in large forest regions is straightforward to forecast, it is better to estimate forest biomass using a non-destructive method. It served as a determining tool to prevent the destruction of forests and to estimate hard-to-measure tree metrics like tree volume, biomass, and carbon stocks from easily measurable tree parameters like diameter at breast height and height[21].

To evaluate the productivity and sustainability of the forest, an estimate of the total biomass in the ecosystem is necessary. It also allows us to estimate the amount of carbon that a forest can sequester from the atmosphere and provides us with an idea of the potential quantity of carbon that can be released when forests are burned or destroyed[22].

Biomass equation. Since the middle of the 1880s, when Central European foresters began modeling the development and yield of their woods using graphical techniques, modeling has been utilized in forestry. Up until new statistical analytic techniques and mechanical calculators were developed, these models were still in use in various settings. Yield and volume tables could be prepared more quickly because to these new statistical methods and tools[23]. For example, Stiellfor[24] and Woessner[25] authors proposed regression equations for volume/biomass prediction of different parts of trees like bole, roots, and branches, and immediately another author, such as Harding & Grigal[26], developed allometric models $Y = ad^{b}$ and $Y = ad^{b}h^{c}$, where Y is the mass, d is the diameter at breast height, h is the height, and *a*, *b*, *and c* are mathematical constants.

Allometric models relate diameter at breast height to other components and provide relatively precise estimates of volume and biomass[27]. These models vary widely, but the commonly used method is the linear model ($Y = a + bx$), where Y is the biomass, a and b are slope and intercept, respectively, and x is the diameter at breast height. The precise estimation of tree volume and biomass in forest ecosystems is essential for above-ground biomass (AGB) and carbon stock assessment.

For sustainable efforts in forest management, harvestable stock and biomass must be accurately quantified. This requires the use of biomass equations. Numerous biomass prediction formulas have been created for both groupings of species[28,29] and individual species[30].

For the following purposes, various allometric equations or models have been developed: (a) species-specific single-site models based on data from a single site; (b) species-specific multi-site models based on data from several sites; (c) general single-site models based on data from one site; and (d) general multi-site models based on data from several sites.

General multi-site models[31] would be the best choice for estimating biomass and carbon in large forest areas with a large number of different tree species. Species-specific allometric equations developed on site provided better biomass estimation than generalized equations[32].

A tree biomass statistical model is adjusted to a collection of indicators, such as tree diameter and/or height, specific wood weight, or kind of forest, to provide an allometric equation[5]. As a result, biomass estimates produced by locally derived, species-specific biomass equations may differ significantly from estimates produced by applying more broadly applicable regional biomass equations without local calibration. The most precise way to estimate tree biomass would be to weigh trees in the field. Allometric equations must be used, nevertheless, because it is exceedingly costly and time-consuming. It's unknown what kind and quantity of data, as well as how many equations, are needed to precisely quantify biomass. It is advisable to use caution when creating and assessing the techniques for calculating above-ground biomass and its constituent parts[4].

Forest carbon pools. The carbon pools found in forest ecosystems are made up of the following: dead matter, which includes standing dead trees, downed woody debris, and litter; living trees' above and below-ground (root) carbon stores; non-tree understory vegetation, and soil organic matter[3]. The various carbon pools receive the carbon dioxide that plants fix during photosynthesis. The majority of a tree's carbon pool is made up of its biomass above ground. It is the most significant and obvious carbon pool in the terrestrial forest ecosystem[20]. This part of the carbon pool is directly impacted by any modifications to the land use system, such as deforestation and degradation of the forests. By moving and storing carbon in the soil, the below-ground biomass which is made up of all the living roots plays a significant part in the carbon cycle. The dead mass of litter and woody debris only makes up a small portion of the carbon stocks in forests, hence it is not a significant carbon pool. Second only to above-ground biomass in terms of contribution to forest carbon stocks is soil organic matter, and soils are a key source of carbon emissions after deforestation[20].

In their natural state, tropical forests have higher levels of aboveground carbon per unit area than any other type of land cover. The active biomass of trees and understory plants, as well as the dead mass of litter, woody debris, and soil organic matter, are the primary carbon reservoirs in tropical forest ecosystems. Deforestation and degradation have a direct influence on the greatest pool of stored carbon, which is found in the aboveground living biomass of trees. Therefore, the first step in calculating the carbon stocks and fluxes from tropical forests is determining the carbon in aboveground forest biomass. In a forest, trees typically make up the majority of the biomass, the remaining carbon reservoirs only contribute a small portion of the overall biomass of the trees.

In tropical forest ecosystems. i) The understory is about 3 % of the above-ground tree biomass. ii) Dead wood, 5-40 %. iii) Fine litter is only 5 % of that in the above-ground tree biomass. iv) Below-ground biomass is more variable. v) Above-ground biomass in trees also responds more rapidly and significantly as a result of land-use change than other carbon pools. As a consequence, the majority of carbon accounting efforts is focused on AGB.

Overview of forest carbon stock measurements. The dead mass of litter, woody debris, and soil organic matter, as well as the active biomass of trees and understory plants, are the primary carbon pools in tropical forest ecosystems. Usually the greatest pool and most directly affected by deforestation and degradation is the carbon stored in the aboveground living biomass of trees. In order to measure carbon stocks and fluxes from tropical forests, calculating aboveground forest biomass carbon is therefore the most important stage. Half of the weight of the dry biomass (carbon content ≈50 % of biomass, can be converted to carbon content. Although this strategy works well in a specific setting, it is too costly, time-consuming, damaging, and impractical for use in analyses at the national level[2].

Conclusion

The forest ecosystem plays a significant role in mitigating CC through photosynthesis. CC is mainly caused by human activity such as burning fossil fuels, deforestation, and land use change. There are mainly two methods (destructive and non-destructive) for biomass estimation of tropical forest ecosystems. Destructive methods of biomass estimation require higher resources than non-destructive methods. Different biomass and carbon proportions are found in different tree components. The highest proportion were found in stem parts. Most of the time below-ground biomass was estimated from above-ground biomass due to below-ground biomass requiring high resources. Biomass and volume allometric equation development widely used tree variables like diameter and tree height. There are five different types of biomass and carbon pools in tropical forest ecosystems.

Recommendations. i) Biomass models considering genus, families, successional groups, climatic variables, and specific density of wood should be adjusted and tested at both local and regional levels, as well as on tropics scales with dry forest. ii) There have been numerous studies carried out to estimate the forest biomass and the forest carbon stocks, but there is still a further need to develop robust methods to quantify the estimates of biomass for all forest components and carbon stocks more accurately.

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Conflicts of interest

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Ethical considerations

I confirm that neither all nor any parts of its content are currently under consideration or published in another journal.

Research limitations

This review focuses on tropical dry forests regardless of other forest ecosystems (moist or wet).

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