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Biomass and Carbon Storage in Forest Management Types: A Review of Forest Reserves, Sacred Groves, and Community Forest Management for Climate Change Mitigation

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Abstract

This review evaluated findings on how varied forest management types – (forest reserves, sacred groves, and community forest management), play important roles in storing biomass and carbon to mitigate climate change. Forest reserves are protected areas, vital for conserving biodiversity and maximizing carbon storage capacity due to their restricted human interference for sustainable management practices. Sacred forests, deeply rooted in cultural customs, play a vital role in storing carbon and display the close connection between indigenous rituals and conservation results. Community forest management stresses the involvement of residents and their responsibility, for effectively improving biomass production and promoting social and economic advantages for the community. By comparing these management practices, this study revealed the unique impacts these management practices have on carbon dynamics and explained their synergistic potential for enhancing forest resilience against climate change. The study shows the significance of integrating traditional ecological knowledge with modern forestry management practices to optimize carbon storage and aid in global climate efforts for mitigation and adaptation. Thus, it is recommended that Governments should strengthen forest reserve protection by enforcing stricter laws against illegal activities and using technologies like satellite imaging for monitoring. Establishing buffer zones and regular enforcement will help safeguard biodiversity and increase carbon sequestration. Engaging local communities in forest management through clear legal frameworks, capacity-building, and financial support can enhance sustainable forestry. Due to the cultural significance of Sacred groves, should be integrated into conservation programs, with community collaboration to preserve biodiversity and carbon storage, while respecting traditional values.

Keywords: Adaptation, Climate-change, Management, Mitigation, Sustainability

INTRODUCTION

Biomass refers to the biodegradable components of biological products, residues, and wastes from forestry, agriculture, and other industries (Konstantinavičienė and Vitunskienė, 2023). It comprises of the total mass of all living things, including above- and below-ground living biomass in a specific area or species, and is typically expressed as dry weight (IPCC, 2006; Chenge and Osho, 2018). Tree biomass is the total living organic matter in a tree. If the mass is expressed as a unit of area, such as tons per hectare, it is termed biomass density, within forest ecosystems, it is referred to as forest biomass. The role of biomass is crucial in signifying both the energy-charging mechanisms within forests and the vegetation's capacity in ecosystems to capture carbon (Wang *et al.*, 2019). The changes in forest biomass have been a focal point because they are linked to the carbon cycle, which affects worldwide climate trends and environmental shifts (Santoro *et al.*, 2019). Other than serving as a key indicator of carbon sequestration, forest biomass also holds significance in gauging energy production within natural ecosystems.

Carbon is non-metal with the molecular sixth (6) position that is found in both pure (graphite and diamond) and almost impure (coal and charcoal) forms. However, it can also mix with other elements to create molecules (Okwundu *et al.*, 2018). Carbon is a common element, accounting for an estimated average of 14% of all dried solid mass in all life forms. This is present in the atmosphere as carbon dioxide (CO_2) at a rate of 0.04%. According to Goel and Agarwal (2014), CO_2 is a neutral, unscented gas that is found in nature. It has a sublimation highest temperature of 70 °C and a vapour density of 1.53. It is water soluble to a degree and is a greenhouse gas responsible for regulating the Earth's temperature (Goel and Agarwal, 2014). Carbon dioxide is a minor constituent of the Earth's atmosphere, with its present atmospheric concentration level of about three hundred and seventy ppm in quantity (Sabine and Feely, 2003). Carbon dioxide and other greenhouse gases, including water vapour, methane, nitrous oxide, and chlorofluorocarbons, help keep the earth warmer than it would be without their presence in the atmosphere by trapping radiation (Sabine and Feely, 2003).

Key greenhouse gases contributing to the Earth's changing climate include CO_2, CH_4, N_2O, and fluorinated gases such as hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride. These gases trap solar heat that would otherwise escape to space (Melissa, 2019). CO_2 is the most prevalent greenhouse gas, making up approximately 76% of all greenhouse gas emissions (GHG, CCES, 2019). Methane, the second most crucial greenhouse gas (GHG), nitrous oxides and fluorinated gases are emitted from industrial activities. Ninety percent (90%) of carbon dioxide (CO_2) is produced through the combustion of fossil fuels such as coal, crude oil, and natural gas. This represents a substantial source of greenhouse gas emissions, with CO_2 being a major contributor to climate change (William and Craig, 2020).

Understanding the origins of heat energy, its utilization, carbon dioxide release rate, and carbon circulation knowledge is essential for the success of any measure to mitigate climate change. The carbon cycling process is a biogeochemical cycle involving the movement of carbon among the earth's biosphere, atmosphere, geosphere, pedosphere, and hydrosphere (Riebeek, 2011). The carbon cycle entails the transfer of carbon through interconnected components such as the oceans, atmosphere, terrestrial ecosystems, and Earth's crust, forming an integrated system (IPCC, 2012). The carbon cycle moves in gigatons of carbon annually, and the atmosphere, land, and sea can all store carbon in gaseous, liquid, or solid form (Melieres and Marechal, 2015).

Carbon is transferred from one or multiple carbon storage areas to another in an ongoing cycle known as carbon flux. Carbon pools are the main reservoirs for the exchange of carbon. These pools include the atmosphere, terrestrial biosphere, forests, oceans, soils, and sediments (Plate 1). The primary factor behind the observed rising trend in global temperatures is the flux of carbon into the atmosphere, with water (O_2) serving as the primary contributor (Katie and Anne, 2020). Carbon is retained in flora species within the biosphere. During photosynthesis, plants use CO_2 from the atmosphere as the building elements of food (Plate 2). Carbon is also present in the soil due to the breakdown of deceased animals and animal waste products (Plate 2) (Bot and Benite, 2005; Jeffrey, 2020). Plants store about 560 petagrams of carbon (PgC), with trees storing the largest amount (UNH-report, 2008).

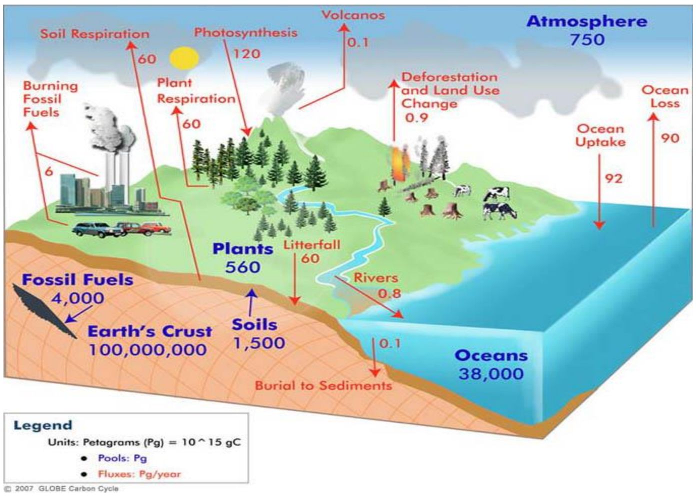

Plate 1: Carbon Cycle Process (left side) and the Earth Carbon Pools (right side). (Source: UNH, 2008).

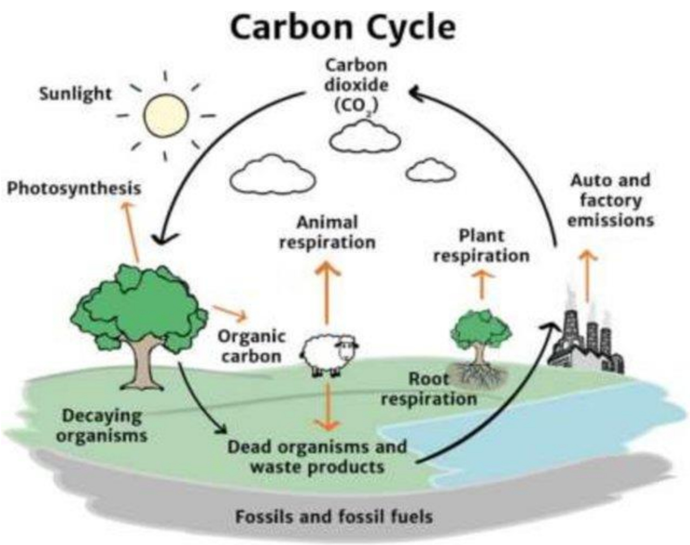

Plate 2: Complete Carbon Cycle (Source: Jeffrey, 2020).

Forests have vital importance in biomass production and the global carbon cycle. Carbon transport between the atmosphere and the terrestrial biosphere is the most important aspect of the forest carbon cycle (Thompson, 2023). The CO_2 in the atmosphere is converted into terrestrial organic carbon using the photosynthetic process, which is subsequently stored as biomass by trees and other plants (e.g. vegetation) (Ontl and Schulte, 2012).

FOREST BIOMASS AND CARBON POOLS

Carbon pools are carbon reservoirs that can absorb and release carbon (FAO, 2020). Forest carbon is reported in seven distinct pools (Skog *et al.*, 2004) (Plate 3), five of which are part of the forest ecosystem (EPA, 2020). The five components are live above-ground biomass (AGB), below-ground biomass (BGB), soil carbon, dead wood, and forest litter (Plate 3). The largest pool is the carbon stored in the AGB of trees (Adeoti *et al.*, 2023). The other two pools include mineral soils derived from rocks and organic soils originating from decomposed organic matter. The area of the earth covered in organic material generates a reservoir of fresh organic matter, predominantly plants, which consist of aboveground and belowground organic matter. Plants, animals, soils, and microorganisms are all examples of organic matter (UNH report, 2008).

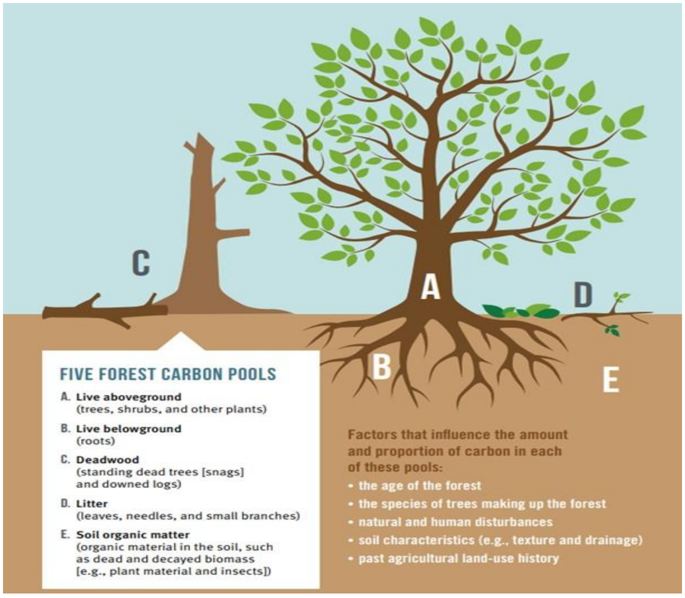

Plate 3: The Carbon Pool of Forest Ecosystem (Source: Catanzaro and D'Amato, 2019).

i. **Above-ground biomass**: Above-ground biomass (AGB) refers to the standing dry mass of woody plants, including trees and shrubs (Wilkes *et al.,* 2018). Differences in forest ecosystems and fluctuations in forest biomass greatly influence the transfer of carbon between land forest ecosystems and the atmosphere. Deforestation and forest degradation directly affect the AGB of trees, influencing the carbon pool in terrestrial ecosystems (Houghton, 2005). Ravindranath and Ostwald (2008) reported AGB as a crucial carbon reservoir in terrestrial forests, emphasizing its susceptibility to alterations in land use systems such as deforestation and forest degradation (Plate 4).

ii. Below Ground Biomass (BGB): The living pools of carbon (C) in forests, particularly the AGB and belowground biomass (BGB), play a substantial role in contributing carbon to the terrestrial ecosystem (Eggleston *et al*., 2006). The BGB, comprising all live roots, significantly contributes to the carbon cycle by participating in the movement and retention of carbon in the soil (Vashum and Jayakumar, 2012). Temperature, rainfall, terrain, forest structure, and forest composition are impacted by land use, human activities, and species numbers, leading to changes in above-ground and below-ground carbon storage in forests (Wei *et al*., 2013; Hu *et al.* 2015; Arasa-Gisbert *et al*., 2018; Arasa-Gisbert *et al*., 2018). Calculating the total amount of plant material below ground, including roots, rhizomes, and related mycorrhizal fungi, is known as estimating BGB. BGB is crucial for assessing how well ecosystem's function, how much carbon is stored, and how nutrients are cycled. Indirect procedures, non-destructive measurements, destructive sampling, and other methods and techniques are used to estimate BGB.

iii. Deadwood biomass: Deadwood constitutes a significant portion of carbon storage and movement, contributing to around 8% (equivalent to 73 petagrams) of the overall carbon reservoir in global forests. This encompasses fallen and upright dead tree trunks, branches, and additional woody materials (Pan *et al*., 2011). The stocks and fluxes of dead wood carbon are highly biogeographic variables. For instance, Pan *et al*. (2011) reported in 2007, that total dead wood carbon stocks across different vegetational zones in the world accounted for between 2.8 and 11.7% of the sum forest C storage (Plate 4). This variability is caused by variations in decomposition rates that are correlated with climate and the wood characteristics of different species (Luyssaert *et al.,* 2017; Adam *et al.,* 2021). Also, harvesting activities, impacts from windstorms, occurrences of wildfires, outbreaks of pests or pathogens, and other small-scale disturbances alter the dynamics of dead wood (McGee, 2000).

iv. Forest litter: Forest litter is also known as litter biomass; it is regarded as a minor pool because it only contributes a small amount of C within the terrestrial pool (Ravindranath and Ostwald 2008). Although litter only makes up about 6% (Plate 4) of the entire carbon stored in the forest. It is a vital component of carbon and a key player when transporting substances within the ecosystem (EPA, 2020). Additionally, it connects the soil carbon, and the vegetation carbon pools (Pan *et al.,* 2011). The amount of carbon stored in a litter can be estimated using data on its known carbon content (Domke *et al.,* 2016), by multiplying litter volume and its carbon content. One can estimate the amount of carbon stored in litter by determining the rate of breakdown and the cycling of organic carbon in the litter layer (Wanlong and Xuehua, 2020).

v. Soil carbon: Soil organic matter is the largest contributor to forest carbon stocks following above-ground biomass (Kumar *et al.,* 2006). The soil represents a significant source of carbon emissions post-deforestation (Page *et al.,* 2002). Within a forest ecosystem, soil organic matter encompasses soil organic carbon (SOC), playing a crucial role in nutrient and carbon cycling between the lithosphere and atmosphere (Lal, 2005). Globally, soils contain approximately 1500 PgC of carbon (Zomer *et al.,* 2017), with organic carbon being the predominant form found in soil.

RATE OF CARBON FLOWS WITHIN FOREST ECOSYSTEM

The quantity of organic carbon tends to decrease with increasing soil depth; routine soil measurements typically extend to a depth of 1 meter (UNH-report, 2008). In most cases, this catches most of the carbon in the soil; however, this does not apply in areas with very deep soil. Most of the carbon in soil comes from decomposing plant matter, which microbes break down. The degradation process releases carbon into the atmosphere since the bacteria's metabolism eventually breaks down most of the organic materials to CO_2 (FAO, 2005).

Over time, the dimensions of these pools and the rate at which carbon passes through them undergo significant fluctuations (Green and Byrne, 2004). The quantity of carbon stored in a forest varies based on the carbon released into the atmosphere through processes such as tree growth, mortality, and decomposition, as asserted by Katie and Anne (2020) (Plate 4). According to Hoover and Riddle (2023), a forest is considered a net carbon sink when it sequesters more carbon than it releases into the surrounding environment. When the total amount of C released by the forest during a given period exceeds the amount of C trapped in the forest, the forest is considered a net carbon source of emissions.

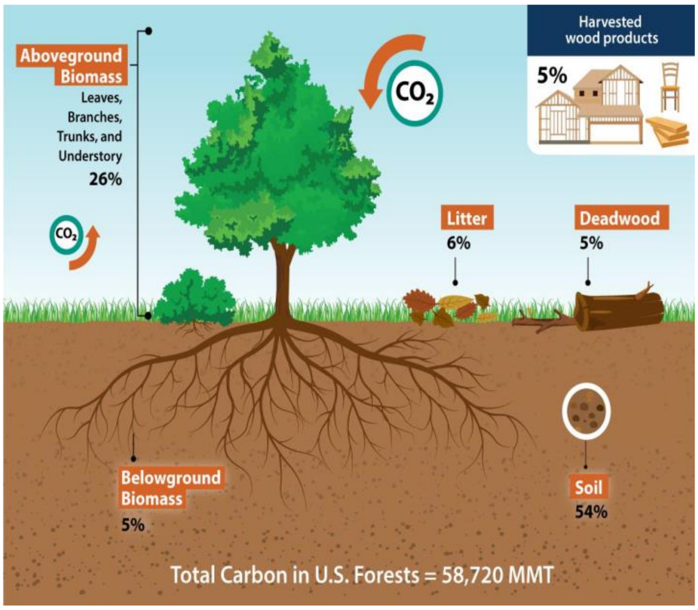

Plate 4: Rate of Carbon Flows within Forest Ecosystem (Source: EPA Inventory Report, 2020).

In carbon sequestration, different processes remove CO_2 from the atmosphere and store it in various reservoirs (forests, soils, seas, and geological formations). CO_2 is extracted from the atmosphere via photosynthesis and stored in tree components and other vegetation, in forest ecosystems. Forests accumulate a substantial amount of C in AGB and BGB (Pan *et al.*, 2013). Carbon accumulates in soils, deadwood, litter (such as fallen leaves and stems), AGB (such as leaves, trunks, and limbs), and BGB (such as roots) in forest ecosystems (EPA, 2018).

Forest ecosystems accumulate organic compounds with an extended carbon residence time, storing a larger amount of C than other terrestrial ecosystems (Lorenz, 2009). Forests are essential to the global carbon cycle, because of their ability to remove carbon dioxide from the atmosphere by photosynthesis and storing it in various components like wood, leaves, and soil. Encompassing nearly one-third of the Earth's land area, forests contribute significantly to the global carbon pool, holding around 80% of all terrestrial above-ground carbon and 40% of all terrestrial below-ground carbon (Meta *et al.,* 2015). The global forest ecosystems store over 650 gigatons (Gt) of carbon, with 289 Gt (44%) in AGB and BGB, 72 Gt (11%) in decaying wood and debris, and 292 Gt (45%) accumulated in the soil (FAO, 2020). While planted forest ecosystems currently make a relatively small contribution to the overall terrestrial carbon balance, it is anticipated that in the future, their capacity to absorb and store carbon will have a greater impact on reducing climate change (Canadell *et al.,* 2007).

Since forests store high amounts of carbon (Meta e*t al.*, 2015), their management could be crucial in lowering or increasing atmospheric CO_2 levels. For example, while anthropogenic factors inject enormous quantities of CO_2 into the atmosphere leading to world warming, sustainable forest management, forest conservation, afforestation and reforestation can either maintain or increase the amount of carbon stored in forests levels (IPCC, 2000), leading to mitigation of global warming.

BIOMASS AND CARBON STORAGE IN FOREST MANAGEMENT TYPES

i. Forest Reserve Management

A forest reserve, as reported by the IUCN, is a safeguarded area that undergoes conservation and effective management for indications of conservation to offer unique opportunities for study or research and is significant for flora, fauna, or features of geological or other special interest (Burhenne-Guilmin, 2011). A forest reserve is a section of woodland, designated by the government to preserve biodiversity from anthropogenic activities such as poaching, and tree felling is prohibited for commercial purposes in forest reserve centers (Ajibola, 2021). It can also be described as an area of land where commercial wood harvesting is controlled or regulated to protect tree species of cultural, economic and ecological importance. Six National Wildlife Parks and one hundred and sixty designated forest reserves are in Nigeria (Adekunle *et al.,* 2013) and are administered by governments.

Aside from the established forest reserves, all other woodlands are considered free areas (Adekunle *et al.,* 2013). The significant loss of animal and plant species in West and Central African forests has raised the need to conserve and sustainably manage vulnerable African ecosystems (Adekunle, 2006). Improving the soil's and trees' capacity to absorb carbon on land, protecting biodiversity, sustaining other ecosystem services and preserving forest reserves, help in absorbing and sequestrating CO_2 that has been emitted into the atmosphere through anthropogenic activities (Griscom *et al.,* 2017).

Numerous studies have been conducted on biomass and carbon sequestration in various forest reserves in different locations. According to Eneji *et al.* (2014), Nagi-Naka and Agan forest reserves in Benue state sequestered an estimated total area of 26,881.8 kg and 26,146.4 kg of CO2, respectively. Mensah *et al*. (2020) observed that the above-ground carbon stocks in Gallery forests, woodlands, and savannahs in West Africa were 42.12 Mg C ha^{-1}, 30.8 Mg C ha^{-1}, and 23.5 Mg C ha^{-1}, respectively. Kendie *et al.* (2019) evaluated the biomass and soil carbon stocks in distinct types of forest (natural forest) in Northwestern Ethiopia. There were distinct patterns in carbon stocks of the carbon pools between the different forest types. While the litter carbon stock decreased as the area was enclosed, in natural forests, the stores of organic carbon in the soil, above ground, and below ground have all risen. Natural forests can help slow climate change because they typically store large amounts of carbon (Kendie *et al.*, 2019). Olufunke *et al.* (2015) researched the carbon storage of some natural forests in Nigeria. According to Olufunke *et al.,* the highest was observed in Osho Forest with a carbon stock value of 29.36 tons, followed by Shasha Forest Reserve with a carbon stock value of 24.36 ton, however Gambari Forest Reserve had the lowest value of 14.84 tons.

Many works on biomass and carbon storage have been conducted in natural forests located within and outside Nigeria (Mitra *et al.*, 2011; Eneji *et al*., 2014; Olufunke *et al.*, 2015; Ige, 2018; Ibrahim *et al.*, 2018; Kendie *et al.*, 2019; Aghimien, 2019; Mensah *et al*., 2020). However, fewer, or no published work on biomass and carbon stock is available for the existing forest reserves in Benue state, Nigeria. This study aims to assess the biomass and carbon storage in different types of forest management such as forest reserves, sacred groves, and community forest management, concerning their potential for contributing to climate change based on the available theoretical and practical evidence published in several literature.

ii. Sacred Groves Management

Sacred groves are unaltered forests with abundant biodiversity guarded by native communities based on taboos, and societal and religious beliefs (Onyekwelu, 2021). A sacred grove (SG) is a community of trees with religious, social, and cultural significance in a society (Maryam and Japheth, 2022). Sacred groves can be found in diverse societies and cultures, taking on various forms like remnants of ancient forests and locations designated for deity worship, celebrations of religion and culture, cemeteries for kings, and chiefs, and ancestral worship centers, among others (Adeyanju, 2020). Sacred groves serve as a sanctuary for endangered native flora and fauna species, and a significant genetic resource (Khan *et al.*, 2008; Rawat *et al.*, 2011; Onyekwelu, 2021). Additionally, sacred groves offer important ecosystem services and sequester C in soils. Quite often, Sacred groves are less disturbed than other forest ecosystems and can serve as a model for effective forest management for mitigating climate change and sequestering carbon (Aioub and Naghi, 2021).

According to Dar *et al.* (2019), the C stock varied from 17.5 to 204.9 mg C ha^{-1}. In 41 sacred groves in Central India, the total amount of soil organic carbon ranged from 22.4 to 112.5 megagrams of carbon per hectare, while biomass production varied from 34.9 to 409.8 (Mg C ha^{-1}). According to Devi *et al.* (2021), two urban sacred forests in Sikkim Himalaya have carbon stocks ranging from 76.58 to 156.04 (Mg C ha^{-1}). 15,084.34 tons of carbon and 55.34 tons of carbon dioxide were found to have been sequestered by the sacred groves in the Kathmandu Valley (Shrestha *et al.*, 2016). In the Gedeo Community, in Southern Ethiopia, Sacred groves were noted to accumulate between 255 and 637 megagrams of carbon per hectare (Mg C ha^{-1}) of biomass and a carbon stock range of 127.5 and 318.5 megagrams of carbon per hectare (Mg C ha^{-1}) (Maru *et al*., 2022). Sacred groves in southwestern Nigeria produced biomass of 87.8 tons ha^{-1} to 231.85 tons ha^{-1} and carbon stock of 43.9 tons ha^{-1} to 115.9 tons ha^{-1} (Onyekwelu *et al.*, 2024).

iii. Community Forest Area Management

Community Forest areas are forest ecosystems existing on communal or state lands and managed by local or community people and leaders (Wiersum, 2004). A community forest consists of institutional structures that allow communities to be fully or partially involved in decision-making regarding forest management, and resources, and provide labour and knowledge to ensure both social well-being and the health of the forests (Danks and Fortmann, 2004). Practicing community forestry as a form of forest management system is undertaken by rural people to support their livelihoods (Wiersum, 2004). It involves determining the utilization and preservation of forest resources within a local community, organizing activities based on shared values, and aligning with the community's interests. Community Forest Management (CFM) refers to a set of institutional arrangements whereby communities provide manpower and information to sustain healthy forests and enhance social well-being, and where they either fully or partially participate in decision-making, and reap the benefits (Danks and Fortmann, 2004).

Community forest management encourages rural people to participate in forest management activities because of their livelihood on forest resources. The participation of community inhabitants in forest management activities helps to protect forests from degradation and deforestation, and thus improves the local community's social and economic well-being by fostering participation, ownership, and decision-making. The effectiveness of CFM is determined by the interaction between communities and resources on the one hand, and government policies and access regulations to forest resources on the other (Client Earth report, 2014).

Forests cover thirty-one percent of the entire expanse of the Earth's surface, local communities and Indigenous people own or manage about 22% of the world's forests. (Bhattarai *et al.*, 2012). The main objective of CFM initiatives, which have been put into effect in several developing countries, is to preserve forests and assist community inhabitants in sustaining their livelihood, especially regarding their daily requirements for fuelwood, fodder, timber, income, and specific non-wood forest resources (Bhattarai *et al.*, 2012). In addition, CFAs offer environmental services that are crucial for both ecosystem health and human well-being, through carbon sequestration, soil conservation, air purification, and water management, among others.

The carbon storage of community forests has been the subject of very few studies. Bhattarai *et al.* (2012) investigated the efficiency of CFM in sequestration of carbon across three distinct physiographic zones of central Nepal that CFM led to consistent growth in carbon stock levels, between 1 to 3 metric tons per hectare annually (t/ha/yr), depending on local circumstances. In three Nepalese community forests, Karky (2008) carried out an inventory of carbon in the forest and produced an annual carbon increment of between 1.13 and 3.1 ha^{-1} yr^{-1}. For the mid-hills of Nepal, Rana (2008) recorded an average carbon increment of 1.4 metric tons per hectare per year (t ha-1 yr-1). Annual carbon increment was 3.7 metric tons per hectare per year (t ha-1 yr-1) for community forests in Uttarakhand, India (Banskota *et al.*, 2008). About 163.9 t ha^{-1} of carbon stock was estimated for ten forest communities in the upper highlands of Asia (Gautam *et al.*, 2009). Few works have been done on biomass and carbon sequestration in community forests in Nigeria. Agbelade and Lawal (2019) estimated the biomass and C stock of Otun Ekiti and Ogun Onire community forests to be 6.07 t/ha and 30.02 t/ha, respectively.

CONCLUSION

Community forest management, sacred groves, and forest reserves are vital for mitigating the effects of climate change by preserving biodiversity and sequestering carbon. Government-managed Forest reserves are essential habitats for wildlife, plants, and ecosystem services. Sacred groves, safeguarded by cultural and religious traditions, play a vital role in conservation and store a substantial amount of carbon. In addition to guaranteeing resource sustainability and improving carbon sequestration, community forest management encourages local participation in forest preservation. Integrating these methods for managing forests, ecological sustainability is promoted, and carbon emissions are reduced. To optimize the environmental benefits of these management types, modern technology integration, community involvement, and effective policy execution are paramount. Thus, it is recommended that Governments should strengthen forest reserve protection by enforcing stricter laws against illegal activities and using technologies like satellite imaging for monitoring. Establishing buffer zones and regular enforcement will help safeguard biodiversity and increase carbon sequestration. Engaging local communities in forest management through clear legal frameworks, capacity-building, and financial support can enhance sustainable forestry. Due to the cultural significance of Sacred groves, should be integrated into conservation programs, with community collaboration to preserve biodiversity and carbon storage, while respecting traditional values.

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