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Review Article

Management, Growth, and Carbon Storage in Miombo Woodlands of Tanzania

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Despite the local livelihoods support function provided by miombo woodlands of Tanzania under participatory forest management, its growth still has potential for carbon storage and sequestration attractive to REDD+ initiatives. This study has revealed the average growth to be significant, despite the local community livelihoods support function. However, climate change mitigation strategy needs to be more innovative to optimize carbon storage and local livelihoods' potentials in forest-dependent communities like miombo woodlands. Carbon credits resulting from the increased carbon stock and sequestration should contribute to sustainable development. This should also help promote participatory forest management and secure miombo woodland products and services upon which billions of people depend.

1. Introduction

Forests and woodlands are sinks and reservoirs which naturally absorb carbon dioxide (CO_2) [1]. Carbon dioxide is one of the greenhouse gases (GHGs) from the atmosphere causing global warming [2]. The gas is stored in the biomass and soil; therefore, forests and woodlands help to mitigate the challenges of climate change [2, 3]. Moreover, livelihoods of significant number of people depend on forests and woodlands through provision of many forest products and environmental services [4]. They also conserve biodiversity [5] and cultural and spiritual values [6, 7]. The discussion about carbon storage and sequestration in forests and woodlands among other climate change mitigation options is increasing [8, 9]. This is mainly due to its cost-effectiveness compared to many engineering solutions [10–12]. Land use change and forest management were included in the post-Kyoto Protocol and are being discussed in several meetings and reports of Intergovernmental Panel on Climate Change [1, 8, 9].

The discussion has raised the increasing demand to maintain and enhance carbon storage and sequestration capacity of forests and woodlands [1, 13]. Tropical forests including miombo woodlands are major component of the world's forests, covering over half of the African continent [14–16]. The woodlands cover between 2.7 and 3.6 million km^2 of eastern and southern Africa [17, 18]. The coverage represents an important plant diversity center with over 8,500 species [5, 19]. Miombo woodlands account for about 30% of the primary production of all terrestrial vegetation, playing crucial role in energy, local livelihoods, and carbon balance [16, 20]. This forest type is encompassing 90% of forested lands of Tanzania, out of the total forested area of about 35.3 million ha [21, 22].

Miombo woodlands are distinguished from other African forest formations by the dominance of tree species in the family Fabaceae, subfamily Caesalpinioideae, particularly in the genera *Brachystegia*, *Julbernardia*, and *Isoberlinia* [19, 23]. Based on these facts, tropical forests including miombo woodlands support much of the Earth's biological diversity and contribute substantially to global carbon balance [22, 24]. Between 0.5 and 0.9 tons of carbon ha^{-1} $year^{-1}$ are being sequestered in miombo woodlands, with maximum sequestration in young miombo [20, 25]. Unfortunately, the capacity of tropical forests and particularly miombo woodlands to provide these services is decreasing rapidly each year due to deforestation and forest degradation [26–28].

For the purpose of elucidating deforestation and forest degradation, this paper adopts the UNFCCC's definition and the full recognition of their limitations [24, 28]. It follows that there is loss of trees and their carbon stocks down to the point that a forested land no longer qualifies as being forested; at this point the area is "deforested." In addition, a "forest" has been taken as an area of >0.05 ha with tree crown cover >20% with a "tree" defined as a plant with the capacity to grow >3 m tall [1].

For example, from 2000 to 2005, Africa experienced a net loss of about 4 million ha of forests, representing 55% of the global forest loss [29]. Tanzania have the highest rate (1.16%) of deforestation and forest degradation in Africa, estimated to be 403,000 ha annually [26, 30]. The challenge is more pronounced in miombo woodlands, if compared to other forest biomes [14, 31–34]. Deforestation and forest degradation is occurring significantly even in the reserved forests [35, 36]. This has significant social, economic, and environmental consequences, including global warming [24, 28, 37].

Local communities in Tanzania as elsewhere will continue to depend on miombo woodland products and services [38–42]. This triggers the need to look for sustainable forest management systems [30, 43, 44]. Participatory forest management (PFM) where communities take the leading role in management and conservation of forests in many Asian and African countries is among the option [11, 45–47]. In Tanzania, PFM is a mainstream forest management approach and it is fairly well developed [48–51]. Interestingly, the national REDD+ strategy is also framed within PFM framework [52, 53].

Although PFM is relatively young in most African countries as compared to Asia, it is believed to deliver sustainable forest management and local livelihood improvements [32, 47, 50, 54]. However, there is concern that the benefits from PFM may not be sufficient to cover the costs imposed to the local communities, therefore, raising doubts over the long-term viability and effectiveness [36, 51].

Nevertheless, PFM contribute to the global demand for land use change aimed at restoring forests and biodiversity in degraded forest ecosystems. It is, therefore, generating carbon credits through reducing emissions from deforestation and forest degradation with enhancement of carbon sink (REDD+) being paramount for PFM viability [55, 56]. This has been evident at Copenhagen Accord adopted on 15th Conference of the Parties (COP 15) to the United Nations Framework Conversion on Climate Change [57] in December 2009. Forest management is eligible under Article 12 of United Nations Framework Conversion on Climate Change [24]. This provides an opportunity for developing countries to give specific attention to sustainable forest management, biomass growth for carbon storage, and sequestration.

The technical options to increase carbon storage and sequestration through forest management include the conservation and management of existing closed forests; the restoration of degraded or secondary forests; and the establishment of plantations, agroforestry systems, and new forests in open areas [24]. Carbon dioxide is sequestered in the process of photosynthesis and stored in the form of biomass of the trees in the process of growth [37]. The Intergovernmental Panel on Climate Change (IPCC) identified five carbon pools of the forest ecosystem, namely, the above-ground biomass, below-ground biomass, litter, woody debris, and soil organic matter [13]. The above-ground biomass constitutes major portion of the carbon pool and it is directly affected by management interventions [1].

Various scholars have estimated the extent of biomass and carbon stock in Tanzanian forest. For example, FAO [26] reported an average forest biomass value of 60 tC ha^{-1} as national average. Forest and Beekeeping Division (FBD) [58] reported an average biomass value of 157 tC ha^{-1} for eastern lowland forest with low to medium levels of degradation and 33 tC ha^{-1} of highly degraded lowland. Satellite based analysis of biomass produced an average estimate of 64 tC ha^{-1} [59]. Limited information exists in context, such as management and growth of specific vegetation types including miombo woodland, to simulate sustainable forest management (SFM) [23, 58]. Elsewhere, Ryan et al. [60] using continuous measurement of net ecosystem exchange of CO_2 in miombo woodlands revealed that understanding of carbon balance of the miombo woodlands as whole remains an open question.

Limited and fragmented information is available on growth, carbon storage, and sequestration in miombo woodlands under PFM [36]. Moreover, there is inadequate information about the effect of PFM intervention on incremental biomass of miombo woodlands and consequence carbon storage and sequestration [61, 62]. This compromises the initiation of carbon storage and sequestration projects to support the sustainable forest management [52, 63]. The information will attract the initiation of climate change mitigation strategies such as REDD+. This also will be useful for sustainable forest management plan and policy support to mitigate climate change.

The objective of this paper is to review and explore the extent of miombo woodlands growth and incremental biomass under PFM to provide insight on the existing potential for climate change mitigation. These information and knowledge are necessary for researchers, policy makers, and forest managers to fully understand the growth pattern and existing potentials of miombo woodlands under PFM for carbon storage and sequestration.

2. Methodology

A comprehensive literature search had been performed with the help of the literature databases such as ISI web of knowledge, Science Direct, Wiley Interscience, and CAB Abstracts. The search used the following keyword terms: forest management and carbon accounting, carbon sequestration, carbon sinks, forestry and land use change, tropical forests and woodlands, Miombo woodlands, and Tanzania. The references obtained from interesting articles were used in additional search. However, the selection was somehow arbitrary but covered the most important aspects of the topic in this review paper. Moreover, locally available materials from Forest and Beekeeping Division (FBD), NGOs, and research and academic institutions were also useful. Major

Table 1: Tanzanian forest types, their description and biodiversity status.

Forest type	Forest description	Biodiversity	Maximum tree height
Miombo woodland	Closed canopy forest on poor soils and deciduous in dry seasons	Moderate biodiversity value	Up to 30 m
Acacia savanna	Open canopy forest in dry areas and dry deciduous in dry seasons	Moderate biodiversity value	Up to 20 m
Montane forests	Closed canopy evergreen forest on either crystalline mountains or on volcanic mountains	High biodiversity value	Up to 40 m
Lowland (coastal) forests	Semievergreen closed canopy forest within mosaic of other vegetation types normally located along the east coast	High biodiversity value	Up to 30 m
Guineo-Congolian forests	Closed canopy evergreen forest found in north-west lowland	High biodiversity value	Up to 50 m
Mangrove forests	Closed canopy evergreen forest in Marine mud	Low biodiversity value	Up to 25 m
Rift valley forests	Closed canopy evergreen forest on crystalline mountains	High biodiversity value	Up to 40 m

Source: Burgess et al. [63].

components addressed in this review include the characteristics of forest management in Tanzania and the state of forests and woodlands. Miombo woodland productivity and growth for carbon stock and critical issues to be addressed to achieve climate change mitigation and local livelihoods objectives in Tanzania.

3. Characterization of Tanzanian Forestlands and Management Regimes

Tanzania is endowed with different forest types (Table 1); however, miombo woodlands comprise large part, 90% of forest cover [21, 63]. Other forest types include rain forests, lowland coastal forests, mangroves, plantation, and acacia savannah detailed in Table 1. These forest types are also very important for climate change mitigation and local livelihoods. Of these various forest types, 14.3 million ha are found within gazetted forest reserves and 2.5 million ha are proposed to be forest reserves [64]. In addition, about 2 million ha are within game reserves or national parks [55].

The forest reserves that fall under the legal authority of central government are called National Forest Reserves or local government forest reserves. These are either designated for production of timber and other productive uses or protection for water catchment and biodiversity [65]. The remaining 15.8 million ha of forests are found outside the reserve networks within villages and general lands [64]. Many of these unreserved forests, however, are poorly managed [32, 36]. The traditional and customary management practices support the conservation and maintenance of forest resources for sacred, religious or social purposes [6, 7, 66].

The Tanzanian forest policy of 1998 and forest Act number 14 of 2002 recognizes and advocates for PFM as the mainstream forest management approach. The basic principle of PFM is that local people are capable of undertaking useful role in forest management and have legitimate right to participate [48, 51, 67]. In reality, the following questions have been extensively reviewed. What drives comanagement? How and why have these regimes emerged? Why is it important in Tanzanian forest management? (e.g. [49–51]) and it is out of scope to this paper.

The fundamental hypothesis of PFM adoption is also found in literature (e.g., [67, 68]). This includes the following. (a) Greater local control over forest management will result in more heather (vigorously growing) forest and woodlands due to better protection and ecologically sustainable utilization. (b) Greater local control increases local community benefits associated with forest and forest management. In Tanzania, PFM took advantage of the country's local government institutional framework. The framework gives local community legal forum through elected village councils and village assemblies. In practice, two pillars of PFM in Tanzania exist, namely, Joint forest management (JFM) and community based forest management (CBFM) (Table 2).

Community based forest management (CBFM) is mostly concentrated in miombo woodlands facing high rate of deforestation. Joint forest management (JFM) is implemented mainly on high mountain forests with high level of biodiversity and catchment values. The extent of these two management arrangement shows wide acceptance to the community and is promising (Figure 1).

CBFM is not only implemented to the most degraded miombo woodlands but also previously open access forests; that is, access was free and unregulated, possibly because rights were only nominal and unenforced [68]. However, JFM allows local communities and states to sign forest management agreement to share management responsibilities and benefits accruing [69]. Ever since its legal recognition and adoption, the extent of forestlands under PFM has been very large (Table 3).

In total, PFM is approximated to cover 4.1 million ha covering different forest vegetation types across different village landscapes [69]. Despite its expansion, is unclear as to what extent the growth of forests and livelihoods objectives have been realized under participatory forest management

Table 2: Different forest management practice and arrangement in Tanzania.

Legal description	Role of community/individual in management	Common name
Village land forest reserve (VLFR) Managed by the entire community	Owner and manager	Community based forest management (CBFM)
Community forest reserves (CFR) Managed by a particular designated group in the community, authorized by the village council	Owner and manager	Community based forest management (CBFM)
Private forests (PF) Managed by individual designated households	Owner and manager	Private forest management
Central or local government forests Where management responsibility is either shared between both central/local government and forest adjacent communities or transferred completely	Comanager	Joint forest management (JFM)
	Designated Manager	Joint forest management (although this form is rarely practiced)

Source [48].

Table 3: The extend and coverage of participatory forest management regime in Tanzania.

Joint forest management		Community based forest management	
Area of forest under JFM	1.77 million ha	Area of forest under CBFM	2.35 million ha
Number of forest reserves under JFM	246	Number of declared or gazetted village land forest reserves	395
Number of villages engaged in JFM	863	Number of villages engaged in CBFM	1,460
Number of villages with signed JMAs	155	Percentage of villages on mainland Tanzania engaged in CBFM	14%
Number of districts engaged in JFM	58	Number of districts engaged in CBFM	63
Most common forest type under this management regime	Montane forest and mangroves	Most common forest types under this management regime	Miombo, acacia, and coastal woodlands
% of forests reserved by central or local government under JFM	13%	% of unreserved forests now under CBFM	12%

Source [69].

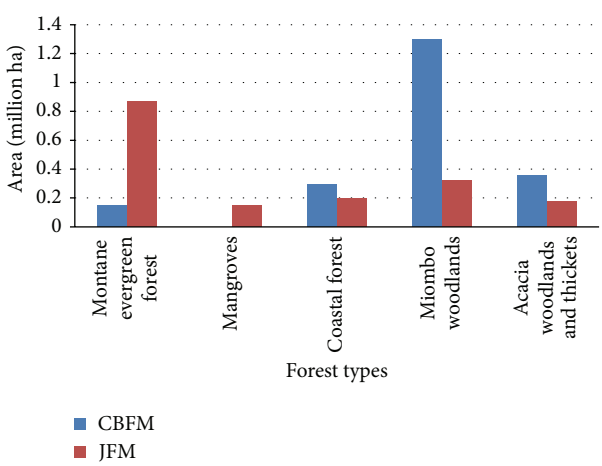

Figure 1: Forest management regime of Tanzania based on forest types and area covered. Source: MNRT [69].

[48]. Although the key feature of Tanzanian PFM is that the central government through specified legal procedures can recentralize management of forests if the village fails to manage the given forest resources [44], yet, still at local levels, forest management especially sustainable forest management remains the challenge [14]. Many forests, particularly miombo woodlands, are severely under threat [23]. Conversion into agricultural land leads to fragmentation and isolation; legal and illegal logging and extensive extraction for fuel wood and wild fire lead to deforestation and forest degradation [22, 70].

4. Biomass Increments in Miombo Woodlands for Carbon Storage and Sequestration

In Tanzanian miombo woodlands the mean annual increments are not precisely known (i.e., [36, 42, 71, 72]). The problem complicates management scenarios, such as setting management priorities including climate change mitigation strategy and defining sustainable harvesting levels [42, 44]. Given the significance of miombo woodlands in Tanzania, acquisition of biomass incremental information is prerequisite to the national climate change mitigation strategies [30, 52].

Table 4: Carbon stock annual increments in selected miombo woodland under PFM.

Forest name	Village	Year	Carbon (t/ha)	CO_2 (t/ha)	Area (ha)	Total CO_2 (t)	Annual increment ($tCO_2/ha^{-1}/year^{-1}$)
Kimuyu	Gwata	2005	19.8	73.3	420	30,769	0.3574
		2006	22.1	81.8		34,343	
		2007	19.5	72.2		30,303	0.4040
Haitemba	Ayasanda	2006	35.9	132.8	500	66,415	0.1295
		2007	36.6	135.4		67,710	
Warib		2006	15.5	57.4	50	2,868	0.111
		2007	16.1	59.6		2,979	

Source: modified from [92].

Table 5: Carbon stock for pristine and degraded forest types of Tanzania.

Forest type	Carbon in pristine forest tons/ha	Carbon in heavily degraded forest tons/ha	Loss through degradation tons/ha
Miombo woodlands	87	33	54
Eastern Arc Mountain rain forest	306	83	223
Coastal forests	157	33	124

Source [65].

Based on the results obtained by Ek [73], the mean annual increments (MAI) of 0.57–2.97 t/ha/year for a period of 13 to 16 years were revealed in Morogoro, Tanzania. However, this was smaller compared to the MAI of young or exploited miombo woodland (0.7 to 4.2 t/ha/year) in the same area. Elsewhere, Grundy [74] observed the mean annual increment in the area protected from fire and human disturbance to be 0.27 cm^{-1} $year^{-1}$. Chidumayo [75] found a mean annual increment of 1.93 m^3 per ha of trees with stump height (0.3 m) and diameter 9 cm. In mature miombo woodland, the biomass increments are between 0.58 and 3 tons per ha, equivalent to 2-3% of above-ground biomass [71, 76]. The increment is vigorously for the young miombo woodland which may range from 1.2 to 3.4 tons per ha, equivalent to 4–7% of above-ground biomass [71]. The MAI in miombo woodland biomass depends on species composition, amount of rainfall, and soil factors [19, 20].

The annual carbon stock increments from selected miombo woodlands managed under PFM provide insight of the incremental carbon stock in miombo woodlands of Tanzania (Table 4). These results are consistent with the mean annual increment (MAI) of above ground carbon storage reported elsewhere [77]. For example, Chidumayo [77] observes 0.9 tCha–1 year–1 over 35-year-old miombo in Zambia, while Stromgaard [78] reported 0.5 tC ha–1 year–1 for 16-year-old miombo in northern Zambia; Williams et al. [25] also reported 0.75 tCha–1 year–1 over 50-year-old miombo woodlands. These variations of incremental carbon stock can be related to species composition and climatic factors [18].

Although the general increments of carbon stock in miombo woodlands are very small, these seem to be the general pattern for the vegetation type. According to the report from Forest and Beekeeping Division [58], the carbon storage in miombo woodlands is smaller compared to other vegetation types in Tanzania (Table 5).

Miombo woodland has much less above-ground biomass per hectare than humid forest and proportionally less above-ground carbon stock on an area basis. It ranges from 17–70 tons carbon/ha compared to 193–200 in equatorial forest [37]. On the other hand, the carbon pool in the soil and biodiversity may be much greater [1, 5].

Based on these findings, it is very clear that the amount of carbon storage and sequestration depends on the level of incremental biomass. This is influenced by different factors including the age of the forests and management practices. Godoy et al. [31] reported the decreasing trend of deforestation from 1.0% $year^{-1}$ in the 1990s to 0.4% $year^{-1}$ in 2000–2007 for Tanzanian miombo woodlands and this is the PFM implementation period. Other scholars have also shown that after two decades of involvement of local communities and civil societies in forest management in Tanzania, forest conditions are improving from deforestation and forest degradation (e.g., [36, 48, 50]).

5. Miombo Woodland Growth Patterns under Appropriate Management Practices

The analysis of data collected from different areas of Tanzania have shown increased growth rate in miombo woodlands managed under PFM [55]. The results were compared with woodlands managed by government alone or under open access (Figure 2). The growth was higher in PFM as compared to non-PFM. These observations provide insight that PFM influences growth pattern of miombo woodlands and, therefore, potential for carbon storage and sequestration.

Most recent empirical research from selected miombo woodlands under PFM from southern part of Tanzania

Table 6: Influence of PFM on the growth of miombo woodland as compared to non-PFM.

Name of miombo forest and its management regime	Number of stems/ha	Average diameter (dbh) (cm)	Average basal area (G) (m^2)	Volume (m^3/ha)	Biomass (ton/ha)	Carbon stock (t/ha)	Sample size (n)
Mandumburu CBFM-Mufindi, Iringa	3664	13.75 (3.44)	11.84 (3.05)	58.63	43.18	21.59	53
Ngombe forest non-PFM, Mufindi	3216	9.77 (3.37)	7.71 (4.84)	51.35	37.91	18.96	40
Shikura CBFM Mbozi, Mbeya	3527	10.61 (4.04)	7.51 (3.64)	25.09	18.39	9.20	32
Shikura non-PFM, Mbozi	1803	8.34 (2.95)	6.74 (2.86)	15.80	13.28	6.64	30
Kitapilimwa JFM Iringa district	2995	12.51 (2.81)	11.13 (4.50)	67.67	42.43	21.21	30
Kinywanganga non-PFM, Iringa district	2,695	10.78 (4.48)	7.59 (5.38)	35.55	22.11	11.05	31
Chumwa range JFM, Mbozi, Mbeya	2931	14.49 (6.99)	9.83 (7.87)	73.27	48.05	24.03	30
Namlonga non-JFM, Mbozi	1757	12.44 (4.89)	9 (5.04)	55.80	37.29	18.65	30

Source: field survey (2013). *Number in parenthesis is standard deviation from the mean.

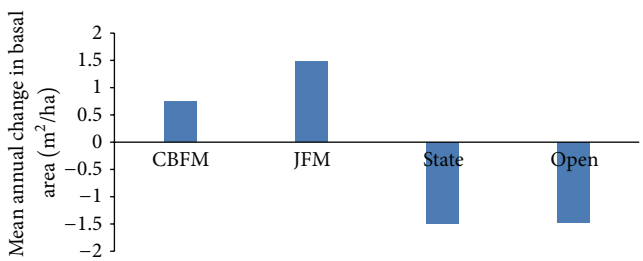

Figure 2: Compared growth patterns of miombo woodlands under PFM and non-PFM in Tanzania. Source: Blomley et al. [55].

(Mbeya and Iringa regions) has further demonstrated this growth patterns (Table 6). PFM seems to be influencing growth of miombo woodlands as compared to non-PFM counterparts. The findings imply that forests under PFM are performing better than non-PFM forests and this could be due to the reduced illegal activities under PFM. The findings are important for mitigation of climate change and biodiversity conservation in miombo woodlands of Tanzania.

Some species in miombo woodlands regenerate so vigorously after being disturbed, followed by good management intervention [23, 72, 79]. However, Frost [19] reported that the few available studies of miombo growth indicate that growth rates decline with lower rainfall, the age of trees, and time since they were last coppiced. He further revealed that growth rate ranged between 1.5 and 11.5% (mean: 4.7%) of total above-ground woody biomass. According to Malimbwi et al. [42], the growth rate of Tanzanian miombo woodland is estimated to be 2.3 m^3/ha/year in regrowth woodland.

In miombo woodlands where different species coexist, there are greater variations in growth, stem densities, and capacity to offset carbon stock (Table 7). For example, Malimbwi [80] and Chamshama et al. [81] revealed that stems per hectare in miombo woodland range from 355 to 1988. Elsewhere, Malaisse [82] reported miombo woodland to have stand density ranging between 380 and 1400 stems per ha. This implies significant variation in miombo woodland growth pattern. The variation can be attributable to age structure, species composition, and the past disturbance history [72]. This also might be related to the ability of miombo woodlands tree species to regenerate mainly from resprouts, coppices, and stumps [19].

In Tanzania, the highest number of stems was reported from Duru Haitemba (1988 stems/ha) and Ksuafr (1027 stems/ha) while the lowest was reported from Handeni Hill (355 stems/ha). This could be explained by management interventions and the degree of effectiveness to limit forests disturbance from human activities. Management practice increases woodland ability to provide ecosystem services including carbon sequestration and storage [83]. Human activities are known to influence miombo woodland structure, species formation, and effect on carbon sequestration and storage potentials [18, 79].

The forest basal area to describe the forest condition has been revealed to be between 7 and 25 m^2 per ha [30, 76, 84]. According to Frost [19], both stand basal area and mean biomass increase with increasing rainfall. Participatory forest management regime, however, has improved the ability of the woodland to recover from human disturbances. FBD [58] reported that miombo woodland recover relatively well following past anthropogenic disturbances through wood cutting, fire, cultivation, and grazing. Human disturbances, such as grazing, frequent fires, and extended cultivation periods may prolong the recovery period [18, 19].

Further analysis of miombo woodland cover change in Tanzania under PFM revealed a declining rate of deforestation [31]. Similarly, various scholars also reported the positive

Table 7: Miombo woodland parameters describing biomass as studied in different sites.

Site name	Number of stems (N)	Basal area (G) (m^2)	Volume (m^3/ha)	Biomass (t/ha)	Carbon stock (t/ha)	Source
Ksuatfr	628–694	7.9–9.9	55.3–74.8	35.2–45.9	17.6–22.9	Zahabu [36]
Kimunyu	701–845	7.9–8.8	72.4–88.2	39.7–45	19.86–22.5	Zahabu [36]
Urumwa FR	583	8.54	58.41			Njana [93]
Duru Haitemba	1988	12.41	97.32			Malimbwi [80]
Ksuatfr	619	10.2	78			Zahabu [94]
Kitulagharo GFR	1085	9	76	43.56	21.78	Chamshama et al. [81]
Handeni Hill	355	11.2	108.99			Malimbwi [80]
Ksuarfr	1027	8.95	76.02	41.40	20.7	Chamshama et al. [81]
Urumwa FR	642	8.7	59.73			Nuru et al. [95]

ecological effects from PFM in Tanzania [36, 69, 85, 86]. The observation corresponds with the findings of Poffenberger [47] for Southeast Asia and Nittler and Tschinkel [87] for Guatemala.

Moreover, miombo woodlands are known for their high regenerative capacity and productivity [18, 79, 88]. This provides potential for woodland to sequester carbon which mainly hinges on the ability of the woody species to regenerate and grow. When the conditions become favorable, such as after harvesting when the canopy opens up and there is protection from fire and browsing, the woodlands are able to rapidly increase their above growth biomass due to the well-established root systems [19, 20]. Woodland regeneration generally involves seed production, seedling development, and vegetative regeneration. In absence of intense disturbance such as frequent late fires and overgrazing, the dominant trend in regenerating woodland is towards recovery to original state.

Consistently, Frost [19] recognized four phases in regenerating woodland: (i) initial regrowth, just after sprouting and coppicing (most woody plants in the initial regrowth phase are less than 1 m tall), (ii) dense coppice, some two to five years after clear felling, (iii) tall sapling phase, starting from six to eight years after regeneration, and (iv) mature woodland. These findings provide clear picture on the growth patterns of most miombo woodlands and the ability to recover after deforestation and forest degradation.

6. Issues Required to Achieve Climate Change Mitigation and Local Livelihood Objectives

The human population densities in miombo woodland regions are much higher than those of humid forests [23]. This implies that more forces of deforestation and forest degradation are likely to represent considerable source of emissions. However the quantity of these emissions is not accurately known [37]. Humans used miombo woodlands on a large scale for at least 10,000 years, but with fluctuating intensity [83]. According to Campbell et al. [23], seventy-five million people inhabit areas covered or formerly covered by miombo woodlands. In addition, the continuing perseverance low income in some African countries including Tanzania reflects an increasing demand for miombo woodland products.

Tanzania is a country with predominantly rural structure; more than 80% of its population resides in rural areas. Local community livelihoods depend on crop and livestock farming and extraction of various products from miombo woodland and other forest resources. Participatory forest management options for mitigation of climate change and implications to forest dependent communities should be well harnessed and implication clearly understood. The sustainability of miombo woodland is threatened by human activities that cause deforestation and forest degradation occurring when local communities strive to earn their livelihoods (e.g., [17]). Therefore, PFM should focus on improving forest production capacity and sustainable extraction of forest products for the local livelihoods. This can only be realized if PFM aims to optimize dual objectives of mitigation of climate change, improving the livelihoods of local communities.

The main use of miombo woodland resources of Tanzania is the source of energy, accounting for 97 percent [89]. The volume of fuel wood demand at national level is nearly 20 times greater than the demand for other forest products combined [90]. For example, according to CHAPOSA, [71], it is estimated that consumption of charcoal grew during 1990–2000 by about 80% in both Lusaka city in Malawi and Dar es Salaam city in Tanzania. The proportion of households who reported charcoal to be their principal fuel increased from about 50 to 70% over the same period.

Based on these facts, the critical challenge to the management of miombo woodland is wood extraction for fuel wood. It is estimated that 17.84 mil m^3 of stacked wood from miombo woodland used for charcoal production in 2002 alone [90]. In addition, the clearing of one hectare of miombo woodland provides an average of 35 m^3 of firewood [71, 91]. However, per capita wood fuel consumption ranges from 0.92 to 1.00 m^3 and can be even higher when supplies are physically abundant [91]. This is a critical problem for the sustainability. Miombo woodlands have been subject to intense human use for millennia and this pressure is intensifying due to the number of complex reasons such as population and poverty [22]. Therefore, some of the critical issues which need to be addressed for the duel objectives of mitigation of climate

Table 8: Important issues for climate change mitigation and local livelihoods objectives.

Need to address causes of deforestation and forest degradation includes the following
(i) Cutting of trees for supply of energy mainly as firewood and charcoal for domestic purposes and use of firewood for agriculture and rural industries
(ii) Cutting of trees for production of poles, wood for carvings, and sawn wood for local use and for export
(iii) Uncontrolled wild fires mainly in miombo woodlands
(iv) Overgrazing in forest areas, mainly during the dry season
(v) Shifting cultivation in miombo woodlands
(vi) Extensive clearing of unreserved forest land for establishment of agriculture and livestock farms
(vii) Clearing of forested land (reserved and unreserved forests) for mining
(viii) Clearing of forested land (reserved and unreserved forests) for settlement
Local livelihoods aspects to be addressed in Tanzania include the following
(i) Macroeconomic, political, and social aspects such as poverty, unsustainable production and consumptions pattern, and ill-defined and implemented structural adjustment programmes
(ii) Institutional and social weakness such as lack of good governance, lack of secure land tenure and uneven distribution of ownership, lack of institutional, technical, and scientific capacity, lack of scientific knowledge, and little or no use of local knowledge and skills on management of natural resources
(iii) Market and economic policy failures such as undervaluation of forest services and products
(iv) Policy failure, such as ill-defined development programmes, ill-defined or unforced regulatory mechanism, and lack of clear environmental policies and agricultural practices.
*Both issues are interlinked with economic, social, and political aspects at local, national, and global levels.

Source: author synthesis.

change and local livelihoods improvement are detailed in Table 8.

It is important for a country to identify drivers of deforestation and forest degradation (i.e., Table 8) in development of national strategies and action plans for climate change mitigation.

7. Conclusion and Recommendations

Participatory forest management (PFM) influences growth of miombo woodlands, reverses the deforestation and forest degradation, and therefore has potential for carbon storage and sequestration. However, the existing socioeconomic and ecological potentials in miombo woodland need to be further examined for their sustainability. Despite miombo woodlands showing potential for carbon storage and sequestration, yet local communities' dependence is significant. The efforts should be on promoting PFM while optimizing trade-offs between multiple functions of miombo woodland products for local livelihoods and climate change mitigation. Innovative finance mechanism through mitigation of climate change, enabling policy, and institutional environment should be used to catalyze PFM. Since the growth of miombo woodland for carbon storage and sequestration takes time, long-term political commitment in PFM and mitigation of climate change are required. Carbon credits resulting from the increased carbon stock and sequestration should contribute to sustainable development. This should also help to secure miombo woodlands products and services upon which billions of people depend.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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