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Impact of Participatory Forest Management Implementation on Forest Condition: A Case Study of Dinsho and Agarfa Districts Forest Reserves, Bale zone, Southeast Ethiopia

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Abstract: Efforts to conserve forest resources have been significant; however, sustainable conservation cannot be achieved without the active involvement of local communities. Participatory Forest Management (PFM) is recognized as an effective strategy for the long-term conservation of Ethiopia's remaining natural forests, particularly in the Bale zone, where community participation is essential. Despite this, the impacts of PFM have not been thoroughly evaluated or documented. This study aims to assess the effects of PFM on forest conditions in selected areas of the Bale zone. The research compares three forests practicing PFM with three that do not. To gather insights on the perceived status of these forests, the study employed semi-structured interviews, focus group discussions, and field observations. These qualitative methods provided a comprehensive understanding of local community perspectives regarding forest health and management practices. Data on forest parameters were collected through systematic sampling, using transects lines at 250-meter intervals across 152 plots, ensuring an equal number of plots for both forest types. Key forest metrics, including diameter at breast height (DBH), tree height, and the number of seedlings and mature trees, were analyzed using Microsoft Excel and various diversity indexes. This quantitative analysis allowed for a robust comparison of forest health indicators between PFM and non-PFM areas. The findings indicate that forests managed under PFM exhibit higher average biodiversity indexes and a greater number of stems per hectare compared to non-PFM forests. Specifically, the average number of trees increased significantly in PFM areas from their initial years to 2018. Additionally, the mean basal area also showed substantial growth in PFM forests, indicating improved forest health and productivity. The study recommends expanding PFM initiatives to all forests in the Bale zone, including smaller patches. It also highlights the need to focus on regenerating seedlings, as they face pressure from animal browsing, which could hinder forest recovery and health. This research contributes valuable insights into the effectiveness of community-based forest management practices in enhancing forest conditions in the Bale zone.

Keywords: Forest, Forest Status, Effect, Livelihood, Participatory and Forest Management

Introduction

Natural forests play a crucial role in global ecosystems by providing various goods and services essential for livelihoods (Abdela et al., 2021). However, balancing societal needs with environmental preservation remains one of the greatest challenges, as forest loss has reached alarming rates, with approximately 13 million hectares lost annually (Hajjar & Innes, 2009; Keenan et al., 2015). The tropics experience the most significant deforestation, with Africa facing the second-highest rate at about 3.4 million hectares yearly (FAO, 2010; Hoang & Kanemoto, 2021). In Ethiopia, historical deforestation rates have varied from 800,000 hectares in the 1950s to recent estimates of 140,000-200,000 hectares annually (Masolele et al., 2022; Tsegaye et al., 2023; Terfassa et al., 2024).

To combat forest degradation, there is a global push toward sustainable forest management practices (Arce, 2019; Peñuelas & Sardans, 2021; Stubenrauch et al., 2022). This shift includes moving from centralized government control to participatory management systems that enhance responsible governance and have shown potential to reduce deforestation (Pokorny, 2019; Begum, 2021; Yami & Mekuria, 2022). Various approaches such as co-management and community-based forest management aim to engage local communities in sustainable resource management (Kitula, 2022; Ngome & Yeom, 2024; Batuwatta, 2024; Thoker et al., 2024). Despite differences in specific objectives and designs, these strategies share a common goal of promoting local participation in forest management (Haji & Hayati, 2020; César, 2020).

Participatory Forest Management (PFM) is a collaborative approach that divides forest management responsibilities between the government and surrounding communities, aiming to enhance forest conditions through user involvement in decision-making and conflict resolution (Luswaga & Nuppenau, 2020; Batuwatta, 2024; Thoker et al., 2024). This method shifts from a top-down management paradigm to a bottom-up, community-centered model, which has been shown to improve forest health by fostering collaboration among stakeholders (Jones et al., 2016; Ma et al., 2023; Díaz-Jara et al., 2024).

In Ethiopia, PFM was introduced in the 1990s through pilot projects led primarily by non-governmental organizations, to promote sustainable forest management (Siraj et al., 2018; Bimir, 2022; Masha et al., 2024). Currently, over 667,498 hectares of forest are managed under the PFM program across more than 556 Forest User Groups (FUGs) and 123 cooperatives (Ameha et al., 2014). While studies on Participatory Forest Management (PFM) have yielded mixed results, many indicate a reduction in deforestation rates and improved forest conditions in PFM areas compared to non-PFM zones (Frey et al., 2021; Oy, 2024; Broggio et al., 2024). Frey et al. (2021) found that PFM initiatives significantly enhanced forest cover and biodiversity in several regions, highlighting the positive impacts of community engagement in forest management. Conversely, Broggio et al. (2024) reported that while PFM improved certain ecological indicators, it did not consistently lead to reduced deforestation rates across all contexts. Research has shown that community-managed forests often exhibit greater forest cover and quality (Mengist et al., 2021; Masha et al., 2024; Gasheye, 2024), although some studies report no significant differences in deforestation rates between PFM and Joint Forest Management areas. This inconsistency suggests that the effectiveness of PFM can vary based on local conditions, governance structures, and community involvement. This highlights a critical gap in the literature regarding the factors that contribute to these discrepancies, particularly in specific geographical contexts like the Bale zone. By addressing these inconsistencies and focusing on the unique aspects of the Bale zone's highland forests, this study aims to provide a comprehensive assessment of how participatory methods can influence PFM outcomes. The Bale zone's distinct ecological characteristics and the presence of over 160 PFM cooperatives present a unique opportunity to explore these dynamics more deeply, thereby filling a significant gap in existing research on PFM effectiveness in this region. This phenomenon, known as the 'leakage effect,' suggests that while PFM areas may see improved conditions, pressure may shift to nearby unregulated forests (Schürings, 2023). The leakage effect refers to the unintended consequences that occur when conservation efforts or management practices in one area lead to increased environmental degradation or emissions in other areas (Zangmo et al., 2024).

Research on the impact of Participatory Forest Management (PFM) in African contexts remains limited, with only a small fraction of studies examining decentralized forest management accounting for confounding factors that might affect comparisons between areas with and without such management (Bowler et al., 2010; Porter-Bolland et al., 2012). Despite calls for further verification due to insufficient empirical evidence, robust assessments are lacking (Blomley et al., 2008; Treue et al., 2014). This knowledge gap is particularly pronounced in the Bale zone's highland forests. The Bale zone is unique due to its diverse ecosystems, including highland forests that support a wide variety of endemic species and distinct habitats, making it a critical area for studying the effectiveness of PFM. This highlights a critical gap in the literature regarding the factors that contribute to these discrepancies, particularly in specific geographical contexts like the Bale zone. Although PFM has been widely adopted in these forests, significant uncertainties persist regarding its effectiveness in improving forest health indicators. Existing research often fails to consider confounding factors and lacks comprehensive assessments of PFM's impact, hindering the understanding of its potential contribution to sustainable forest management in the region. This study aims to fill this significant gap by focusing specifically on the Bale zone's highland forests and utilizing participatory methods to assess the impact of PFM on forest health indicators, thereby providing valuable insights into the effectiveness of community-based management practices in this unique ecological context. To fill this gap, the study assessed the impact of PFM on forest health indicators through comparative analyses of forests with and without PFM practices and by comparing pre-and post-PFM implementation data. Participatory resource appraisal data collected during PFM establishment served as a baseline for evaluating changes in forest status following intervention. Ultimately, this research aims to provide scientific evidence on the outcomes of PFM in the Bale highlands and contribute to a deeper understanding of its effectiveness in promoting sustainable forest management.

Materials and Methodology

Description of Study Area

The Bale Zone, located in Ethiopia's Oromia Regional State, is characterized by its geographic coordinates of 5°11'03"N to 8°09'27"N latitude and 38°12'04"E to 42°12'47"E longitude (Figure 1). This region features significant topographic diversity, including highlands, lowlands, rugged terrains, deep river valleys, and flat-topped plateaus. The study area includes gentle slopes and high mountain massifs with elevations ranging from 2,800 to 4,000 meters above sea level, resulting in notable environmental variations. Proximity to Bale Mountains National Park enhances its ecological richness, supporting a wide variety of flora and fauna. Vegetation varies with elevation and rainfall patterns, transitioning from scattered trees and bushes at lower elevations to denser shrublands at higher altitudes. Dominant tree species include Erica arborea, Juniperus procera, Hypericum revolutum, and Hagenia abyssinica.

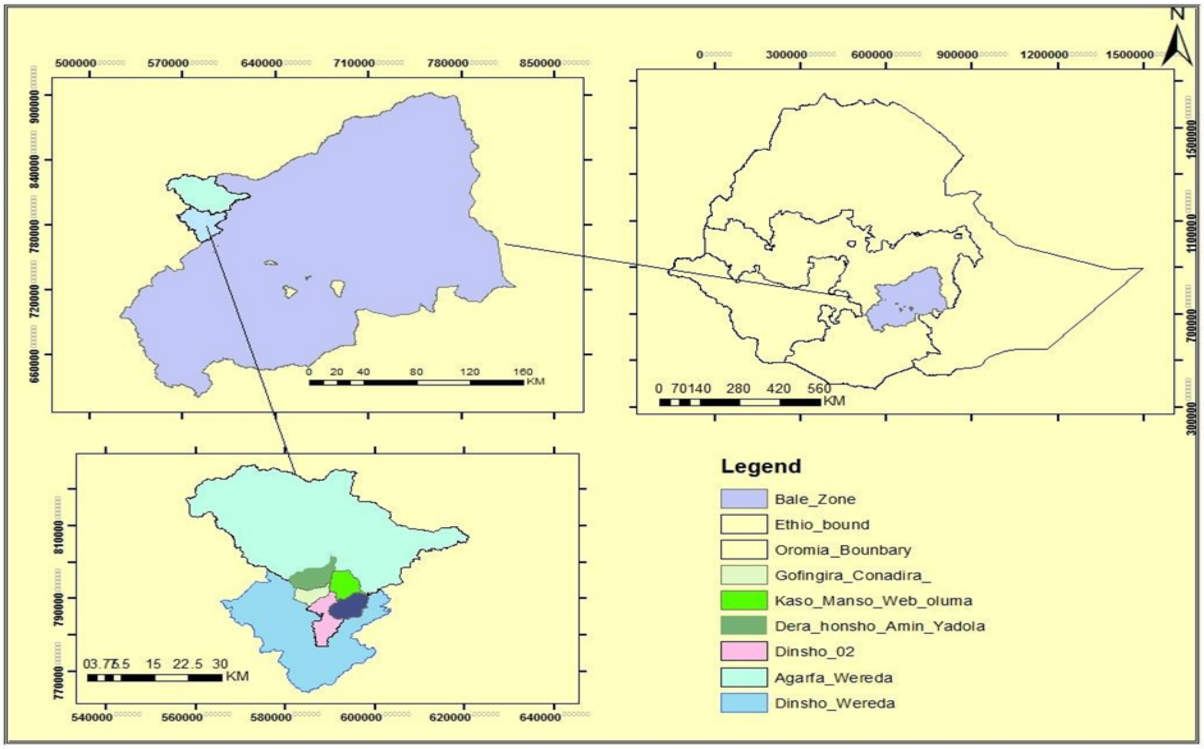


Figure 1: Location map of the study area

Site selection

Site selection for this study involved purposive sampling, where six forest villages were strategically chosen based on their varying levels of Participatory Forest Management (PFM) implementation and accessibility. The criteria for purposive sampling included the level of PFM implementation, accessibility to the villages for research purposes, and the ecological diversity in each location. These specific villages were selected because they represent a range of experiences with PFM, allowing for a comprehensive analysis of its effects on forest health indicators. Furthermore, these villages differ in terms of socio-economic factors, community engagement in forest management practices, reliance on forest resources for livelihoods, and historical land use patterns.

Accordingly, these villages, located in the Dinsho and Agarfa districts of the Bale Zone in Ethiopia, included Abakara (504 ha), Darahonsho (2,434.9 ha), Kasomanso (30 ha), Gofangira (1,600 ha), Dinsho-02 (788 ha), and Zallokarari (359 ha), totaling a substantial forest area of 5,715.9 hectares. The selection process categorized forests based on PFM implementation status, with three villages having established PFM practices for over three years and three adjacent areas with similar ecological characteristics identified for comparison. In order to effectively manage and address confounding variables that could introduce bias between Participatory Forest Management (PFM) and non-PFM forest areas, several strategies were employed throughout the study.

First, the baseline of forest conditions data was meticulously assessed to ensure comparability between PFM and non-PFM sites. This involved gathering data on key ecological metrics such as soil quality, tree density, and historical land use patterns prior to PFM implementation. By establishing a clear understanding of these baseline conditions, the study aimed to minimize the risk of attributing differences in outcomes solely to the presence or absence of PFM practices. Second, the study prioritized areas with similar socio-economic contexts. This approach aimed to reduce variability that could skew results, ensuring that any observed differences in forest conditions attributed to PFM practices rather than external socio-economic factors. The selected forests under PFM Dinsho-02, Gofangira, and Darahonsho totaled 4,822.9 hectares, while Abakara, Kasomanso, and Zallokarari, totaling 893 hectares, were not under PFM. This methodology aligns with findings emphasizing the importance of selecting suitable forest areas for effective PFM implementation based on socio-economic and ecological factors.

Study Design, and Sampling Procedure

The study employed a mixed methods approach, integrating both quantitative and qualitative data collection techniques to comprehensively assess the impact of Participatory Forest Management (PFM). For the forest inventory, systematic transect sampling was utilized to ensure representative data across diverse landscapes, minimizing variance in estimates as supported by existing literature. A nested plot design captured vegetation data at multiple scales, focusing on tree diameter, height, species identification, and overall plot conditions using standardized methods. Although the target was to establish 160 plots, logistical constraints led to the completion of 152 plots, evenly distributed between PFM and non-PFM forests for balanced comparison. Each site featured parallel transect lines spaced 250 meters apart, with plots positioned at 500-meter intervals, including a 20x20 m main plot, a 5x5 m sub-plot, and a 2x2 m inner plot. Qualitative data were gathered through Focus Group Discussions (FGDs) with community participants and key informant interviews with experts to gain insights into local perspectives on forest management, emphasizing community involvement in PFM processes. Secondary data analysis complemented primary findings to provide historical context. The study aimed to explore the role of PFM in forest conservation by collecting data directly from the field through FGDs, interviews, and inventories focused on relevant vegetation parameters, evaluating local community views on forest conditions and perceived effects before and after PFM implementation while comparing effectiveness across three specific forest villages with PFM practices against those without.

Method of Data Collection

Socio-Economic Data Collection

This study investigated the impact of Participatory Forest Management (PFM) on forest health status parameters in the Bale Highlands of Ethiopia, employing a mixed-methods approach to gather comprehensive data and understand local perspectives. Integral to this approach was the collection of socio-economic data, which provided insights into how PFM practices influence both forest health and community livelihoods. Qualitative data were gathered through purposive sampling, engaging 12 participants in one focus group discussion (FGD) that included forest officers, members and non-members of Forest User Groups (FUGs), village leaders, women representatives, NGO experts, and village council members. Participants were selected based on their roles and experiences with PFM, ensuring a diverse representation of perspectives. These discussions explored various aspects of PFM implementation and the changes observed before and after its introduction. In addition to FGD, one KII consisting of eight members of key informants were interviewed to gain in-depth insights into community perceptions regarding changes in forest conditions associated with PFM practices. Key informants included local government officials, NGO representatives, and community leaders who possessed expertise in forest management and socio-economic dynamics within the Bale Highlands. Their roles provided valuable context for understanding the broader implications of PFM initiatives. Existing secondary data sources, including reports from organizations involved in PFM interventions such as the Oromia Forest and

Wildlife Enterprise, FARM Africa, and MELCA-Ethiopia, were also utilized to enrich the analysis with historical context. The combination of FGDs, key informant interviews, and secondary data analysis provided a comprehensive foundation for evaluating the effectiveness of PFM practices in promoting forest health within the Bale Highlands. This study aims to fill a significant knowledge gap by assessing how socio-economic dynamics interact with ecological outcomes in participatory forest management, ultimately contributing to a better understanding of PFM's role in enhancing forest health indicators.

Forest data collection/Inventory

The forest status inventory in the Bale Highlands utilized a systematic approach with parallel transect lines spaced 250 meters apart, positioning sampling plots at 500-meter intervals to ensure comprehensive vegetation data collection across various growth stages and species. This design effectively captured a representative range of data while minimizing variance in estimates. Each sampling unit consisted of three nested plot sizes: 20m x 20m for trees with a diameter at breast height (DBH) of 5 cm or greater, 5m x 5m for saplings with a DBH between 2.5 cm and 10 cm, and 2m x 2m for seedlings, allowing for detailed assessments of forest structure and composition. The nested plot design allowed for a structured approach to assessing forest parameters based on size and growth stage. The larger plot of 20m x 20m size was used to measure mature trees, providing insights into the overall tree density, species composition, and biomass within the forest of study. In addition to the largest plot, the heights of the three nearest trees to the plot center were measured, alongside evaluations of canopy cover, soil quality, and signs of disturbance. The medium-sized plot (5m x 5m) focuses on saplings, for understanding recruitment rates and future forest structure. Finally, the smallest plot (2m x 2m) targets seedlings, allowing researchers to evaluate the regeneration potential and the health of young plants. Forestry tools, such as measuring tapes and clinometers, ensured accurate data collection, with each tree recorded by its vernacular name and later converted to its scientific name using a comprehensive identification manual supported by district forestry experts. This systematic transect sampling method aligns with best practices in forest inventory, as highlighted by recent studies emphasizing its effectiveness in ensuring spatial balance and reducing variance in estimates. The nested plot design allows for detailed examination of forest structure at multiple scales, effectively capturing variations in vegetation composition and density. The nested plot design facilitates the assessment of forest structure at different scales, effectively capturing variations in vegetation composition and density across growth stages. Overall, this methodological framework enhances the robustness of findings related to PFM practices and provides critical insights into how these practices influence forest health over time.

Method of Data Analysis

Forest inventory data analysis

The analysis of forest inventory data in the Bale Highlands commenced with a comprehensive tree species list, aligning local names with their corresponding botanical names to ensure data accuracy and relevance for subsequent ecological assessments and management decisions. Following the creation of this list, the regeneration status of the forest was evaluated by calculating the number of seedlings and saplings per hectare, which provided insights into the forest's potential for natural regeneration and sustainability. Basic stand parameters, including the number of stems per hectare (N) and basal area (G)(Equation 3&4), were computed using Microsoft Excel to facilitate efficient data organization and analysis. Additionally, various diversity indices were calculated to assess the ecological health and diversity of the forest, including the Shannon-Wiener index (H') (equation 1), species abundance, species richness, equitability, relative density, relative frequency, relative dominance, and the importance value index (IVI)(Equation 1&2). These calculations followed standard formulas outlined by Magurran (1988), adopted in recent ecological studies for comparing biodiversity across different management practices. This comprehensive analysis enabled meaningful comparisons between forests managed under Participatory Forest Management (PFM) practices and those without such interventions. The methodological approach reflects established best practices in forest inventory data analysis, emphasizing systematic sampling designs to ensure spatial balance and reduce variance in estimates. By employing rigorous methods, this study aimed to provide reliable data that can inform assessments of PFM's impact on forest health and biodiversity.

$$H' = -\Sigma\,(\text{pilnpi}) ------------------------- \text{Equation 1}$$

Where H´ = Shannon diversity index; pi = the proportion of individuals or the abundance of i^{th} species expressed as a proportion of total cover; ln = natural logarithm base e.

The evenness Index:

$$(E) = \frac{\text{H}'}{\text{Ln}(S)} = \frac{\text{H}'}{\text{Hmax}} ------------------------- \text{Equation 2}$$

Where H´max = Ln(S); H´ = Shannon diversity index; S = total number of species in the sample.

The basal area of individual species with DBH ≥ 2 cm was calculated using the formula developed by Hovinda and Rieck (1970) to calculate stand basal area (G) in square meters per hectare (m2/ha):

$$G = \frac{[\pi\ (\text{DBH}^2)\ /\ 40{,}000]}{\text{plot size}} ---------------------- Equation\ 3$$

Where (DBH at 1.3 m) is the diameter at breast height in centimeters and π = 3.14. DBH was measured in centimeters; hence the conversion factor of 10,000 was used to calculate the basal area.

To calculate total volume per hectare, the study employed the formula developed by Vanclay (1994),

$$\text{V} = a\ \times\ (DBHb) \times\ (Hc) ------------------ \text{Equation 4}$$

Where: V = Volume of the tree (m^3), a = Coefficient based on local species and conditions, DBH = Diameter at breast height (cm), H = Height of the tree (m), b and c = Exponents determined through regression analysis based on local data

The relative ecological importance of each woody species, commonly referred to as the importance value index (IVI), was determined by summing up its relative frequency (RF), relative density (RD), and relative dominance (RDO) for both forest sites. These parameters were calculated as follows (Kent & Coker, 1992):

$$RF = \ (\text{Frequency of a particular species/Total frequency of all species})\text{x } 100 ------- \text{Equation 5}$$

$$RD = \text{(Density of a particular species/Total density of all species)} \times 100 --------- \text{Equation 6}$$

$$RDO = \text{(Basal area of a particular species/Total basal area of all species)} \times 100 --------- \text{Equation 7}$$

To compare the similarity in woody species composition between the two regime forests, Sorensen's similarity coefficient (S) was used. Values close to 0 suggest a lower similarity, whereas values close to 1 indicate greater similarity. The S of 70 is a substantial similarity (Kent & Coker, 1992). An independent t-test was performed to compare mean differences in vegetation variables between the two forest sites. The mean difference between the two forest management locations is significant (p.05). The analysis was carried out using Microsoft Excel 2010 and the SPSS Version 20 software package. Variations in diameter distribution for the distinct size classes in both forests were displayed using histograms.

Qualitative Data Analysis

The analysis of forest inventory data in the Bale Highlands began with the preparation of a comprehensive tree species list, matching local names with their corresponding botanical names to ensure data accuracy and relevance, which is critical for subsequent ecological assessments and management decisions (Girma et al., 2023). Following this, the regeneration status of the forest was evaluated by calculating the number of seedlings and saplings per hectare, providing insights into the forest's potential for natural regeneration and sustainability, consistent with methodologies that emphasize regeneration's role in forest health (Masresha et al., 2023). Basic stand parameters, including the number of stems per hectare (N) and basal area (G), were computed using Microsoft Excel, facilitating efficient data organization and analysis; this software is commonly employed in forestry research for its ability to manipulate and visualize data effectively (Tinkham et al., 2021). Various diversity indices were also calculated to assess ecological health, including the Shannon-Wiener index (H'), species abundance, species richness, equitability, relative density, relative frequency, relative dominance, and the importance value index (IVI), following standard formulas as outlined by Magurran (1988) and widely adopted in ecological studies for comparing biodiversity across management practices (Bakala et al., 2022). This comprehensive analysis enabled meaningful comparisons between forests managed under Participatory Forest Management (PFM) practices and those without such interventions. The methodological approach reflects established best practices in forest inventory data analysis, emphasizing systematic sampling designs to ensure spatial balance and reduce variance in estimates (Nelson et al., 2021; Sherrill et al., 2022). By employing these rigorous methods, this study aimed to provide reliable data that can inform assessments of PFM's impact on forest health and biodiversity.

Results

The implementation of Participatory Forest Management (PFM) significantly impacted local people's attitudes towards forest conservation.

The self- and community-led projects associated with Participatory Forest Management (PFM) have fostered a sense of ownership and responsibility among participants, leading to significant improvements in knowledge regarding forest resource management. Compared to the pre-PFM era, participants including both members and non-members of Forest User Groups (FUGs) exhibited higher to moderate levels of understanding, while non-participating households demonstrated lower awareness. This highlights a key benefit of PFM: as communities engage in its implementation, their understanding of forest value and user rights improved, motivating active participation in forest management practices. The study also revealed a strong community interest in PFM, driven by factors such as the involvement of relatives in the system and awareness campaigns by implementing organizations. Notably, 93% of participants believed that forest health had improved under PFM due to enhanced management practices that reduced encroachment on natural forests and promoted replanting activities, which contributed to decreased soil erosion through increased vegetative cover. These findings support the notion that PFM can lead to improved forest health through community engagement and responsible management. A significant shift in local attitudes toward forest conservation was observed following PFM implementation, with self-governance and community-driven initiatives cultivating a sense of shared responsibility (Fontanet et al., 2020). The study found a positive correlation between PFM participation and knowledge of forest resource management, aligning with the understanding that community engagement enhances awareness of sustainable resource use (Ribot et al., 2010; Fidler et al., 2024). Additionally, PFM fosters a sense of shared responsibility, which is crucial for promoting sustainable forest management (Lijo et al., 2023). Similar studies in Nepal (Bishnu, 2024) and Tanzania (Kegamba et al., 2022) have documented increased community support for conservation initiatives when local people are involved in decision-making and benefit-sharing.

Local Participation in participatory forest management activities

Following the implementation of Participatory Forest Management (PFM) in the Bale Highlands, a significant shift in community commitment to forest protection was observed (Table 1). Community members actively engaged in forest management activities, adhering to resource use regulations and participating in efforts to prevent illegal logging, agricultural expansion, and fire outbreaks within their designated forest blocks. Survey data revealed that 48.1% of PFM participants were directly involved in forest protection activities, while 51.9% reported incidents of illegal encroachment to village forest committees. An impressive 97% of participants perceived positive changes in water availability, forest regeneration, and reduced soil erosion, attributing these improvements to increased forest cover. Despite a high level of awareness regarding the boundaries of their cooperatives (98%), concerns about encroachment persisted, with nearly half (49.5%) believing these boundaries were not fully respected; primary reasons included the creation of new farms (64.9%) and land scarcity (22.3%). Illegal activities such as tree cutting for timber and firewood were reported but perceived as less extensive (59%) in PFM forests compared to non-PFM reserves. This study highlights the positive impact of PFM on community engagement and forest health, demonstrating a significant increase in community commitment towards forest protection post-PFM adoption. The findings align with research by Fontanet et al. (2020), which suggests that PFM fosters a sense of ownership among local communities, motivating them to steward their natural resources effectively. Similar studies in Nepal (Bishnu, 2024) and Tanzania (Kegamba et al., 2022) have documented positive environmental outcomes associated with increased community involvement in forest management, reinforcing the notion that participatory approaches can lead to sustainable forest management practices that benefit both the environment and local livelihoods.

Table 1. Status of Plants species in the past and present in selected forest villages

Species number	The dominant and the most important plant species in the past	Availability in the present (*number and % of the respondents*)					
		High		Medium		Low	
		No	%	No	%	No	%
1	*Hagienia abyssinica*			5	62.5		
2	*Hypercom revolutum*					7	87.5
3	*Juniperus procera*			8	100		
4	*Schefflera volkensii*					4	50
5	*Pittosporum viridiflorum*					8	100
6	*Rapanea simensis*	6	75				
7	*Erica arborea*			8	100		
8	*Discopodium eremanthum*			4	50		
9	*Dovyalis abyssinica*					7	87.5

Participants' Perception of forest condition

This study explored the impact of Participatory Forest Management (PFM) on forest health and local communities in the Bale Highlands of Ethiopia, revealing a significant shift in community attitudes and behaviors post-PFM adoption. Community members actively participated in forest management activities, such as patrolling their designated forest blocks and preventing illegal logging, agricultural expansion, and fires. Survey data supported this engagement, with 48.1% of PFM participants involved in forest protection activities and over half reporting illegal encroachment incidents. Furthermore, 97% of participants perceived positive changes in water availability, forest regeneration, and reduced soil erosion, which they attributed to increased forest cover. These findings align with research by Fontanet et al. (2020), indicating that PFM fosters a sense of ownership among local communities, motivating them to become active stewards of their natural resources. Similar positive environmental outcomes have been documented in studies from Nepal (Ojha et al., 2009) and Tanzania (Persha et al., 2011). Despite these positive trends, challenges related to forest boundaries and encroachment persists. While most PFM participants were aware of their cooperative boundaries, nearly half expressed concerns about encroachment due to new farm creation were stemming from land scarcity and illegal activities like tree cutting. Interestingly, the study found a lower perceived rate of depletion within PFM forests compared to non-PFM areas. Additionally, 58% of respondents perceived an overall improvement in forest health compared to pre-PFM times, although 40% reported a decline in forest health, particularly in non-PFM areas and some PFM forests. This suggests that the positive impacts of PFM may not be universally experienced across all reserves, necessitating further investigation into the reasons behind these mixed perceptions, which could include variations in PFM implementation effectiveness and baseline forest health.

The results in Table 2 reveal significant insights into the perceptions of Participatory Forest Management (PFM) among members and non-members. Overall, PFM members express a more favorable view of forest conditions compared to non-members, as evidenced by higher mean scores across most statements. For instance, 50% of PFM members strongly agree that the overall health of the forest has improved since the implementation of PFM, with a mean score of 4.20. In contrast, only 30% of non-members share this sentiment, resulting in a lower mean score of 3.80. This disparity suggests that PFM initiatives are perceived to have a direct positive impact on forest health by those actively involved in management. The data also indicate that PFM members observe greater increases in tree cover and improved water availability, with mean scores of 4.14 and 4.04, respectively. These perceptions are crucial as increased tree cover can enhance biodiversity, improve soil stability, and contribute to better water retention in the ecosystem. Non-members, however, report lower mean scores (3.70 for tree cover and 3.70 for water availability), highlighting a potential gap in awareness or experience regarding the benefits of PFM practices.

Participation in forest management activities is notably higher among PFM members (mean score of 4.00) compared to non-members (mean score of 2.90). This difference underscores the importance of community involvement in sustainable forest management practices. Active participation fosters a sense of ownership and responsibility towards forest resources, reflected in the high mean score (4.24) for the statement regarding ownership among PFM members. Additionally, perceptions regarding ecological outcomes such as biodiversity and soil erosion illustrate positive trends among PFM members. With a mean score of 4.00 for increased biodiversity and 3.90 for decreased soil erosion, these findings suggest that PFM initiatives are effectively promoting healthier ecosystems. Non-members report lower scores (3.70 for biodiversity and 3.60 for soil erosion), indicating that they may not fully recognize or benefit from these ecological improvements.

Table 2. Likert Scale Results Table showing Perceptions of PFM Members and Non-Members

Statement	Group	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean Score
1. The overall health of the forest has improved since the implementation of PFM.	PFM Members	3%	7%	10%	30%	50%	4.20
	Non-Members	8%	12%	20%	30%	30%	3.80
2. I have noticed an increase in tree cover in my community's forest.	PFM Members	2%	5%	15%	35%	43%	4.14
	Non-Members	6%	10%	25%	30%	29%	3.70
3. Water availability in our area has improved due to better forest management.	PFM Members	2%	5%	20%	35%	38%	4.04
	Non-Members	5%	10%	30%	25%	30%	3.70
4. I actively participate in forest management activities (e.g., patrolling, reporting).	PFM Members	5%	10%	15%	25%	45%	4.00
	Non-Members	15%	20%	25%	20%	20%	2.90
5. The PFM initiatives encourage community members to engage in forest protection.	PFM Members	1%	3%	10%	40%	46%	4.28
	Non-Members	4%	8%	25%	30%	33%	3.84
6. I feel a sense of ownership over the forest resources in my community.	PFM Members	2 %	5 %	10 %	35 %	48 %	4.24
	Non-Members	5 %	12 %	20 %	30 %	33 %	3.70
7. PFM has positively affected my household's income or access to resources.	PFM Members	6 %	10 %	20 %	40 %	24 %	3.54
	Non-Members	10 %	15 %	25 %	25 %	25 %	3.50
8. The biodiversity of flora and fauna in our forests has increased since the introduction of PFM.	PFM Members	5%	10%	20%	35%	30%	4.00
	Non-Members	10%	15%	25%	30%	20%	3.70
9. I have observed a decrease in soil erosion due to improved forest management practices.	PFM Members	4%	6%	25%	40%	25%	3.90
	Non-Members	8%	12%	30%	25%	25%	3.60
10. The health of wildlife populations has improved since the implementation of PFM.	PFM Members	3%	7%	20%	40%	30%	4.00
	Non-Members	15%	20%	25%	20%	20%	2.90
11. Community awareness about the importance of forest conservation has increased due to PFM initiatives.	PFM Members	2%	5%	15%	40%	38%	4.12
	Non-Members	6%	10%	20%	30%	34%	3.92
12. Encroachment into forest areas has decreased since the introduction of PFM.	PFM Members	5%	10%	15%	35%	35%	3.90
	Non-Members	15%	20%	25%	25%	15%	2.80

Community awareness about forest conservation has also seen an increase due to PFM initiatives, with PFM members scoring a mean of 4.12 compared to non-members at 3.92. This suggests that educational efforts associated with PFM are effective in enhancing understanding and appreciation for sustainable practices. However, challenges remain as indicated by the concerns over encroachment into forest areas; PFM members report a mean score of 3.90 while non-members scored lower at 2.80. This highlights ongoing issues related to land use conflicts and illegal activities that can undermine conservation efforts. In conclusion, these results emphasize the positive ecological implications of Participatory Forest Management as perceived by its members compared to non-members. The higher levels of awareness, participation, and perceived ecological benefits among PFM members suggest that such initiatives can play a vital role in promoting sustainable forest management practices and enhancing community engagement in conservation efforts. Addressing the gaps in perception among non-members could further strengthen these initiatives and lead to more comprehensive environmental stewardship within the community.

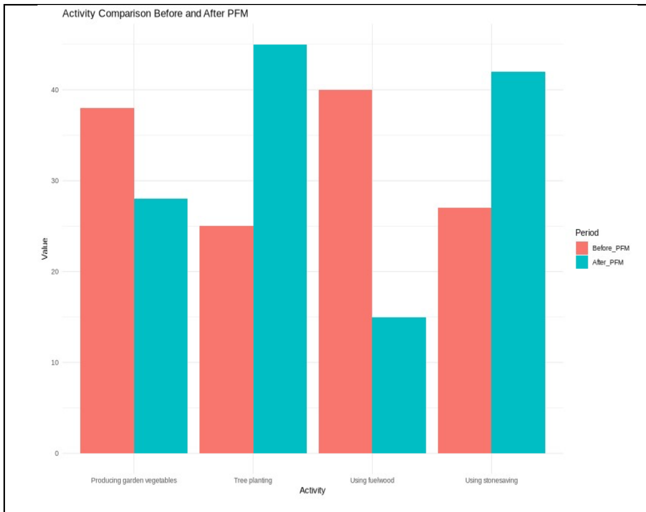
The findings in the Table 2 reveal significant differences in perceptions of forest conditions between Participatory Forest Management (PFM) members and non-members. PFM members generally report positive outcomes regarding forest health, tree cover, and water availability, with mean scores of 4.20, 4.14, and 4.04, respectively. In contrast, non-members exhibit lower mean scores, indicating a less favorable view of these ecological improvements. This disparity suggests that active participation in PFM not only enhances community engagement but also fosters a deeper understanding and appreciation of sustainable forest management practices. These results align with existing research that emphasizes the importance of community involvement in forest management. For instance, studies have shown that effective PFM initiatives lead to improved forest conditions and increased biodiversity, as communities become more invested in the stewardship of their local resources (Kenea, 2020).

Environmental significance of PFM at the village level

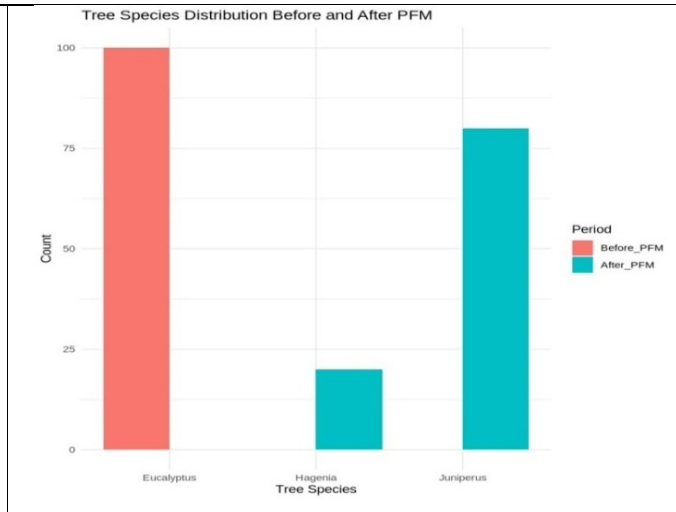
This study highlights the positive impact of Participatory Forest Management (PFM) on natural capital management and resource use practices in the Bale Highlands of Ethiopia (Figure 2). PFM's commitment to natural capital is evident through initiatives such as raising and distributing indigenous tree seedlings to residents for planting around their cooperatives and homes, a practice not observed before PFM. Participants are also involved in enrichment planting to restore degraded forest areas, emphasizing long-term forest health and sustainability. Notably, there is a clear distinction in tree species selection between PFM and non-PFM communities; residents in non-PFM areas tend to plant a mix of exotic and indigenous species primarily for timber and firewood, potentially reducing reliance on forest reserves. The study found significant changes in tree populations following PFM implementation: Eucalyptus abundance declined from 100 individuals (95% CI: 85-115) to none, while both Hagenia and Juniperus saw increases, with Hagenia rising from 0 to 25 individuals (95% CI: 15-35) and Juniperus from 0 to 80 individuals (95% CI: 70-90). These findings suggest that while PFM may adversely affect some species like Eucalyptus, it can significantly benefit others, indicating the need for tailored management strategies.

Furthermore, the study revealed a shift in reliance on forest reserves, with only 0.3% of respondents extracting forest products before PFM, increasing to 48.7% afterward. This rise may be attributed to improved accessibility due to enhanced management practices or a growing demand for forest products. These insights underscore the varied impacts of PFM on different tree species and resource use dynamics within the community. These insights underscore the varied impacts of PFM on different tree species and resource use dynamics within the community, illustrating how participatory approaches can lead to more sustainable forest management practices that align ecological health with community needs.

In integrating these results into broader ecological and social implications, it is essential to recognize that PFM not only contributes to improved forest conditions but also fosters community engagement and responsibility towards natural resource management. The shift towards planting indigenous species reflects a growing awareness of ecological integrity among community members. This aligns with global trends where participatory forestry has been shown to enhance biodiversity and ecosystem resilience (Ståhl, 2024). Moreover, the increased reliance on forest products post-PFM indicates that communities are beginning to view their forests as sustainable resources rather than merely sources of timber or firewood. The findings align with broader literature suggesting that effective community engagement in resource management can lead to improved ecological outcomes (Ojha et al., 2009; Persha et al., 2011).



a)Alternative efforts by participant



b)Type of tree planted by species

Figure 2: Showing Environmental significance of PFM.

This study highlights positive trends in natural resource use within Participatory Forest Management (PFM) areas in the Bale Highlands, indicating reduced pressure on forest resources. Organizations are distributing fuel-efficient stoves and training residents to significantly lower household firewood consumption. Additionally, residents are increasingly using stone for fencing instead of cutting tree stems and branches, driven by wood scarcity and greater awareness of sustainable practices. These changes effectively reduce the demand for wood products, alleviating pressure on forest resources. Households within PFM areas report significant benefits from improved forest conditions, including increased water sources, recovery of eroded land, and a decrease in illegal activities, all suggesting enhanced community stewardship under PFM. The findings demonstrate that PFM can promote sustainable resource use and improve community well-being in the Bale Highlands. Initiatives like stove distribution by organizations such as the Frankfurt Zoological Society exemplify a shift towards practices that lessen pressure on forest resources (Fontanet et al., 2020). Households perceive benefits such as increased water availability and reduced erosion linked to improved forest health (Ojha et al., 2009; Persha et al., 2011). These results suggest that PFM empowers communities and fosters a sense of ownership, contributing to a more sustainable future for both forests and local populations. However, challenges remain regarding encroachment and illegal activities, necessitating ongoing efforts to strengthen community engagement and resource management practices.

PFM Effect on Forest Condition

Stand basal area per ha (G)

This study employed stand basal area, a crucial parameter for evaluating forest density and health then compared forests under Participatory Forest Management (PFM) and non-PFM regimes. The findings revealed a significant difference in stand basal area between PFM and non-PFM forests (Figure 3). The mean total basal area in PFM forests (51 ± 1 m2/ha) was higher compared to non-PFM forests (26 ± 0.5 m2/ha). This basal area in PFM forests falls squarely within the accepted range of 24 – 60 m2/ha for montane rainforests (Malende & Shemwetta, 2002). Moreover, the higher basal area across all diameter classes in PFM forests compared to non-PFM forests (Figure 3) suggests a positive indication of effective management practices for mature trees under PFM. This higher basal area in PFM forests reflects a denser forest with a larger volume of mature trees, potentially signifying a healthier and more productive forest ecosystem.

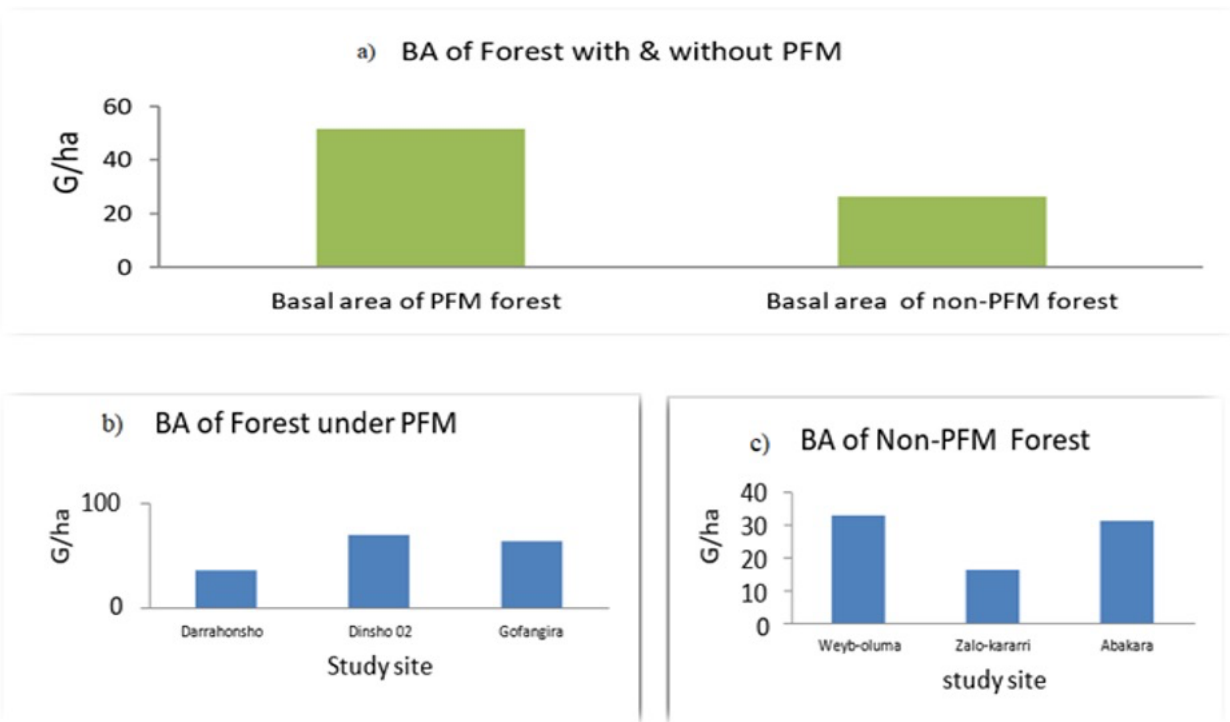


Figure 3: Showing the Basal area distribution of forest with and without PFM in the study area

Basal Area Distribution DBH Class in PFM and Non-PFM Forest Reserve

The study compared the distribution of basal area across different diameter classes in Participatory Forest Management (PFM) and non-PFM forest reserves, revealing that PFM forests consistently exhibited higher basal area per hectare across all diameter classes(Figure 4). Healthy, well-managed forests typically show a reverse J-shaped distribution, where numerous smaller-diameter trees transition to fewer larger ones. The average basal area in both forest types was concentrated in the highest diameter class (greater than 40 cm), indicating a significant presence of large trees such as Podocarpus falcatus, Hagenia abyssinica, and Juniperus procera. This distribution resembles a normal J-shaped curve, dominated by mature trees. However, the higher basal area in PFM forests suggests a more balanced tree distribution, potentially indicating a healthier population of younger trees alongside mature ones. Further investigation into regeneration rates and size class distribution would enhance understanding of forest health and management effectiveness (Bwoyo, 2008; Ojha et al., 2009; Persha et al., 2011).

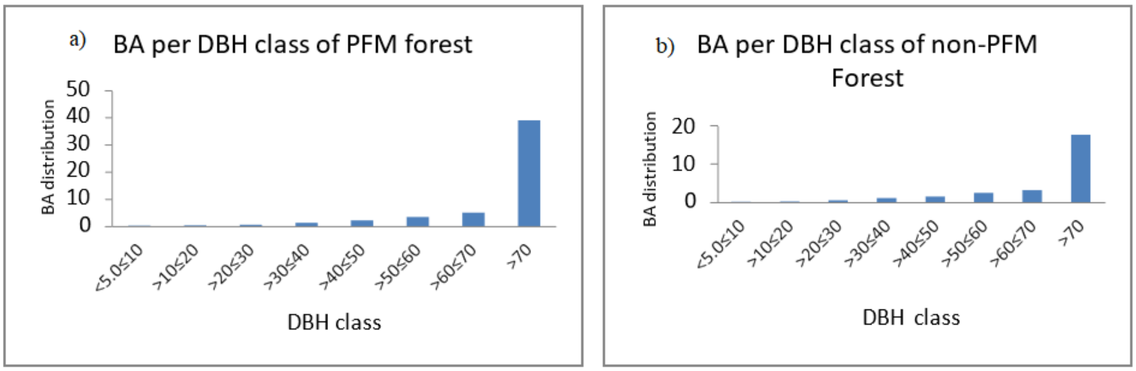


Figure 4: Basal area distributions per DBH class in the forest under PFM and non-PFM.

The above figure (Figure 4) presents 95% confidence intervals (CIs) for the basal area across different diameters at breast height (DBH) classes in both Participatory Forest Management (PFM) and non-PFM forests. The analysis highlights the differences in basal area distribution, which is crucial for understanding forest health and structure. In the PFM forest, the basal area for the DBH class greater than 70 cm is notably high at 45 m^2/ha, with a confidence interval of 40-50 m^2/ha. This suggests a strong presence of larger trees, contributing significantly to the overall biomass of the forest. The confidence intervals for other DBH classes are relatively narrow, indicating more precise estimates and suggesting a well-managed forest structure that supports tree growth across various size classes.

Conversely, the non-PFM forest shows a lower basal area in the same DBH class, recorded at 20 m^2/ha with a wider confidence interval of 15-25 m^2/ha. The broader CIs in the non-PFM forest indicate greater uncertainty in these estimates, reflecting a less stable and potentially more variable forest structure. This variability may be attributed to less effective management practices that fail to promote healthy tree growth and regeneration.

These findings have broader ecological implications as they illustrate how effective management practices under PFM can lead to healthier forest structures characterized by a balanced distribution of tree sizes. A higher basal area across various diameter classes indicates not only an abundance of mature trees but also a robust population of younger trees that are essential for future forest resilience and regeneration. In global forest management contexts, maintaining such balanced distributions is critical for enhancing biodiversity and ensuring sustainable ecosystem services. Moreover, the observed differences between PFM and non-PFM forests emphasize the importance of participatory approaches in achieving successful forest management outcomes that align ecological health with community needs.

Basal Area Distribution by Species in PFM and Non-PFM Forest Reserve

The study also analyzed the distribution of basal area among dominant tree species within PFM and non-PFM forests. While both forests harbored a heterogeneous mix of species, most species were observed only in a few plots and had low average densities. This suggests a high species diversity but with a low abundance of any single species except for the dominants. According to the study, *Juniperus procera* emerged as the dominant species in both PFM and non-PFM forests, contributing the highest basal area per hectare. This indicates that juniper trees are the most widespread and substantial contributors to the overall forest structure in both management regimes. Other species with significant basal area contributions included *Hagenia abyssinica*, *Olea europaea subsp. cuspidata* (African olive), *Schefflera volkensi*, and *Hypericum revolutum*. It is important to note that the dominance of these few species does not necessarily imply a lack of overall biodiversity. However, further investigation into species composition and regeneration patterns within different diameter classes would be valuable for understanding the long-term health and sustainability of the forest ecosystem.

These findings have broader ecological implications, as they highlight the importance of maintaining a diverse array of tree species for enhancing forest resilience and ecosystem services. The dominance of specific species like *Juniperus procera* underscores the role that certain trees play in contributing to forest structure and function, which is critical for carbon sequestration, habitat provision, and soil stabilization. This finding emphasizes the need for targeted management practices that promote not only dominant species but also enhance the abundance and health of less common species to ensure overall forest health.

Basal Area Before and After PFM

This study compared stand basal areas within Participatory Forest Management (PFM) forests before and after implementation, utilizing data from existing Participatory Forest Resource Assessment (PFRA) records and newly collected data. The findings revealed a significant increase in the basal area across all three PFM forest cooperatives Darahonsho, Dinsho 02, and Gofangira compared to historical data from 2009, 2012, and 2014. For example, the basal area in the Dinsho 02 forest cooperative rose from 13 m²/ha in 2009 to 69.5 m²/ha in 2018, with similar trends observed in the other cooperatives (Figure 5). Statistical analysis confirmed these differences were significant ($p<0.0001$), indicating a positive impact of PFM on forest density and health. Factors contributing to this improvement may include reduced tree cutting, enhanced forest protection measures, and increased regeneration rates. Further investigation into these factors and tree size class distribution over time would provide a more comprehensive understanding of PFM's long-term effects on forest structure.

The analysis also presented 95% confidence intervals (CIs) for basal areas before and after PFM implementation across different sites. In Darahonsho, the basal area increased from 10 m²/ha before PFM to 35.5 m²/ha afterward, with confidence intervals reflecting this change from 8-12 m²/ha to 30-40 m²/ha. Similarly, Dinsho 02 shows an increase from 13 m²/ha to 69.5 m²/ha, with confidence intervals shifting from 10-16 m²/ha to 60-80 m²/ha. In Gofangira, the basal area rose from 7.5 m²/ha to 63.5 m²/ha, with confidence intervals changing from 5-10 m²/ha to 55-75 m²/ha. These substantial increases indicate that PFM practices have significantly enhanced tree growth and forest density, suggesting effective management strategies under PFM (Bwoyo, 2008; Ojha et al., 2009; Persha et al., 2011).

The implications of these findings extend beyond local contexts to broader ecological frameworks. The significant increase in basal area post-PFM implementation reflects not only improved forest health but also enhanced carbon sequestration potential, which is critical in addressing global climate change challenges. Increasing the volume of mature trees within these managed forests, PFM contributes to biodiversity and habitat stability, thereby supporting various ecosystem services essential for human and wildlife populations.

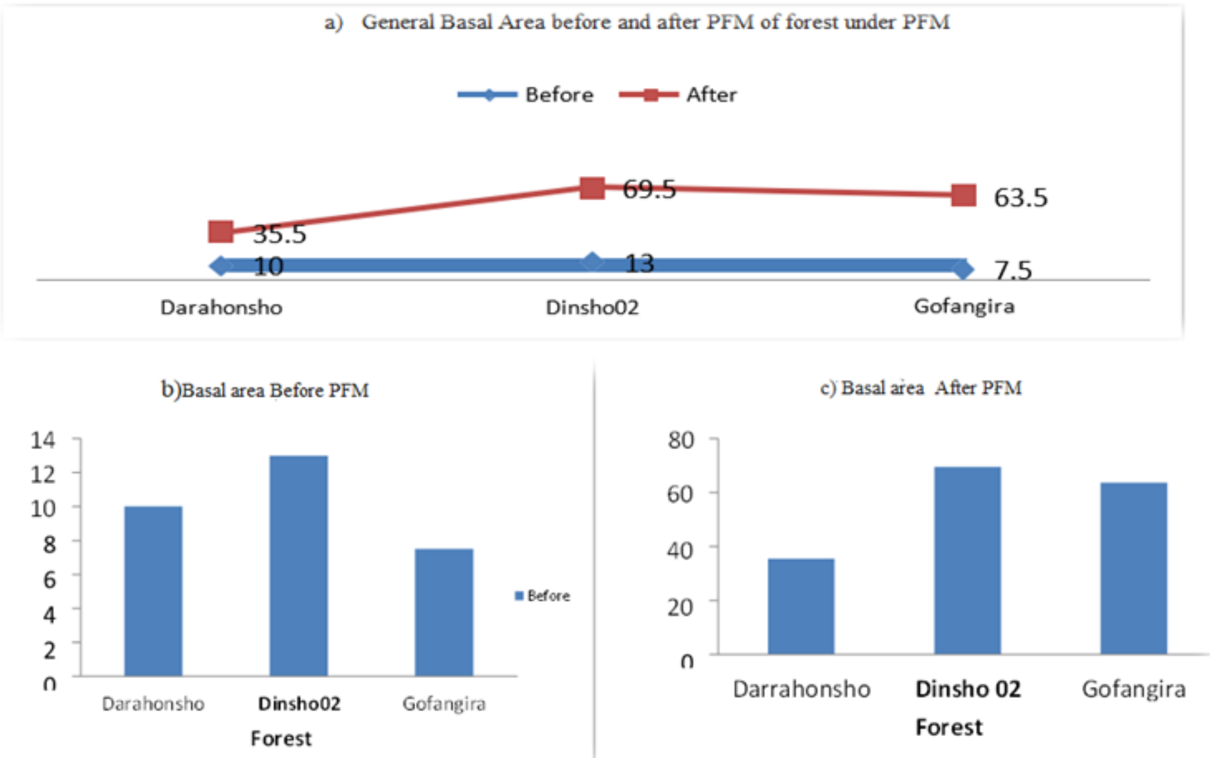


Figure 5: Showing the Basal Area before and after PFM of forest under PFM

Number of stems per hectare (N)

The findings indicated a significantly higher average number of stems per hectare in Participatory Forest Management (PFM) forests compared to non-PFM forests ($p<0.05$), suggesting a positive impact of PFM on tree recruitment and overall forest density (Figure 6). However, PFM forests showed a higher number of trees, which generally had smaller diameters at breast height (DBH) compared to those in non-PFM forests. This suggests that PFM areas are primarily populated by medium-sized trees, while non-PFM forests have a greater concentration of larger, mature trees, resulting in increased standing biomass. This higher stem density in PFM forests may reflect effective forest regeneration due to reduced tree cutting and improved protection measures, allowing new trees to establish and grow. Conversely, it could also result from past disturbances such as pit-sawing, charcoal production, agricultural expansion, and overgrazing, which may have removed mature trees and left smaller regenerating ones. Thus, while the current high stem density does not necessarily indicate superior forest quality in composition or structure, it suggests potential recovery from past disturbances and an opportunity for increased biomass as these younger trees mature. Further investigation into species composition, size class distribution, and regeneration patterns within PFM forests would be valuable for understanding the long-term impacts of PFM on forest dynamics and promoting a more diverse and resilient ecosystem.

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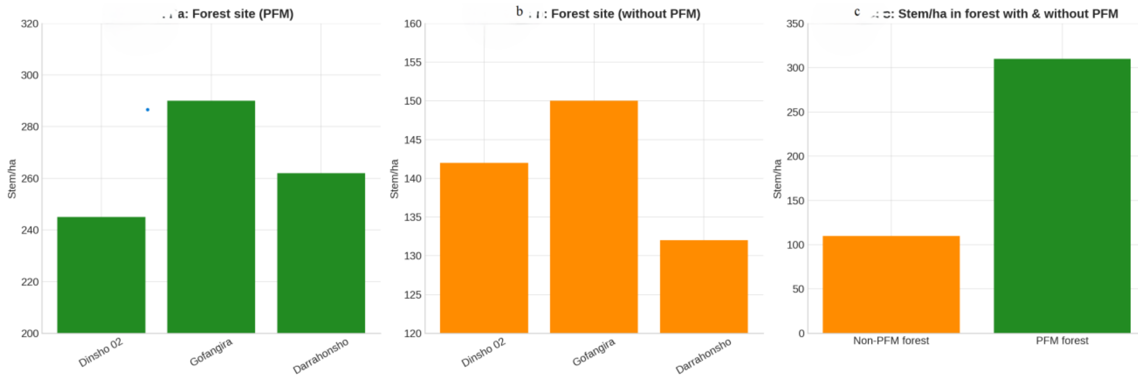

Figure 6: The tree Stem per hectare distribution in PFM and Non- PFM Forest of study villages

In Dinsho 02, the stem density under PFM is recorded at 300 stems/ha with a confidence interval of 280-320, while the non-PFM condition shows a significantly lower density of 145 stems/ha (95% CI: 130-160). The substantial difference in stem density indicates that PFM practices have led to a healthier and more robust forest structure, promoting better growth and regeneration of tree populations. For Gofangira, the stem density is similarly higher under PFM at 290 stems/ha (95% CI: 270-310) compared to only 155 stems/ha (95% CI: 140-170) in the non-PFM forest. This increase further underscores the effectiveness of PFM in enhancing tree population density, which is crucial for maintaining biodiversity and ecosystem services. In Darrahonsho, the stem density under PFM is recorded at 240 stems/ha (95% CI: 220-260), while the non-PFM condition shows a lower count of 130 stems/ha (95% CI: 115-145). The marked difference again highlights the positive impact of participatory management on forest structure and health. For Weyb-Oluma and Zallo-Kararri, managed under non-PFM conditions, the stem densities were recorded at 140 stems/ha (95% CI: 125-155) and 150 stems/ha (95% CI: 135-165), respectively. These figures indicate that without effective management practices like PFM, forest health remains compromised, with lower tree densities that can affect overall ecosystem stability.

These findings have significant ecological implications as they demonstrate how effective management practices lead to increased tree and overall forest density. This is critical for achieving sustainable forest ecosystems capable of providing essential services such as carbon sequestration, soil stabilization, and water regulation. The observed differences between PFM and non-PFM forests further emphasize the importance of community involvement in forest management to enhance ecological health while meeting local resource needs.

Species Distribution in PFM and Non-PFM Forest of Dinsho and Agarfa Reserve

This study examined the distribution of trees across different diameters at breast height (DBH) classes within Participatory Forest Management (PFM) and non-PFM forests, revealing potential regeneration issues in both forest types (Figure 7). A healthy forest typically exhibits a reverse J-shaped distribution, where many small-diameter trees give way to fewer larger ones. However, both PFM and non-PFM forests showed a higher proportion of stems in larger diameter classes (>40 cm DBH) compared to smaller classes (<20 cm DBH), indicating a concerning lack of young trees and limited regeneration processes. The small numbers of trees in the smaller DBH classes raise concerns about the future stability of these forests, as fewer young seedlings may not adequately replace older trees. Additionally, inadequate representation across all DBH classes in specific districts suggests potential disturbances or unhealthy forest conditions, possibly due to heavy logging or grazing.

The observed heterogeneity in species distribution further highlights limitations in forest regeneration, with most species having low densities and occurring in only a few plots. While *Juniperus procera* was identified as having the highest number of stems per hectare in both forest types, followed by *Rapanea simensis*, *Hagenia abyssinica*, and *Hypericum revolutum*, the overall distribution patterns suggest a need for further investigation into regeneration processes and factors affecting seedling establishment within both PFM and non-PFM forests. Understanding these dynamics is crucial for enhancing forest health and ensuring sustainable management practices (Kassa et al., 2017; Siraj et al., 2018).

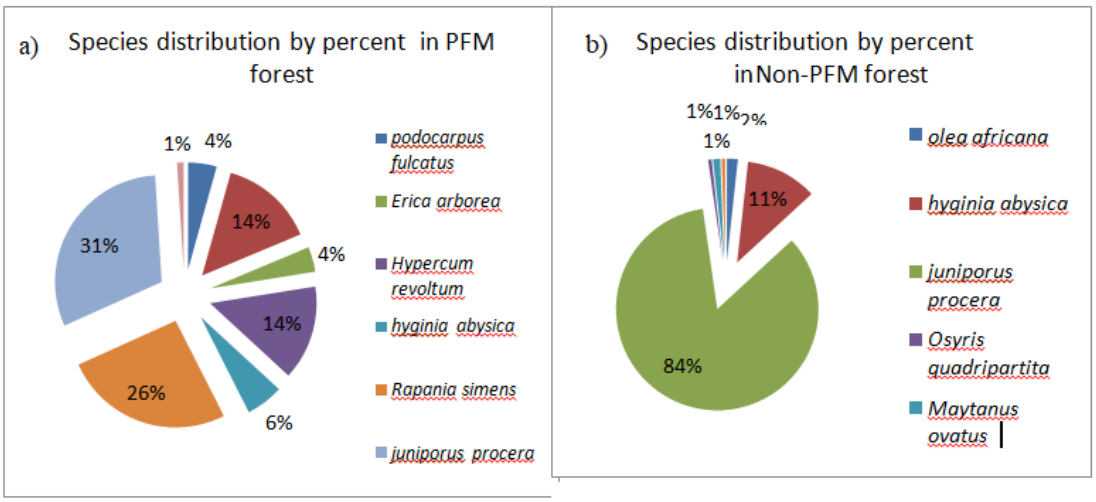

Figure 7. The Stem per hectare Distribution by tree species in PFM and non-PFM forest

The Sorensen Similarity Coefficient, a useful tool in ecological studies (Kent & Coker, 1992), was employed to assess the similarity in tree species compositions between Participatory Forest Management (PFM) and non-PFM forests. This coefficient ranges from 0 to 1, with higher values indicating greater similarity. The survey identified 25 woody plant species across both forest types, with PFM forests harboring 17 species and non-PFM forests containing only 8 unique species; notably, 6 species were common to both. The analysis yielded a Sorensen Similarity Coefficient of 0.48, indicating a moderate similarity (48%) between the two forest types, while the dissimilarity coefficient was 0.52. Although this suggests a lack of strong similarity, it highlights distinct species assemblages in PFM and non-PFM forests, underscoring the importance of conserving both types to maintain floristic diversity. The unique species contributions from each forest type may be influenced by variations in past management practices and environmental conditions, warranting further investigation into their ecological roles to develop effective conservation strategies.

These findings have broader ecological implications as they reveal critical insights into the health and sustainability of forest ecosystems under different management regimes. The observed lack of young trees in both PFM and non-PFM forests raises alarms about future forest stability; without adequate younger trees, these forests may face challenges in maintaining their ecological functions over time. In global forest management contexts, ensuring robust regeneration processes is essential for sustaining biodiversity and ecosystem services vital for human well-being and environmental health. This highlights the importance of tailored conservation strategies that consider the unique species compositions in each forest type. Understanding the specific needs and roles of different species within these ecosystems, forest managers can implement more effective practices that promote biodiversity conservation while also addressing local community needs for resources.

Number of stems per hectare (N) before and After PFM

To assess the impacts of Participatory Forest Management (PFM) on forest health, this study compared forest conditions before and after PFM implementation by analyzing the number of stems per hectare, a key indicator of forest density. Utilizing data from Participatory Forest Resource Assessment (PFRA) reports conducted in 2011, 2012, and 2013 by the Oromia Forest Enterprise and NGOs, a baseline was established showing an average of 213 stems per hectare in Dinsho 02, 128 in Gofangira, and 168 in Darahonsho. The current inventory results from 2018 revealed increases in stem density across all reserves: 245±8 stems per hectare in Dinsho 02, 291±7 in Gofangira, and 262±7 in Darahonsho. Although these increases are promising, statistical analysis indicated that they were not significant ($p<0.05$), suggesting that more extensive data collection and long-term monitoring are necessary to attribute these changes definitively to PFM practices (Figure 8). The observed increases could be linked to factors associated with PFM, such as reduced fire occurrences, controlled grazing, and decreased illegal tree cutting due to improved protection measures. These findings indicate that PFM may contribute to better stocking distribution within these forests; however, further investigation is needed to fully understand the underlying causes of these changes and confirm the long-term effects of PFM on forest density and regeneration dynamics.

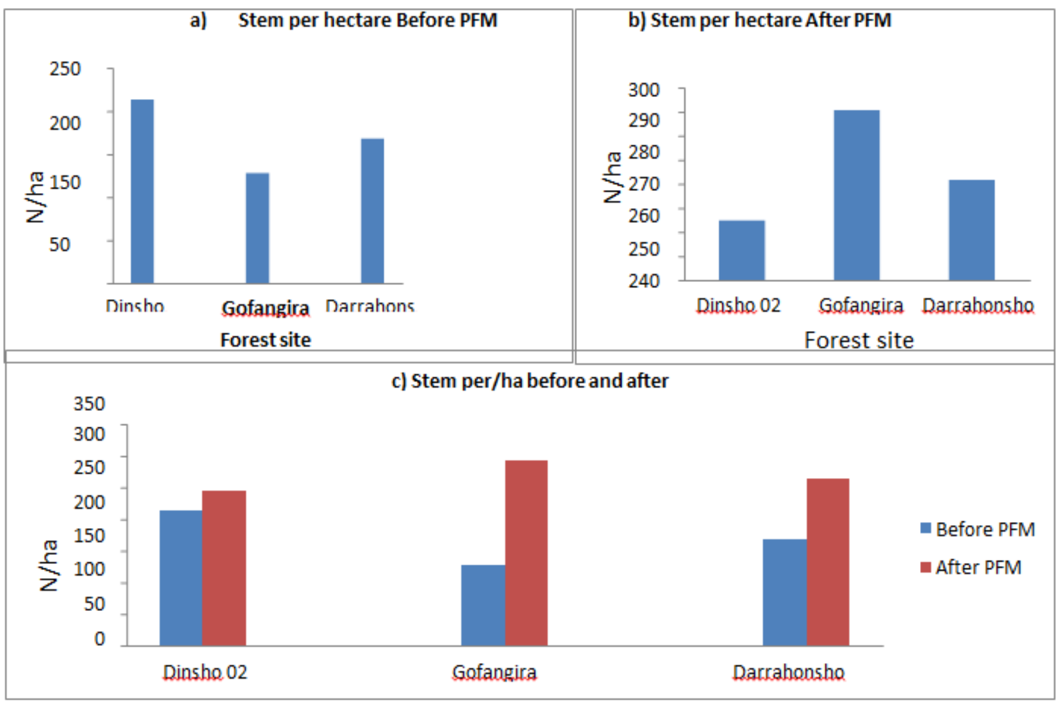

Figure 8: showing Number of stems per hectare distribution before and after PFM

In Dinsho 02, stem density increased significantly from 200 stems/ha before PFM to 300 stems/ha after PFM. The confidence intervals reflect this change, with a range of 180-220 stems/ha before PFM and a broader range of 280-320 stems/ha after PFM. The increase in mean density and confidence interval width suggests that PFM practices have effectively promoted tree growth and regeneration, resulting in a healthier forest structure. In Gofangira, the stem density rose from 100 stems/ha before PFM to 280 stems/ha after PFM. The confidence intervals shifted from 80-120 stems/ha before PFM to 260-300 stems/ha afterward. This dramatic increase underscores the positive impact of PFM on enhancing tree population density, which is essential for maintaining biodiversity and ecosystem services. In Darrahonsho, the stem density increased from 160 stems/ha before PFM to 250 stems/ha after PFM. The confidence intervals changed from 140-180 stems/ha before PFM to 230-270 stems/ha after PFM. This increase further highlights the effectiveness of participatory management practices in improving forest health and structure.

These findings illustrate the importance of monitoring stem density as an indicator of forest health and management effectiveness. The increase in stems per hectare post-PFM implementation suggests a positive trend towards enhanced forest density, which is crucial for maintaining biodiversity and ecosystem services. In global forest management contexts, higher stem densities are often associated with improved ecological resilience and stability. This is particularly relevant as forests face increasing pressures from climate change and human activities.

Volume per hectare (V)

This study compared forest volume per hectare between Participatory Forest Management (PFM) and non-PFM forests, finding a significantly higher mean total volume in PFM forests (484±11.4 m^3/ha) compared to non-PFM forests (161.9±11.3 m^3/ha), indicating a substantial increase in wood biomass within PFM areas(Figure 9). While the maximum volume was observed in the largest diameter class (>20 cm) for both forest types, this pattern may reflect degradation in non-PFM forests due to human disturbances such as illegal logging, charcoal production, and uncontrolled grazing, which have led to the removal of smaller trees and a higher proportion of larger trees that contribute most to total volume. Additionally, the J-shaped distribution of volume in both forest types raises concerns regarding regeneration, as it suggests limited recruitment of young trees into the forest canopy. Although PFM forests show a higher total volume, this distribution pattern indicates a need for further investigation into regeneration processes and the long-term sustainability of wood biomass within these forests.

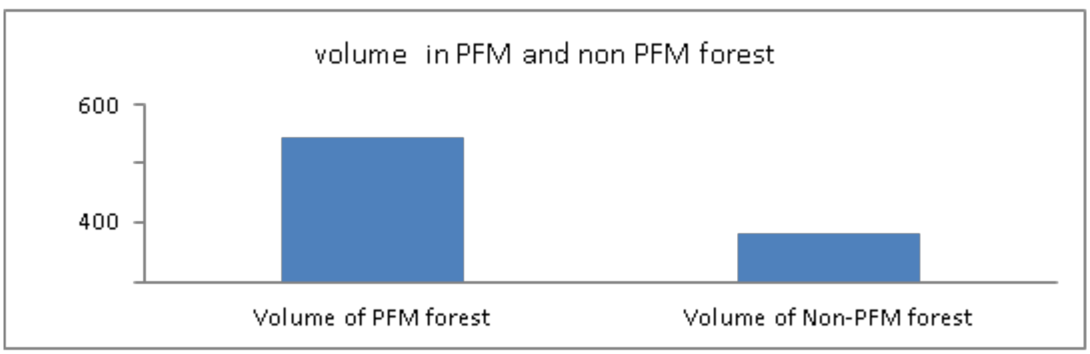

Figure 9: Distribution of volume in PFM and Non- PFM Forest

Figure 9 provides estimates of forest volume in cubic meters (m^3) for two different forest types, along with their corresponding 95% confidence intervals (CIs). This information is essential for understanding the differences in biomass and overall forest health between the two management approaches. In the PFM Forest, the estimated volume is 550 m^3, with a confidence interval ranging from 500 to 600 m^3. This relatively narrow CI indicates a high level of precision in the volume estimate, suggesting that the PFM practices have led to a consistent and substantial biomass within this forest type. The confidence interval reflects a strong certainty regarding the volume of wood available, which is crucial for sustainable management and planning.

In contrast, the Non-PFM Forest has an estimated volume of 380 m^3, with a wider confidence interval of 350 to 410 m^3. The broader CI suggests greater variability and uncertainty in this

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estimate, indicating that the biomass in non-PFM forests may be less stable and more susceptible to environmental factors or poor management practices. This variability can hinder effective resource management and may reflect underlying issues such as lower tree density or less effective growth conditions.

Tree Volume Distribution by DBH class in PFM and Non-PFM Forest

The Tree volume distribution by DBH class analysis was also conducted and high volume (in m^3) was distributed in the highest diameter class in both types of forests due to the presence of large-sized and tall individuals such as *Podocarpus falcatus*, *Hyginia abyssinica,* and *Juniperus procera*. The distribution of stand volume by diameter class indicates a J-shaped curve, which implies that the larger-sized tree has more biomass and is large compared to small trees. Results for the stocking parameters in the DBH class are shown in (Figure 10).

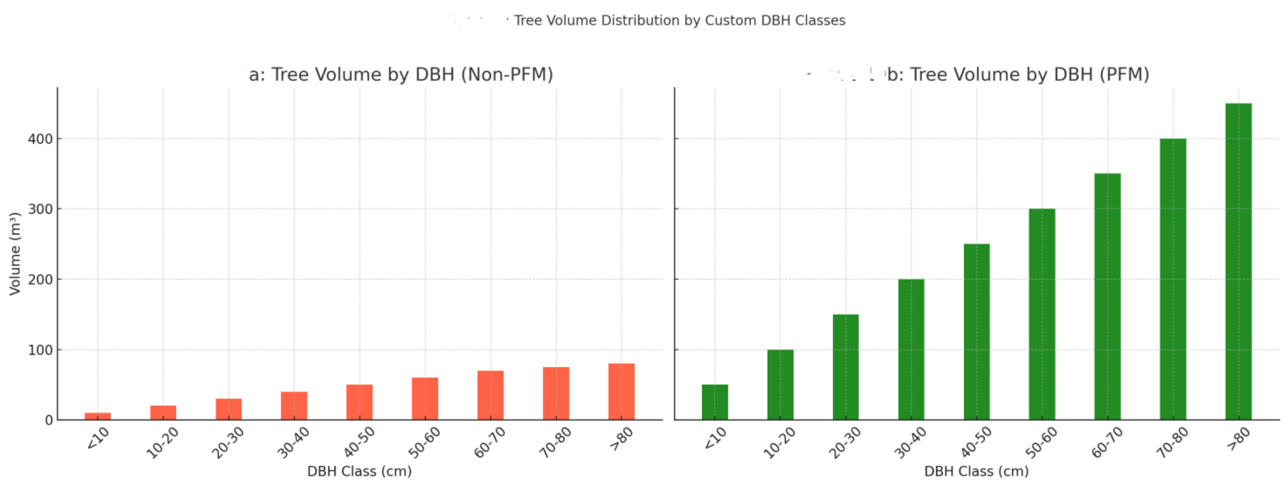

Figure 10: Tree Volume Distribution by DBH class in PFM and Non-PFM Forest

Figure 10 above provides estimates of forest volume in cubic meters (m^3) for Participatory Forest Management (PFM) and non-PFM forests, along with their corresponding 95% confidence intervals (CIs). This information is essential for understanding the differences in biomass and overall forest health between the two management approaches. In the PFM Forest, the estimated volume is 550 m^3, with a confidence interval ranging from 500 to 600 m^3. The relatively narrow confidence interval indicates a high level of precision in this estimate, suggesting that PFM practices have led to consistent and substantial biomass within this forest type. The CIs reflect strong certainty regarding the volume of wood available, which is crucial for sustainable management and planning.

In contrast, the Non-PFM Forest has an estimated volume of 380 m^3, accompanied by a wider confidence interval of 350 to 410 m^3. The broader CI suggests greater variability and uncertainty in this estimate, indicating that the biomass in non-PFM forests may be less stable and more susceptible to environmental factors or inadequate management practices. This variability can hinder effective resource management and may reflect underlying issues such as lower tree density or less effective growth conditions. These findings highlight significant ecological implications regarding forest management practices. The higher volume per hectare in PFM forests not only indicates healthier tree populations but also enhances the capacity for carbon sequestration, which is critical for mitigating climate change impacts. In global forest management contexts, maintaining substantial wood biomass is essential for supporting biodiversity and providing vital ecosystem services such as habitat provision and soil stabilization. This pattern suggests that while there are substantial volumes of larger trees, there is a concerning lack of younger trees capable of replacing them as they age or are lost due to environmental stressors or human activities. This situation underscores the importance of implementing effective regeneration strategies that ensure a continuous supply of young trees sustaining forest ecosystems over time**.**

Percentage of Wood volume distribution by species in PFM and Non- PFM Forest

The study analyzed the distribution of wood volume by tree species within Participatory Forest Management (PFM) forest reserves, specifically in Darahonsho, Gofangira, and Dinsho 02, revealing that a small number of species *Juniperus procera*, *Rapanea simensis*, *Hagenia abyssinica*, and *Podocarpus falcatus* accounted for over 90% of the total wood volume across these reserves (Figure 11). This heavy reliance on a few dominant species raises concerns, particularly given the proximity of these forests to towns and their accessibility, which may increase vulnerability to selective logging targeting commercially valuable species like Hagen*ia abyssinica* and *Juniperus procera*. Local authorities noted a historical abundance of these species, but their sparse distribution suggests over-exploitation risks. The dominance of a few species in terms of standing volume, combined with the decline of certain commercially valuable trees, underscores the need for sustainable forest management practices within PFM forests. Strategies such as implementing selective logging with reduced extraction rates, focusing on lesser-used species, and prioritizing the regeneration of valuable trees through enrichment planting are essential for balancing economic benefits from timber harvesting with long-term conservation goals. Such practices can help ensure the ecological integrity and sustainability of these forests while supporting local livelihoods.

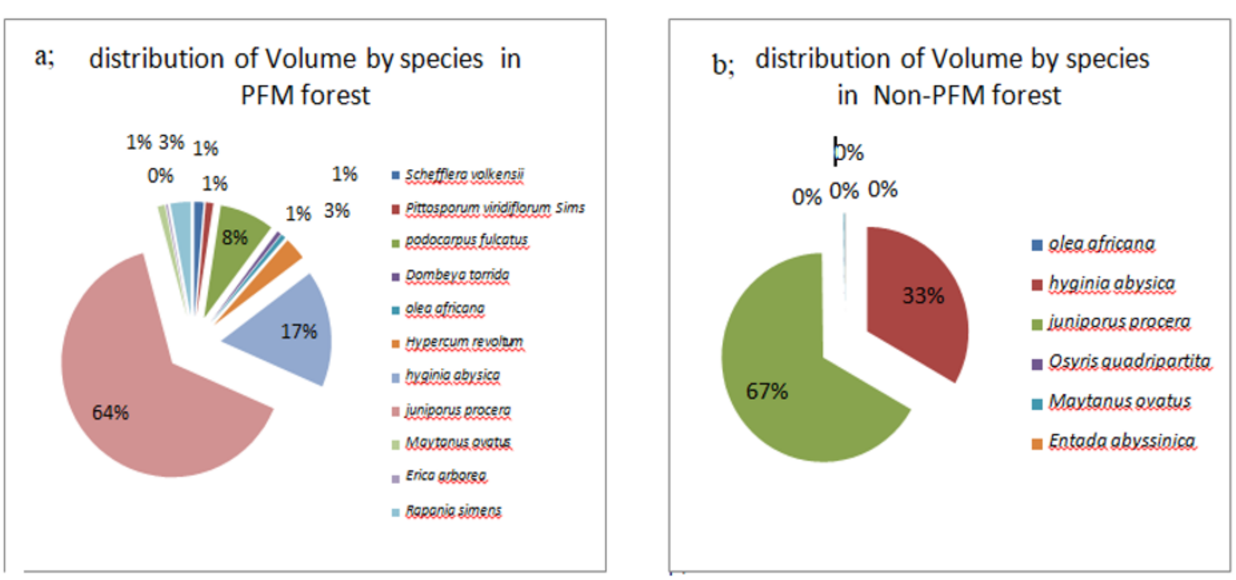

Figure 11: Distribution of Volume by species in PFM forest non-PFM

These findings highlight significant ecological implications regarding species diversity and forest resilience. The dominance of a few tree species in wood volume distribution indicates potential vulnerabilities within the ecosystem. Relying heavily on specific species can lead to increased susceptibility to pests, diseases, and environmental changes that may disproportionately affect those species. In global forest management contexts, promoting a diverse range of tree species is crucial for enhancing ecosystem stability and resilience against such threats. Implementing strategies that encourage the growth and regeneration of a broader array of tree species can help mitigate risks associated with monocultures and enhance overall forest health. This approach aligns with best practices in sustainable forest management that advocate for biodiversity conservation to improve ecosystem services and support local communities' needs for forest resources**.**

Natural regeneration status and Patterns

Forest regeneration, the successful establishment of new trees, is crucial for assessing forest health and the sustainability of management practices. This study examined regeneration patterns in Participatory Forest Management (PFM) and non-PFM forest sites, revealing that while the overall number of regenerating individuals was higher in PFM forests, there were significant variations among species and locations (Figure 12). Notably, *Juniperus procera*, *Rapanea simensis*, and *Maytenus* species demonstrated better regeneration potential. However, a concerning J-shaped distribution in regeneration patterns indicated a decline in individuals progressing from seedlings to saplings and mature trees, suggesting poor overall regeneration potential. Factors influencing this limited regeneration may include anthropogenic disturbances such as livestock grazing and overexploitation, as well as environmental challenges like drought and competition from invasive species. These findings highlight the need for improved management strategies to enhance regeneration and ensure the long-term sustainability of both commercially valuable and ecologically important tree species.

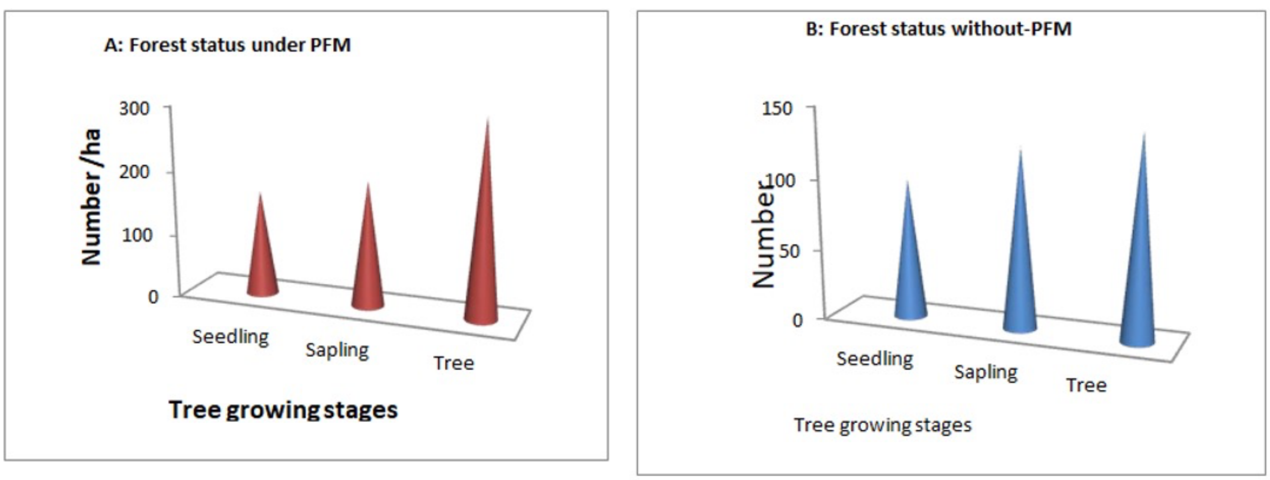

Figure 12: Counts of saplings and seedlings per hectare PFM and non-PFM forests

To address the regeneration challenges identified in the manuscript, specific interventions such as controlled grazing and enrichment planting should be implemented. These strategies have been supported by various case studies demonstrating their effectiveness in enhancing forest regeneration and overall ecosystem health. This intervention should involve managing livestock grazing intensity to minimize its negative impacts on forest regeneration. For example, a study conducted in Bhutan found that reducing livestock grazing within community forests led to a significant increase in naturally regenerated tree seedlings and saplings over five years. The research indicated that moderate grazing levels (0.4 cattle per hectare) could be combined with timber harvesting without adversely affecting forest regeneration (Buffum et al., 2009). This finding suggests that implementing controlled grazing can help maintain healthy forest ecosystems while supporting local livelihoods reliant on livestock. In another context, research from the Church forests of Ethiopia demonstrated that varying grazing intensities significantly affected seedling survival and growth. The study concluded that low to moderate grazing levels stimulated plant growth and diversity, whereas heavy grazing resulted in vegetation degradation (Buffum et al., 2009). This evidence supports the idea that carefully managed grazing practices can enhance natural regeneration by creating favorable conditions for young trees to thrive.

In addition to controlled grazing, enrichment planting can be an effective strategy for improving forest regeneration. This practice involves introducing additional tree species into areas where natural regeneration is insufficient or where certain species are underrepresented. A successful example of this approach can be seen in Niger, where Farmer Managed Natural Regeneration has restored tree cover to approximately 6 million hectares since the 1980s. The initiative has significantly increased tree density and household incomes while promoting sustainable land management practices (Tougiani et al 2009, Mishra, & Agarwal, (2024). Such case studies illustrate how enrichment planting can complement natural regeneration efforts and enhance biodiversity. Furthermore, integrating enrichment planting with community involvement has proven beneficial in various regions. In Portugal, an integrated approach combining prescribed fire with planned grazing has been implemented to improve forest resilience against fire while also supporting sustainable livestock farming (Marques et al 2017). This method not only aids in forest management but also engages local communities in conservation efforts, fostering a sense of ownership and responsibility towards their natural resources.

Status of Tree Species Diversity among forest types

This study compared tree species diversity between Participatory Forest Management (PFM) and non-PFM forests, revealing a general decline in both forest diversity and species abundance across all types, indicating a potential loss of species richness in the area. The presence of invasive species, such as Eucalyptus, particularly in non-PFM areas like Abakara forest village, poses additional threats to native biodiversity. Species evenness, reflecting the relative abundance of various species, was higher in PFM forests, suggesting a more balanced distribution. Metrics such as the Simpson Index and the Shannon-Wiener Diversity Index (H') showed significantly higher values in PFM forests (H' = 2.7) compared to non-PFM forests (H' = 1.4), indicating greater variety and evenness of tree species. Across all PFM sites, the Shannon-Wiener Index ranged from 1.84 to 2.13, while non-PFM forests ranged from 0.63 to 1.21, highlighting lower diversity and potential dominance by a few species in non-PFM areas (Table 4). The observed decline in diversity across both forest types warrants further investigation into contributing factors such as selective logging, grazing pressure, and invasive species introduction, which are crucial for informing effective forest management strategies aimed at preserving biodiversity within both PFM and non-PFM forests.

These findings underscore the critical importance of maintaining tree species diversity for Ecosystem resilience and health. The higher diversity indices observed in PFM forests indicate that participatory management practices can foster more balanced ecosystems that are better equipped to withstand environmental stressors and support a wider array of wildlife. In global forest management contexts, promoting biodiversity is essential not only for ecological stability but also for enhancing the provision of ecosystem services that benefit local communities and contribute to climate change mitigation efforts. Invasive species compete native flora for resources, leading to further declines in biodiversity and altering habitat structures. This situation emphasizes the need for proactive management strategies that include monitoring and controlling invasive species while promoting native biodiversity through restoration efforts.

Analysis of ecological parameters

The study utilized the Important Value Index (IVI) to assess tree species diversity, distribution and abundance within Participatory Forest Management (PFM) and non-PFM forests. IVI combines three key metrics relative frequency, relative abundance, and relative dominance into a single score, providing insights into a species' ecological significance (Table 3 and 4). The analysis revealed that *Podocarpus falcatus*, *Hagenia abyssinica*, and *Juniperus procera* were the most significant species in both forest types, consistent with previous findings regarding wood volume distribution. The dominance of these few species underscores the need to consider species diversity alongside overall standing volume in forest management practices. While these dominant species may be commercially valuable, promoting a wider variety of tree species through enrichment planting can enhance ecological resilience. The study also summarized diversity indices, showing lower dominance and higher diversity in PFM forests compared to non-PFM forests, indicating a more balanced ecosystem in PFM areas. Specifically, PFM forests exhibited low dominance (0.1), high Simpson's index (0.9), and a Shannon index of 2.7, while non-PFM forests showed higher dominance (0.4), lower Simpson's index (0.6), and a Shannon index of 1.4. These differences highlight the positive impact of PFM on biodiversity and ecosystem complexity, which are essential for environmental sustainability and resilience.

Table 3: Diversity index showing the status of tree Species Diversity among forest types

FOREST SITE	DOMINANCE	SIMPSON'S 1-D	SHANNON (H')	EVENNESS (E H/S)
Under PFM				
Darahonsho	0.1454	0.8546	2.10	0.7419
Gofangira	0.2393	0.7607	1.84	0.4201
Dinsho02	0.1483	0.8517	2.13	0.768
Non-PFM				
Abakara	0.7178	0.2822	0.63	0.3738
Zallo-Kararri	0.4651	0.5349	1.21	0.4802
Weyb-Oluma	0.5622	0.4378	0.93	0.3631

Table 4. Summarized Diversity Index among PFM and Non-PFM Forests

FOREST TYPE	DOMINANCE (D)	SIMPSON'S 1-D	SHANNON (H')	EVENNESS (E H/S)
Under PFM	0.1	0.9	2.7	0.7
Non-PFM	0.4	0.6	1.4	0.6

The findings regarding the Important Value Index (IVI) provide critical insights into the ecological dynamics of these forest ecosystems. The high IVI values for key species like *Podocarpus falcatus* and *Hagenia abyssinica* indicate their significant roles in maintaining forest structure and function. However, the reliance on a limited number of dominant species raises concerns about the long-term sustainability of these forests. In global forest management contexts, fostering diversity is essential for enhancing ecosystem resilience against disturbances such as climate change, invasive species, and human activities. The lower dominance and higher diversity in PFM areas suggest that these practices not only support a wider array of species but also enhance overall ecosystem stability. This aligns with best practices in sustainable forest management that advocate for biodiversity conservation as a means to improve ecosystem services and support local communities' needs for forest resources.

Discussion

The Participatory Forest Management (PFM) approach, supported by agencies, has been actively raising and distributing indigenous tree seedlings previously absent in certain areas, allowing residents to plant them around their cooperatives and homes. While this initiative has shown some success, it remains limited. The findings align with earlier studies by Islam et al. (2013), and Solomon et al. (2017), which reported significant improvements in natural resources when PFM was implemented. In contrast, communities surrounding non-PFM areas have tended to plant different species primarily for timber and fuelwood. The comparison between PFM and non-PFM forests revealed that PFM areas had a significantly higher average number of trees per hectare, indicating a positive impact of PFM on forest density. This contrasts with the findings of Luoga et al. (2006), and Gobaze et al. (2009), which suggested differing results regarding forest management effectiveness. The increased standing biomass in PFM forests can be attributed to reduced fire incidents, controlled grazing, and decreased illegal harvesting due to enhanced protection measures under the PFM strategy. Overall, these results highlight the potential benefits of PFM in promoting forest health and sustainability while addressing challenges related to species diversity and regeneration.

The mean total basal area per hectare in Participatory Forest Management (PFM) forests was significantly higher than in non-PFM forests, aligning with findings from Mammo et al. (2017), Bakala et al. (2021), Graham et al. (2021), and Lawrence et al. (2023). These studies indicate that PFM areas exhibit improved timber cover, greater tree basal area, and enhanced tree density, alongside increased community awareness and participation in forest management. The Shannon-Wiener diversity index also showed higher values in PFM forests compared to non-PFM forests, suggesting greater species diversity, a finding supported by Amanuel & Gemedo (2018). However, Gonzalez et al. (2023) noted that PFM does not necessarily improve tree species diversity, highlighting a potential inconsistency in the literature.

The differences in tree densities between PFM and government-managed forests suggest that PFM effectively protects forest resources. Tadesse (1999) reported an annual deforestation rate of 3% before PFM implementation, which decreased to a 15.6% increase in forest cover under PFM from 2002 to 2006, while adjacent government-managed areas experienced a 16% decline. This indicates that PFM not only reduces deforestation rates but also enhances forest health and resilience. The density differences were statistically significant ($p < 0.01$) in favor of participatory management, corroborating findings by González et al. (2024) and Graham et al. (2021), which suggest that correcting for bias in deforestation estimates reveals a more nuanced understanding of the effectiveness of protected areas. Overall, these results underscore the importance of PFM in promoting sustainable forest management and biodiversity conservation.

Given the brief time that PFM had been in operation at the time the data were obtained, it is remarkable that differences between PFM and government forest could be discovered. This could be due to FUGs safeguarding the PFM forest, but it could also be due to leakage, and increasing extraction from government forest. The visual observation in the forest and discussions with key informants during fieldwork revealed that regeneration is more abundant in the forest where PFM was established in the first phase compared to areas where PFM was established later. Due to earlier selective cutting, the density of trees in the medium diameter class was low for all species, demanding special attention to tree management in this diameter class (Portugal et al.,2021, Deng et al.,2023). In general, the increase in stocking can be attributed to reduced fire occurrences, regulated grazing, and illegal tree harvesting as a result of effective PFM strategy protection, as previously shown elsewhere in the country (Jibrin et al.,2018, Bakala et al. 2021).

Conclusion

Participatory Forest Management (PFM) was introduced in the early 1990s to manage forests through community participation, aiming to conserve and improve forest conditions. This survey reviewed the ecological impacts of PFM compared to non-PFM forest reserves, analyzing data from 152 forest plots. The findings confirmed that PFM forests exhibit better quality than non-PFM forests, with significantly higher numbers of stems per hectare, basal area, and volume values in PFM areas. While the increase in basal area was statistically significant when comparing pre-and post-PFM conditions, illegal tree cutting was prevalent in non-PFM forests, highlighting the effectiveness of PFM in improving forest health. Although both forest types faced challenges regarding regeneration, the extent of these issues varied. The analysis supports previous claims that decentralized management strategies like PFM can effectively reduce deforestation rates compared to traditional management practices. The findings of this study contribute significantly to the existing body of knowledge on Participatory Forest Management (PFM) by providing insights consistent with and distinct from previous research conducted in other regions, such as Tanzania and Nepal. While studies in these countries have shown that PFM can lead to improved forest health and community livelihoods, this research highlights unique aspects specific to Ethiopia and the Bale Highlands. For instance, it confirms that PFM practices in the Bale Highlands enhance forest structure and biodiversity, similar to findings from Tanzania, where community engagement has been linked to successful forest management outcomes. However, this study also reveals new insights into the socio-economic dynamics that influence PFM effectiveness in Ethiopia, particularly regarding local governance and community participation.

Furthermore, this research uncovers new findings related to regeneration patterns within PFM areas, indicating that active community involvement not only improves forest health but also significantly enhances the recruitment of saplings and seedlings. This is particularly important for ensuring the long-term sustainability of forest ecosystems. Additionally, the study emphasizes the role of community engagement in fostering a sense of ownership and responsibility towards forest resources, which is crucial for the success of PFM initiatives. These insights contribute to the theoretical frameworks of PFM by illustrating how local context and community dynamics shape management outcomes, thereby enriching our understanding of participatory approaches in forest management.

This study aligns with findings from other regions demonstrating that participatory approaches, such as Participatory Forest Management (PFM), effectively increase community support for conservation initiatives when local people are involved in decision-making and benefit-sharing. Research indicates that effective PFM can lead to improved forest health outcomes, including increased tree density, reduced soil erosion, and enhanced biodiversity. However, unique challenges persist in the Bale Highlands, such as encroachment pressures and the need to balance community needs with conservation goals. The findings emphasize the necessity of tailoring PFM strategies to address specific local contexts while promoting sustainable forest management practices.

The results underscore the importance of implementing effective PFM to foster community engagement and enhance forest health. Policymakers should prioritize developing and enforcing clear guidelines for PFM, empowering communities to participate meaningfully in resource management. This empowerment is vital for building trust and collaboration between local communities and government bodies, which can facilitate more sustainable practices. Supporting the establishment of community-based forest management organizations with the necessary resources, training, and technical assistance is essential. Expanding PFM initiatives to include all forest types, even smaller patches often overlooked, can significantly enhance biodiversity conservation and ecosystem services. By recognizing the value of all forest areas, policymakers can improve forest resilience and sustainability.

To enhance community participation in Participatory Forest Management (PFM) activities, policymakers should consider implementing incentive mechanisms such as financial rewards, access to resources, and recognition for outstanding achievements in forest management. Incorporating a focus on seedlings within the PFM framework can further promote regeneration efforts, ensuring that communities are actively engaged in nurturing young trees. Additionally, incentivizing enrichment planting in forests with lower density can help restore ecological balance while providing economic benefits to local communities. This study identified encroachment as a significant challenge to forest conservation, necessitating strategies that address root causes like land scarcity and poverty. Measures to protect forest boundaries and prevent illegal activities are crucial, potentially involving community-led monitoring initiatives that empower residents to safeguard their forests while providing alternative livelihoods.

Regular monitoring and evaluation of PFM programs are essential for assessing effectiveness and identifying areas for improvement. Policymakers should allocate resources for robust monitoring systems that collect data on forest health, biodiversity, and community engagement, vital for informed decision-making and adaptive management strategies. Forest managers must prioritize building strong relationships with local communities by involving them in all stages of forest management planning and implementation. This engagement fosters a sense of ownership and commitment to sustainable practices. Providing training and capacity-building opportunities will enhance community knowledge and skills in sustainable forest management, including the importance of seedlings and techniques for enrichment planting. Effective monitoring systems should track the progress of PFM initiatives, allowing managers to assess outcomes and identify areas needing improvement. Developing conflict resolution strategies among stakeholders is also essential; facilitating dialogues between interest groups can address grievances and foster collaborative solutions. Ultimately, ensuring that PFM practices are sustainable requires adopting strategies that enhance biodiversity while meeting community needs.

Recommendations

To enhance forest regeneration in study area, a series of targeted recommendations could be implemented, focusing on specific actions that involve various stakeholders. First, local government authorities and community leaders should develop and enforce controlled grazing practices to manage livestock pressure in forested areas. This involves setting grazing limits based on ecological assessments and creating designated zones. Training programs for local herders on sustainable grazing practices will enhance community to have bylaws and compliance, particularly in areas experiencing high livestock pressure. Initiating this program during the dry season, when grazing pressure is typically highest, will help ensure its effectiveness.

In addition, promoting enrichment planting is essential. Community forest association groups and local NGOs should collaborate to initiate enrichment planting programs that introduce native tree species in areas where natural regeneration is insufficient. Facilitating Assisted Natural Regeneration (ANR) is another effective strategy that local forestry sectors and community members can implement. Protecting existing vegetation and minimizing disturbances in selected areas, ANR can promote natural recovery processes. This can be achieved through fencing or creating buffer zones around key regeneration sites.

Engaging a diverse range of stakeholders is crucial for addressing ongoing challenges in PFM areas. Government departments, NGOs, community organizations, and private sector actors should work together to involve various stakeholders in environmental conservation efforts. Organizing stakeholder meetings, workshops, and forums will facilitate information exchange and collaborative initiatives, scheduled quarterly to review progress and adjust strategies as necessary.

Empowering individual growers by granting them responsibility for specific sections of community timber resources can significantly enhance conservation efforts. Local governments and community leaders should implement a system of accountability that tasks individuals with maintaining their sections while providing training on sustainable forestry practices.

Promoting community-led initiatives through enrichment planting and in-situ conservation will foster a sense of ownership among community members while curbing encroachment. Community members and local NGOs should organize workshops that educate communities about the benefits of these practices while providing hands-on training sessions for implementation during the rainy season when conditions are favorable for planting. The Oromia Forest and Wildlife Enterprise (OFWE) could establish tree seedling nurseries to produce quality seedlings for distribution to communities or support villages willing to cultivate their own. Utilizing OFWE's expertise in nursery management will provide local communities with access to the necessary seedlings for reforestation efforts.

Collaboration with NGOs such as FZS, KFW, EU, MELCA-Ethiopia and Farm Africa is recommended to enhance conservation efforts in targeted regions like Dinsho and Agarfa. These partnerships can provide additional resources, expertise, and support for implementing effective forest management practices. Conducting large-scale awareness campaigns and training programs targeting village leaders and natural resource management committees is critical for fostering community involvement in forest conservation. Local governments, NGOs, and educational institutions should implement these initiatives through forums, workshops, study tours, and experience exchange visits that build capacity in sustainable forest management practices within local communities. Launching these campaigns at the beginning of the planting season will capitalize on heightened interest in forestry activities.

Finally, establishing a monitoring framework to assess the effectiveness of implemented regeneration strategies over time is essential. Local forestry departments should collaborate with community groups and research institutions to evaluate progress using indicators such as seedling survival rates, species diversity, and biomass growth. Regular field assessments and stakeholder feedback sessions will inform adaptive management strategies. Implementing monitoring protocols immediately after interventions begin, with evaluations conducted semi-annually, will ensure continuous improvement in regeneration efforts.

Furthermore, the future studies should adequately address confounding variables, including socio-economic influences, that may skew comparisons between Participatory Forest Management (PFM) and non-PFM areas to provide a more comprehensive understanding of the impacts of PFM on forest health and community livelihoods

Data availability

Data for this research is available and will be organized and uploaded/shared uponrequest.

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The finance for this research is covered by the author. I also declare that there are noconflicts of interest over the manuscript

Conflicts of interest

The authors declare that there is no conflict of interestfor contribution to the manuscript.

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