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RESEARCH ARTICLES

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RESEARCH ARTICLES

WOODY SPECIES PREFERENCE, MANAGEMENT PRACTICES AND THEIR CONTRIBUTION TO SOIL PRODUCTIVITY OF PARKLAND AGROFORESTRY IN ASSOSA DISTRICT, WESTERN ETHIOPIA

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ABSTRACT: This study aims to assess woody species preference, management practices and their effect on the soil productivity of parkland agroforestry in Assosa District, western Ethiopia. Three administrative kebeles and 114 households were randomly selected for the study. Descriptive statistics were used to analyze the data. Additionally, focus groups and key informant interviews were included in the data collection process. The results revealed that 34.2 % of the total respondents manage trees/shrubs for soil improvement, 21.9 % for fuel wood, 20.2% as a source of timber/construction, 8.8 % for making different tools, 4.4% for shelter, 3.5% as a source of food, 3.5% for fodder, 2.6% to generate income and the rest (0.9%) for medicine. Pruning (62.28%), lopping (24.56%), and coppicing (6.14%) were the most important woody species management practices for enhancing soil productivity by reducing the competition between tree-crop interfaces. The majority of the household respondents (95.6%) perceived woody species management practices to increase soil productivity under tree canopy. Species such as *Cordia africana*, *Mangifera indica*, *Melia azedarach*, and *Sesbania sesban*, were the suggested woody species to increase soil productivity of the parkland agroforestry systems by applying different management practices. Therefore, it is recommended that maintaining and managing these versatile woody species is crucial to minimize the tree-crop interaction and improve soil productivity in the parkland agroforestry system in the study area.

Keywords: Productivity, Scattered tree, Soil fertility.

INTRODUCTION

Agroforestry is the intentional integration of woody vegetation, such as trees and shrubs, with crops and/or livestock simultaneously or sequentially on a land management unit at any scale (Van Noordwijk et al., 2019). It is a well-known strategy that is being used in many parts of the world, particularly Africa, to improve food security and nutrition, diversify economies, and build resilience (Abreha and Gebrekidan, 2014; Bajigo and Abraham, 2017; Brown et al., 2018; Kuyah et al., 2020; Sheppard et al., 2020;

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Gebreegziabher et al., 2020). In different parts of Ethiopia, indigenous agroforestry practices developed over time are prevalent (Alemu, 2016), with parkland agroforestry being a commonly adopted practice. Parkland agroforestry is the constant existence of well-grown trees in cultivated or late-plowed fields (Achiso and Masebo, 2019). The presence of scattered trees on croplands has been found to have effects on the micro-climate, flora, fauna, and other components of the ecosystem through bio-recycling of mineral elements, environmental modifications, and changes in flora and fauna composition (Manjur et al., 2014). Parkland agroforestry practices can play an important role in a sustainable agricultural production that is characterized by combining scattered woody perennials with annual crops and/or animals in the same piece of land (Matocha et al., 2012; Mbow et al., 2014; Gebrewahid et al., 2018).

Parkland agroforestry practices in Ethiopia have demonstrated a beneficial impact on soil properties, encompassing enhanced soil fertility, improved nutrient cycling, effective soil erosion control, and efficient water management (Madalcho and Tefera, 2016; Wolle et al., 2021). The specific characteristics of tree species are crucial in determining which species to plant on farmland, considering factors like utility, drought resistance, compatibility with other crops, and potential for improving soil fertility (Bannister and Nair, 2003). The primary goal of the land use system in the parkland is to preserve soil-improving trees to enhance agricultural production. Thus, the interacting species within this ecosystem must contribute to the long-term sustainability of soil productivity (ICRAF, 2000). These practices have long been utilized by local communities and farmers in Ethiopia, in promoting sustainable agriculture and land management in the region.

Previous studies (Asfaw, 2016; Yismaw and Tadesse, 2018; Bussa and Feleke, 2020; Gebrewahid and Meressa, 2020; Wolle et al., 2021; Tsedeke et al., 2021) have examined tree species diversity and its relationship with carbon stock in the parkland agroforestry practices, but farmers' woody species preferences and the purpose of keeping scattered trees in parkland agroforestry remains poorly understood. Moreover, there is a lack of detailed understanding regarding the potential effects of woody species management practice and their role in soil productivity of parkland agroforestry practice in the study area. Thus, an investigation of woody species preference, management practices, and their role in the soil productivity of parkland agroforestry was conducted to answer the following questions: (1) how and why do local farmers keep woody species on their parkland agroforestry in the study area? (2) How do local farmers manage woody species in their parkland agroforestry in the study area? (3) How do local farmers perceive the practice of managing woody species to enhance soil productivity in parkland agroforestry in the study area? The present study provides information about appropriate species selection, management practices, and their role in the soil productivity in the parkland agroforestry, by reducing competition and enhancing soil productivity of the areas.

MATERIALS AND METHODS

Study area

The study was conducted in the Assosa District, Assosa Zone, Benishangul Gumuz Regional State, Western Ethiopia. It is located between 9º 42' 0" to 10º 12' 0" N latitude and 34º 12' 0" to 34º 42' 0" E longitude (Figure 1) and at a distance of 687 km from the capital city, Addis Ababa.

Assosa district has 74 kebeles' (CSA, 2020) and out of these about 49 kebeles' (66.22 %) of the district's households in the kebeles practice parkland agroforestry while, the other 25 kebeles (33.78%) households depend on daily labor, shifting cultivation, monoculture, trade, traditional mining, etc. (ADANRMO, 2023). The area is renowned for its extensive home garden and parkland agroforestry practices, as well as its rich indigenous knowledge of traditional plant uses (Kifle and Asfaw, 2016).

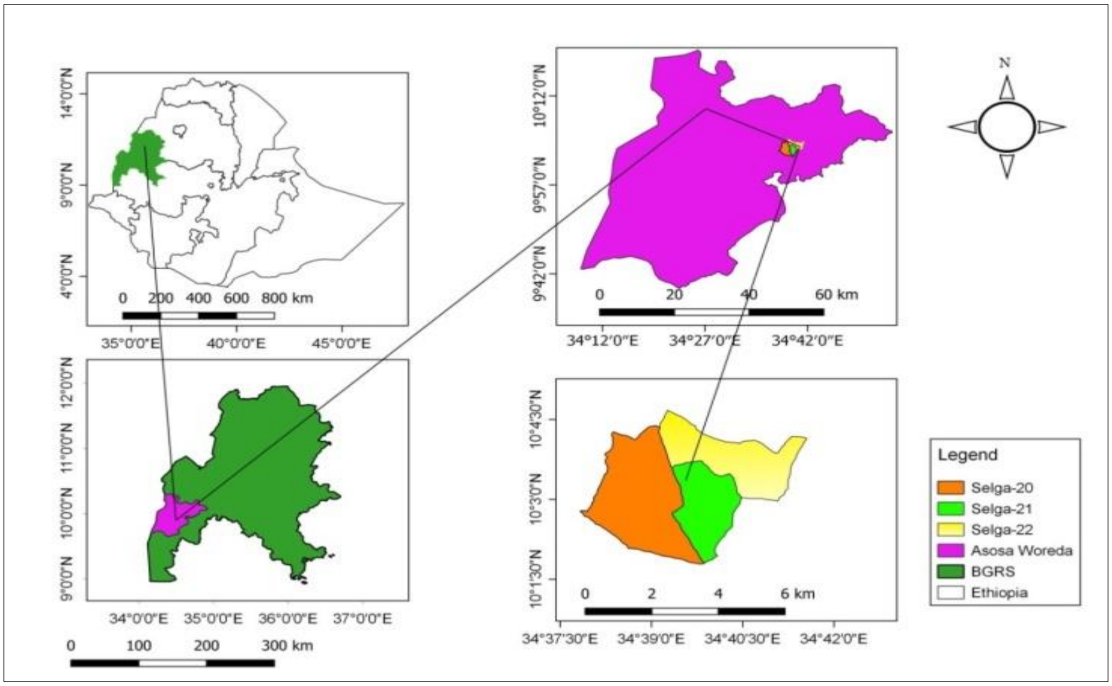

Figure 1. Map showing geographic location of the study area.

The total population of Benishangul Gumuz region was 460,459 which gives a population density of 9 persons/Km^2. Assosa zone, has a total area of 1,519 Km^2 and a population of 28, 970 (population density of 19.1 persons/Km^2) (CSA, 2020). The topography of the study area is characterized by undulating elevation which decreases gradually toward the western part to an average altitude of 500 m along the Ethiopia - Sudanese border (Mosissa and Wakjira, 2020). The study area has a mono-modal rainfall pattern ranging from the end of April to October. The average annual rainfall in the area is approximately 1240 mm (IFPRI, 2017).

The soils are characterized by very poor organic carbon and nitrogen contents, indicating a low soil fertility status which is driven by the limited use of both organic and inorganic fertilizers and the loss of nutrients mainly through leaching (Kifle and Asfaw, 2016). Subsistence agriculture is the major economic activity, engaging approximately 80% of the population. Major agricultural products are cotton, soybeans, sesame, millet, sorghum, maize, and mango. These crops are produced by rain-fed and to some extent irrigated agriculture (Mosissa and Wakjira, 2020).

Sampling techniques and sample size determination

A multi-stage sampling technique was selected to ensure accurate and comprehensive primary data from the sample households. First, out of 49 kebeles within the district three kebele were selected randomly based on the existence of parkland agroforestry practices namely; Selga-20, Selga-21, and Selga-22. Then, two villages were randomly selected from each kebele administration. The number of sample households was determined by using proportionate random sampling following a simplified formula provided by (Yamane, 1967) at 92 percent confidence interval.

$$n = \frac{N}{1 + N(e^2)}$$

$$n = \frac{422}{1+422(0.08^2)} = 114$$

Where, n = the sample HHs of the study area, N=the population size of the study area, e = allowed errors which is 8%.

Thus, using a simple random sampling technique, from the three kebeles, 114 HHs were randomly selected from a total of 422 kebele households provided by the Kebele agricultural development office and Kebele administration. The total number of households from which sample size was determined in each village (KA) were; from Selga-20 kebele 221 HHs (Ketena 1 = 112, Ketena 2 = 109), Selga-21 kebele 98 HHs (Ketena 2 = 48, Ketena 3 = 50), and Selga-22 kebele 103 HHs (Ketena 1 = 47, Ketena 2 = 56).

A 'Ketena' or village is the smallest sub-unit of a kebele, and it contains several sub-units called 'Gots'. In total, 422 (N) households in the sampled Kebeles were the target households of the study. A proportional sampling formula was applied to each Kebele to ascertain the sample household size.

$$n1 = \frac{N1}{N} * n$$

Where, n1= sample household size in KA1, N1= is the total household in KAs 1, n = is a total sampled household from the three KAs and N = is the total households in the three kebele. Hence, from Selga-20 kebele 59 HHs (30 from Ketena 1, 29 from Ketena 2), from Selga- 21 kebele 27 HHs (13 from Ketena 2, 14 from Ketena 3), and from Selga-22 kebele 28 HHs (13 from Ketena, 15 from Ketena 2) were randomly selected proportionally based on the number of households heads residing in each Kebele.

Method of data collection

To achieve the study’s objectives quantitative and qualitative data and both primary and secondary data sources were used. Secondary data were collected from published and unpublished sources. The primary data were gathered through household surveys, key informant interviews, and focus group discussions. Closed and open questionnaires were developed and semi-structured and face-to-face interviews were conducted to collect qualitative and quantitative data from respondents. The household questionnaires were prepared in English and translated into Benishangul, Amharic, and Afan Oromo, the languages spoken in the study area. Enumerators who were knowledgeable about the area were involved in data collection. Before interviewing household respondents, the objectives of the study were explained to enumerators, and they were trained in data collection and interview methods. For qualitative data, both key informant interviews and focus group discussions were conducted. In this study, key informants are individuals who are knowledgeable about woody species, the purpose of keeping them, and management practices, and residents who lived in the respective kebele for more than 30 years. The key informants were selected using the snowball sampling method (Bernard, 2017). Twelve key informants (six per kebele) were interviewed for the entire study. The purpose of selecting key informants was to identify the local names of tree species and cross-check the number of households practicing parkland agroforestry in their kebeles. The following points were addressed during key informant interviews: farmer’s woody species preferences, purpose of keeping, management practices, and their effect on the soil productivity of parkland agroforestry practices in the study areas. In the focus group discussion, model farmers, youths, and women households were selected from each kebele. The purpose of the discussions was to verify farmers’ tree needs and management practices. The information generated here was used to validate the information obtained from household respondents.

Data analysis

The data were analyzed by using both quantitative and qualitative methods. The farmers' woody species preference, management practices and their contribution to soil productivity of parkland agroforestry practice were analysed and described in terms of frequency, percentage, and means by using Statistical Package for Social Sciences (SPSS), Version 20.0 (IBM Corporation, USA) and Microsoft Excel 2010. Data from key informant interviews and focus group discussions were analyzed qualitatively to support the quantitative data.

RESULTS

Purpose of keeping scattered trees in the parkland agroforestry system

Regarding the maintenance of a variety of tree species, farmers in the research area keep and cultivate trees for various reasons (Table 1). No single tree species can be considered optimal for every household's needs.

Table 1. Reasons for keeping scattered trees and percent of respondents.

No.	Uses of tree/Shrubs	% of HH respondents
1	Soil improvement	34.21
2	Fuelwood	21.93
3	Timber/Construction	20.18
4	Tools	8.77
5	Shade/Shelter	4.39
6	Fodder	3.51
7	Food	3.51
8	Income	2.63
9	Medicine	0.88

Woody species management practice

The study area's farmers employ a variety of management techniques for the various woody species that inhabit their parklands (Table 2).

Table 2. Response of surveyed households on management practices of some woody species recorded in different parklands of the study area (N=114).

Woody species	**Woody Species Management Practice**				
	Coppicing	Pruning	Thinning	Lopping	Pollarding
Ziziphus mucronata	-	4	-	3	2
Cordia africana	5	34	1	15	-
Mangifera indica	1	4	1	2	1
Ficus sycomorus	-	2	-	-	2
Albizia gummifera	-	1	-	-	-
Terminalia brownii	-	3	-	-	-
Combretum molle	-	5	-	-	-
Syzygium guineense	-	12	-	-	-
Melia azedarach	-	4	-	7	-
Stereospermum kunthianum	-	1	-	-	-
Oxytenanthera abyssinica	1	-	-	-	-
Sesbania sesban	-	1	-	-	-
Dombeya torrida	-	-	-	1	1
Percentage	**6.14**	**62.28**	**1.75**	**24.56**	**5.26**

Farmer's perception on the impact of woody species management on soil productivity

Information acquired from focus group discussion and key informants showed that the management of woody species is a strategy for managing the competition between trees and crops in parklands (Figure 2). The effectiveness of the parkland agroforestry system in the study areas was influenced by the choice and management of the woody species introduced.

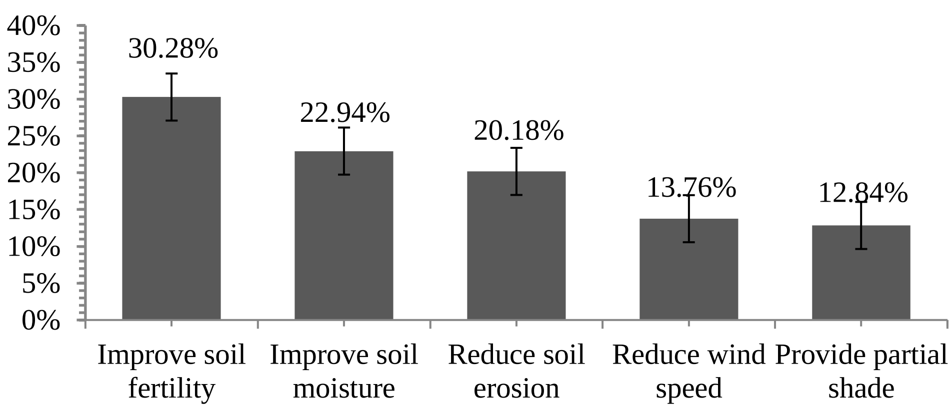

Figure 2. Household perceptions (%) on why soil productivity increased under tree canopy in the parklands of the study areas.

Preferred woody species for soil productivity

The farmers in the study area were familiar with both woody and non-woody components of parkland agroforestry. As a result, they can identify the specific characteristics of woody perennials that make them suitable for agroforestry practices in parklands. The preferred species are indicated in table 3.

Table 3. Some preferred woody species for soil productivity in the parkland of the study area.

No.	Species	% of HH respondents
1	*Cordia africana*	41.23
2	*Mangifera indica*	11.40
3	*Melia azedarach*	9.65
4	*Ziziphus mucronata*	7.89
5	*Sesbania sesban*	7.89
6	*Syzygium guineense*	7.02
7	*Combretum molle*	4.39
8	*Ficus sycomorus*	3.51
9	*Terminalia brownii*	2.63
10	*Dombeya torrida*	1.75
11	*Albizia gummifera*	0.88
12	*Stereospermum kunthianum*	0.88
13	*Oxytenanthera abyssinica*	0.88

DISCUSSION

Participants in this study explained the benefits of the tree species preferred in parkland agroforestry system which include soil fertility improvement, animal fodder, bee forage, timber, food, income generation, house construction, fuel wood, shade, and medicine and farm tools. This result is consistent with research by Yakob et al. (2014), Lemage and Legesse (2018), and Legesse and Negash (2021), who reported that planting or keeping various woody species depends on the practical benefits and services they provide to the farm household.

Participants in the focus group discussion and key informants stated that farmers in the study area traditionally managed the retained/planted tree species in their parklands to get multiple benefits. Pruning and lopping were the most important woody species management practices for enhancing soil productivity by reducing the competition between tree-crop interfaces in the study area. This outcome is in consistent Negash (2007) which indicated the presence different approaches to manage woody species in parkland agroforestry, the two main ones being pollarding and lopping of side branches. According to other studies, several regions of Ethiopia have similar woody species management practices (Agidie et al., 2013; Madalcho and Tefera, 2016; Misgana et al., 2020).

Soil productivity was defined by farmers in the study area as the capacity of soil to increase a particular crop yield under a specified management system. Key informants explained that the purpose of woody management practices undertaken by household members in the study area was mainly to enhance soil productivity by improving soil fertility through litter fall decomposition, preserving soil moisture, and mulching, to provide partial shade, and to reduce competition for lights.

Household respondents indicated that farmers in the study area have the knowledge of different woody species management practices and of which woody species require a different set of management practices and appropriate time to accomplish these activities in order to improve soil productivity. Accordingly, the suitable time for woody species management was at the end of the dry season or early summer to enhance the decomposition of litterfall and the dead wood materials that maintain soil fertility. Similar perception reported from Meskan District, Ethiopia (Bongers (2010).

The management of woody species is perceived to have an effect on the parkland's soil productivity, according to all the HH respondents. Of those, 95.6% (N=109) of the HH respondents said that the woody species management technique raises soil productivity beneath tree canopy by preserving soil moisture, lowering wind speed, minimizing soil erosion, and giving partial shade for understory crops in the study area. This outcome is consistent with studies conducted by Guyassa and Raj (2013) in the Southern Zone of the Tigray region; Dilla et al. (2018) in Ethiopia's Central Rift Valley; and Bussa and Feleke (2020) in the West Guji Zone of Ethiopia. These studies found that the goals of using various woody species management practices were to increase soil productivity by minimizing the detrimental effects at the tree-crop interface and to obtain tree products for different purposes.

In this study, key informants and participants of focus group discussion indicated that crop yield was higher under tree canopies than in the open fields due to improved soil nutrient concentrations and moisture levels associated with greater organic matter. This result is in line with the findings of Hadgu et al. (2009) who reported similar results in the highlands of Tigray; Tesfaye et al. (2018); Dilla et al. (2018) who reported similar results in the Central Rift Valley of Ethiopia.

Household respondents indicated that the choice of tree species for the parkland agroforestry system depends on the farmer's objective, whether it's ecological or economic. According to HH respondents, woody species that shed their leaves have high biomass, decompose quickly, and are added to parklands because they can increase soil productivity by breaking down dead wood, as well as by fallen litter (leaves and twigs) for composting. *Cordia africana*, *Mangifera indica*, *Melia azedarach*, *and Sesbania sesban* were among the suggested woody species to increase soil productivity of the parkland agroforestry systems by applying different management practices. Moreover, these species are highly preferred by farmers in the study area due to their ease in adaptability, propagation, and management regimes. This finding is in consistent with the findings of Abdella et al. (2020) who observed comparable outcomes in Eastern Oromia, and Mamo and Asfaw (2017) who reported similar results in West Haraghe zone, Ethiopia.

The focus group discussion and key informants described how farmers in the study area perceive that certain woody species in parklands can improve soil productivity. They observed that the fallen leaves of these trees decompose more easily in comparison to other tree species, such as *Oxytenanthera abyssinica*. This result is similar to the finding of Lemage and Legesse (2018) who reported a similar outcome in Tembaro District, Southern Ethiopia.

CONCLUSION AND RECOMMENDATION

The present study has provided valuable information on the assessment of farmers' preferences for woody species and woody species management practices and their contribution to the soil productivity of parkland agroforestry in Assosa district, western Ethiopia. The result of this study showed that employing different woody species management practices for different woody species reduces tree-crop competition and increases soil productivity in the parkland agroforestry system in the study area. Pruning, lopping and coppicing were reported to be the most important woody species management practices for enhancing soil productivity by reducing the competition between tree-crop interfaces in the study areas. These management practices need to supported by governmental and non-governmental organizations through improved research, and extension services to obtain optimum results. The species *Cordia africana*, *Mangifera indica*, *Melia azedarach*, and *Sesbania sesban* were the most preferred woody species to increase soil productivity of the parkland agroforestry systems in the study area. Further studies should examine the impacts of these woody species on the understory herbs and crop species of parkland agroforestry practice of the region, especially in the study area.

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REFERENCES

Abdella, M. Nigatu, L. and Akuma, A. 2020. Impact of parkland trees (*Faidherbia albida* (*Delile*) and *Cordia Africana* lam) on selected soil properties and sorghum yield in eastern Oromia, Ethiopia. *Agriculture, Forestry and Fisheries,* **9(3):54-66**.

Abreha, A. and Gebrekidan, W. 2014. Woody plant inventory and diversity in traditional agroforestry of selected peasant association of south Gonder zone, northwest Ethiopia. *Journal of Environment and Earth Science,* **4:8–16**.

Achiso, Z. and Masebo, N. 2019. Parkland agroforestry practices on biodiversity conservation-a review. *International Journal of Life Sciences*, **5:2412-20**.

ADANRMO. 2023. Assosa District Agriculture and Natural Resource Management Office. Annual unpublished Report, pp.8-12.

Agidie, A. Ayele, B. Wassie, A. Hadgu, K. M. Aynekulu, E. and Mowo, J. 2013. Agroforestry practices and farmers' perception in Koga Watershed, Upper Blue Nile Basin, Ethiopia. *Agriculture and Forestry* **60(2):177-192**.

Alemu, M.M., 2016. Indigenous agroforestry practices in Southern Ethiopia: the case of Lante, Arba Minch. *Open Access Library Journal*, **3(12):1-12**.

Asfaw, Z. 2016. Woody species composition and soil properties under some selected trees in parkland agroforestry in the central rift valley of Ethiopia. *International Journal of Development Research*, **6(11):10150-10156**.

Bajigo, A. and Abraham, T. 2017. The impact of farm tree degradation on rural livelihood in Manna District of Jima Zone, Ethiopia. *The International Journal of Asian and African Studies*, **31:41–47**.

Bannister, M. E. and Nair, P. K. R. 2003. Agroforestry adoption in Haiti: the importance of household and farm characteristics. *Agroforestry systems*, **57:149-157**.

Bernard, H.R. 2017. Research methods in anthropology: Qualitative and quantitative approaches. 5th ed. Maryland, Rowman and Littlefield publishers.

Bongers, G. 2010. Dynamics in people-tree interactions in farm fields; farmers' perspectives in Meskan District, Ethiopia. *Wageningen: Wageningen University*.

Brown, S.E., Miller, D.C., Ordonez, P.J. and Baylis, K. 2018. Evidence for the impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in high-income countries: a systematic map protocol. *Environmental evidence*, **7:1-16**.

Bussa, B. and Feleke, K. 2020. Contribution of parkland agroforestry practices to the rural community livelihood and its management in southern Ethiopia. *Humanities and Social Sciences*, **8:104-111**.

CSA. 2020. Population and Housing Census of Assosa Branch: Unpublished Annual Report; Central Statistical Agency: Assosa, Ethiopia.

Dilla, A. Smethurst, P. J. Barry, K. Parsons, D. and Denboba, M. 2018. The potential of the APSIM model to simulate the impacts of shading on maize productivity. *Agroforestry Systems*, **92:1699-1709**.

Gebreegziabher, Z. Mekonnen, A. Kassie, M. and Köhlin, G. 2020. Household tree planting in Tigrai, Northern Ethiopia: Tree species, purposes, and tenure security. *Land Use Policy*, **96:104635**.

Gebrewahid, Y. and Meressa, E. 2020. Tree species diversity and its relationship with carbon stock in the parkland agroforestry of Northern Ethiopia. *Cogent Biology*, **6(1):1728945**.

Gebrewahid, Y. Gebre-Egziabhier, T. B. Teka, K. and Birhane, E. 2018. Carbon stock potential of scattered trees on farmland along an altitudinal gradient in Tigray, Northern Ethiopia. *Ecological processes*, **7: 1-8.**

Guyassa, E. and Raj, A. J. 2013. Assessment of biodiversity in cropland agroforestry and its role in livelihood development in dryland areas: A case study from Tigray region, Ethiopia. *Journal of Agricultural Technology*, **9(4):829-844**.

Hadgu, K.M., Kooistra, L., Rossing, W.A. and van Bruggen, A.H. 2009. Assessing the effect of Faidherbia albida-based land use systems on barley yield at field and regional scale in the highlands of Tigray, Northern Ethiopia. *Food Security*, **1:337-350**.

ICRAF. 2000. Paths to Prosperity through Agroforestry. ICRAF's Corporate Strategy, 2001-2010. Nairobi: International Centre for Research in Agroforestry.

IFPRI, 2017. International Food Policy Research Institute (IFPRI) and Datawheel. [Online] available at: https://DataAfrica.io. Accessed [July, 2024].

Kifle, E. T. and Asfaw, Z. 2016. Woody Species Richness, use diversity and management in agroforestry practices: The case of Assosa District Benishangul Gumuz Region, Ethiopia. *Journal of Biodiversity Management and Forestry*, **5:4**.

Kuyah, S., Sileshi, G.W., Luedeling, E., Akinnifesi, F.K., Whitney, C.W., Bayala, J., Kuntashula, E., Dimobe, K. and Mafongoya, P.L. 2020. The potential of agroforestry to enhance livelihood security in Africa. *Agroforestry for Degraded Landscapes,* **1:135-167**.

Legesse, A. and Negash, M. 2021. Species diversity, composition, structure and management in agroforestry systems: the case of Kachabira district, Southern Ethiopia. *Heliyon*, **7(3):e06477**

Lemage, B. and Legesse, A. 2018. Management and socioeconomic determinants of woody species diversity in parkland agroforestry in Tembaro District, Southern Ethiopia. *Biodiversity International Journal*, **2(5):456-462**.

Madalcho, A. B. and Tefera, M. T. 2016. Management of traditional agroforestry practices in Gununo Watershed in Wolaita Zone, Ethiopia. *Forest Research*, **5(1):1-6**.

Mamo, D. and Asfaw, Z. 2017. Status of selected soil properties under *Croton macrostachyus* tree at Gemechis District, West Hararghe Zone, Oromia, Ethiopia. *Journal of Biology, Agriculture, and Healthcare*, ***7*(8):36-43.**

Manjur, B. Abebe, T. and Abdulkadir, A. 2014. Effects of scattered F. albida (Del) and C. macrostachyus (Lam) tree species on key soil physicochemical properties and grain yield of Maize (*Zea mays*): a case study at Umbulo Wacho watershed, Southern Ethiopia. *Journal of Agricultural Research*, **3(3):063-073**.

Matocha, J. Schroth, G. Hills, T. and Hole, D. 2012. Integrating climate change adaptation and mitigation through agroforestry and ecosystem conservation. In: P. Nair, D. Garrity, ed., *Agroforestry - The Future of Global Land Use*. Advances in Agroforestry, vol 9. Springer, Dordrecht.

Mbow, C. Smith, P. Skole, D. Duguma, L. and Bustamante, M. 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Current opinion in Environmental Sustainability*, **6:8-14**.

Misgana, D. Shibru, S. and Chauhan, R. 2020. Woody species diversity, structure, and biomass carbon of parkland agroforestry practices in Gindeberet District, West Shoa Zone, Oromia Regional State, Ethiopia. *International Journal of Biodiversity and Conservation*, **12(1):1-14**.

Mosissa, D. and Wakjira, D. 2020. Large scale agricultural investment and a fragile soil paradox in Benishangul Gumuz regional state: Organic carbon stock of broadleaf and deciduous forests of Combretum–Terminalia woodlands of Benishangul Gumuz Regional State, Western and northwestern Ethiopia. *Journal of Agricultural Sciences and Botany*. **4 (3):1-13**.

Negash, M. 2007. Trees management and livelihoods in Gedeo's agroforests, Ethiopia. *Forests, Trees and Livelihoods*, **17(2):157-168**.

Sheppard, J.P., Bohn Reckziegel, R., Borrass, L., Chirwa, P.W., Cuaranhua, C.J., Hassler, S.K., Hoffmeister, S., Kestel, F., Maier, R., Mälicke, M. and Morhart, C. 2020. Agroforestry: an appropriate and sustainable response to a changing climate in Southern Africa? *Sustainability*, **12(17):6796**.

Tesfaye, S. S., Baudron, T.S.S., Deme, A.D., Tolera, M. and Giller, K.E. 2018. Excessive pruning and limited regeneration: are *Faidherbia albida* parklands heading for extinction in the Central Rift Valley of Ethiopia. *Land Degradation and Development*, **29(6):1623-1633**

Tsedeke, R.E., Dawud, S.M. and Tafere, S.M. 2021. Assessment of carbon stock potential of parkland agroforestry practice: the case of Minjar Shenkora; North Shewa, Ethiopia. *Environmental Systems Research*, **10:1-11**.

Van Noordwijk, M., Coe, R. and Sinclair, F. 2019. Agroforestry paradigms. IN: M. Van Nordwijk, ed., *Sustainable development through trees on farms: agroforestry in its fifth decade*. World Agroforestry (ICRAF) Southeast Asia Regional Program, Bogor, Indonesia.

Wolle, H.S., Barberi, P. and Carlesi, S. 2021. Effect of home garden and parkland agroforestry practices in Ethiopia on selected soil properties. *African Journal of Food, Agriculture, Nutrition and Development*, **21(5):18115-18130**.

Yakob, G. Asfaw, Z. and Zewdie, S. 2014. Wood production and management of woody species in home gardens agroforestry: the case of smallholder farmers in Gimbo district, southwest Ethiopia. *International Journal of Natural Sciences Research*, **2(10):165-175**.

Yamane, T. 1967. Statistics: An Introductory Analysis. 2nd Edition, Harper and Row, New York.

Yismaw, M.T. and Tadesse, B. 2018. The contribution of agroforestry system to tree biodiversity conservation and rural livelihood: The case of Lay Armachiho District, Gondar, Ethiopia. *International Journal of Scientific Research and Management*, **6(05):129-139**.

CARBON STOCK VARIATION OF WOODY SPECIES ALONG ALTITUDINAL GRADIENTS OF MUHABURA VOLCANO, NORTHERN RWANDA

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ABSTRACT: The study estimated the woody plant species' carbon stock along the Muhabura volcano's altitudinal gradient. Three strata namely low, middle, and high altitudes were created within the study site depending on vegetation appearance and elevation gradients. A total of 60 plots of 20 x 20 m with four transect lines and 100 m apart from one another, were established along the transect to collect data on the carbon in above-ground, below-ground biomass, dead litter, and soil. Height, and Diameter at Breast Height (DBH) of each woody species that had a DBH bigger than 5 cm were measured. The allometric equations were used to estimate the above-ground biomass and below-ground biomass. The result showed 326 individual species belonging to 21 woody plant species and 16 families in the study area. No woody plant species with DBH ≥ 5 cm were found at high altitudes. The estimated total carbon stock in low, middle, and high altitudes were 162.029±9.094 tC ha^{-1},142.767±0.398 tC ha^{-1}, and 132.923±18.806 tC ha^{-1}, respectively, and they showed a significant difference ($P < 0.05$). Likewise, the organic carbon in soil differed significantly ($P < 0.05$) across different depths (0-30 cm, 30-60 cm) in altitudinal gradients. The largest carbon pool in all the three altitudinal gradients was the soil organic carbon pool, sinking the highest carbon amount of 397.551±77.307 tons ha^{-1}. The results showed that Muhabura Volcano can be important for carbon stocks, and effectively conserving this mountain has a considerable contribution to climate change mitigation and biodiversity conservation.

Keywords: Carbon Sequestration, Climate Change, Volcanoes National Park

INTRODUCTION

Global climate change is a pressing environmental issue resulting in extreme weather patterns, global warming, natural disasters, biodiversity loss, and rising sea levels (Siraj, 2019). The primary cause of this is greenhouse gases including nitrous oxide, methane, and carbon dioxide generated from anthropogenic

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activities such as deforestation, and the burning of fossil fuels (Liu et al., 2018). According to the Intergovernmental Panel on Climate Change, per decade, a 0.3°C increase in global mean temperature is expected during the next century, and this increase is anticipated to grow by 1.4 to 5.8 °C by 2100 (IPPC, 1990). Carbone dioxide has been seen to be the most important greenhouse gas. The two main causes of the carbon cycle distortion are changes in land cover, land use, and the use of fossil fuels. Practically, the burning of fossil fuels for transportation, building heating and cooling, and the production of cement and other commodities accounts for roughly 75% of the world's CO_2 emissions (Fischer et al., 2019). The significance of soil and forests in reducing greenhouse gas emissions (methane, carbon dioxide, and other gases) was acknowledged by the Kyoto Protocol. As possible sinks for increased carbon dioxide emissions, forests and soils are taken into account for determining the permissible offset (Mulugo et al., 2020). The extension of wooded areas and sustainable forest development is an economical, safe, and ecologically friendly method of storing, and capturing significant volumes of carbon from the atmosphere and financial incentives are provided for taking carbon storage into account when making decisions about forest management by the parallel creation of marketable carbon credits (Fischer et al., 2019). According to the latest estimates, the earth has 3952 million hectares of forest where 16% are found in Africa (Nel, 2018). Tropical natural vegetation is regarded as a significant storage of carbon globally (Gizachew et al., 2018) and has the potential to balance the amount of CO_2 in the atmosphere. This is due to having higher Carbon (C) content per unit area compared to any other terrestrial ecosystem. While climate change in Africa is complex, the Rwandan situation is even more complex (Ototo and Vlosky, 2018; Kazoora et al., 2019; Mawa et al., 2022). Historically, deforestation in Rwanda has been reported in most of the country's regions attributed to extensive anthropogenic activities such as grazing, agricultural expansion as well as residential land expansion, and fuelwoods related to increasing population demands, all coupled with climate change (RoR, 2016; Namanji et al., 2019; Mwawa et al., 2022). To restrict further forest degradation, most of the natural forests are protected either as national parks or as forest reserves. Protected areas cover around 10.8

% of the country and the total forest cover is about 30.4% of the dry country land (RoR, 2015; Chapman et al., 2018; RoR, 2018). The increment of forest cover has affected more the carbon sink where between 2001 and 2022, the forests in Rwanda removed 4.61 $MtCO_2e$/year, and in the same period, an average of 1.29Mt/year was released into the atmosphere as a result of tree cover loss in Rwanda. This represents a net carbon sink of 3.32 $MtCO_2e$/year (MoE, 2019). Hence, mitigating the emission of greenhouse gases as a source of climate change leading to ecosystem degradation is crucial. This can be achieved through sustainable management of existing natural vegetation that can attract potential financial, and technical incentives from industrialized nations to developing nations like Rwanda through climate finance funds such as REDD+ (Tumushabe et al., 2023). However, there are limited studies on quantifying carbon stocks sequestered by natural forests in Rwanda (Nsabimana, 2009; Nsengumuremyi et al., 2022; Mugabowindekwe et al., 2023). In this context, consistent and accurate data that meet international standards with a favourable environmental policy are the most critical requirements to derive the benefits from climate funds. For achieving international standards, it is important to bridge the gap in characterizing biomass, and carbon stock of the Rwandan natural vegetation such as the one found at Muhabura volcano, using standardized carbon stock accounting methods. Therefore, this study aimed to estimate the potential of carbon sequestration of woody species and its variation along altitudinal gradients at Muhabura volcano in the North of Rwanda.

MATERIALS AND METHODS

Description of the study area

Muhabura Volcano lies partly in the Volcanoes National Park (VNP) situated in the Albertine Rift of the Great African Rift Valley, in northwestern Rwanda and borders Virunga National Park in the Democratic Republic of Congo and Mgahinga Gorilla National Park in Uganda. Muhabura is an extinct volcano in the Virunga massif (1°21'-1°35'S, 29°22'-29°44'E) with an altitude ranging from 2300 m to 4,500 m above sea level on the border between Rwanda and Uganda (Derhe et al., 2020; Zajadacz and Uwamahoro, 2021)

(Figure 1). Muhabura Volcano receives a steady stream of rain and mist. Combined with the high altitude, this means that the climate is wet and cold with wind speed variation with altitude (Akayezu et al., 2019). Temperatures of 16°C during the day do not change much throughout the year and at night, it cools off to about 6°C. The range of altitudes means a range of climatic conditions. The temperature drops by about 6.5°C for every 1,000 m climbed. According to Dondeyne et al. (2017), the soils at Muhabuara Volcano are fertile and of volcanic type and there is a variation in composition from one area to another. They are in the category of andosols and andic soils with a black colour. Fine alluvial peat formation in the wetland occurs. In addition, soils are generally characterized by high moisture, rich organic matter content, high pH levels, and high permeability. Furthermore, in the Eastern part of Muhabura volcanoes the soil is dry and rocky soil with silt or silty-clay textile in most cases. The bulk densities in all horizons are very low mostly between 0.2 and 0.7 gcm^{-3} for oven-dry samples (Uwitonze et al., 2016; Turamyenyirijuru et al., 2019). Muhabura volcano harbors 245 plant species; 17 of which are threatened and 13 species of orchids (REMA, 2009; IUCN, 2019). Vegetation varies with altitudinal gradients and the forest is characterized by an open canopy and frequent wind like in the savanna (Ngiramahoro et al., 2018). In general, the VNP has been constantly under direct or indirect threat due to pressure from the farming population in search of fertile volcanic soils in its immediate vicinity. Currently, it covers 160 km^2 (Owiunji et al., 2005). Particularly, a large part of Muhabura was highly disturbed by a fire outbreak in 2009 due to beekeeping along the edge, in addition to the agriculture of a dense population bordering on its bottom (Ngiramahoro et al., 2018).

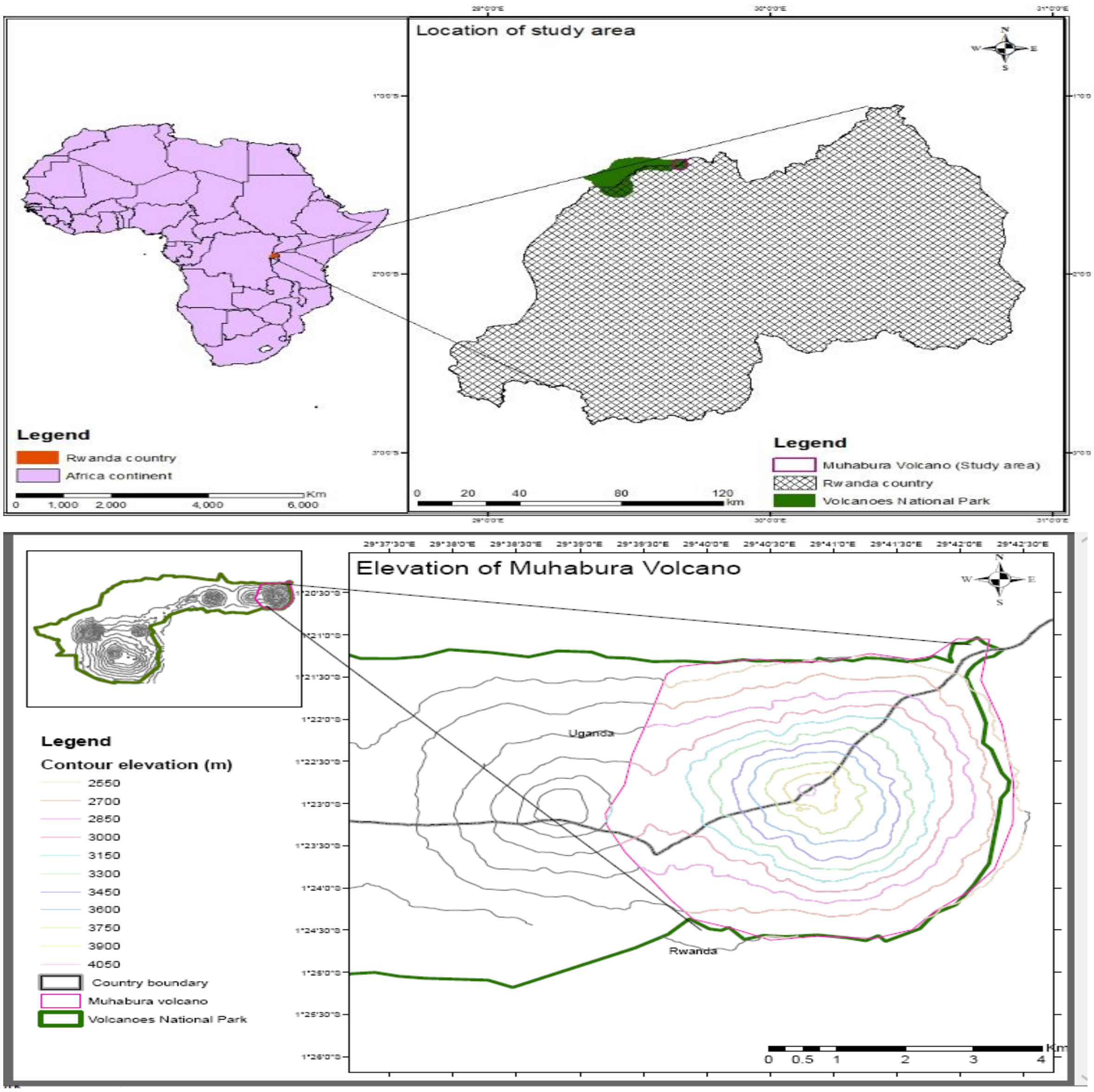

Fig 1. Map of the study area.

Data Collection

To form relatively homogenous units and obtain accurate data from the fieldwork, stratified sampling by elevation segments was used since the area under the study presents an altitudinal variation (Mlotha, 2018). That helped to determine the elevation variations as predictor variables to relate with forest carbon stocks. The study area was classified into three altitudinal gradients based on the physical appearance of vegetation using GPS: lower altitude between 2502-2882 m a.s.l. (stratum 1), middle altitude between 2883-3109 m a.s.l. (stratum 2), and upper altitude between 3110-4127 m a.s.l. (stratum 3), based on a reconnaissance survey. In each stratum, a total of four transect lines, 100 m apart from each other, were established systematically, along with five plots of 20 m x 20 m plots and subplots of 1 m x 1 m (4 at the corner 1 at the center of each plot) for litter and soil samples within the main plots. The plots were laid out at 100 m intervals along the transect for woody species records and carbon stock potential (Matakala et al., 2023).

A total of 60 plots were established in the study area. All woody species individuals encountered in the area were recorded. The diameter at breast height was measured at 1.3 m above the ground using a diameter tape (Abere et al., 2017; Aabeyir et al., 2020). In the case of multi-stemmed woody species above 1.3 m in height, the tree was treated as a single individual. In the case where the tree forks below 1.3 m, measurement of each stem was done (Snowdon et al., 2002; Bilous et al., 2024). Diameter data for all tree species individuals with a DBH ≥ 5cm were collected. This is due to the fact that the study area was a degraded montane forest with small trees and secondary forest in some zones where woody species with small DBH were present. The heights of all trees were also measured using Suunto and Haga hypsometers. Trees on the border of the plot were included if more than 50% of their basal area fell within the plot or excluded if more than 50% of their basal area fell out of the plot (Bhishma, 2010). Trees with their trunks inside the plot but their branches hanging outside were included but those overhanging in the plot were excluded.

All litter samples in the sub-plots of 1 m × 1 m were collected manually in each main plot at each corner and center. A 100 g composite sample was prepared for field wet weight and taken for laboratory analysis at a later stage. The litter samples were oven-dried at 105^0C for 48 hrs using the dry ashing method (Allen et al., 1986). Oven-dried samples were taken in pre-weighed crucibles. Then the samples were ignited at 550^0C for one hour in a muffle furnace. After cooling, the crucibles with ash were weighed and the percentage of organic carbon was calculated. Finally, carbon in litter (t ha^{-1}) was determined for each sample.

Soil samples of 100 g each from two depths of 0-30 cm and 30-60 cm were collected from five pits in the main plot (one at the center, and four at the corners of each plot) and mixed properly in their respective layers and a composite sample was prepared. Two depths were considered in this study (BSSS, 2023; Freeze, 2024; Raffeld et al., 2024) due to severe fire disturbance of the topsoil (30 cm) in the study site, which showed a high variation of soil organic components and other soil properties (Lu et al., 2017; Agbeshie et al., 2022). Soil samples were placed in plastic bags labeled separately and taken to INES Ruhengeri laboratory for analysis using the Walkley and Black method (Walkley and Black, 1934). These samples were air-dried and passed through a 2 mm sieve at the soil laboratory to remove the soil moisture and finally, the bulk density and soil organic carbon percentage were calculated (Pearson et al., 2005).

Data analysis

Carbon stock analysis

Above-ground woody species biomass (AGB): this study applied equations developed via dimensional analysis, as the only reasonable method to estimate tree biomass without destructive sampling (Yilma and Derero, 2020). The equation by Chave (2014) was used to estimate the above-ground biomass. The allometric equation considers DBH, height, and density of trees; and then, the above-ground biomass (AGB) was computed as follows:

$\text{AGB} = 0.0673\text{x } (PxD^2xH)^{0.076}$ (Chave, 2014).. Equation 1

Where AGB= above-ground biomass in kg, D= diameter at breast height in cm, H= height in m, P = density in g cm^{-3}. The wood density of each tree species was obtained from the global woody density database.

Results were then converted into tonnes per hectare (Tuffour et al., 2014). Finally, the carbon content in the biomass was estimated by multiplying by 0.47 a conversion factor according to REDD and IPCC defaults, while multiplication factor 3.67 was used to estimate CO_2 equivalent (IPCC, 2006)**.**

In the case of multi-stemmed trees prone to multi-stem below 1.3 m diameter, the measurement of the diameter was calculated by the diameter equivalent (de) as follows:

$de = \sqrt{\sum_{i=1}^{n} di2}$ (Snowdon et al., 2002; Bilous et al., 2024).. Equation 2

where, de = diameter equivalent, di = diameter of the i^{th} stem at 30 cm height. The results were recorded in a prepared data sheet.

Below-ground woody species biomass (BGB)

The equation developed by MacDicken (1997) to estimate below-ground carbon was used.

$BGC = AGC\ x\ 0.2$ (Yilma and Derero, 2020).. Equation 3

where BGC is below ground Carbon, AGC is above-ground carbon, and 0.2 is the conversion factor (or 20% of AGC).

Estimation of carbon stock in litter biomass (LB)

The equation by Pearson et al (2005) adopted by Toru and Kibret (2019), estimates the amount of biomass in the litter as used.

$LB = \frac{\text{Wfield}}{\text{A}} \times \frac{\text{Wsub sample (dry)}}{\text{Wsub sample (fresh)}} \times 0.0001$ .... Equation 4

Where, LB = Litter biomass (ha^{-1}), Wfield = weight of wet field sample of litter sampled within an area of size 1 m^2 (g), A = size of the area in which litter was collected (ha^{-1}), Wsub-sample (dry) = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g) and Wsub-sample, (fresh) = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g). The litter samples were oven-dried at 105^0C for 48 hrs using the dry ashing method (Allen et al., 1986). Oven-dried samples were taken in pre-weighed crucibles. Then the samples were ignited at 550 ^{0}C for one hour in a muffle furnace. After cooling, the crucibles with ash were weighed and the percentage of organic carbon was calculated. Therefore, carbon stored in litter was calculated as:

$LC = LB\ x\ \%CC$ .... Equation 5

Where Where, LC = Litter carbon, LB = Litter biomass (ha^{-1}), CC= carbon concentration

Estimation of carbon stock in the dead wood biomass

For the standing stump of dead wood, the amount of biomass was estimated using the allometric equation from REDD (2009) adopted by Dondo et al. (2019)

$$BSDW = \frac{1}{3} \times \pi \times \left(\frac{D}{200}\right) 2 \times H \times S \text{ .... Equation 6}$$

Where, BSDW= Biomass of Standing Dead Wood (kg), H = Height of Standing Dead Wood (m), D = Basal Diameter of Standing Dead Wood (cm), and S = Mean Wood Density of Dead Wood (gcm^{-3}). The specific density is estimated at 0.5 gcm^{-3} as a default value, but 0.8 can be used for dense hardwoods and 0.3 for very scattered species in tropical regions. In this study, the total carbon stock in dead wood was computed by multiplying the total biomass of the dead wood by 0.5 (Pearson et al., 2005; Sakai et al., 2008).

Soil organic carbon estimation

Collected composite soil samples were examined for soil organic carbon estimation for all three strata using the Walkley-Black method (Dondo et al., 2019). The soils were sieved through a 2 mm sieve mesh and mixed to a uniform consistency, and then a sub-sample of soil was taken and carbon analysis was done. SOC was calculated as follows:

$$\text{Soil organic carbon} = \text{bulk density x depth } x \text{ \% } Carbon \text{ .... Equation 7}$$

where: Bulk density (gcm^{-3}) = oven-dry mass (g)/volume (cm^3), % Carbon = carbon concentration (%). Soil bulk density was determined after oven drying of the soil samples as recommended by Solomon et al. (2018).

Bulk density (ρ_b)

Soil bulk density was determined after oven drying from the soil samples that were taken with a core sampler as recommended by Pearson et al. (2005) and adopted by Toru and Kibret (2019).

$V = h \text{ x } \pi r^2$ Where: V = volume of the soil in the core sampler in cm^3, h = height of the core sampler in cm, π= 3.14, r = the radius of the core sampler in cm. Then, the bulk density of a soil sample was calculated as follows:

$$\rho b = \frac{Wav,dry}{v} \text{ .... Equation 8}$$

Where ρ_b is the bulk density of the soil sample per plot (gcm^{-3}), Wav, dry is the average dry weight of soil sample per plot, V is the volume of the soil sample in the core sampler auger in cm^3 (Pearson et al., 2007).

Total carbon stocks estimation

The total carbon stock was estimated by summing the carbon stock densities of the individual carbon pools of the stratum using the Pearson (2005) formula.

The carbon stock density of a study area was calculated as follows:

$CT = AGC \text{ x } BGC + LC + SOC$ .... Equation 9

Where, CT = total carbon stock for all pools (t /ha^{-1}), AGC = above ground carbon stock (t /ha^{-1}), BGC = below ground carbon stock (t /ha^{-1}), LC = litter carbon stock (ton/ha) and SOC= soil organic carbon (t /ha^{-1}). The total carbon stock was then converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 as indicated by Pearson et al. (2007).

Analysis of Variance

R software version 4.0.1 was used to analyze data and analysis of variance was used to compute the mean of soil organic carbon across the soil depths and altitudinal ranges, and also to analyze the mean of change in carbon stocks with change in strata. The least significant difference was also used to separate the means at a significant level of $p < 0.05$.

RESULTS

Woody species identified at Muhabura Volcano

The families, genus, and species names, the number of individuals in each species (NoS), their corresponding percentage, and the number of plots (NP) these individual species were found at Muhabura Volcano is presented in Table 1. A total of 21 woody species distributed in 16 families were identified in which all 16 families were identified in low altitude and 4 families in middle altitude. No woody species with DBH ≥ 5 were identified in high altitudes. The high number of individuals' woody species were 30, 24, and 15 for *Hagenia abyssinica*, *Faurea saligna*, *and Neoboutonia macrocalyx* respectively in low altitude. *Erica arborea* had a high number of individuals (155) compared to other species in the middle altitude. Low number of individuals (1) was recorded for *Anthocleista grandiflora*, *Carapa grandiflora*, *Yushania alpina* and *Prunus Africana* in low altitude while 2 individuals were recorded as low number for *H. abyssinica* in middle altitude (Table 1).

Table 1. Families with their corresponding species at Muhabura Volcano.

AG	Family Name	Genus Name	Species Name	NoS	%S	NP
Lower	Asteraceae	*Solanecio*	*Solanecio mannii* (Hook.f.)	3	2.38	3
Lower	Betulaceae	*Alnus*	*Alnus acuminata* Kunth	3	2.38	2
Lower	Celastraceae	*Catha* Forssk	*Catha edulis* (Vahl) Forssk. *ex*	3	2.38	2
Lower	Ericaceae	*Erica L.*	*Erica arborea L.*	5	3.96	4
Lower	Ericaceae	*Agauria*	*Agauria salicifolia (*Comm. *ex*	2	1.58	1
Lower	Euphorbiaceae	*Neoboutonia*	*Neoboutonia macrocalyx* Pax	15	11.9	6
Lower	Euphorbiaceae	*Macaranga*	*Macaranga kilimandscharica* Pax	2	1.58	1
Lower	Gentiaceae	*Anthocleista*	*Anthocleista grandiflora* Gilg	1	0.79	1
Lower	Meliaceae	*Carapa*	*Carapa grandiflora* Sprague	1	0.79	1
Lower	Hypercaceae	*Hypercum*	*Hypercum revolutum* Vahl.	4	3.17	3
Lower	Meliaceae	*Lepidotrichilia*	*Lepidotrichilia volkensii* (Gürke)	10	7.93	4
Lower	Moraceae	*Ficus* Tourn. ex	*Ficus thonningii* Blume	2	1.58	1
Lower	Myrtaceae	*Syzygium* Gaertn.	*Syzygium guineense* (Willd.) DC.	3	2.38	2
Lower	Myrtaceae	*Eucalyptus*	*Eucalyptus maidenii* F.Muell.	2	1.58	1
Lower	Pentaphylacacea	*Balthasaria*	*Balthasaria schliebenii (*Melch.)	3	2.38	2
Lower	Poaceae	*Yushania*	*Yushania alpina*	1	0.79	1
Lower	Podocarpaceae	*Podocarpus*	*Podocarpus latifolius* Wall.	3	2.38	2
Lower	Proteaceae	*Faurea* Harv.	*Faurea saligna* Harv.	24	19.04	11
Lower	Rosaceae	*Hagenia*	*Hagenia abyssinica* (Bruce) J. F.	30	23.81	12
Lower	Rosaceae	*Prunus* L.	*Prunus Africana* (Hook. f.)	1	0.79	1
Lower	Sterculiaceae	*Dombea* Cav.	*Dombea torrida* (J.F.Gmel.)	8	6.34	6
Middle	Ericaceae	*Erica* L.	*Erica arborea L.*	155	77.5	20
Middle	Ericaceae	*Agauria*	*Agauria salicifolia (Comm. ex*	12	6	7
Middle	Hypercaceae	*Hypercum*	*Hypercum revolutum* Vahl.	17	8.5	9
Middle	Proteaceae	*Faurea* Harv.	*Faurea saligna* Harv.	14	7	7
Middle	Rosaceae	*Hagenia*	*Hagenia abyssinica (*Bruce) J. F.	2	1	2

AG=Altitudinal Gradients, NoS=Number of individuals of a species, %S=Percentage of species, NP=Number of plots where species presented.

Variation in carbon pool

The AGC for all altitudinal levels were 0.0015±0.0001138 and 0.0013±0.000033 for low altitude, and middle altitude respectively and no woody species were recorded in high altitude, the reason for AGC absence. The BGC for all altitudinal gradients did not show any significant difference at $p < 0.05$ and the estimated mean of BGC stocks were as follows, 0.0003±0.0000234 and 0.0003±0.0000069 tC/ha for low, and middle altitude respectively while no BGC for high altitude. Deadwood carbon stocks along altitudinal levels did not show any significant difference, ($p=0.08$; Table 2). The mean DWC stocks for lower and middle altitudes were 0.0008±0.00262 and 0.0003±0.006 t C/ha respectively. Mean SOC were 135.6636±0.1797, 128.966±0.2870 and 132.9230±18.8068 for low, middle and high altitudes respectively with a significant difference at $p > 0.05$. Carbon stock in litter for low and middle altitudes showed a significant difference at $p < 0.05$. The mean carbon stock in litter biomass in low and middle altitudes were 26.36±8.91 t/ha and 13.80±10.54 t/ha respectively (Table 2).

Table 2. The variation of carbon pools to altitudinal gradients at Muhabura volcano.

Carbon pools	Altitudinal gradients			p-value
	Low	Middle	High	
AGC	0.0015±0.0001138^{Ba}	0.0013 ±0.000033^{Ba}	-	0.000
BGC	0.0003±0.0000234^{Ba}	0.0003 ±0.0000069^{Ba}	-	0.000
DWC	0.0008 ±0.00262^{Ba}	0.0003±0.0060 ^{Ba}	-	0.085
SOC	135.6636±0.1797^{Aa}	128.966±0.2870^{Aa}	132.9230±18.8068^{Aa}	0.577
LC	26.36100 ±8.9120^{Ba}	13.80 ±0.10547^{Bb}	-	0.000
Total	162.0299±9.0944	142.7676±0.3984	132.9230±18.8068	

AGC = above ground carbon, BGC = Below ground carbon, DWC = dead wood carbon, SOC = soil organic carbon, LC = litter carbon. The values are in mean and standard deviation. The small letter compares the mean in a row and the capital letters compare the means in the column. Different letters show significant between means at $p < 0.05$.

Soil organic carbon

The results showed that the mean soil organic carbon stocks for low middle and high altitude were 135.6636±0.1797, 128.966±0.287 and 132.923±18.8068 t ha^{-1}, respectively and they did not show any significant difference at $p < 5$ ($p=0.577$, Table 3). The results showed that the soil carbon stock at 0-30 cm and 30-60 cm depth of three altitudinal levels were not significantly different in each group. However, SOC at the 0-30 cm depth showed a significant difference with SOC at 30-60 cm in all altitudinal gradients.

Table 3. Distribution of SOC content with depth at altitudinal gradients of Muhabura volcano.

	Soil depth		
Altitudinal gradients	**0-30 cm**	**30-60 cm**	**Mean**
Low	170.227 ±34.012^{Aa}	101.100 ±10.479^{Ab}	135.663±22.245
Middle	154.060 ± 51.009^{Aa}	103.871 ± 12.896^{Ab}	128.965±31.952
High	164.482 ±38.253^{Aa}	101.364 ±7.984^{Ab}	132.923±23.110
Total			397.551±77.307

Note: Means showed by similar superscripts (letters) within a column or within a row is not significantly different at a 5% level of significance. The values in the Table are means of triplicate samples.

Analysis of correlation among different carbon pools

The results of this study showed that there was a strong and positive correlation (0.99) between BGC and AGC. This means that BGC depends on BGC and any destruction of above-ground woody species can affect directly the below-ground carbon (Table 4). A positive correlation of 0.744 and 0.741 was found between LC with AGC and BGC respectively. However, there was a weak correlation between DWC and AGB, BGC, and LC, meaning that each carbon pool affected the other (Table 4).

Table 4. Pearson correlation analysis results of carbon pools at Muhabura volcano

	AGC	**BGC**	**DWC**	**SOC**	**LC**
AGC	1.00				
BGC	0.999**	1.00			
DWC	0.131	0.129	1.00		
SOC	-0.020	-0.017	-0.127	1.00	
LC	0.744**	0.741**	0.142	-0.071	1.00

AGC = above ground carbon, BGC = Below ground carbon, DWC = dead wood carbon, SOC = soil organic carbon, LC = litter carbon. **Correlation is significant at α=0.01; *Correlation is significant at α =0.05

DISCUSSION

Carbon stock in above and below ground biomass

Low and middle altitudes of Muhabura volcano did not show any significant difference in AGC and BGC and the study showed low AGC in the same altitudinal gradient. Biodiversity is linked to carbon stock in the way that a low number of woody plant species often linked to reduced biodiversity which in return negatively affects the ecosystem's stability to hold carbon (Ntukey et al., 2022). According to Youan et al. (2018) tree species attributes such as stand structure, woody density, and height play a significant role in the storage of carbon. In a disturbed forest ecosystem, the loss of tree species with a high potential to sequester carbon can considerably reduce AGC. The number of individuals and species of woody plants is reduced by different disturbances such as logging and deforestation, resulting in low AGC (Ntukey et al., 2022). This is in line with the current study where the number of woody species individuals recorded was the result of disturbance by human activities in the previous years before the current enforced protection in addition to low regeneration of woody species after fire outbreak (Ngiramahoro et al., 2018). This is supported by a study which revealed that fire characteristics and environmental conditions shape vegetation communities via regeneration strategy along altitudinal gradients where selective species can be more affected (Day et al., 2020). According to Bunker (2005), tropical forest biodiversity, functional diversity, and relative abundance influence both the magnitude and variability of aboveground biomass. Furthermore, aboveground biomass substantially determines an ecosystem potentiality for above-ground carbon storage, which plays an important role in regulating atmospheric CO_2 and global climate change (Tebeje, 2020). Biodiversity, however, is changing rapidly in response to a variety of anthropogenic drivers (Isbell, 2010; Sintayehu, 2018). The potential for terrestrial above-ground carbon sequestration could be altered sharply by ensuing changes in species composition (Daba et al., 2022; Ngute et al., 2020).

The findings in low BGC stocks of the lower and middle altitudes have contradicted the results of Binyam (2012) revealing that trees have much more potential to produce a larger quantity of BGC. This is due to a positive relation between AGC and BGC in the way that above-ground forest structure and composition influence the variability of below-ground carbon fluxes and content in tropical forests. Hence, a low AGC content in vegetation results in low BGC content (D’Andrea et al., 2020). A low number of individual woody species in addition to the Muhabura volcano's sharp slope and climatic factors might explain the low AGC and BGC found (Owiunji et al., 2005; Derhe et al., 2020).

Carbon stock in standing stamp of dead wood biomass

All strata showed a very low amount of carbon in standing stump of dead wood which might be due to woody species that are not closely and evenly distributed in a disturbed area (Ngiramahoro et al., 2018) and thus, therefore, a low contribution to the dead wood carbon pool. The results of this study are supported by the study of Paletto and Tosi (2010) showing that dead wood is an important component for conserving carbon stock and maintaining species diversity in forests. In natural forests, deadwood results from tree mortality caused by senescence processes or by tree competition, while in semi-natural and managed forests deadwood may be due to natural disturbances or human interventions (Lu et al., 2017; Woodall et al., 2019). Therefore, the presence or absence, variation in quantity structure, and function of deadwood in forest ecosystems change over time depending on natural disturbances (e.g., windstorms, forest fires, landslides, avalanches) and human interventions (e.g., thinning, selective cutting, clear cutting) applied under the priorities of forest management planning. These may determine the number of lags in the forest ecosystem leading to a given DWC content (Woodall et al., 2019).

Carbon stock in litter biomass

The findings on carbon stock in litter for both low and middle altitudes were recorded lower than the value cited in IPCC (2006) of about 49 t ha^{-1} for tropical forests. This might be attributed to young woody species, disturbance by fire or human activities, soil and climate in the study area, which caused little litter drop and made some deviation to the currently estimated result from a similar study conducted on other tropical forests (Ngiramahoro et al., 2018; Gebrewahid and Meressa, 2020). Leff et al. (2012) stated that the aboveground litter biomass in forests is likely to change due to changes in atmospheric carbon dioxide (CO_2) concentrations, temperatures, and rainfall patterns. Litterfall accumulation can be controlled by age and density of woody species, soil nutrient levels, species composition, quantity and quality of annual litter accumulation in combination with decomposition rate (Taylor et al., 2007; Sayer et al., 2011), human disturbances, and management history (Zhang and Wang, 2010). As litter fall represents a major flux of carbon from vegetation to soil, changes in litter inputs have direct consequences for soil carbon dynamics. According to Leff et al. (2012), the increase in aboveground litter production as a result of global climate change has the potential to cause considerable losses of soil carbon to the atmosphere in tropical forests. Physical characteristics of the atmosphere, sloppy tropical montane forest, and tropical storms are unlikely to decrease litterfall production, and canopy disturbance has large and lasting effects on carbon and nutrient cycling (Sayer et al., 2011). The physical and climatic condition of Muhabura volcano might be linked to low carbon stock in litter biomass.

Soil organic carbon

The findings of this study revealed a decrease in SOC with increased soil depths in all strata. Higher organic carbon content was observed at soil depth 0-30 cm compared to 30-60 cm. The higher organ carbon content in the top layer could be attributed to the rapid decomposition of forest litter in a favorable environment. This is supported by recent studies that have reported high SOC content in topsoil 0-20 cm (Dibaba et al., 2019), 0-25cm (Parras –Alcantara et al., 2015), 0-30cm (Shedayi et al., 2016). The results showed as well that SOC content decreased from low to middle altitude and then increased at high altitude. The higher SOC stock found in low altitudes might be due to the type of woody species and vegetation found in this altitudinal range and the frequent addition of litterfall (Chimdessa et al., 2023). Soil organic matter can also increase or decrease depending on numerous factors, including climate (Von Fromm et al., 2021), altitudinal and topographic variation (Chinasho et al., 2015), vegetation types (Gachhadar et al., 2022), nutrient availability, and soil types (Bukombe et al., 2022), disturbance, and management practice (Mayer et al., 2020; Nave et al., 2022). Though no woody species (DBH >5) in high altitudes were recorded, it had higher mean SOC content than at middle altitudes. This might be due to silt or silty clay, the carbon-rich soils resulting from a fire outbreak that burned almost all vegetation mainly the high altitude in the eastern part of Muhabura volcano slopes (Ngiramahoro et al., 2018). Decreasing SOC along high altitudes (±3000 m a.s.l) can be attributed to a considerable decrease in temperature and low decomposition rate (Shedayi et al., 2016). This is the same altitudinal range of middle altitude (2863-3112) of Muhabura volcano.

This study revealed a strong correlation between DWC and AGB, BGC, and LC. These correlations highlight how change in one carbon pool can impact others. Meng et al. (2021), revealed a critical linear relationship between above-ground biomass and below-ground biomass, signifying that the increase in above-ground biomass results definitely in an increase in below-ground biomass in the forest ecosystem. The process of deadwood decomposition enhances the release of nutrients into the soil, thereby encouraging the development of aboveground biomass (Yuan et al., 2018). Fallen small branches and leaves (litter) are decomposed to make soil organic carbon. From this process, soil fertility is maintained which plays a significant role in plant growth, affecting in return above-ground and below-ground biomass. The interaction between SOC and LC is a key component of the carbon cycle in tropical rainforest ecosystems (Salunkhe et al., 2018). However, the disturbance of the ecosystem by anthropogenic activities such as logging, land use, and deforestation can lead to a reduction in carbon stock capacity (Lu et al., 2017). The regime of disturbances such as bushfires and landslides can also impact the correlation between other carbon pools and soil organic carbon by changing the balance between the inputs and outputs of carbon (Dibaba et al., 2019). This is in line with a negative weak correlation estimated between SOC and LC, DWC, AGC, and BGC can be linked as well to the high disturbance of the study area by bushfires, human activities, and climatic conditions (Ngiramahoro et al., 2018).

Total carbon stocks

In the three altitudinal levels studied, low altitude showed high total carbon stock and the lowest total carbon stock was found in the high altitude. Numerous factors can be attributed to such findings such as climate and temperature. The lower altitude zones of the mountain present a warmer temperature which enhances the growth of vegetation and the continuous production of biomass. This results in sequestration of the large amounts of carbon in above and below-ground biomass (Cuni-Sanchez, 2021). Soils in lower elevations are more fertile attributed to the runoff from the higher altitude, leading to continuous accumulation of nutrients. This serves as a support for the robust growth of plants and enormous carbon accumulation in the soil (Solomon et al., 2024). Low elevations tend to hold more dense and diverse vegetation in forest ecosystems explained by the fact that the variability of plant species plays an important role in storing high amounts of carbon in their biomass (Tura et al., 2013; Solomon et al., 2024). Ahmed and Lemessa (2024) revealed that lower altitude areas of the Afromontane zone present often water availability that promotes the production of plant growth and biomass production which in return contributes to higher carbon storage. Moreover, in the protected areas, due to conservation interventions, lower altitudes areas can present large amounts of carbon storage attributed to effective conservation (Ahmed and Lemessa, 2024).

The results showed that the largest total carbon pool in all three strata was the total SOC pool contributing to sequestering the highest amount of carbon (Tsozue et al., 2019). According to Sheikh et al. (2009), about 40% of the total SOC stock of the global soils resides in forest ecosystems and is considered as the largest pool of terrestrial organic carbon, soils interact strongly with atmospheric composition, climate, and land cover change. In this study, despite recording zero number of woody species in the high altitude, it also presented a mean SOC due to grasses, herbs, and mosses, and typical volcanic soil rich in organic matter after the fire outbreak (Owiunji et al., 2005; Shedayi et al, 2016). This may also be attributed to longer vegetative growing periods at high altitudes without human interference than at low altitudes (Ngiramahoro et al., 2018; Tsozue et al., 2019; Derhe et al., 2020).

CONCLUSION AND RECOMMENDATION

The study revealed the variation of carbon stocks of woody species along the altitudinal gradient of Muhabura volcano. However, in altitudinal gradients, some estimated carbon pools were low compared to standards, attributed to the low number of individual woody species recorded resulting in reduced biomass and the overall Muhabura Volcano's carbon sequestration potential. Therefore, the protection of Muhabura volcano by supporting its carbon stock through assisting woody species regeneration has to be the center of attention in integrating the maintenance of the mountain to meet the objectives of both conservation and climate change mitigation. The results also provided information for future researchers, managers, and policymakers for developing and implementing management policies and plans for Muhabura volcano ecosystem. Policies should be implemented to take advantage of its carbon sequestration for probable carbon marketing to boost the overall management of Muhabura Volcano and Volcanoes National Park in general. This aligns with Rwanda's vision for 2015-2030 in its 2020 updated Nationally Determined Contribution (NDC) target of mitigation by sequestering a large amount of CO_2 through proper natural forest conservation and management. The reduction of emissions from deforestation and forest degradation by properly managing and sustainably utilizing the existing flora at Muhabura Volcano and Volcanoes National Park in general, may continue to bring financial and technical incentives from industrialized nations to Rwanda through REDD+ and other climate funds. Moreover, further studies with accurate and consistent data that meet international standards, are highly needed to obtain data for deriving benefits from climate funds and drawing national environmental policies related to climate change mitigation and adaptation.

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REFERENCE

Aabeyir, R., Agyare, W.A. and Weir, M.J. 2020. Allometric models for estimating above ground biomass in the tropical woodlands of Ghana, West Africa. *Forest Ecosystems*, **7(1):1-23**, doi : org/10.1186/s40663-020-00250-3.

Abere, F., Belete, Y., Kefalew, A. and Soromessa, T. 2017. Carbon stock of Banja forest in Banja district, Amhara region, Ethiopia: An implication for climate change mitigation. *Journal of Sustainable Forestry*, **36(6): 604-622**.

Agbeshie, A.A., Abugre, S. and Atta-Darkwa, T. 2022. A review of the effects of forest fire on soil properties. *Journal of Forestry Research*, **33:1419–1441**, doi: 10.1007/s11676-022-01475-4.

Ahmed, S. and Lemessa, D. 2024. Patterns and drivers of the above- and below-ground carbon stock in Afromontane Forest of southern Ethiopia: implications for climate change mitigation. *Tropical Ecology*, **65: 508–516**, doi: 10.1007/s42965-024-00334-z.

Akayezu, P., van Duren, I.C., Groen, T.A., Grueter, C.C. and Robbins, M.M. 2019. Abundance and spatial distribution of the main food species for mountain gorillas in the Virunga Massif, Rwanda. *Biodiversity and Conservation*, **28:3597-3620**.

Allen, S.E, Grimshaw, H.M. and Rowland, A.P. 1986. Chemical Analysis. In: P.D. Moore, S.B. Chapman, ed. *Methods in Plant ecology*, Blackwell Scientific Publications, London, UK. pp. 285-344.

Bhishma, P. S. 2010. Forest carbon stock measurement: Guidelines for measuring carbon stocks in community-managed forests. *In Asia Network for Sustainable Agriculture and Bioresources* ***(ANSAB)*** Kathmandu: Nepal, pp. 17-43.

Bilous, A., Zadorozhniuk, R., Makarevych, A., Svynchuk, V., Lashko, A., Bilous, M. and Matsala, M. 2024. Sampling protocol for measuring mean diameter at breast height of forked urban trees. *Forests*, **15(3):458**, doi.org/10.3390/f15030458.

Binyam, A.E. 2012. Carbon stocks potential of woodlands and land use and land cover changes in Northwestern lowlands of Ethiopia. M.Sc Thesis, Hawassa University, Wondo Genet College of Forestry and Natural Resources. Wondo Genet, Ethiopia.

BSSS 2023. Guidance note on soil carbon. British Society of Soil Science. [online] available at: https://soils.org.uk/wp-content/uploads/2023/06/BSSS_Science-Note_June-23_Soil-Carbon-Stocks_FINAL-DIGITAL_300623.pdf. [Accessed September 20, 2024].

Bukombe, B., Bauters, M., Boeckx, P., Cizungu, L. N., Cooper, M., Fiener, P. and Doetterl, S. 2022. Soil geochemistry and not topography–as a major driver of carbon allocation, stocks, and dynamics in forests and soils of African tropical montane ecosystems. *New Phytologist*, **236(5):1676-1690**.

Bunker, D.E. 2005. Species loss and aboveground carbon storage in a tropical forest. *Science*, **310(5750):1029–1031**, doi:10.1126/science.1117682.

Chapman, C.A., Bortolamiol, S., Matsuda, I., Omeja, P.A., Paim, F.P., Reyna-Hurtado, R., Sengupta, R. and Valenta, K. 2018. Primate population dynamics: variation in abundance over space and time.

Biodiversity and Conservation, **27(5):1221–1238**, doi:10.1007/s10531-017-1489-3.

Chave J., 2014. Improved allometric models to estimate the above ground biomass of tropical trees. *Global change biology*, **20:3177–3190.**

Chavula, P., Shepande, C. and Feyissa, S. 2023. Comparative analysis of effects of climate-smart agriculture practices and conventional agriculture on selected soil physicochemical properties in Nyimba district, Zambia. *Studia Biologica*, **17(4):85–102**, doi:10.30970/sbi.1704.744.

Chimdessa, T. 2023. Forest carbon stock variation with altitude in Bolale natural forest, Western Ethiopia. *Global Ecology and Conservation*, **45:e02537**.

Chinasho, A., Soromessa, T. and Bayable, E. 2015. Carbon stock in woody plants of Humbo forest and its variation along altitudinal gradients: the case of Humbo district, Wolaita zone, southern Ethiopia. *International Journal of Environmental Protection and Policy*, **3(4):97-103**.

Cuni-Sanchez, A., Sullivan, M.J.P., Platts, P., Lewis, S.L., Marchant, R., Imani, G., Wannes, H. et.al. 2021. High above-ground carbon stock of African tropical montane forests, *Nature*, **25**. doi: 10.1038/s41586-021-03728-4.

D'Andrea, E., Guidolotti, G., Scartazza, A., De Angelis, P. and Matteucci, G. 2020. Small-Scale forest structure influences spatial variability of belowground carbon fluxes in a mature Mediterranean beech forest. *Forests*, **11(3):255**, doi:10.3390/f11030255.

Daba, D.E., Dullo, B. W. and Soromessa, T. 2022. Effect of forest management on carbon stock of tropical moist Afromontane Forest. *International Journal of Forestry Research*, ***Article ID 3691638***.

Day, N.J., White, A.L., Johnstone, J.F., Degré-Timmons, G.É., Cumming, S.G., Mack, M.C. and Baltzer, J.L. 2020. Fire characteristics and environmental conditions shape plant communities via regeneration strategy. *Ecography*, **43(10):1464-1474**, doi:10.1111/ecog.05211.

Derhe, M.A., Tuyisingize, D., Eckardt, W., Emmanuel, F. and Stoinski, T. 2020. Status, diversity, and trends of the bird communities in Volcanoes National Park and Surrounds Rwanda. *Bird Conservation International*, **30(1):1-20**.

Dibaba, A., Soromessa, T. and Workineh, B. 2019. Carbon stock of the various carbon pools in Gerba-Dima moist Afromontane Forest, South-western Ethiopia. *Carbon balance and management*, **14:1-10**.

Dondeyne S., Deckers J A. and Chapelle J. 2017. Soil and vegetation of Bisoke volcano (Rwanda). *Pedologie*, **43(2):301-322**.

Dondo, G., Workeneh, D. S. and Desta, M. A. 2019. Assessment of carbon stocks under different land cover types in Hallaydeghe Wildlife Reserve, North-eastern Ethiopia. Doctoral Dissertation, Haramaya University.

Fischer, K., Giertta, F. and Hajdu, F. 2019. Carbon-binding biomass or a diversity of useful trees?(Counter) topographies of carbon forestry in Uganda. *Environment and Planning E: Nature and Space,* **2(1):178–199**.

Freeze, P. 2024. Testing for carbon stock: part two soil sampling for carbon. [Online] Available at: https://www.wardlab.com/testing-for-carbon-stocks-part-2-soil-sampling-for-carbon [Accessed September 20 2024].

Gachhadar, P., Baniya, C. B. and Mandal, T. 2022. Soil organic carbon stocks in the forests of different continents. *Our Nature*, **20(1):57–69**.

Gebrewahid, Y. and Meressa, E. 2020. Tree species diversity and its relationship with carbon stock in the parkland agroforestry of northern Ethiopia. Cogent Biology **6:17728945**, doi.org/10.1080/23312025.2020.1728945.

Gizachew, B., Solberg, S. and Puliti, S. 2018. Forest carbon gain and loss in protected areas of Uganda: Implications to carbon benefits of conservation. *Land*, **7(4):138**, doi.org/10.3390/land7040138.

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Steen, M. Greenhouse gas emissions from fossil fuel-fired power generation systems. European Union Joint Research Center, EUR 19754 EN; 2000. [online] available at: https://www.ipcc-nggip.iges.or.jp/pu. [Accessed 14 Feb 2021].

IPPC. 1990. Climate Change: The IPCC Scientific Assessment. In: J.T. Houghton, G.J. Jenkins and J.J. Ephraums, ed., *Report prepared for Intergovernmental Panel on Climate Change by Working Group I.* Cambridge University Press, Cambridge.

Isbell, F. 2010. Causes and Consequences of Biodiversity Declines. *Nature Education Knowledge*, **3(10):54**.

IUCN. 2019. The IUCN red list of threatened species. Version 2019-1. [Online] available at: https://www.iucnr edlis t.org [Accessed 05 May 2021].

Kazoora, C., Irumba, D., Smith, N., Mutamba, M., Nkabiheebwa, P., Katumba, G. and Nakiyingi, E. 2019. A review of collaborative forest management in Uganda. Ministry of Water and Environment, Kampala, Uganda.

Leff, J.W., Wieder, W.R., Taylor, P.G., Townsend, A.R., Nemergut, D. R., Grandy, A. S and Cleveland, C. C. 2012. Experimental litterfall manipulation drives large and rapid changes in soil carbon cycling in a wet tropical forest. *Global Change Biology,* **18(9):2969–2979**, doi:10.1111/j.1365-2486.2012. 02749.x.

Liu, X., Trogisch, S., He, J.-S., Niklaus, P. A., Bruelheide, H., Tang, Z., Erfmeier, A., Scherer-Lorenzen, M., Pietsch, K. A. and Yang, B. 2018. Tree species richness increases ecosystem carbon storage in subtropical forests. *Proceedings of the Royal Society B*, **285(1885):20181240**.

Lu, X., Hu, H. and Sun, L.2017. Effect of fire disturbance on active organic carbon of *Larix gmelinii* forest soil in Northeastern China. *Journal of Forestry Research*, **28:763–774**.

MacDicken, K.G. 1997. A guide to monitoring carbon storage in forestry and agroforestry projects. Winrock International Institute for Agricultural Development.

Matakala, N., Chirwa, P. W., Mwamba, T. M. and Syampungani, S. 2023. Species richness and phytoremediation potential of mine wastelands-native trees across the Zambian Copperbelt Region. *Heliyon*, **9(3):e13585**, doi:10.1016/j.heliyon.2023.e13585.

Mawa, C., Babweteera, F. and Tumusiime, D. M. 2022. Conservation outcomes of collaborative forest management in a medium altitude semideciduous forest in mid-western Uganda. *Journal of Sustainable Forestry*, **41(3–5):461–480**.

Mayer, M., Prescott, C.E., Abaker, W.E.A., Augusto, L., Cécillon, L., Ferreira, G.W.D. and Vesterdal, L. 2020. Influence of forest management activities on soil organic carbon stocks: a knowledge synthesis. *Forest Ecology and Management*, **466:118127**.

Meng, Y., Bai, J., Gou, R., Cui, X., Feng, J., Dai, Z. and Lin, G. 2021. Relationships between above-and below-ground carbon stocks in mangrove forests facilitate better estimation of total mangrove blue carbon. *Carbon balance and management*, **16:1-14**.

Mlotha, M. J. 2018. Analysis of land use/land cover change impacts upon ecosystem services in montane tropical forest of Rwanda: forest carbon assessment and REDD+ preparedness. PhD thesis. Antioch University, New England.

MoE. 2019. Ministry of Environment, Rwanda, National Environment and Climate Change Policy. [Online] available at *http://www.fonerwa.org/sites/default/files/202106/Rwanda%20National%20Environment%20and%20Climate%20Change%20Policy%202019.pdf*. [Accessed November 10, 2023].

Mugabowindekwe, M., Brandt, M., Chave, J., Reiner, F., Skole, D. L., Kariryaa, A. and Fensholt, R. 2023. Nation-wide mapping of tree-level aboveground carbon stocks in Rwanda. *Nature Climate Change*, **13(1):91-97**.

Mulugo, L. W., Galabuzi, C., Nabanoga, G. N., Turyahabwe, N., Eilu, G., Obua, J., Kakudidi, E. and Sibelet, N. 2020. Cultural knowledge of forests and allied tree system management. *Journal of forestry research*, **31:1787-1802**.

Namanji, S., Francis, C., Ssekyewa, C. and Lieblein, G. 2019. Field assessment of environment policy operationalization in forest tree biodiversity conservation in Uganda. *Biodiversity Management and Forestry*, **8:2**. doi: 10.37532/jbmf.2019.8(2).214

Nave, L. E., DeLyser, K., Domke, G. M., Holub, S. M., Janowiak, M. K., Kittler, B. and Swanston, C. W. 2022. Disturbance and management effects on forest soil organic carbon stocks in the Pacific Northwest. *Ecological Applications*, **32(6):e2611**.

Nel, A. 2018. The neoliberalisation of forestry governance, market environmentalism and re-territorialisation in Uganda. *Third World Quarterly*, **36(12):2294–2315**, doi.org/10.1080/01436597.2015.1086262

Ngiramahoro M., Tuyisingize D., Winnie Eckardt, Ndagijimana F. and Maniragaba A. 2018. Analysis of plant responses to the aftermath of fire outbreak in Muhabura Volcano, Rwanda. *East African Journal of Science and Technology*, **8(2):60-80**, doi.org/10.62103/unilak.eajst.8.8.163.

Ngute, A. S. K., Sonké, B., Nsanyi Sainge, M., Calders, K., Marchant, R. and Cuni-Sanchez, A. 2020. Investigating above-ground biomass in old-growth and secondary montane forests of the Cameroon Highlands. *African Journal of Ecology*, **58(3):503-513**.

Nsabimana, D. 2009. Carbon stock and fluxes in Nyungwe forest *and Ruhande Arboretum* in Rwanda. Phd thesis. University of Gothenburg, Sweden.

Nsengumuremyi, C., Fischer, E., Nsabimana, D., Harbusch, M., Seidel, S., Zaninka, M. C. and Mutayomba, L. 2022. Carbon sequestration and carbon stock of agroforestry tree species around Cyamudongo isolated rain forest and Arboretum of Ruhande, Rwanda. *Turkish Journal of Agriculture-Food Science and Technology*, **10(12):2597-2608**.

Ntukey, L.T., Munishi, L.K. and Treydte, A.C. 2022. Land use land/cover change reduces woody plant diversity and carbon stocks in a lowland coastal forest ecosystem, in Tanzania. *Sustainability*, **14(14):8551**.

Ototo, G. and Vlosky, R. P. 2018. Overview of the forest sector in Kenya. *Forest Products Journal*, **68(1):6–14**.

Owiunji, I., Nkuutu, D., Kujirakwinja, D., Liengola, I., Plumptre, A., Nsanzurwimo, A. and McNeilage, A. 2005. The biodiversity of the Virunga Volcanoes. Unpublished report, Wildlife Conservation Society, New York.

Paletto, A. and Tosi, V. 2010. Deadwood density variation with decay class in seven tree species of the Italian Alps. *Scandinavian Journal of Forest Research*, **25(2):164–173**, doi:10.1080/02827581003730773.

Parras-Alcántara, L., Lozano-García, B and Galán-Espejo, A. 2015. Soil organic carbon along an altitudinal gradient in the Despeñaperros Natural Park, southern Spain. *Solid Earth*, **6(1):125–134**, doi:10.5194/se-6-125-2015.

Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for land-use change and forestry projects. Arlington: Winrock International and the Bio-carbon fund of the World Bank.

Pearson, R.G., Raxworthy, C.J., Nakamura, M. and Townsend Peterson, A. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography*, **34(1):102-117.**

Raffeld, A.M., Bradford, M.A., Jackson, R.D., Rath, D., Sanford, G.R., Tautges, N. and Oldfield, E.E. 2024. The importance of accounting method and sampling depth to estimate changes in soil carbon stocks. *Carbon Balance and Management PMC* **26:19** PMCID: PMC10811869, doi: 10.1186/s13021-024-00249-1.

REMA. 2009. Forest and Protected Areas. Rwanda State of Environment and Outlook. Rwanda Environment Management Authority.

RoR. 2018. Third National Communication: Report to the United Nations framework convention on climate change. Republic of Rwanda, Kigali.

RoR. 2015. Forest investment program for Rwanda from 1984-2015 Republic of Rwanda, Ministry of Lands and Forestry.

RoR. 2016. National Biodiversity Strategies Action Plan. Republic of Rwanda. [Online] available at: https://www.rema.gov.rw. [Accessed on November 10 2023].

Sakai Y., Takahashi, M, and Ishizuka, S. 2008. Estimating decay rates of dead wood by changes in wood density in coniferous plantations in Japan. *Japan Journal for Environment,* **50:153-165.**

Salunkhe, O., Khare, P. K., Kumari, R. and Khan, M.L. 2018. A systematic review on the aboveground biomass and carbon stocks of Indian forest ecosystems. *Ecological processes*, **7:1-12**.

Sayer, E., Heard, M., Grant, H. 2011. Soil carbon release enhanced by increased tropical forest litterfall. *Nature Climate Change*, **1:304–307**, doi:10.1038/nclimate1190.

Shedayi, A.A., Xu, M., Naseer, I. and Khan, B. 2016. Altitudinal gradients of soil and vegetation carbon and nitrogen in a high-altitude nature reserve of Karakoram ranges. *SpringerPlus*, **5:1-14**.

Sheikh, M.A., Kumar, M. and Bussmann, R.W. 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in G Garhwal Himalaya. *Carbon Balance and Management*, **4:6**.

Sintayehu, D.W. 2018. Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. *Ecosystem Health and Sustainability*, **4(9):225–239**, doi:10.1080/20964129.2018.1530054.

Siraj, M. 2019. Forest carbon stocks in woody plants of Chilimo-Gaji Forest, Ethiopia: Implications of managing forests for climate change mitigation. *South African Journal of Botany*, **127:213–219**.

Snowdon, P., Raison, J., Keith, H., Ritson, P., Grierson, P., Adams, M., Montagu, K., Bi, H., Burrows, W and Eamus, D. 2002. Protocol for sampling tree and stand biomass. national carbon accounting system technical report No. 31.

Solomon N., Pabi O., Annang, T., Asante, I.K and Birhane, E. 2018. The effects of land cover change on carbon stock dynamics in a dry Afromontane Forest in northern Ethiopia. *Carbon Balance Manage* **13:14**, doi:10.1186/s13021-018-0103-7.

Solomon, N., Birhane, E. and Teklay, M. 2024. Exploring the role of canopy cover and environmental factors in shaping carbon storage in Desa'a forest, Ethiopia. *Carbon Balance Manage* 19, 30, doi:10.1186/s13021-024-00277-x.

Taylor, A.R., Wang, J.R and Chen, H.Y. 2007. Carbon storage in a chronosequence of red spruce (*Picea rubens*) forests in central Nova Scotia, Canada. *Canada Journal for Research*, **37(11):2260–2269**.

Tebeje, Y. 2020. A Review Paper on the role of terrestrial carbon stocks for climate change mitigation mechanisms.

Toru, T. and Kibret, K. 2019. Carbon stock under major land use/land cover types of Hades sub-watershed, eastern Ethiopia. *Carbon balance and management*, **14:1-14**.

Tsozue, D., Nghonda, J.P., Tematio, P. and Basga, S.D. 2019. Changes in soil properties and soil organic carbon stocks along an elevation gradient at Mount Bambouto, Central Africa. *CATENA*, **175:251–262**, doi: 10.1016/j.catena.2018.12.028.

Tuffour H., Yeboah, I., Bonsu, M., Adjei-Gyapong, T., Khalid, A.A., Awudu, M. and Caleb K.P. 2014. Soil organic carbon: Relating the Walkley-Black wet oxidation method to loss on ignition and clay content. *International Journal of Scientific Research in Knowledge*, **2:249-256**.

Tumushabe, J.T., Turyasingura, B. and Chavula, P. 2023. the sustainability of carbon markets for climate-smart agriculture among smallholder farmers in Uganda. *Asian Journal of Research in Agriculture and Forestry*, **9(4): 337–345**, doi: 10.9734/ajraf/2023/v9i4263.

Tura, T. T., Argaw, M., and Eshetu, Z. 2013. Estimation of carbon stock in church forests: implications for managing church forest to help with carbon emission reduction. In: *Climate-Smart technologies: Integrating renewable energy and energy efficiency in mitigation and adaptation responses*. Springer Berlin Heidelberg, pp. 403-414.

Turamyenyirijuru, A., Nyagatare, G., Gesimba, R. M., and Birech, R. J. 2019. Assessment of soil fertility in smallholder potato farms in Rwanda. *Agricultural Science Digest-A Research Journal*, **39(4):280-285**.

Uwitonze, P., Msanya, B. M., Mtakwa, P. W., Uwingabire, S., and Sirikare, S. 2016. Pedological characterization of soils developed from volcanic parent materials of the Northern Province of Rwanda. *Agriculture, Forestry and Fisheries*, **5(6):225-236**.

Von Fromm, S.F., Hoyt, A.M., Lange, M., Acquah, G.E., Aynekulu, E., Berhe, A. A. and Doetterl, S. 2021. Continental-scale controls on soil organic carbon across sub-Saharan Africa. *Soil*, **7(1):305-332**.

Walkley, A. and Black, I.A. 1934. An examination of the method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, **37 (1):29-38.**

Woodall, C. W., Monleon, J. V., Fraver, S., Russel, M. B., Hatfield, M. H., Campbell, J. L. and Domke, G. M. 2019. The downed and dead wood inventory of forests in the United States. *Scientific Data*, **6(1):180303**, doi: 10.1038/sdata.2018.303.

Yilma, G. and Derero, A. 2020. Carbon stock and woody species diversity patterns in church forests along church age gradient in Addis Ababa, Ethiopia. *Urban Ecosystems***, 23:971-983**, doi:10.1007/s11252-020-00961-z.

Yuan, Z., Wang, S. and Ali, A. 2018. Aboveground carbon storage is driven by functional trait composition and stand structural attributes rather than biodiversity in temperate mixed forests recovering from disturbances. *Annals of Forest Science* 75(67), doi:10.1007/s13595-018-0745-3.

Zajadacz, A., and Uwamahoro, J. 2020. Diversity of the geographical environment of national parks in Rwanda as centers of nature-based tourism. *Prace Geograficzne*, **165:53-67**.

Zhang, Q. and Wang, C. 2010. Carbon density and distribution of six Chinese temperate forests. *Science China*, **53(7):831–840.**

SEED STORAGE BEHAVIOUR AND PRETREATMENT METHODS FOR *ACOKANTHERA SCHIMPERI* (A. DC.) SCHWEINF. USING A COMBINATION OF EXPERIMENTAL APPROACH

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ABSTRACT: *Acokanthera schimperi* (A. DC.) Schweinf is one of the known medicinal plants in the rural community of Ethiopia. However, there is no information on seed storage behaviour and the appropriate conservation method. The aim of the present study is to determine the appropriate seed pretreatments and to investigate the impact of moisture content, storage temperature, and storage duration on seed germination and storage behaviour of *A. schimperi*. To provide information on the seed storage behaviour of the species, we combined an experimental technique based on critical moisture content, storage temperature, and duration analysis. The initial moisture content of the seeds was determined and the effects of dehydration and cold storage on seed viability, germination, and subsequent seedling vigour were examined. The best pretreatment method and seeding medium for the species were also determined. The results showed that the initial moisture content of *A. schimperi* seeds was 55.8%, with almost 100% viability. Seed germination ranged from 75% (mechanical scarification) to 95% (cold water treatment). The *A. schimperi* seed exhibits non-physiological dormancy, allowing for simple germination in a controlled environment using filter paper or sand media. Viability of *A. schimperi* seeds was significantly affected by seed moisture content ($p < 0.01$). However, the interaction effect of storage temperature and duration on seed viability was not significant ($P=0.06$). These results provide the first concrete evidence of *A. schimperi*'s recalcitrance and practical guidance for handling the seeds in a practical way and developing sustainable conservation strategies for the species.

Key words: *Acokanthera schimperi*, Moisture content, Recalcitrance, Seed viability, Storage behaviour

INTRODUCTION

Seed storage refers to keeping seeds alive for a long time by preserving them in a controlled environment. Before selecting the best storage options, it is necessary to assess the seed storage behaviour between species which allows to distinguish among the orthodox, intermediate, and recalcitrant nature of the seeds (Hong et al., 1996). Storage behavior of seeds ascertains whether the species can be successfully maintained over the

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long term, the medium term, or only the short term for practical seed storage purposes, particularly genetic resource conservation (Hong and Ellis, 1996). Seeds can be classified according to seed storage behaviour as Orthodox (seeds that do not lose viability when stored at low temperatures and with low seed moisture content), Recalcitrant (seeds that lose viability at low moisture content level), and Intermediate (seeds that exhibit storage characteristics between orthodox and recalcitrant seeds) (Hong and Ellis, 1996). Most recalcitrant seeds, unlike orthodox seeds, are unable to withstand dehydration or cooling (less than 10 °C) and could not be kept for a long period of time (Shih et al., 2008).

Acokanthera schimperi (A. DC.) Schweinf belongs to the Apocynaceae family, which is a shrub or tree with a height of 1 to 9 m. It is found in dry evergreen ecosystem and is a well-known species in East Africa distributed in Ethiopia, Eritrea, Tanzania, Uganda, Rwanda, DR Congo and Yemen (Hedberg, 1996). *Acokanthera schimperi*, also known as "kararu" locally, is a small, densely rounded tree with glabrous branches, cuspidate leaves, soft, brown bark, and fragrant flowers (Bussmann et al., 2021). The species' leaf extract is widely used in the conventional treatment of malaria, wounds and a number of illnesses, including common cold tonsillitis, bacterial nail infections, leprosy, tinea capitis, dermatitis, and sexually transmitted diseases (Mohammed et al., 2014). Additionally, root fusion is used for the treatment of swelling, elephantiasis, and headache. The stem and bark extracts are used as anti-venom for snake bites and rheumatoid pain, headaches, scabies, and warts (Kassa et al., 2020). Therefore, it is important to preserve the genetic resource of this multipurpose plant species. Seed storage is one of the conservation methods of genetic resources.

Due to a number of challenges, such as deforestation, habitat degradation, climate change, and the introduction of invasive species, many tree species in the tropics, including Ethiopia, are in danger of going extinct. Thus, knowledge of the seed storage behaviour of a target species is required in order to determine whether or not seed storage is suitable as a method of genetic conservation, and to handle seeds appropriately during collection and germplasm exchange (Hong and Ellis, 1996). However, there is a dearth of information available on the seed storage behaviour for the majority of the numerous forest types that exist in Ethiopia (Teketay, 2005). Similarly, no information is available on seed storage behaviour and appropriate conservation method pertinent to *A. schimperi*. Therefore, the objective of the present study is to fill this gap by examining pretreatment conditions for germination and the seed storage behaviour of this medicinal and economically valuable tree species.

MATERIALS AND METHODS

Site description

The *A. schimperi* seed was collected from the Bishan Gari dry Afromontane natural forest located in the Heban Arsi district of the West Arsi Zone of the Oromia National Regional State (Figure 1). The area is 200 km away from Addis Ababa, Ethiopia's capital, in southeast direction. It lies between the coordinated 07°32'30.16"–07°35'34.52"N and 38°47'43.93"–38°49'46.51"E. The elevation of the seed collection site ranged from 1591 to 1626 m a.s.l. The soil has a sandy texture and has a deep brown colour. It has an annual temperature of 10 to 25 °C and annual precipitation of 500 to 1000 mm. The vegetation type of the collecting site is found in dry Afromontane forest (Mekonnen et al., 2018). *Acacia* species, *Mimusops kummel*, *Ficus* species, *Celtis africana*, *Olea species*, *Podocarpus falcatus*, *Cordia Africana*, *Calpurnia aurea*, *Euclea racemosa* and *Carissa spinarum* are common and associated tree and shrub species in this vegetation (Mewded et al., 2022).

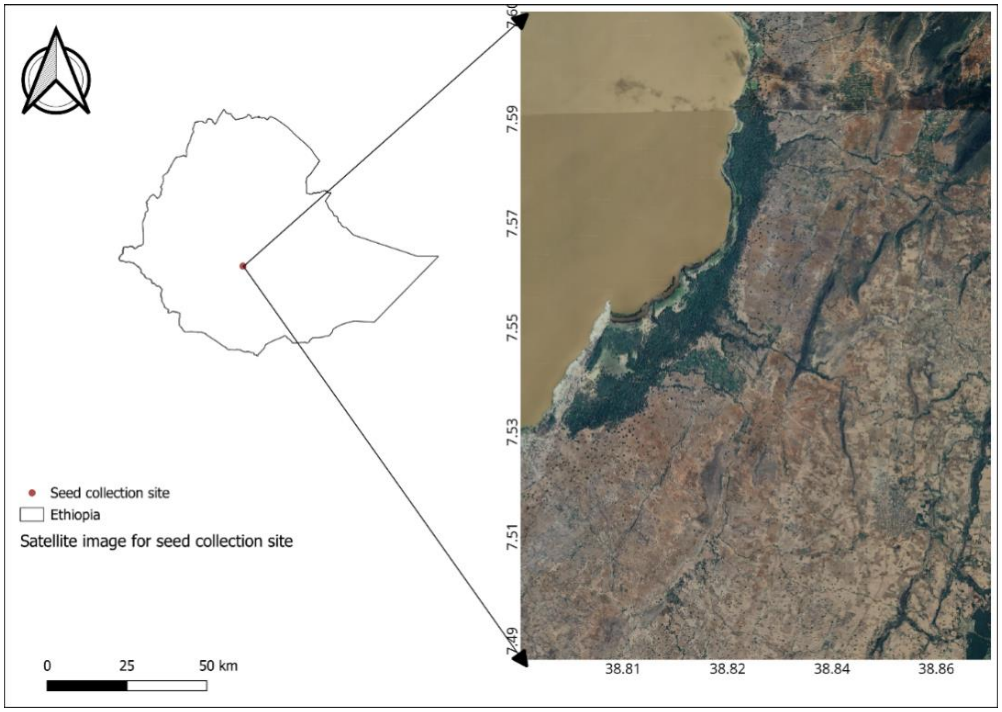

Figure 1. Map showing *A. schimperi* seed collection site.

Seed harvesting and cleaning

The potential geographic location and phenology of the species (flowering, fruiting and seed-bearing times) was identified before seed collection by reconnaissance survey. Individual mother trees were randomly and evenly selected from the same population of *A. schimperi* to collect seeds at the same site. After selecting and marking the mother trees, tarpaulin under the plant was used to catch fallen seeds and fruit when the branches are shaken. Seeds at the stage of dispersal were collected by hand and pruner, and secateur was used to cut fruit on the branch. Unripen and infested seeds were removed from the composite sample. A composite sample was obtained by mixing the primary sample, which was taken randomly from each individual tree (IBPGR, 1982). The seeds were transported to the Ethiopian Biodiversity Institute's seed laboratory in an aerated plastic bag. The seeds were separated from the fruit, rinsed and cleaned under pressure with running tap water to remove any gelatinous coatings and vegetative parts (Figure 2). The seeds were spread thinly on the plastic sheet and allowed to air dry.

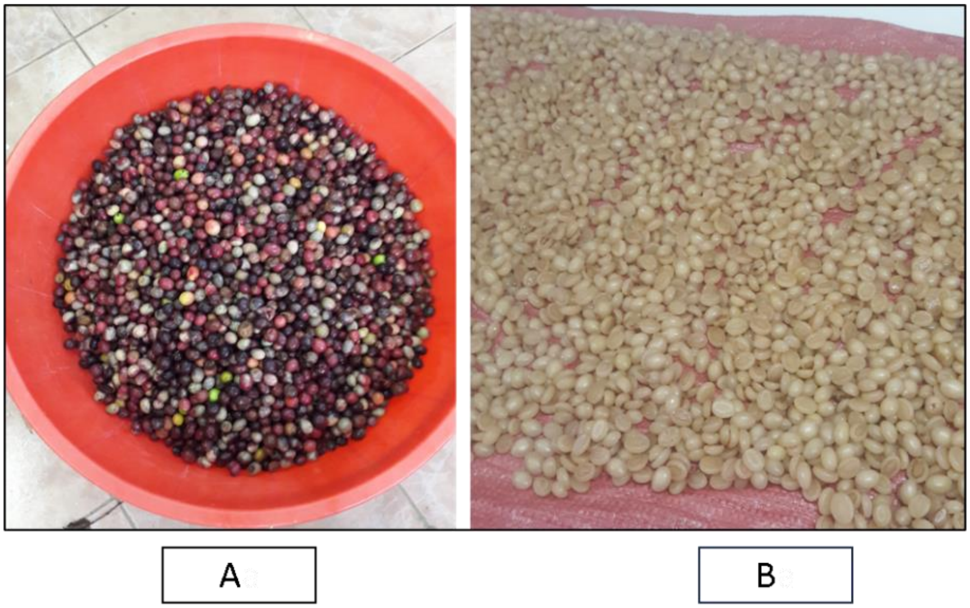

Figure 2. Seeds of A. schimperi with fleshy fruit (A) and seeds after cleaning (B).

Thousand-seed weight (TSG) determination

Cleaned 1000 *A. schimperi* seeds were counted using seed counter and the weight of the 1000 seeds was recorded. The procedure was repeated for the second trial and the mean of the two trials was recorded. The whole working sample was put through the seed counting machine and the number of seeds in the sample was noted. The total weight of the seed sample was weighted to the same number of decimal places as in the purity analysis. The thousand seed weight was determined using the following calculation:

$$TWS = W/S * 1000$$

Where TWS- is the Thousand Seed Weight (grams per 1000 seeds)

W- the total weight of seeds (gram)

S- the total number of seeds

Seed moisture content determination

After seed cleaning and thousand seed weight determination, the initial moisture content of the seed was determined using destructive (Oven drying) method as described in ISTA (2005). Low constant temperature method of oven drying method was adopted to determine the initial moisture content of the seed. To do this, sample from the cleaned seed was taken and ground using seed grinder to promote uniform and complete drying. Small stainless-steel containers, including the lids, were labelled and weighed using a sensitive balance. Half (0.5) gram of sub-sample was taken from the ground sample and placed in two separate containers which will serve as two replicates. The drying oven was adjusted to 103 ° C following the low constant temperature method of ISTA (2005). The sample-containing containers were placed in a drying oven and the lids were removed to subject the sample to temperature. The samples were dried for 17 hours at 103 °C. The lids were replaced on each container after the end of drying. The containers were moved to the desiccator and allowed to cool for 45 minutes. The weights of the containers, including the samples, were recorded, and the initial moisture content of the sample was calculated using the following formula (Rao et al., 2006).

$$Moisture\ content\ (MC)(\%) = \frac{\mathrm{W2} - \mathrm{W3}}{W2 - W1} * 100$$

Where, W1 = weight of container with lid; W2 = weight of container with lid and sample before drying; and W3 = weight of container with lid and sample after drying.

Seed drying

After determining the initial moisture content of the seed, seeds were placed in drying room (chamber) with the temperature of 15 ^{o}C and 15% humidity. The moisture determination procedure was repeated weekly until the seeds reach the final moisture content level. Seeds with initial MC were taken and placed in three different environments (room temperature (20 ^{o}C), +4 ^{o}C and -10 ^{o}C) (IBPGR, 1982).

Pretreatment and growth media

Mechanical scarification, cold water soaking, and hot water soaking were the three pretreatment techniques used to determine the best way for seed germination. Forty seeds were used for each type of pretreatment. For mechanical scarification, the seed coats were mechanically opened with sterile pliers to allow water to enter and promote germination. For the cold-water treatment, seeds were immersed for 24 hours in a beaker filled with cold water at room temperature. Following the removal of the water, the seeds were sown on the top filter paper using a petri dish. For the hot water treatment, seeds were placed in beakers with water that had been heated to about 100 ° C. The beakers were then allowed to stand for five minutes before the seeds were sown.

Germination and viability test

The top of paper method was used to test the viability of the seeds as the germination test is the most accurate and reliable method in the viability test. Petri dishes, forceps, and other materials were sterilized by wiping with 80 % alcohol to limit fungal contamination (Sutherland et al., 2002). Filter paper was placed on labelled petri dish. The seeds were spread uniformly on the surface of the filter paper using forceps, ensuring that none of the seeds touch each other and the appropriate amount of distilled water was added. The petri dish was covered to ensure that there is no air lock resulting from excess moisture on the covers and placed in incubator maintained at 30^{o}C. For the germination test using sand, a plastic tray was filled with enough amount of sterilized sand and seeds were placed in holes and covered with sand (Figure 3).

The test was run for a month and germinated seeds were recorded in every five days. At the end of the experiment, germinated seeds, viable but not germinated seeds and seeds that failed to germinate, and dead seeds were counted. The percentage of germination and viability were calculated using the following formula (FAO and IPGRI, 1994).

$$\%\ of\ germination = \frac{number\ of\ germinated\ seeds}{total\ number\ of\ seeds\ sown} * 100$$

$$\%\ of\ viability = \frac{number\ of\ germinated\ seeds + number\ of\ viable\ seeds}{total\ number\ of\ seeds\ sown} * 100$$

Figure 3. Germination test for the selection of best germination media and pretreatment. Germination test using top of paper method (A) and seed sowing using sterilized sand (B).

Data analysis

The R statistical software version 4.2.2 was used for data analysis. Analysis of variance (ANOVA) was used to evaluate the percentages of seed germination and effects of pretreatment, moisture content, storage temperature, and storage period. One-way ANOVA was used to determine the interaction effect of two and more factors on the germination of seeds.

RESULTS

Thousand seed weight determination

The mean thousand seed weight (TSG) of *A. schimperi* was 657.5 grams. The total number of *A. schimperi* seeds was 4550 (Table 1). About 2991 grams of *A. schimperi* seed was required for base and active collection.

Table 1. Thousand seed weight determination and amount of seeds required for storage of *A. schimperi*.

TSG Trial 1	TSG Trial 2	Mean TSG	Total number of seeds	Total amount of seed required for storage
651.64	663.36	657.5	4550	2991

TSG – thousand seed weight (in grams)

Seed moisture content

The initial moisture content (MC) of *A. schimperi* was 55.8 %. This MC declined significantly to 13.5%, 8.9 %, 8.4 % and 8.1 % in the first, second, third and fourth drying week, respectively (Figure 1). In this experiment, the final MC of *A. schimperi* seed was 7.4% at constant temperature and humidity. The decrease in moisture content of the seeds showed an inverted J-shaped pattern from initial to final MC. Four MC levels were selected for storage behaviour investigation; initial (55.8 %), intermediate (13.5%), intermediate (8.4%) and final (7.4%) MC.

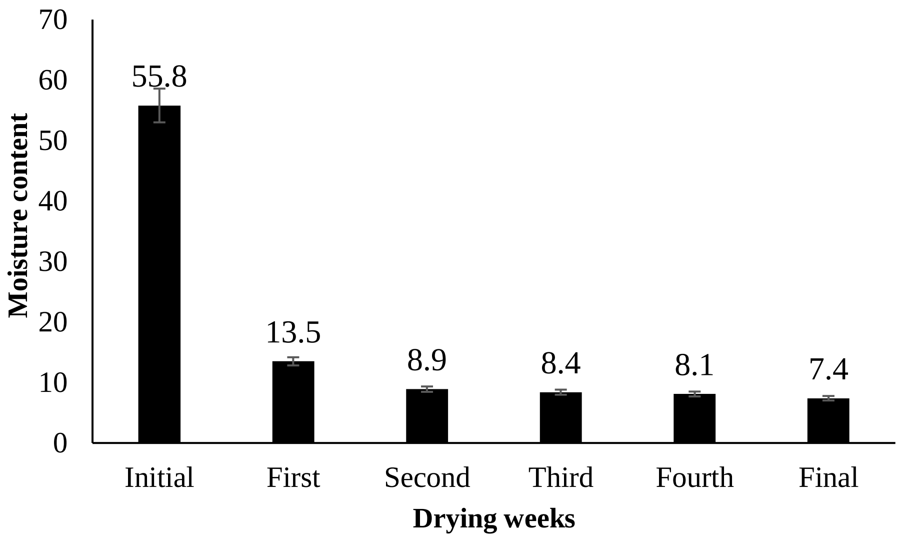

Figure 4. Moisture content of *A. schimperi* seeds in different drying weeks including initial and final MC.

Germination pretreatment and media

The initial germination test indicated variation in germination and viability among different pretreatment methods ($p < 0.01$). The highest seed germination and viability was recorded in cold water treatment with 95% of germination followed by the control (without any treatment) with 90% of germination (Table 2). The lowest seed germination was recorded in scarification method with 75% of germination. Seed germination in sand media was 85%. Since seed germination using on top of paper method and cold-water treatment gave better results, these were selected for the rest of the investigation.

Table 2. Different pretreatments used and percent of germination.

Treatments	Total seeds sown	Germinated seeds	Fresh seeds	Dead seeds	Germinated seeds (%)	Viable seeds (%)
Scarification	40	30	0	10	75	75
Coldwater	40	38	0	2	95	95
Hot water	40	34	0	6	85	85
Control	40	36	0	4	90	90
Sand	40	34	2	4	85	90
Total	200	172	2	26	86	87

Effect of moisture content on seed viability

The percentage of viability of *A. schimperi* seed was significantly affected by moisture content level (p = 0.01). The highest percentage of viability was recorded in MC level of 55.8 (90%) followed by MC 13.5 and 8.4 MC with 2.5% of viability (Figure 5). At final MC level of 7.4%, the percentage of viability becomes zero. That means the seed has totally died and indicated that the species was sensitive to change in MC level.

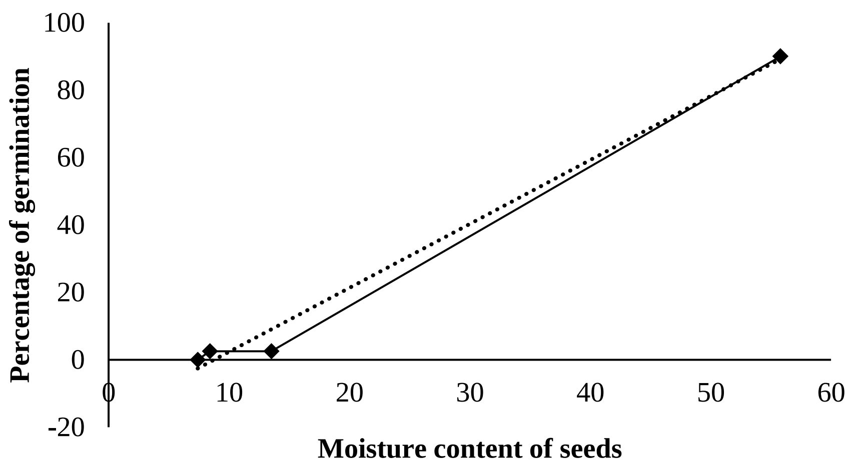

Figure 5. Percentage of germination in different moisture content level (55.8%, 13.5%, 8.4% and 7.4%) of *A. schimperi* seeds.

Effect of storage temperature and duration on seed viability

The interaction effect of storage temperature and duration on seed viability was not significant (P=0.06). At the third month of storage, 2.5% of seed germination was recorded in all storage temperatures (-10 ^{0}C, + 4

^{0}C and +20 ^{0}C) tested. In the rest of storage durations, total loss of seed viability was observed except in the sixth month at room temperature (+20 ^{0}C) (Table 3). This indicated that the seeds have lost their viability with decrease in temperature and increase in storage duration.

Table 3. Effects of storage temperature (-10^{0}C, +4^{0}C and 20^{0}C) and duration (3, 6, 9, 12 months) on seed germination and viability.

Storage environment	Storage months	Percentage of germination
- 10^{0}C	3	2.5
	6	0
	9	0
	12	0
+ 4^{0}C	3	2.5
	6	0
	9	0
	12	0
+20^{0}C (Room temperature)	3	2.5
	6	2.5
	9	0
	12	0

Effect of seed storage duration on seed viability

Seed storage duration was the other determinant factors that affected seed germination and viability of *A. schimperi* seeds. However, the effect is not significant (p = 0.44) (Figure 6). The percentage of seed viability in *A. schimperi* seed at initial moisture content (55.8) was 90%. The percentage of viability of the seed decreased significantly at the third month of storage to 7.5% of germination. At the sixth, ninth and twelfth month of storage, the percentage of seed germination and viability become nearly zero.

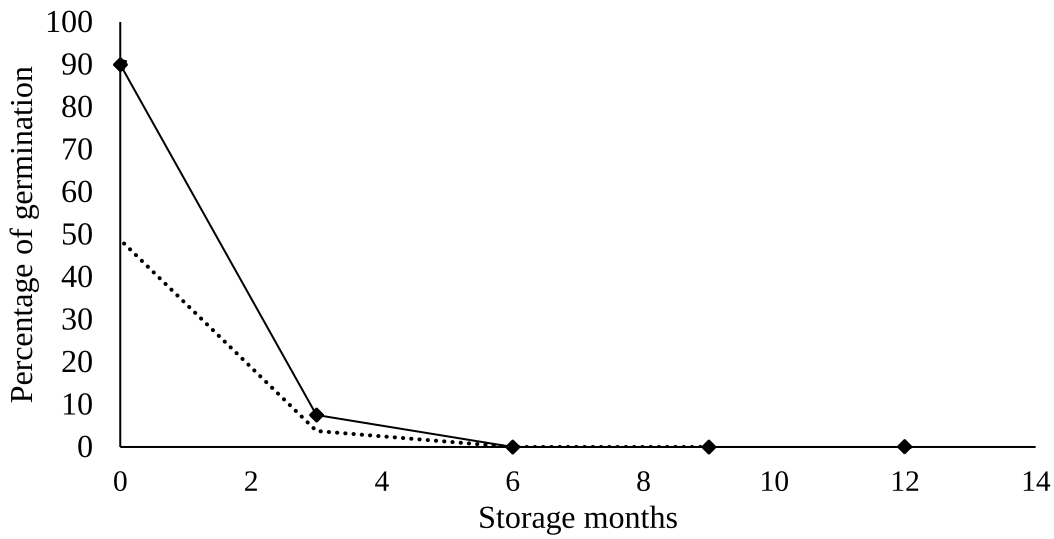

Figure 6. Percentage of germination in different storage duration (months).

DISCUSSION

The findings in this research showed that the seed of *A. schimperi* are most probably recalcitrant seed type in terms of storage behaviour. As a result, long term storage of *A. schimperi* seed in cold storage is not feasible. Species with recalcitrant seeds were often harvested at or above 30% moisture content, and they rarely sustained desiccation below 12–10% moisture level (Hong and Ellis, 1996). Once dried to a moisture content below a reasonably high critical value, recalcitrant seeds no longer have a chance of surviving (Chin et al., 1989). In this study, the initial moisture content of *A. schimperi* (55.8) reflected behaviour of recalcitrance and it has lost its viability almost totally within a week of dehydration. Seed death may result from either the moisture content dropping below a particular critical level or just a normal physiological decline over time (Chin et al., 1989). Recalcitrant seeds depend on plasmodesmata for intercellular transport because of their large seed size, which can be interrupted by drying and result in a loss of viability subsequently (Livingston, 1964). Numerous elements, such as plant species, environmental conditions during seed development and maturation, physiological state of the seed at maturity, and seed storage techniques, have an impact on seed viability (Hong et al., 1996; Pritchard and Dickie, 2003; Probert et al., 2009). However, seed moisture content, temperature, and oxygen concentration in the storage environment have the greatest impact on how long seeds last (Ibrahim and Roberts, 1983; Roberts, 1972; Roos, 1980).

The viability of *A. schimperi* seeds was highly affected by a decrease in seed moisture level. Seed moisture content is highly influenced by change in temperature and relative humidity (Kauth and Biber, 2015). As seed moisture content decreased, longevity and viability increased with exception of highly desiccation sensitive species (Finch-Savage, 2003). Decrease in moisture content leads to oxidation of lipids and protein resulting in seed deterioration (Ranganathan and Groot, 2023). Additionally, dehydration alters the structure of enzymes, damages cell membranes, and releases phenolic chemicals that decrease enzyme activity (Loomis and Battaile, 1966).

The seed germination of *A. schimperi* was affected by the time of storage and the storage temperature (P=0.06). Recalcitrant tropical species seeds typically lose viability from a few weeks to several months (Berjak and Pammenter, 2008). Though seed viability potential of many species is increased by decrease in temperatures, it has been observed that low temperatures to have negative effects on the viability of severs recalcitrant species (Ranganathan et al., 2015). The occurrence of a temperature-dependent, rate-limiting process, the lack of which results in lethal metabolic disruption; the lack of a protective component in seeds resistant to chilling; and the release of a toxic substance as a result of alterations in membrane permeability brought on by freezing are suggested to be the possible reasons for the rapid decline in viability of recalcitrant seeds due to decrease in temperatures (Chin et al., 1989).

CONCLUSION

The present study examines the seed germination pretreatment and storage behaviour of *A. schimperi* tree species. To our knowledge, recalcitrance has never been previously documented in the *A. schimperi* tree species. Hence this study will contribute to selecting appropriate methods and strategies for conservation of the species. The seed of *A. schimperi* exhibits non-physiological dormancy, which makes it simple to germinate in a controlled setting with media such as sand or filter paper. The results also showed that the seed germination potential of *A. schimperi* is significantly influenced by the seed moisture content, storage temperature, and their interactions. Low storage temperature and dehydration reduced the species' seed vigor. Before being dehydrated and stored at low temperatures, *A. schimperi* seeds with a moisture content of 55.8% can germinate to a significant degree. We recommend the option of using cryopreservation for the long-term storage of *A. schimperi* seeds.

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REFERENCES

Berjak, P. and Pammenter, N.W. 2008. From Avicennia to Zizania: Seed recalcitrance in perspective, *Annals of Botany*, **101(2):213–228**, doi.org/10.1093/aob/mcm168.

Bussmann, R.W., Paniagua-Zambrana, N.Y. and Njoroge, G.N. 2021. *Acokanthera schimperi* (A. DC.) Benth. & Hook. f. ex Schweinf. Euphoprbiaceae. In: R.W. Bussmann, ed., *Ethnobotany of the mountain regions of Africa*. Springer International Publishing, Cham, pp. 107–109.

Chin, H.F., Krishnapillay, B. and Stanwood, P.C. 1989. Seed Moisture: Recalcitrant vs. Orthodox seeds. In: P.C. Stanwood, M.B. McDonald, ed., *Seed moisture*. Crop Science Society of America, Madison, WI, USA, pp. 15–22.

Finch-Savage, W.E. 2003. Seed development onset of desiccation tolerance. In: *Encyclopedia of Applied Plant Sciences*. Elsevier, pp. 1279–1284.

Hedberg, I. 1996. Flora of Ethiopia and Eritrea. In: L.J.G. van der Maesen, X.M. van der Burgt, J.M. van Medenbach de Rooy, ed., *The biodiversity of African plants*. Springer, Dordrecht. doi.org/10.1007/978-94-009-0285-5_104.

Hong, T.D. and Ellis, R.H. 1996. A protocol to determine seed storage behavior, IPGRI Technical Bulletin. International Plant Genetic Resources Institute, Rome.

Hong, T.D., Linington, S. and Ellis, R. H. 1996. Seed storage behaviour a compendium. International Plant Genetic Resources Institute, Rome.

Ibrahim, A.E. and Roberts, E.H. 1983. Viability of lettuce seeds: I. Survival in hermetic storage. *Journal of Experimental Botany*, **34:620–630**, doi.org/10.1093/jxb/34.5.620.

IBPGR, 1982. The design of seed storage facilities for genetic conservation. [online] available at https://cropgenebank.sgrp.cgiar.org/images/file/learning_space/genebankmanual1.pdf [accessed June 13 2023].

IPGRI and FAO. 1994. Genebank standards. International Plant Genetic Resources Institute, and Food and Agriculture Organization Rome.

ISTA (2005) International rules for seed testing. International Seed Testing Association. Bassersdorf, Switzerland.

Kassa, B., Ambaw, D.M. and Mengistu, G. 2020. Wound healing effect of *Acokanthera schimperi* Schweinf (Apocynaceae) methanol leaf extract ointment in mice and its in-vitro antioxidant activity. *Clinical Pharmacology: Advances and Applications*. **12:213-222**, doi.org/10.2147/CPAA.S288394.

Kauth, P.J. and Biber, P.D. 2015. Moisture content, temperature, and relative humidity influence seed storage and subsequent survival and germination of *Vallisneria americana* seeds. *Aquatic Botany*, **120: 297-303**, doi.org/10.1016/j.aquabot.2014.09.009.

Livingston, L.G. 1964. The nature of plasmodesmata in normal (living) plant tissue. *American Journal of Botany* **51:950–957**, doi.org/10.1002/j.1537-2197.1964.tb06723.x.

Loomis, W.D. and Battaile, J., 1966. Plant phenolic compounds and the isolation of plant enzymes. *Phytochemistry*, **5:423–438**, doi.org/10.1016/S0031-9422(00)82157-3.

Mekonnen, Z., Habtemariam, K., Woldeamanuel, T. and Asfaw, Z. 2018. Analysis of observed and perceived climate change and variability in Arsi Negele District, Ethiopia. *Environment, Development and Sustainability*, **20**, doi.org/10.1007/s10668-017-9934-8

Mewded, B., Legesse, A., Ahmed, S., Shibabaw, A., Negussie, H., Getachew, E., Seyum, A. and Teka, Y. 2022. Moisture content and temperature effect on the conservation and germination of *Mimusops kummel* seeds: an exploratory data analysis. *Journal of Global Ecology and Environment*, **15(2):31-39**.

Mohammed, T., Erko, B. and Giday, M. 2014. Evaluation of antimalarial activity of leaves of *Acokanthera schimperi* and *Croton macrostachyus* against *Plasmodium berghei* in Swiss albino mice. *BMC Complementary and Alternative Medicine* **14:314**, doi.org/10.1186/1472-6882-14-314.

Pritchard, H. and Dickie J.B. 2003. Predicting seed longevity: the use and abuse of seed viability equations. In: R.D. Smith, ed. Seed conservation: turning science into practice. Royal Botanic Gardens Kew, UK.

Probert, R., Daws, M. and Hay, F. 2009. Ecological correlates of ex situ seed longevity: A comparative study on 195 species. *Annals of Botany*, **104:57–69**, doi.org/10.1093/aob/mcp082.

Ranganathan, U. and Groot, S.P.C. 2023. Seed longevity and deterioration. In: M. Dadlani, D.K. Yadava. eds., Seed S*cience and technology: Biology, production, quality*. Springer Nature, Singapore, pp. 91–108, doi.org/10.1007/978-981-19-5888-5_5.

Ranganathan U.R., Aadhavan, E.K. and Faisal, M.M. 2015. Understanding poor storage potential of recalcitrant seeds. *Current Science*, **108(11):2023-2034**.

Rao, N.K., Hanson, J., Dulloo, M.E., Ghosh, K., Nowell, D. and Larinde, M. 2006. Manual of seed handling in genebanks: Handbooks for Genebanks No. 8. Bioversity International. Rome, Italy.

Roberts, E.H. 1972. Storage environment and the control of viability. In: E.H. Roberts ed., Viability of seeds. Springer Netherlands, Dordrecht, pp. 14–58. doi.org/10.1007/978-94-009-5685-8_2.

Roos, E.E. 1980. Physiological, biochemical and genetic changes in seed quality during storage. *Hortscience*, **15:781–784**, doi.org/10.21273/HORTSCI.15.6.781.

Shih, M.-D., Hoekstra, F.A. and Hsing, Y.I.C. 2008. Late embryogenesis abundant proteins. *Advances in Botanical Research*. **48:211–255**, doi.org/10.1016/S0065-2296(08)00404-7.

Sutherland, J.R., Diekmann, M. and Berjak, P. 2002. Forest tree seed health for germplasm conservation, IPGRI technical bulletin. International Plant Genetic Resources Institute, Rome.

Teketay, D. 2005. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: II. Forest disturbances and succession. *Tropical Ecology*, **46(1):45-64**.

PREDICTING POTENTIAL DISTRIBUTION OF *PARTHENIUM HYSTEROPHORUS* UNDER CLIMATE CHANGE SCENARIOS IN ETHIOPIA

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ABSTRACT: The high spread of *Parthenium hysterophorus* in Ethiopia had become a major threat to the various suitable ecosystems in the country. Therefore, the identification of factors facilitating its distribution and mapping of suitable habitats is vital to design future management strategies. A total of 1,352 *P. hysterophorus* occurrence records and 19 bioclimatic variables were collected from different sources. An ecological niche model was used to map the current and future (the years 2050 and 2070) habitat suitability for *P. hysterophorus*. The ensemble model revealed that 72.8%, 18.5%, 6.8%, and 1.9% of the total area were unsuitable, low, moderate, and high suitable habitats under current climate conditions respectively. The high suitability area by 2050 and 2070 under Representative Concentration Pathway (RCP) scenarios RCPs 2.6, 4.5, and 8.5 will be 8.4%, 8.5%, 9.6%, and 7.8%, 6.1%, and 16%, respectively. We found that the current predicted unsuitable area will probably be vulnerable to loss of 176.9%, 188% and 125% under RCPs 2.6, 4.5, 8.5 respectively by 2050 whereas vulnerable loss of 166.7%, 164.7%, 3,500% were predicted under RCPs 2.6, 4.5, and 8.5 by 2070. The mean diurnal range, precipitation of the coldest quarter, and annual mean temperature were identified as the most determinant of the distribution of the species. The threats of this species on native biodiversity and the economy will be high in the future unless management action is undertaken. Our study suggests that all relevant stakeholders should be organized to combat the expansion of this invasive species to new areas particularly protected areas.

Keywords: Invasion, Habitat suitability, Climate change, Species distribution models, Ethiopia.

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INTRODUCTION

Biological invasion has become one of the key causes of environmental degradation and economic loss in most of the countries across the world (Simberloff, 2011). It is one of the main drivers of biodiversity loss (Thapa et al., 2018) and its impacts have been predicted to increase even further under global climate change (Singh et al., 2011; Bukombe et al., 2013). Climate change refers to statistically identifiable changes in the mean and/or variability of climate properties that persist over an extended period, particularly over decades (Ochieng et al., 2016). It will exacerbate the long-term distribution of invasive species (Bellard et al., 2018). Species are forced to adapt or to alter their geographical range tracking climatic changes, and many species migrations have already been documented in a variety of habitats under climate change conditions (Grimm, 2013). In comparison with native species, invasive species are more likely to adapt to new climatic conditions because they are usually abundant, tolerate a broad range of climatic conditions, cover wide geographic ranges, and have highly competitive biological traits (Subhashni and Lalit, 2014). Both expansion and contraction of habitat suitability of invasive species following climate change were reported (Roger et al., 2015; Ahmad et al., 2019). Therefore, more detailed studies need to be undertaken to analyze how climate change will modify the existing plant invasions (Manzoor et al., 2018).

Parthenium hysterophorus L. (Asteraceae) is an annual or perennial (short-lived) flowering plant that degrades natural ecosystems and causes a significant hypersensitive reaction in people and domesticated livestock (Adkins and Shabbir, 2014). It's native to America and is thought of as a serious weed globally (Bukombe et al., 2013). Currently, it is known to occur in several countries in Africa including Ethiopia, South Africa, Kenya, Tanzania, Somalia, Madagascar, and Mozambique (Zuberi et al., 2014). The high spread of *P. hysterophorus* in Ethiopia has become a major threat to the various suitable ecosystems including flora, fauna, and microbes (Shiferaw et al., 2018).

The threat of *P. hysterophorus* has been increasing with the rapid growth of globalization and the changing climate (Tamiru, 2017). *P. hysterophorus* weed can invade a range of crops, and a particular concern is the invasion of cereal crops such as rice, wheat, maize, teff and sorghum (Adkins and Shabbir, 2014). In such crops, it is reported to reduce yields by as much as 40% in India and by as much as 40% and above in Ethiopia, if not managed (McConnachie et al., 2011). The yield reduction in Ethiopia is a serious threat to Ethiopian food security. The species is a major problematic weed to agriculture due to its ability to invade large areas in a short space of time (Amare, 2018).

A variety of factors have been suggested to influence invasiveness. These factors govern the extent to which a species introduced outside its native range may overcome various biotic and abiotic barriers to determine its establishment in a new environment (Singh et al., 2011). Resource availability may be a key factor that determines the susceptibility of a community to invasion by exotic species (Meyer et al., 2021). The fluctuating resources hypothesis states that a plant community becomes more liable to invasion whenever there is a rise in the number of unused resources (Zhang et al., 2022). Climate and edaphic conditions are thought to be fundamental determinants of the potential distribution of invasive species (Ahmad et al., 2016). Physiological properties and reproductive and life-history characteristics are also cited frequently to clarify the invasiveness of plant species (Zuberi et al., 2014).

The importance of the factors role in explaining the success of plant invaders, their establishment, spread, and better performance within the invaded range depends on the sort of species, spatial scale, and native environmental context (Funk, 2013; Kueffer et al., 2014); Van Kleunen et al., 2015). This happens as a result of the effect of the complex interactions between plants, climate, and soil at an area scale (Kardol et al., 2014; Svenning et al., 2014), thereby influencing invasiveness. Therefore, factors that influence patterns of invasion observed in one site or continent are also difficult to extrapolate to other continents or sites because those observations are specific to a time, place, and spatial scale. Strikingly, factors that deter or promote the establishment and invasion of *P. hysterophorus* under climate change are not well known in developing countries including Ethiopia, as most studies were conducted in developed countries.

Despite its recognition to be as among the worst invasive alien species, its potential distribution under climate change scenarios in Ethiopia has yet to be investigated. It is therefore important to understand its spatial distribution across landscapes and predict its potential shifts and impacts on various ecosystems. Species distribution models (SDMs) are scientifically proven tools for assessing and predicting the impacts of climate change on the distribution of flora and fauna from occurrence (presence only or presence and absence) data (Thapa et al., 2018).

This study is therefore designed (1) to explore the potential distribution of *P. hysterophorus* under current and three future Representative Concentration Pathway scenarios (RCP 2.6, RCP 4.5, and RCP 8.5) for the two time periods (2050 and 2070), and (2) to identify if environmental factors (precipitation and temperature) derived bioclimatic variables influenced the invasion of *P. hysterophorus*.

MATERIALS AND METHODS

Study area description

Ethiopia is located in the horn of Africa between 3° 15' N and 48º E. Ethiopia is in the tropical zone lying between the equator and the tropics of cancer. It has an area of about 1.13 million km^2. In Ethiopia, the climate varies mostly with altitude, and it goes from the hot and arid climate of the lowlands to the cool climate of the plateau (Fazzini et al., 2015). Lying just north of the equator, the country experiences little variations in temperature throughout the year (Figure 1).

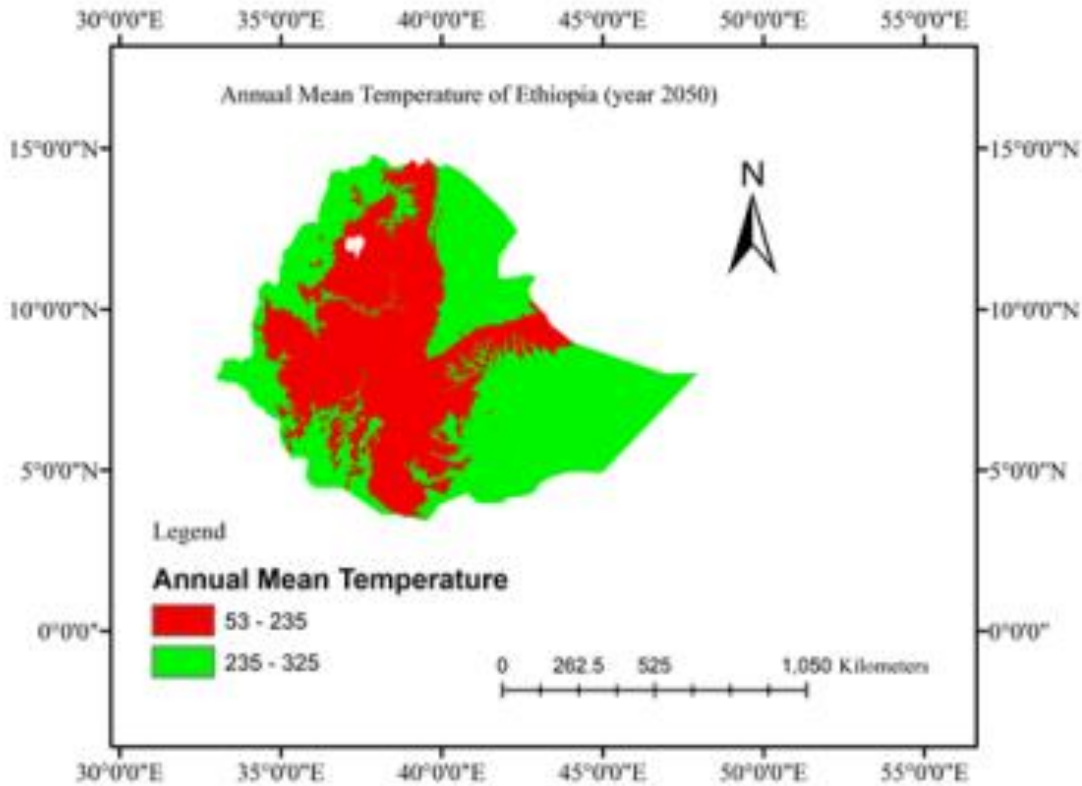

Figure 1. Location of the study area.

Ethiopia has three different traditional climate zones based on elevation (Fazzini et al., 2015). The primary climate zone is *Kolla* (tropical zone) is below 1830 meters in elevation and has an average annual temperature of about 27ºC with an annual rainfall of about 510 millimetres. The Danakil Depression is about 125 meters below sea level and also the hottest region in Ethiopia where the temperature climbs up to 50ºC. The second is *Woina Dega* (Subtropical zone). This includes the highlands areas of 1830 to 2440 meters in elevation have an average annual temperature of about 22ºC with annual rainfall between 510 and 1530 millimetres. The third is *Dega* (cool zone) is above 2440 meters in elevation with an average annual temperature of about 16ºC with annual rainfall between 1270 and 1280 millimetres. The major soil types vary in response to parent materials and landforms among other factors of soil formation. Rock types affect soil texture and mineralogy while landform affects the spatial distribution of soils due to complex erosion and depositional processes. Nitisols and Vertosols dominate basalt formation whereas leptosols exclusively dominate hill slopes irrespective of the geological formation (Abebe et al., 2023). This physiographic diversity makes the country suitable for the invasion of *P. hysterophorus*.

Parthenium hysterophorus occurrence point data collection

A total of 1,184 species occurrence records of *P. hysterophorus* were obtained from the Global Biodiversity Information Facility (GBIF) database (www.gbif.org) https://doi.org/10.15468/dl.eh3qux, (accessed on 29 August 2020). To check the ground truth, we collected 168 occurrences of the species in the study area employing a Global Positioning System (GPS). The species occurrence points were collected at 500 m successive intervals. We selected a maximum of 1 km sampling interval to reduce sampling bias using the spatial thinning method. Finally, a total of 1,162 occurrence records were used to run the models.

Environmental variables

Nineteen current bioclimatic variables were downloaded from the WorldClim database version 2 (www.worldclim.org) at a spatial resolution of 30 seconds approximately~1km^2 (Table 1). These variables were computed from minimum, maximum, and average values of monthly, quarterly, and annual ambient temperatures further as precipitation values recorded from 1970 to 2000 (Fick and Hijmans, 2017). For future projection, we used bioclimatic variables representing simulations for 3 climate change RCP scenarios (RCP 2.6, RCP 4.5, and RCP 8.5) for the two time periods (2050 and 2070).

Table 1. The 19 bioclimatic variables downloaded from the WorldClim database.

List of variables	Code	Scaling	Units
Annual Mean Temperature	Bio1	10	Degrees Celsius
Mean Diurnal Range (Mean of monthly	Bio2	10	Degrees Celsius
Isothermality (BIO2/BIO7)	Bio3	100	Degrees Celsius
Temperature Seasonality (Standard Deviation)	Bio4	100	Degrees Celsius
Max Temperature of Warmest Month	Bio5	10	Degrees Celsius
Min Temperature of Coldest Month	Bio6	10	Degrees Celsius
Temperature Annual Range (BIO5-BIO6)	Bio7	10	Degrees Celsius
Mean Temperature of Wettest Quarter	Bio8	10	Degrees Celsius
Mean Temperature of Driest Quarter	Bio9	10	Degrees Celsius
Mean Temperature of Warmest Quarter	Bio10	10	Degrees Celsius
Mean Temperature of Coldest Quarter	Bio11	10	Degrees Celsius
Annual Precipitation	Bio12	1	Millimeters
Precipitation of Wettest Month	Bio13	1	Millimeters
Precipitation of Driest Month	Bio14	1	Millimeters
Precipitation Seasonality	Bio15	100	Fraction
Precipitation of Wettest Quarter	Bio16	1	Millimeters
Precipitation of Driest Quarter	Bio17	1	Millimeters
Precipitation of Warmest Quarter	Bio18	1	Millimeters
Precipitation of Coldest Quarter	Bio19	1	Millimeters

Sources: Fick et al, 2017

Modelling approach

Several species distribution models (SDM) are widely employed in many ecological applications (Ahmad et al., 2019). These models establish relationships between occurrences of species and biophysical and environmental factors in the study area. However, one model does not provide the most effective predictive accuracy in SDM. Therefore, an ensemble of many SDM algorithms was employed to produce better accuracy. We used five modeling algorithms analyzed under the SDM packages in R statistical software (a generalized linear model (GLM), support vector machine (SVM), a random forest algorithm (RF), boosted regression tree (BRT), and multivariate adaptive regression splines (MARS)) to construct most effective predictive accuracy.

As these bioclimatic variables are often correlated, it ends up in poor model performance and misleading interpretations (Dormann et al., 2013). Therefore, Pearson's correlation analysis was performed. Then, each pair of highly correlated variables with Pearson's parametric statistic ($r^2 < 0.8$) was selected for modelling the species distribution. After pairwise correlations among predictors variables with correlations below $|r| < 0.8$ were considered unproblematic. We removed the highly correlated pairs and also the minor variable after assessing variable importance. Finally, seven variables remained for model fitting.

Forecasting accuracy and substantiation of the models were assessed supported area under receiving operator curve (AUC), and sensitivity (true positive rate) against 1-specificity (false positive rate). AUC values range from 0 to 1. The values of AUC between 0 - 0.5 were considered poor, 0.5 - 0.8 fair, 0.8 - 0.9 good and 0.9 - 1 superb while validating the importance of variables (Ahmad et al., 2019). Only the model with a good forecasting index and AUC > 0.8 was built for the final ensemble model from the projection outputs (Gallien et al., 2012).

The Receiving Operator Curve (ROC) provides another technique for the assessment of the accuracy of ordinal score models. The development of the ROC utilizes all possible thresh for classifying the scores into confusion matrices, obtaining each matrix sensitivity and specificity; and then comparing sensitivity against the corresponding proportion of false positives (equal to 1-specificity). Evaluation of accuracy was assessed by dividing the presence points into training and test points per species. The training dataset comprised 70% of the data and therefore the test dataset comprised 30% of the species occurrence points. Finally, one ensemble projection of the current and six ensemble projections of future habitat suitability reminiscent of three RCPs (2.6, 4.5, and 8.5) for the years 2050 and 2070 were obtained.

Image classification and analysis

The changes in habitat suitability between current and future climate conditions were assessed under all RCPs by identifying climate suitability areas where suitable habitat was projected in the present and future.

The habitat suitability changes for the current and future were examined under four categories to spot areas of unsuitable, low, moderate, and high suitability using ArcGIS 10.6. We used two indicators to research the role of climate change on the distribution of *P. hysterophorus*. The primary indicator was changes in the percentage of the unsuitable area (AC) and the second indicator was the share gain or loss area for 2050 and 2070 (CH). The indicators were calculated as per Sintayehu et al. (2020) using the subsequent formula.

$$\mathrm{AC} = \frac{\mathrm{Af} - \mathrm{AC}}{\mathrm{AC}} \times 100\% \qquad (1)$$

$$\mathrm{CH} = \frac{\mathrm{Af} - \mathrm{AC}}{\mathrm{Af}} \times 100\% \qquad (2)$$

Where Af is the predicted suitability area in the future and, AC is the non-suitable predicted habitat under current climate conditions.

Variable's importance

The variable's grandness provides statistics on the significance of each variable in the model. It was assessed by employing the getVarimp function in R software with permutation-based on two metrics (Pearson Correlation and AUC) method. The percent contribution of each variable was calculated as 1-correlation values by keeping the other variables constant (Harisena et al., 2021).

RESULTS

Model performance

The mean of each model was presented (Table 2). The final ensemble model has a mean AUC value of 0.91. This showed the prediction accuracy of the model was high.

Table 2. The model mean performance based on AUC value in predicting the potential distribution of *Parthenium hysterophorus* in Ethiopia.

Model	GLM	SVM	RF	BRT	MARS
AUC	0.84	0.89	1	0.9	0.9

'AUC' = Area Under Receiving Operating Curve, GLM = Generalized Linear Model, SVM = Supportive Vector Machines, RF = Random Forest Algorithm, BRT = Boosted regression Tree, MARS = Multivariate adaptive regression splines.

The mean area under the receiving operating curve for the training dataset and test dependence of the ensemble model were 0.85 and 0.84 respectively (Figure 2). The mean area under the ROC of the ensemble model showed that the prediction accuracy of the model in predicting the potential distribution of the *P. hysterophorus* under changing climate change was 0.84 under current climate conditions.

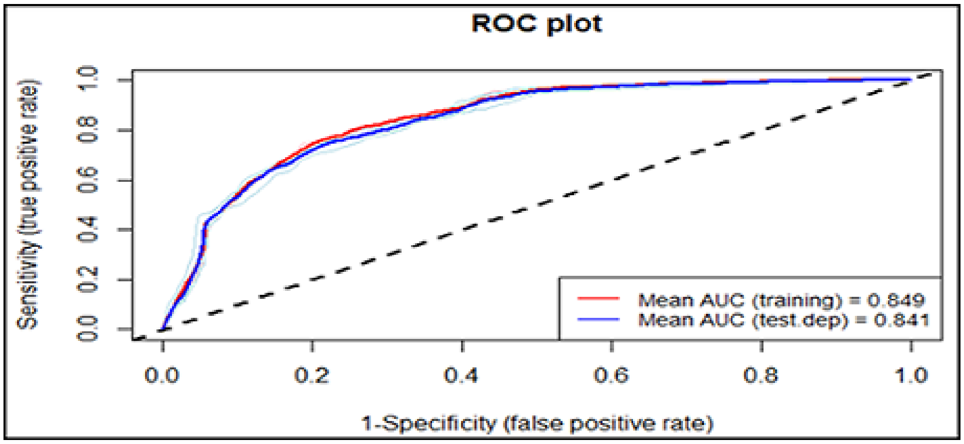

Figure 2. Average sensitivity (true positive rate) vs. 1-specificity (false positive rate) of *Parthenium hysterophorus* in Ethiopia.

Current predicted suitable area

The current habitat suitability area percentages and distribution map are shown in Table 2 and Figure 3. The ensemble model showed that 72.8% of the area of the country is not suitable for the distribution of *P. hysterophorus.* The model also depicted that 18.5%, 6.8%, and 1.9% areas were identified as low, moderate, and high suitability areas for the *P. hysterophorus* respectively.

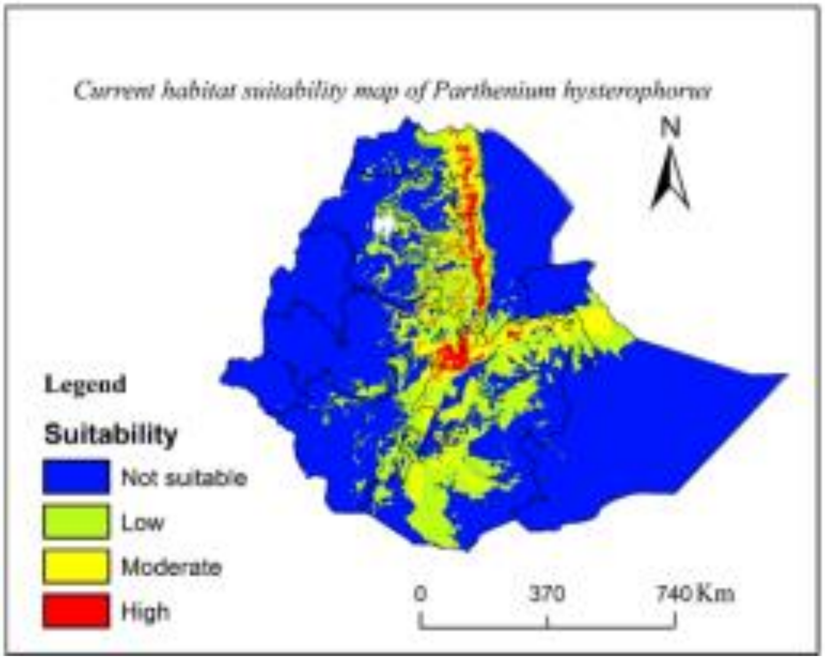

Figure 3. Current habitat suitability maps for *P. hysterophorus* in Ethiopia.

Future predicted *P. hysterophorus* habitat suitability area

Compared to the current habitat suitability, the total predicted area of high suitability by 2050 will gradually increase by 8.4%, 8.5%, and 9.6% under RCP (2.6, 4.5, and 8.5) respectively (Table 3, Figure 5). Similarly, the highly suitable area by 2070 will be expected to increase by 7.8%, 6.1%, and 16% under RCPs (2.6, 4.5, and 8.5) respectively. But compared to the future predicted high suitable area of the year 2050, the predicted high suitable area by 2070 will be expected to decrease by 0.6 % and 2.4% under RCP (2.6 and 4.5) respectively.

Table 3. Percent (%) predicted area of habitat suitability of *Parthenium hysterophorus* under changing climate scenarios for current and future periods (2050 and 2070) in Ethiopia.

Years	Scenarios	Total suitability (%)			
		Unsuitable	Low	Moderate	High
Current	_	72	19.0	6.8	2.0
2050	RCP2.6	26	44	21.7	8.4
	RCP4.5	25	44.6	21.7	8.5
	RCP8.5	32	43.4	15	9.6
2070	RCP2.6	27	44.5	20.7	7.8
	RCP4.5	27.2	45.7	21	6.1
	RCP8.5	2.0	25	57	16

Variable's importance

The evaluation of the selected variable importance (training gain) of the selected variables based on correlation metrics is shown in Figure 4. Among the selected variables, the mean diurnal range (Bio2) (53.9%) followed by precipitation of coldest quarter (Bio19) (26.1%) and annual mean temperature (Bio1) (11.4%) contributed a high percentage.

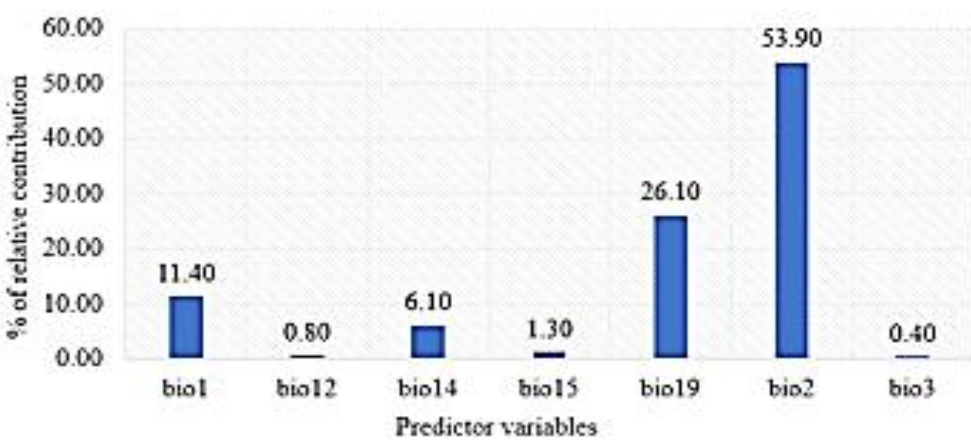

Figure 4. Mean percent contribution of each variable to the ensemble model for prediction of suitable habitat for *P. hysterophorus* in Ethiopia (bio1= annual mean temperature, bio12= annual precipitation, bio14 = precipitation of driest month, bio15 = precipitation seasonality, bio19 = precipitation of coldest quarter, bio2 = mean diurnal range, bio3 = isothermality).

Vulnerability assessment or change detection

Future habitat suitability projections map under RCP (2.6, 4.5, and 8.5) for the years 2050 and 2070 showed that compared to current habitat suitability, the future unsuitable habitat will be invaded under future climate change scenarios by *P. hysterophorus* (Figure 5). In 2050, the current unsuitable habitat will be vulnerable to invasion by -176.9%, -188%, and -125% under RCP 2.6, 4.5, and 8.5, respectively (Table 4).

Table 4. Percentage of change (gain or loss) of habitat suitability of *Parthenium hysterophorus* for current and future periods (2050 and 2070) under RCP (2.6, 4.5, and 8.5) in Ethiopia.

Decades	Scenarios	% Change compared to the current suitability			
		Unsuitable	Low	Moderate	High
Current	-	-	-	-	-
2050	RCP2.6	-176.9	56.8	68.7	76.2
	RCP4.5	-188	57.4	68.7	76.5
	RCP8.5	-125	56.2	54.7	79.2
2070	RCP2.6	-166.7	57.3	67.1	74.4
	RCP4.5	-164.7	58.4	67.6	67.2
	RCP8.5	-3,500	24	88.1	87.5

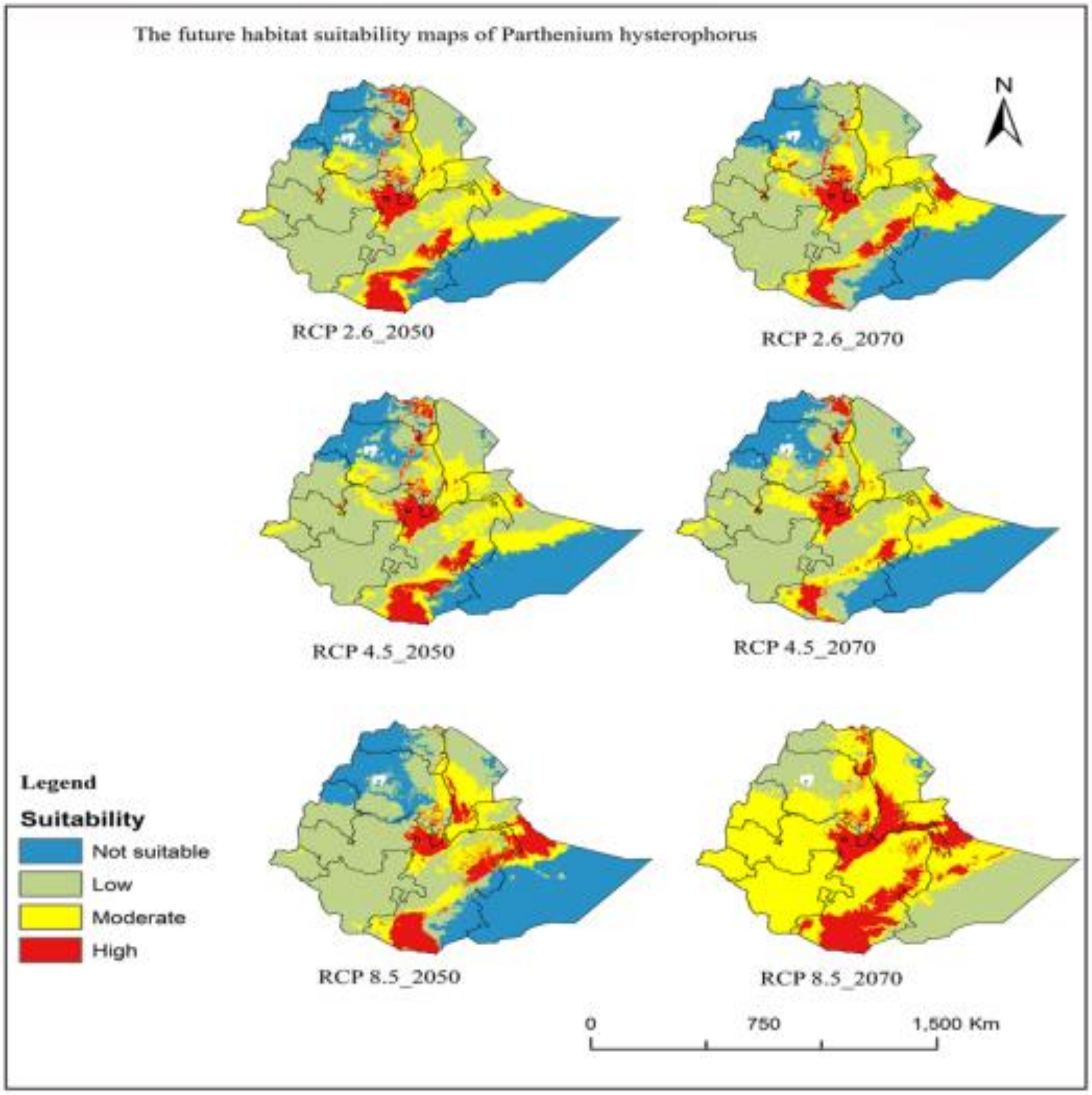

Figure 5. Future habitat suitability projections map for *Parthenium hysterophorus* under RCP (2.6, 4.5, and 8.5) for 2050 and 2070 years in Ethiopia.

DISCUSSION

The statistical models within their respective high means scores from the five algorithms were used to construct the final ensemble model by applying a weighted mean approach. The result indicated the robustness of the model in discriminating the habitat suitability of *P. hysterophorus* with greater accuracy (AUC = 0.9). The suitability maps revealed that most parts of the country's regions including the West, East, and North Shewa, west and east Hararge around Dire Dawa of Oromia Regional State, Eastern Amhara bordering the Afar region, Northern Somali, Sidama, and southeast of Tigray regions are currently under the invasion of *P. hysterophorus*. The current prediction map showed a high invasion of *P. hysterophorus* was observed along the long road running from Addis Ababa to the Northern region and the eastern parts of the country.

A narrowing of overall habitat suitability for the study species was seen under future climate change scenarios with highly suitable habitats under RCP 4.5 for the year 2070. This agreed with some recent studies that have reported a loss of range expansion of invasive plant species including *P. hysterophorus* following climate change. A study conducted to predicting the invasion potential and niche dynamics of *P. hysterophorus* in India under projected climate change reported the reduction of range expansion of the species under future climate change (Ahmed et al., 2019). However, climate change is favoring the range expansion of invasive species rather than range reduction (Finch et al., 2021). It creates favorable conditions for the spread of invasive species by altering the invasion pathways and environmental factors such as temperature and precipitation which facilitate the range expansion of the invasive species.

The ensemble model outputs revealed that the mean diurnal range (53.90%) followed by precipitation of the coldest quarter (26.10%) and annual mean temperature (11.40%) were the most predictor variables of the potential distribution of the study species. Hence, these variables are the most determinant of the distribution of *P. hysterophorus* in Ethiopia. This is in agreement with some studies that state both temperature and precipitation-derived bioclimatic variables as the main governors of the distribution of invasive species including *P. hysterophorus* (Ahmad et al., 2019; Sintayehu et al., 2020).

A reduction of habitat suitability for the *P. hysterophorus* was seen under future climate change scenarios with highly suitable habitats under RCP 2.6 and 4.5 for the year 2070 compared to 2050. Our study is in agreement with a few other studies that have reported a reduction in the distribution of invasive species both globally as well as regionally following climate change (Panda et al., 2018; Ahmad et al., 2019). Roger et al. (2015) conducted a study on naturalized alien species in Australia and concluded that the majority of the species showed a decrease in habitat suitability under climate change.

Several studies concluded that climate change encourages the distribution of invasive species by creating favorable conditions, shifts in species range, and species richness (Panda et al., 2018; Sintayehu et al., 2020). Similarly, our ensemble model showed that temperature and precipitation-derived bioclimatic variables will facilitate the distribution and spread of *P. hysterophorus* by creating favorable conditions in Ethiopia. The decrease in precipitation coupled with an increase in temperature under projected climate change may adversely affect the distribution of *P. hysterophorus*. The temperature fluctuation (the mean diurnal range) coupled with moisture availability of the driest month associated with this country may facilitate its distribution under climate change.

Parthenium hysterophorus expands along roadsides and spreads quickly due to disturbance by vehicular movement. It distributes quickly along the roadsides due to transportation. The seed is spread by animals, wind, water, vehicles, agricultural and road construction machinery and fodder as well as other human activities (Masum et al., 2013). The protected areas, which are in direct contact with the road in Ethiopia like Awash National Park, Babile Elephant Sanctuary, Nechisar National Park, and others are at high risk of invasion by the species. Agricultural lands, and protected areas found around the suitable habitat of *P. hysterophorus* including mountains and hot areas are also predicted to be at high risk of invasion under RCP.4.5 and RCP 8.5 in 2050 and 2070.

CONCLUSION AND RECOMMANDATION

Parthenium hysterophorus had already been distributed in several parts of Ethiopia causing adverse effects on biodiversity, ecosystem, agriculture, and therefore the economy. Fast and mass invasion could be a key issue of this invasive species, thanks to its rapid dispersion. If climates change, then the species may disperse into novel climate regions. It's predicted to invade most parts of the country under future temperature change scenarios. Mapping the suitability habitat is critical in identifying environmental factors for the distribution of *P. hysterophorus* and helps in developing management strategies. For decision-makers, our risk maps essentially represent a prioritization surface that guides them in allocating tactics aimed at detecting and controlling the spread of the species. The risk maps are very useful to structure an early detection survey and to describe the potential extent of the impact. Monitoring, early detection, and rapid response are the foremost effective options for *P. hysterophorus* management.

DISCLAIMER

Findings, opinions conclusions, and recommendations expressed in this material are those of the Authors and the funding agencies do not accept any liability in this regard.

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REFERENCES

Abebe, B., Ayalew, D., Regassa, A. and Taye, G. 2023. Geology and Geomorphology In: S. Beyene, A. Regassa, B. B. Mishra, and M. Haile, ed., *The Soils of Ethiopia*. Springer International Publishing. pp. 51–69.

Adkins, S., and Shabbir, A. 2014. Biology, ecology and management of the invasive parthenium weed (*Parthenium hysterophorus* L.). *Pest Management Science*, **70(7):1023–1029**.

Ahmad, R., Khuroo, A. A., Hamid, M., Charles, B. and Rashid, I. 2019. Predicting invasion potential and niche dynamics of *Parthenium hysterophorus* (Congress grass) in India under projected climate change. *Biodiversity and Conservation*, 28(8–9), 2319–2344. doi.org/10.1007/s10531-019-01775-y.

Ahmad, Z., Khan, S. M., Abd Allah, E. F., Alqarawi, A. A. and Hashem, A. 2016. Weed species composition and distribution pattern in the maize crop under the influence of edaphic factors and farming practices: A case study from Mardan, Pakistan. *Saudi Journal of Biological Sciences*, **23(6), 741–748**. doi.org/10.1016/j.sjbs.2016.07.001.

Amare, T. 2018. Allelopathic effect of aqueous extracts of Parthenium (*Parthenium hysterophorus* L.) parts on seed germination and seedling growth of maize (Zea Mays L.). *Journal of Agriculture and Crops*, **4(12):157-163**. doi.org/10.32861/jac.412.157.163.

Bellard, C., Jeschke, J. M., Leroy, B. and Mace, G. M. 2018. Insights from modeling studies on how climate change affects invasive alien species geography. *Ecology and Evolution*, **8(11):5688–5700**.

https://doi.org/10.1002/ece3.4098.

Bukombe, J., Mweya, C. N., Mwita, M., Kija, H. and Fyumagwa, R. 2013. Prediction of suitable habitat for potential invasive plant species *Parthenium hysterophorus* in Tanzania: A Short Communication. *International Journal of Ecosystem*, **4:82–89**.

Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J. R. G., Gruber, B., Lafourcade, B., Leitão, P. J., Münkemüller, T., Mcclean, C., Osborne, P. E., Reineking, B., Schröder, B., Skidmore, A. K., Zurell, D. and Lautenbach, S. 2013. Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, **36(1), 27–46**. doi.org/10.1111/j.1600-0587.2012.07348.x

Fazzini, M., Bisci, C., and Billi, P. 2015. The climate of Ethiopia. In: P. Billi, ed., Landscapes *and landforms of Ethiopia* Edition: World geomorphological landscapes, Springer Verlag, pp. 65–87. doi.org/10.1007/978-94-017-8026-1_3.

Fick, S. E. and Hijmans, R. J. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, **37(12):4302–4315**. doi.org/10.1002/joc.5086.

Finch, D. M., Butler, J. L., Runyon, J. B., Fettig, C. J., Kilkenny, F. F., Jose, S., Frankel, S. J., Cushman, S. A., Cobb, R. C., Dukes, J. S., Hicke, J. A. and Amelon, S. K. 2021. Effects of climate change on invasive species. In: T.M Poland, T.P. Weynand, D.M. Finch, C.F. Miniat, D.C. Hayes, V.M. Lopez, ed., *Invasive Species in Forests and Rangelands of the United States*. Springer International Publishing, pp. 57–83. doi.org/10.1007/978-3-030-45367-1_4.

Funk, J. L. 2013. The physiology of invasive plants in low-resource environments. *Conservation Physiology*, **1(1):1–17**. doi.org/10.1093/conphys/cot026.

Gallien, L., Douzet, R., Pratte, S., Zimmermann, N. E. and Thuiller, W. 2012. Invasive species distribution models - how violating the equilibrium assumption can create new insights. *Global Ecology and Biogeography*, **21(11):1126–1136**. doi.org/10.1111/j.1466-8238.2012.00768.x

Grimm, N. B., Chapin, F. S., Bierwagen, B., Gonzalez, P., Groffman, P. M., Luo, Y., Melton, F., Nadelhoffer, K., Pairis, A., Raymond, P. A., Schimel, J., & Williamson, C. E. (2013). The impacts of climate change on ecosystem structure and function. *Frontiers in Ecology and the Environment*, *11*(9), 474–482. doi.org/10.1890/120282

Harisena, N. V., Groen, T. A., Toxopeus, A. G. and Naimi, B. 2021. When is variable importance estimation in species distribution modelling affected by spatial correlation? *Ecography*, **44(5):778–788**. doi.org/10.1111/ecog.05534.

Kardol, P., Dickie, I. A., St. John, M. G., Husheer, S. W., Bonner, K. I., Bellingham, P. J. and Wardle, D.

A. 2014. Soil-mediated effects of invasive ungulates on native tree seedlings. *Journal of Ecology*, **102(3): 622–631**. doi.org/10.1111/1365-2745.12234.

Kueffer, C., Daehler, C., Dietz, H., McDougall, K., Parks, C., Pauchard, A., Rew, L., Alexander, J., Arévalo, J. R., Cavieres, L., Edwards, P. J., Haider, S., Loope, L., Mack, R. N., Milbau, A., Naylor, B. J., Otto, R., Pollnac, F., Reshi, Z. A. and Walsh, N. 2014. The mountain invasion research network (MIREN): Linking local and global scales for addressing an ecological consequence of global change. *GAIA - Ecological Perspectives for Science and Society,* **23(3):263–265**. doi.org/10.14512/gaia.23.3.11.

Manzoor, S. A., Griffiths, G., Iizuka, K. and Lukac, M. 2018. Land cover and climate change may limit invasiveness of *Rhododendron ponticum* in Wales. *Frontiers in Plant Science*, **9:664**. doi.org/10.3389/fpls.2018.00664.

Masum, S. M., Hasanuzzaman, M. and Ali, M. H. 2013. Threats of *Parthenium hysterophorus* on agro-ecosystems and its management : a review. *Interantional Journal of Agriculture and Crop Sciences*, **6(11):684–697**.

Mayer, S., Callaham, M.A., Stewart, J.E., and Warren , S.D. 2021. Invasive species response to natural and anthropogenic disturbance. In: T. M. Poland, T. Patel-Weynand, D. M. Finch et al. ed., *Invasive species in forests and rangelands of the United States*. Springer, pp. 85-110.

Mcconnachie, A. J., Strathie, L. W., Mersie, W., Gebrehiwot, L., Zewdie, K., Abdurehim, A., Abrha, B., Araya, T., Asaregew, F., Assefa, F., Gebre-Tsadik, R., Nigatu, L., Tadesse, B. and Tana, T. 2011. Current and potential geographical distribution of the invasive plant *Parthenium hysterophorus* (Asteraceae) in eastern and southern Africa. *Weed Research,* **51(1):71–84**. doi.org/10.1111/j.1365-3180.2010.00820.x.

Ochieng, A. O., Nanyingi, M., Kipruto, E., Ondiba, I. M., Amimo, F. A., Oludhe, C., Olago, D. O., Nyamongo, I. K. and Estambale, B. B. A. 2016. Ecological niche modelling of Rift Valley fever virus vectors in Baringo, Kenya. *Infection Ecology and Epidemiology*, ***6*(1)**. doi.org/10.3402/IEE.V6.32322.

Panda, R. M., Behera, M. D. and Roy, P. S. 2018. Assessing distributions of two invasive species of contrasting habits in future climate. *Journal of Environmental Management,* **213:478–488**. doi.org/10.1016/j.jenvman.2017.12.053.

Roger, E., Duursma, D. E., Downey, P. O., Gallagher, R. V., Hughes, L., Steel, J., Johnson, S. B. and Leishman, M. R. 2015a. A tool to assess potential for alien plant establishment and expansion under climate change. *Journal of Environmental Management,* **159:121–127.** doi.org/10.1016/j.jenvman.2015.05.039.

Shiferaw, W., Demissew, S. and Bekele, T. 2018. Invasive alien plant species in Ethiopia: ecological impacts on biodiversity a review paper. *International Journal of Molecular Biolo*gy, **3(4):171-178**. doi.org/10.15406/ijmboa.2018.03.00072.

Simberloff, D. 2011. How common are invasion-induced ecosystem impacts? Biological Invasions. *Biological Invasions*, **13:1255–1268**. doi.org/10.1007/s10530-011-9956-3

Singh, R. P., Singh, R. K. and Singh, M. K. 2011. Impact of Climate and Carbon Dioxide Change on Weeds and their Management-A Review. *Indian Journal of Weed Science*, **43:1–11**.

Sintayehu, D. W., Dalle, G. and Bobasa, A. F. 2020. Impacts of climate change on current and future invasion of Prosopis juliflora in Ethiopia: environmental and socio-economic implications. *Heliyon*, **6(8)**, e04596. doi.org/10.1016/j.heliyon.2020.e04596.

Subhashni, T. and Lalit, K. 2014. Impacts of climate change on invasive *Lantana camara* L. distribution in South Africa. *African Journal of Environmental Science and Technology*, **8(6):391–400**. doi.org/10.5897/ajest2014.1705.

Svenning, J. C., Gravel, D., Holt, R. D., Schurr, F. M., Thuiller, W., Münkemüller, T., Schiffers, K. H., Dullinger, S., Edwards, T. C., Hickler, T., Higgins, S. I., Nabel, J. E. M. S., Pagel, J. and Normand, S. 2014. The influence of interspecific interactions on species range expansion rates. *Ecography*, **37(12):1198–1209**. doi.org/10.1111/j.1600-0587.2013.00574.x.

Tamiru, G. 2017. Invasive alien weed species distribution, impacts on agriculture, challenge and reaction in Ethiopia: A Review. *Journal of Biology, Agriculture and Healthcare*, **7(7):136-146**.

Thapa, S., Chitale, V., Rijal, S. J., Bisht, N., and Shrestha, B. B. 2018. Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PLoS ONE*, ***13*(4)**. doi.org/10.1371/journal.pone.0195752.

van Kleunen, M., Dawson, W., Essl, F., Pergl, J., Winter, M., Weber, E., Kreft, H., Weigelt, P., Kartesz, J., Nishino, M., Antonova, L. A., Barcelona, J. F., Cabezas, F. J., Cárdenas, D., Cárdenas-Toro, J., Castaño, N., Chacón, E., Chatelain, C., Ebel, A. L. and Pyšek, P. 2015. Global exchange and accumulation of non-native plants. *Nature*, **525(7567):100–103**. doi.org/10.1038/nature14910.

Zhang, Z., Liu, Y., Hardrath, A., Jin, H. and van Kleunen, M. 2022. Increases in multiple resources promote competitive ability of naturalized non-native plants. *Communications Biology*, ***5*(1):1–6**. doi.org/10.1038/s42003-022-04113-1.

Zuberi, M. I., Gosaye, T. and Hossain, S. 2014. Potential threat of alien invasive species : *Parthenium hysterophorus* L . to subsistence agriculture in Ethiopia. *Sarhad Journal of Agriculture*, **30(1):9**.

DIVERSITY OF WOODY PLANT SPECIES IN THE GALLERY FORESTS OF BABESSI SUB DIVISION, NORTH-WEST REGION OF CAMEROON

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ABSTRACT: This study aimed at documenting and comparing the floristic diversity and forest structure of woody plant species in the four villages in Babessi subdivision, Ngo-ketunjia Division. Systematic sampling was used to collect data from 8 main plots (50 m×50 m each). Two main plots were selected from each of the four villages. Each main plot was then subdivided into five subplots of 10 m×10 m. By moving through these subplots all the woody plant species with diameter at breast height (DBH) superior or equal to 5 cm (1.3 m above the ground) were individually measured and recorded. The parameters of floristic diversity such as species richness, basal area, Pielou's evenness index, Sorensen similarity coefficient, Simpson's index of dominance, the Shannon-Wiener index, and frequency were calculated using Microsoft Excel 2016. A total of 105 woody plant species distributed in 80 genera and 37 families were inventoried. The 3 most important families in terms of similarity, diversity and dominance were Rubiaceae (13), Euphorbiaceae (12) and Fabaceae (10). Five species were of high conservation priority. Bangolan had the highest number of woody plant species diversity (49) and abundance followed by Baba I (45), Babessi (37) and Babungo (25) respectively. Anthropogenic activities, unsustainable means of exploitation coupled with urban growth were major threats to the gallery forests of this locality. Therefore, it is recommended that appropriate timely measures should be taken by all stakeholders to sustain utilization of vegetation of the study area so as to maintain its biodiversity and provision of ecosystem services.

Keywords: Biodiversity, Gallery Forest, species diversity, and woody plants.

INTRODUCTION

Gallery forests are part of tropical savannas and mostly found in narrow forest patches in proximity to streams and rivers (González-Abella et al., 2021). Gallery forests in savannas represent one of the few examples of naturally fragmented tropical forests (Ajonina et al., 2020). They are generally rich in woody plant species like, *Ficus* spp, *Vitex doniana*, *Polyscias fulva*, which form a ridge of forests and are postulated

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to have provided refugee for tropical forest species in areas deforested during the Pleistocene drought (Ajonina et al., 2020).

Forests are important to humans as humans depend directly or indirectly on forest products like firewood, food, medicine and other non-timber forest products (Megeyand, 2013) as well as other ecosystem services (regulatory, supporting and cultural) (González-Abella et al., 2021). Thus, there is a rapid and increasing change in land use for local subsistence in the Western Highland regions of Cameroon which has resulted to an unprecedented destruction and fragmentation of riparian areas of gallery forests resulting in a few scattered forest patches on the landscape (Solefack et al., 2018).

There has been a growing interest of ecological research in ascertaining the processes underlying the assembly, dynamics, and structure of ecological communities. Such information is useful not only in understanding plant community structure and species distribution variability at a spatial scale (Solefack et al., 2018) but also in providing insight into the environmental requirements of the tree species needed for successful ecological restoration and biodiversity conservation.

This ecosystem has been under serious pressure from the local people. Despite the rich biodiversity of this ecosystem, there exists very little documentation on the species composition and vegetation structure in the Western Highlands of Cameroon. There are very few studies on the potentials of this ecosystem in the world (González-Abella et al., 2021; González-Rivas et al., 2006) and in Cameroon (Ajonina et al., 2020; Zeh et al., 2019). A threat on this ecosystem could lead to the local extinction of some globally threatened plant species, disturbance of watershed and affect livelihoods. These studies have not given enough information on the diversity of woody plants and vegetation structure in the Western Highlands of Cameroon. Furthermore, no research work has been done on the diversity of woody plant species in the gallery forests of Babessi subdivision. This work therefore aims to contribute to the documentation of biodiversity focusing on the diversity, forest structure and distribution of woody plants species in the gallery forests of the four villages of Babessi subdivision in Cameroon.

MATERIALS AND METHODS

Description of the study area

Babessi subdivision is located in Ngo-ketunjia division in the North West Region of Cameroon between latitude $6^{0}01'00''$ to $6^{0}8'00''$ N and longitude $10^{0}34'00''$ to $10^{0}24'00''$ E (Njoya, 2016). It consists four villages: Babungo, Baba I1, Babessi and Bangolan (Figure 1). The climate of this Subdivision is made of two distinct seasons: dry season starting from November to February and the rainy season from March to October. The average rainfall in this area varies from 1270mm to 1778mm. The maximum annual temperature varies from 27.2 to 33^{0}C and the minimum range between 7.8 and 15.0^{0}C. The main vegetation type is savannah with short stunted trees. Natural gallery forests are found in some valleys alongside man planted vegetation like palm trees and raffia palms (Njoya, 2016).

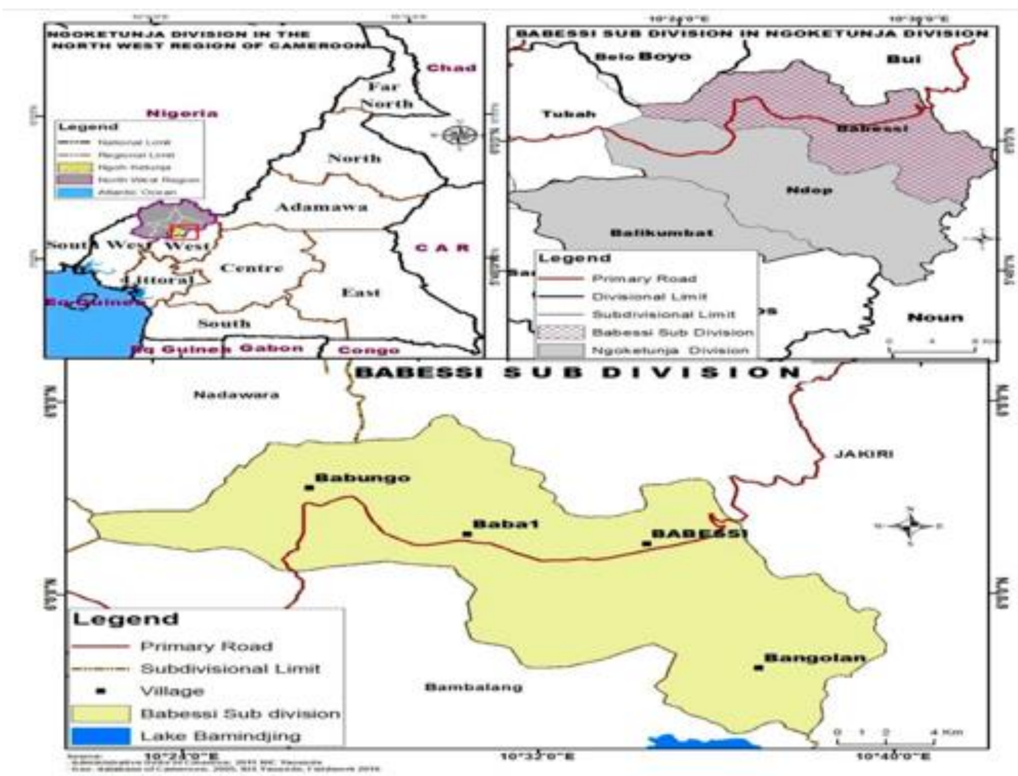

Figure 1. Map of Babessi subdivision showing the study site.

Source: Administrative units of Cameroon 2011. NIC Yaounde Geo-data base of Cameroon 2005 NIS Yaounde, field work 2016.

Sample collection

Data were collected in the four villages that constitute Babessi subdivision that is Bangolan, Babessi, Baba I and Babungo from March to May 2018. In each village, two gallery forests were selected for the study based on information gathered from villagers on the state of conservation, and the potential diversity. In each gallery forest, 2 main plots of 50 m × 50 m (2500 m^2) were mapped out using a decameter in the most conserved part of the gallery forest at a distance of 100 m apart. After taking the coordinates using a global positioning system (GPS Garmin etrex 10), each plot was subdivided into 10 m ×10 m subplots. A botanic walk was made through all the subplots and all the woody plant species of diameter DBH ≥ 5 cm at 1.3 m above the ground were identified, individually measured, and the number of individual trees in each subplot was counted for all the villages in the subdivision and recorded. The DBH of the woody plant species at 1.3 m above the ground were measured using a diameter tape. Trees were identified to species level where possible by an experienced taxonomist and the use of vegetative characters and field guides such as Manuel de Botaniques forsetiere d'Afrique (Letouzey, 1982) and samples of unidentified trees were collected and added to those already identified for proper identification at the Cameroon National Herbarium Yaoundé (YA). This permitted the establishment of a preliminary checklist of woody plant species in the gallery forest of the Subdivision. The conservation status of each species was investigated using the Red data book of the flowering plants of Cameroon (Onana et al., 2011).

Data analysis

All data were analyzed using Microsoft Excel 2016 of Microsoft office software package version 2.

Comparison of woody plant species diversity

To assess and compare the plant diversity in the Sub-Division and among the villages, some parameters were evaluated, these included: taxonomic richness, Shannon diversity index (H'), Pielou's evenness index (J), Simpson diversity index (D'), Sorensen similarity coefficient (Ss), and Frequency.

Taxonomic richness was evaluated by taking into consideration the number of taxa at the rank of species, genera and families.

The Shannon-Weaver Diversity Index (H') is a measure of the potential for interaction between the species that make up a community. This index takes into account the number of species present and the distribution of individuals within those species. It was calculated using the following formula:

$$H' = -\sum (\mathrm{ni/N}) \ln (\mathrm{ni/N})$$

Where, ni is the number of individuals of a given species i, and N the total number of individuals within the plot.

Pielou's evenness index (J') was calculated using the formula:

$$J' = \mathrm{H'}/\ln \mathrm{S}$$

Where, ln S = H' max (the maximum value of Shannon diversity) is what H' would be if all the species in the community had an equal number of individuals; S is the number of species. When J=1, it indicates little variation within species and J=0 indicates high variation between species.

The Simpson's diversity index (D') is the probability that two randomly selected individuals are of different species. It was calculated using the formula below. The maximum diversity is represented by the value 1 and the minimum diversity by the value 0.

$$D' = 1/\ \Sigma \mathrm{Pi2}$$

Where, Pi = the proportional abundance of species.

Sorensen similarity coefficient (Ss) is an index used for comparing the similarity of two samples in a community. It is calculated using the following formula:

$$Ss = 2\mathrm{C/A + B}\ \times\ 100$$

(where A= number of species found only in site I; B = number of species found only in site II and C = number of species found in both sites).

The relative frequency of species occurrence was calculated using the formula below according to Raunkiaer (1934).

$F = \mathrm{n/N}$

In the equation, “F” represents the frequency, “n” the number of villages where the species was found and “N” the total number of villages involved in the study.

As the degree of presence allows to appreciate the floristic homogeneity of plant communities (Dajet, 1976), the species were classified in four classes since the study was done in four villages. Hence, the follows were adapted Class A: 25% (species present only in one village, considered as rare species), Class B: 50% (species present only in two villages, considered as fairly common species), Class C: 75% (species present only in three villages, considered as common species) and Class D: 100% (species present in the four villages, considered as ubiquitous or very common species).

Assessment of the vegetation structure of the gallery forests

Vegetation structure was determined by parameters such as density, basal area and distribution of individuals by diameter classes (DBH). For density (D), the number of individuals per hectare was calculated by converting the total number of individuals encountered in all plots to equivalent number per hectare, following the formula below where D is the density (stems ha-1), N is the number of stems present on the considered surface and S the area considered.

$D = \mathrm{N}/S$

For diameter classes, the trees were grouped into 7 DBH classes of class size 20 grouped as follows: 5 - 25 cm, 26-45 cm, 46-65cm, 66-85cm, 86-105cm, 106-125 cm and 126-145.

Concerning the basal area (BA) that provides information on the area occupied by tree sections at 1.30 m from the ground, the formula used was:

$BA = \pi/4 \sum (\mathrm{Di}^2)$

Where, BA is basal area (m^2 ha-1) and Di is diameter (m) for each measured tree section (i).

RESULTS

Woody plant diversity and distribution in gallery forests of Babessi subdivision

Preliminary check list of species

A total of 105 woody plant species were identified in the subdivision. The preliminary check list of woody plant species in the gallery forests of this subdivision are presented in Appendix 1. Among these species, five were found to be of conservation priority. These included *Polyscias fulva, Khaya senegalensis, Mitragyna stipulosa, Allophylus hematus* and *Vitellaria paradoxa*.

Taxonomic richness

The distribution of the 105 species identified in the subdivision ranged from 49 in Bangolan to 25 in Babungo. A similar trend followed for the genera with 42 for Bangolan to 22 in Babungo but for the family with 26 in Bangolan to 15 in Babungo (Figure 2).

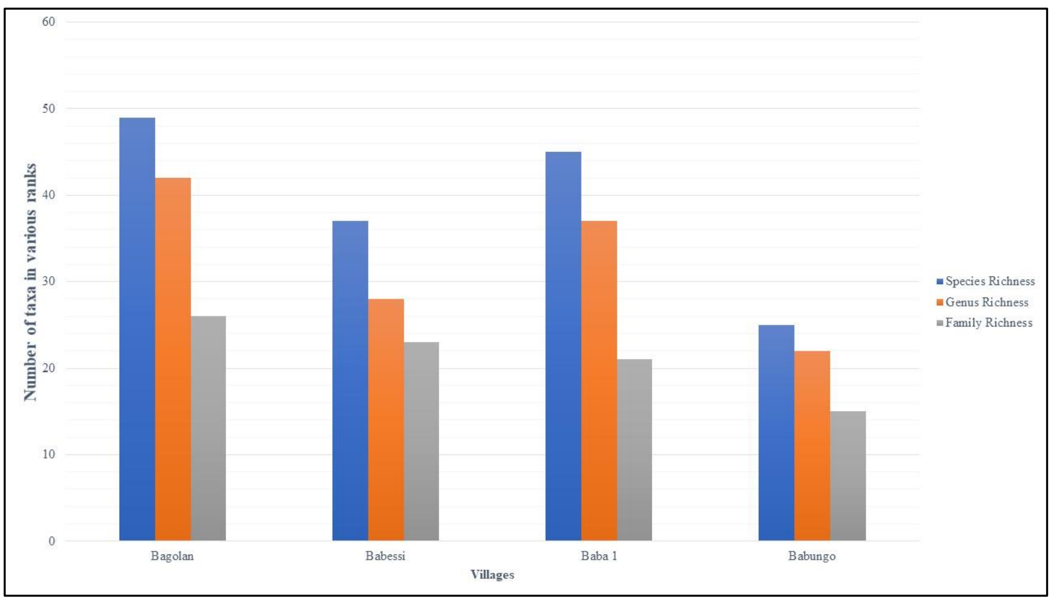

Figure 2. Bar charts showing species, genera and family richness per village.

The distribution of the dominant families in the subdivision varies from one village to another (Figure 3), with families Moraceae, Rubiaceae, Eurpobiaceae and Fabaceae having the highest number of species in the area.

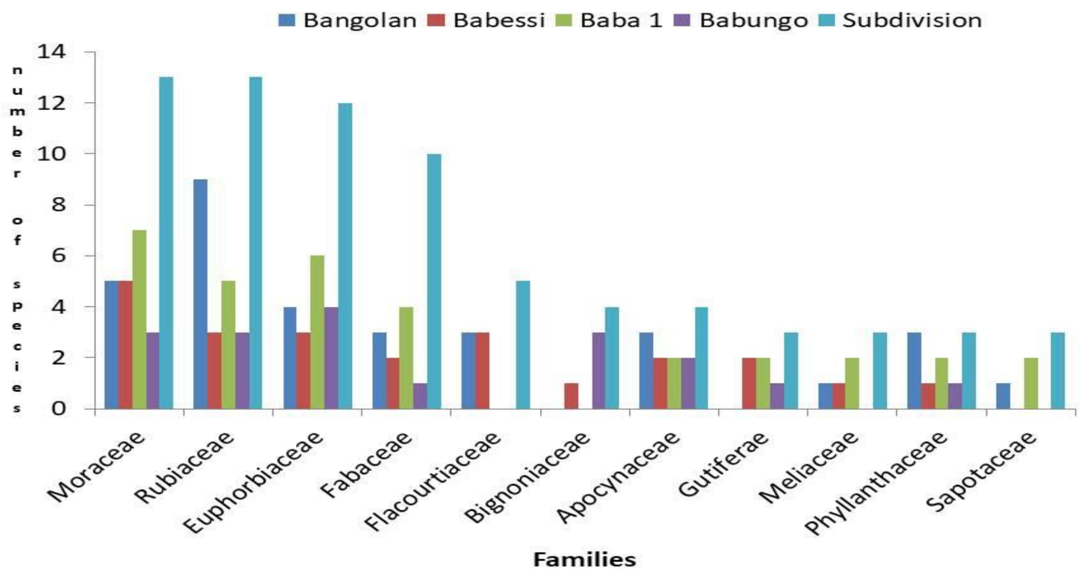

Figure 3. Dominant families and distribution in Babessi Sub-division

Floristic diversity of the different study sites

The floristic diversity of the Subdivision is poor. The Shannon-Weiner diversity index ranged from 3.371 in Baba I to 2.688 in Babungo. Simpson dominance index value ranged between 0.042 - 0.091. The Pielou's evenness index values ranged from 0.538 in Bangolan to 0.705 in Babessi (Table 1).

Table 1. The Shannon-Weiner diversity index (H'), Pielou's evenness index (E), and Simpson's index of dominance (D) of the different study sites.

	No. of Species	H'	D	E
Babungo	25	2.688	0.091	0.589
Babessi	37	3.296	0.047	0.705
Baba I	45	3.371	0.042	0.636
Bangolan	49	2.994	0.083	0.538

Sorenson similarity index

The similarity index values varied from 0.0 652 between Bangolan and Baba I to 0.0949 between Baba I and Babungo being the highest in the subdivision (Table 2).

Table 2. Similarity indices between the four villages.

	Babungo	Babessi	Baba I	Babungo
Babungo	1			
Babessi	0.0677	1		
Baba I	0.0949	0.085	1	
Bangolan	0.0672	0.0815	0.0652	1

Frequency

The histogram below (Figure 4) shows a reversed J-shape. This implies that the species of low frequency (Class A species or rare species) are dominant with 76 species. Those of class B (fairly common species) follow with 12 species. The Common species (Class C) with 6 species have the lowest number of species. These species include among others *Schefflera hierniana*, *Vernonia cinerea*, *Cordia platythyrsa*, *Combretum molle*. The very common species (Class D) include 8 species of which among others are *Voacanga thouarsii*, *Polyscias fulva*, *Canariun schweinfurthii*, *Macaranga occidentalis*

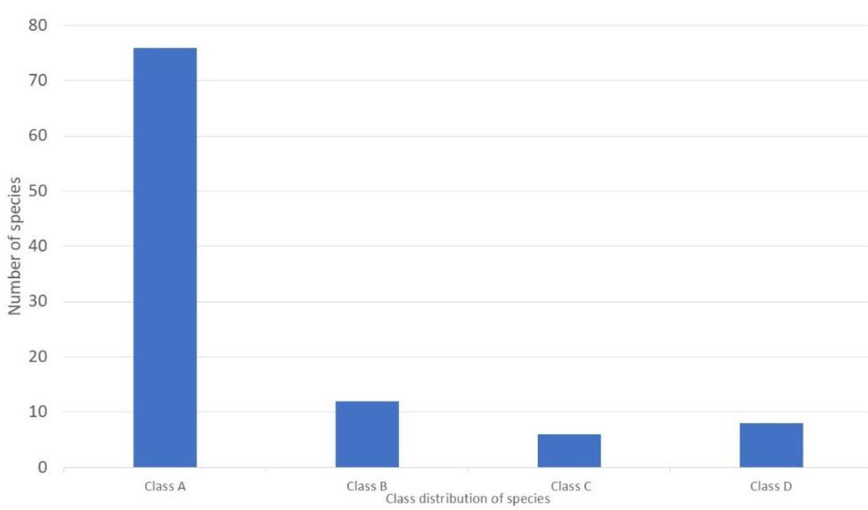

Figure 4. A bar graph of number of occurrence of species according to classes

Assessment of the vegetation structure of the gallery forests

Density of individual trees

The density of trees in the subdivision varies from 254 individuals per hectare (ind/ ha) in Babessi to 500 individuals per hectare in Bangolan. Averagely the density of individual trees is 357 individuals per hectare in the subdivision (Table 3).

Table 3. Density of individual trees per village in hectares

	P1	P2	Total no. of ind / 500 m2	Total no. of ind / ha.
Bangolan	171	79	250	500
Baba I	97	82	179	358
Babessi	72	55	127	254
Babungo	114	44	158	316
Average for the subdivision			178.8	357

Basal area (BA)

The basal area of trees in the subdivision was averagely 38.2 m^2/ha. It varies from 32 m^2/ha in Bangolan to 42.1m^2/ha in Baba I. (Figure 5). The highest BA value of the subdivision was contributed by *Pseudospondias microcarpa* (13.9 m^2 /ha). In Babungo the highest BA was contributed by *Pseudospondias microcarpa* (23.6%), followed by *Vitex doniana* (16.7%), and then *Ficus asperifolia* (14.5%). In Baba I the highest BA was contributed by *Ficus asperifolia* (24.2%), followed by *Pseudospondias microcarpa* (19.9%) then *Vitex doniana*. In Babessi the highest BA was from *Pseudospondias microcarpa* (25.2%) followed by *Ficus asperifolia* (19.9%) and then *Canarium schweinfurthii* (11.7%). In Bangolan the highest BA was contributed by *Olea hostchsteteri* (36.9%) followed by *Polyscias fulva* (6.6%) and then *Macaranga occidentalis* (6.5%).

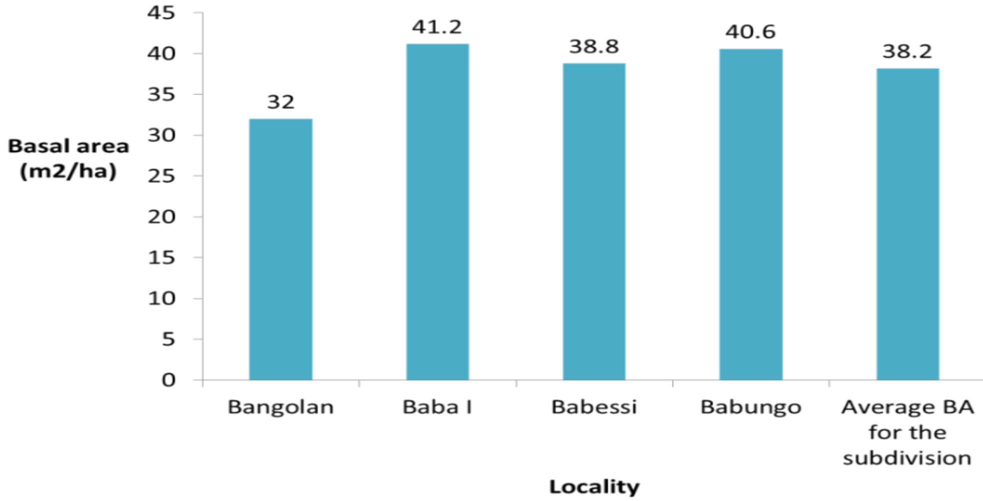

Figure 5. Basal area of woody plants in the subdivision and the different study sites

Diameter size class (DBH)

The distribution of individual trees in different DBH classes showed the highest number of individuals (414) in the lowest DBH size class 5 - 25 cm (53.07 %) and the lowest number of individuals (6) in the highest DBH size class 126-145 (0.77%). The number of individual woody plants decreased with increasing DBH size class, such that the general pattern of DBH class size distribution forms an inverted J-shape for each village and for the subdivision (Figure 6).

The biggest trees in Babessi were represented by *Ficus asperifolia*, *Canarium schweinfurthii* and *Pseudospondias microcarpa* with DBH of 210, 170, and 150 cm respectively. In Bangolan, the biggest trees were represented by *Olea hostchsteteri, Ficus estrangulaire* and *Polyscias fulva* with DBH of 160,110 and 75 cm respectively. In Baba I, we had *Ficus mucuso*, *Pseudospondias microcarpa* and *Ficus asperifolia* with DBH of 130,120 and 110 cm respectively while in Babungo the largest trees were represented by *Hallea stipulosa*, *Ficus asperifolia* and *Pseudospondias microcarpa* with DBH of 150,150 and 110cm respectively.

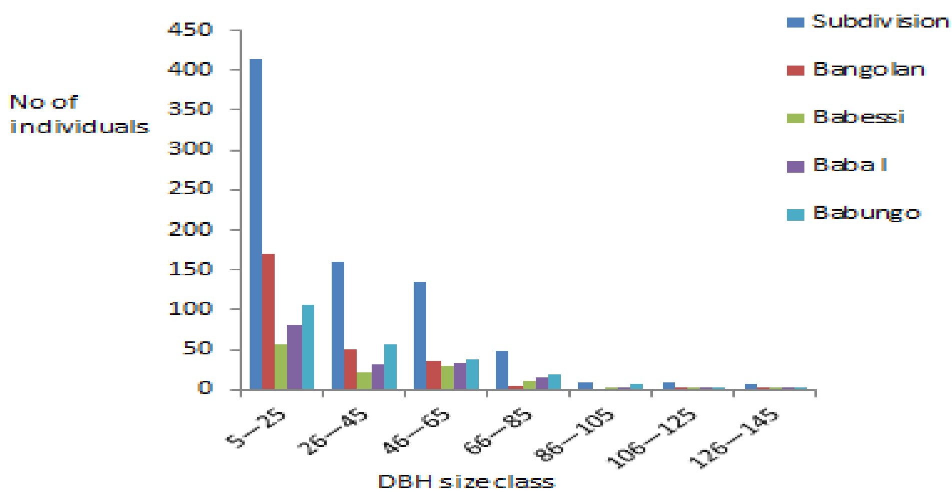

Figure 6. DBH size class distribution of plant species in the different study sites (Bangolan, Babessi, Baba I, Babungo) of the subdivision.

DISCUSSION

Woody tree composition of the subdivision is comprised of at least 105 woody plant species of DBH ≥ 5 cm recorded in the four villages of the subdivision ranging from 25-49 species, 22-42 genera, and 15-26 families. Species richness of woody plants at DBH ≥ 5cm in this area differs from one village to another. This difference is as a result of geographical location and method of exploitation and or protection of the gallery forests by the people over a long period of time (Moutoni, 2019).

The number of woody species found in this study is higher than that of 25 species as was found in Ijim Rigde gallery forest of Bamenda highlands (Ndamason, 2016) and also greater than 60 species found in the Koupa Matapit gallery forest (Soléfack et al., 2018). Also 61 tree species were identified in a gallery forest in the Sudanian savannah ecosystem of Togo (Fousseni et al., 2014). In this study species richness was more in Bangolan (49). This is due to the position of the village at the boundary with Bangourain in the West Region which hinders or reduces the pressure of over exploitation of the forests. As the neighboring village, Bangourain is located in a subdivision of another region with language and sociocultural differences, this reduces the rate of interaction and exploitation of the gallery forests in Bangolan (Moutoni, 2019). The culture of the people through myth and religion reduces the exploitation of the forest to a certain degree of sustainability (Tiokeng et al., 2024). Agriculture and livestock which are major activities here alongside collection of fuel wood go a long way to reduce the richness of gallery forest of this subdivision. This observation was also made during the study of the diversity and uses of woody resources of Koupa Matapit (Atoupka, 2016). The other reasons for differences in diversity of woody plants from one location to another may be related to the intensity and frequency of floods, variation in topography, variations in climate and disturbances regimes imposed on the riparian forest by upland environment (Naiman et al., 2008).

Baba I is second in species richness. This trend is same in all the villages and similar to the findings made in the study of floristic composition, diversity and analysis of forest cover change in the Kedjom-Keku community forest, N.W. Cameroon (Tsitoh, 2018). A similar observation was made in the study of floristic diversity and carbon stock of woody stands in some sacred forests in the West Cameroon Region (Tiokeng et al., 2024). This is probably due to the fact that the gallery forests are often flooded, inaccessible and many resource users here are located far away from the forests. In addition, women and children only visit the gallery forests occasionally. Also, the presence of *Spondianthus preussii* which is poisonous to cattle scares away many grazers from getting close to the gallery forest (Barikpoa et al., 2021).

In Babessi village many gallery forests are being destroyed for agriculture and construction. The gallery forests are also exploited for timber and non-timber forest products. Very little or no conservation method is in place.

Babungo has the lowest species richness. This is because of over exploitation in order to obtain wood for carving. The Babungo palace museum and the Prince Handicraft center are exerting a lot of pressure on the gallery forests in this village even though very powerful traditional conservation methods are in place. Also, the forests are very accessible and fertile favoring agriculture around and within it. The forests are also exploited by neighboring villages like Oku, Baba I and Bamunka for medicine, timber, fuel wood and other non-timber forests products, this explains the low species richness. In the study of the swamp forests there is almost daily human presence within the forests (Dan et al., 2012). The search and harvesting of non-timber forest products alongside habitat destruction are at the origin of the loss or disappearance of species in Babungo in particular and the subdivision in general.

Floristic diversity

The mean Shannon-Weiner diversity index (H') obtained in the gallery forests of the Babessi subdivision is low. Species diversity is an important attribute of a natural community that influences functioning of an ecosystem. A forest community is said to be diverse if it has a Shannon-Weiner diversity value greater than or equal to 3.5 (Kent and Coker, 1992). All the four villages of the subdivision had Shannon-Weiner Diversity index values below 3.5 making these forests poor in diversity. These values are greater than those obtained in the study carried out in some sacred forests in West Region of Cameroon (Tiokeng et al., 2024). The reason for the difference in species diversity in Baba I and Babessi villages more than Bangolan and Babungo is due to community held beliefs and myths that forbids children and women from frequenting the forests, coupled with control by traditional authorities, social and religious purposes. A similar conclusion was made concerning the management of sacred forests and trees in the study of cultural and biological interactions in the savanna woodlands of Northern Ghana (Blench, 2004). The poor diversity here is also due to numerous intense human activities by traditional healers, pastoralists or livestock farmers, fuel wood sellers, carpentry, agriculture, carving and deforestation. This observation is similar to that obtained during the study on the diversity and uses of woody resources in the Koupa-Matapit area (Atoupka, 2016). This finding is also in line with that observed among the rural folks in Northern Ghana who also heavily depend on the vegetation around them for food, fuel wood, income, medicine, spiritual protection and a host of ecosystem services which often lead to loss of tree species in particular and biodiversity in general (Ziblim et al., 2013).

Pielou’s evenness index (E) values obtained in this study fall within the optimal range of 0.6 to 0.8 (Odum, 1976). These values indicate that there is equitable distribution of individuals across species in the gallery forests of some villages of Babessi Subdivision. These results are similar to those observed in the study of Woody species diversity and ecological characteristics of the Mawouon forest, in the Western highlands of Cameroon (Ngnignindiwou et al., 2021).

The Simpson index of dominance was low in all the villages of the subdivision (0.042 to 0.091). The Simpson's index of dominance (D) maximum value is 1, which is obtained in the case of a single species dominating implying no diversity. Low values are obtained when numerous species are present (no dominance), such that each species represents only a small fraction of the total value (Simpson, 1949). The low Simpson value implies each species represented only a fraction of the total due to a high level of heterogeneity of the species in the forests. Thus, in this study the probability that two individuals selected at random belong to the same species is slow. The results obtained from this study is similar to that obtained in the study of floristic diversity of Western Highlands savannas of Cameroon (Wouokoue et al., 2017).

The Sorenson similarity index values were low indicating that the woody plant species were not similar in the subdivision. A total of 8 species were found to be common in all the villages. The low level of similarity index was due to the fact that the forests are conserved, exploited as well as managed differently in these villages coupled with the differences in the density of the population and consequent pressure on this forest. This finding is similar to that observed in the study of floristic diversity in two villages of the South region of Cameroon (Nganwa, 2003).

Rubiaceae, Moraceae, Euphorbiaceae, Fabaceae, Apocynaceae and Phyllantaceae are the most dominant families in this subdivision with at least a representative in all the 4 villages. This finding is similar to the one recorded in the study of the diversity and the structure of the woody plant of the submountain forest of the Kala mount region of Yaoundé (Madiapevo, 2008). Also, this finding falls in line with that observed in the study of floristic inventory of woody Species in the Manengouba Mountain Forest, Cameroon (Noumi, 2013). Flacourtiaceae, Bignoniaceae, Gutiferae, Sapotaceae and Meliaceae are represented in at least two villages.

The highest numbers of species occur in class A. Even with the absence of class E, the study still reveals a reversed J-shape characteristic of law of frequency (Raunkiaer, 1934). According to the law, species poorly distributed or dispersed in an area are likely to be presented more than those with more dispersion. In other words, A is greater than B, and B is greater than C, and C less than D. This pattern is probably due to human pressures in the gallery forests principally on woody resources for energy, medicine, handicraft, fuel wood and food. This finding is in corroboration with the observation noted that human activities (e.g. changes in disturbance regimes, such as wood cutting) may directly or indirectly affect the regeneration of species and therefore the low frequency in the study area may be due to over harvesting of its fruits, bark and roots for use in rural diets, for medicine, fuel wood and raw materials for processed goods (Stephenne and Lambi, 2004).

Vegetation structure

This study revealed that highest density of woody individual trees was found in the lowest DBH size class. This is because the lowest diameter classes include most of the species which are not big enough for many uses and the highest diameter class includes only few species since most of them are exploitable. This observation is similar to the one viewed in the study of plant species composition and structure in South Eastern Ethiopia (Lulekal et al., 2008). The number of individuals decreased with increase in diameter in all the villages but for Babessi where there is a higher density in 46-65 DBH size class which would indicate unstable regeneration as time passes. This type of vegetation distribution is very close to the findings in the sacred forests of Bafou (Ngougni, 2017). However, the number of individuals decreases as the diameter class increases showing an inverted J-shaped structure. This observation is in conformity with the observation made in the study of flora composition, structure and diversity in the Kimbi Fungom National Park (Zeh et al., 2019).

The Basal area observed in this study ranged from 32 to 41.2 m^2 ha-1 which are typical of a forest in good state of conservation. These values are similar to those found in the study of floristic diversity and stand structural analysis of gallery forests in Ajei highland watershed community forest, North West Cameroon (Ajonina et al., 2020). Baba I has the largest BA value in the subdivision. It is characterized by trees of large DBH such as *Pseudospondias microcarpa, Vitex doniana* and *Ficus asperifolia*. This large BA is accounted for by the physical factors and the richness of these species alongside proper management. Similar values were obtained in the study of sacred forests of Bazou in the Western region of Cameroon (Mounmeni, 2021 and in the study of soil, site and management component of variation in species composition of Agricultural Grasslands in Western Norway (Myklestad, 2004). In the subdivision of Babessi, trees with the largest DBH and BA were *Ficus asperifolia* and *Canarium schweinfurthii* with 210 cm and 170 cm respectively. The relatively large values for *Ficus asperifolia* is probably due to the fact that it is not used by the indigenes while for *Canarium schweinfurthii* is because its highly conserved for its fruits as food coupled with its many category of uses. The same conclusion was arrived at in the study of what controls the distribution of tropical forest and savanna (Murphy and Bowman, 2012).

The DBH size class with the highest number of individuals was found in the lowest DBH class (5 -25) where the trees were not mature enough for many uses. The least number of trees was found in class 126-145 cm probably because they were mature and large enough for exploitation for a wider variety of uses. This suggests a good reproduction and healthy regeneration potential of the woody species in the gallery forest. This observation is in concomitance with the findings obtained the study of effects of wild coffee management on species diversity in the Afromontane rainforests of Ethiopia (Senbeta, 2006). Trees were present in all the DBH classes except in Bangolan where there was no tree in the 86-105 class. Babungo had the highest number of large exploitable trees, followed by Baba I, Babessi and then Bangolan. This variation is probably due to the different methods of conservation, intensity of use and reasons for exploitation. The same findings were made in the study conducted in Wotagisho forest in Ethiopia (Dikaso and Tesema, 2016).

CONCLUSION AND RECOMMENDATION

This study on the diversity of woody plant species in the four villages of Babessi Subdivision revealed a low species richness in all the four villages. The most predominant species and families are different from one village to another. The distribution of individuals by diameter class is characteristic of a forest disturbed by human activity but with a high potential of regeneration if there is proper management. According to the International Union for Conservation of Nature (IUCN) red data list of species, there are five species in conservation priority in the gallery forests, which calls for even greater attention to be paid to them. This study showed that the gallery forests of Babessi subdivision and Western High lands of Cameroon in general, despite their relatively small surface area, they are of great importance in maintaining woody plant diversity. Management strategies for these relic forests should be strengthened by including all the stakeholders in this area in a bottom - up approach in order to optimize their stewardship in a sustainable manner.

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REFERENCES

Ajonina, N., Lucie, F. T., Mbacham, C. I., Ngoh, M. L., Prince, E., & David, C. F. 2020. Floristic diversity and stand structural analysis of gallery forests in Ajei highland watershed community forest, North West, Cameroon: Implications for forest conservation and management. *International Journal of Biodiversity and Conservation*, **12(3):185–201**.

Atoupka, A.M. 2016. Diversités et usages des ressources ligneuses dans le terroir de Koupa Matapit, Ouest Cameroun. Mémoire d'Ingénieur des Eaux, Forêts et Chasses, FASA, Cameroun, 143.

Barikpoa, U. and Sorbari,V. J. 2021. Acute Effects of Spondianthus Preussii leaf Powder on Clarias gariepinus fly. IIARD International Journal of Agriculture and Earth Science ,**7(2):109**

Blench, R. 2004. Cultural and biological interactions in the savanna woodlands of Northern Ghana: Sacred forests and management of trees. Paper presented at the Conference Trees, Rain and Politics in Africa.

607-609.

Dan, C. B. S., Sinsin, B. A., Mensah, G. A., and Lejoly, J. 2012. Influence des activités anthropiques sur la diversité floristique des communautés végétales de la forêt marécageuse de Lokoli au Sud-Bénin. *International journal of chemical science*, **6(6):3064-3081**.

Dajet, J 1976. Les méthodes mathématiques en écologie. Collection d'écologie, (8) Paris, Masson. 172

Dikasso, U.G and Tesema T.T. 2016. Floristic composition and diversity of woody plant species of wotagisho forest, Boloso Sore Woreda, Wolaita Zone, Southwest, Ethiopia. *International Journal of Natural Resource Ecology and management*, **1(3):63-70**.

Fousseni, F., Marra, D., Wala, K., et al. (2014) Basic overview of Riparian forest in Sudanian Savanna Ecosystem: Case Study of Togo. *Review écologique*, **69:24-38**.

González-Abella, J. S., Aldana, A. M., Correa, D. F., Casas, L. F., and Stevenson, P. R. 2021. Forest structure, diversity and dynamics in terra firme and igapó gallery forests in the colombian orinoco basin. *Forests*, **12(11):1–16**.

González-Rivas, B., Tigabu, M., Gerhardt, K., Castro-Marín, G., and Odén, P. C. 2006. Species composition, diversity and local uses of tropical dry deciduous and gallery forests in Nicaragua. *Biodiversity and Conservation*, **15(4):1509–1527**.

Kent, M. and Coker, P. 1992.Vegetation description and analysis, Belhaven Press, London, UK. 53

Letouzey, R. 1982. Manuel de botanique forestière d'Afrique tropicale. Centre technique forestier tropical. Nogent-sur-Marne.

Lulekal, E., Kelbessa E., Bekele, T. and Yinger, H. 2008. Plant species composition and structure of the Mana Angetu moist montane forest, Southeastern Ethiopia. *Ethiopian Journal of Africa Natural History*, **97:165-185**.

Madiapevo, S. N. 2008. Study of the diversity and the structure of the woody plant of the submountain forest of the Kala mount region of Yaoundé. Master's thesis, University of Yaoundé I, 71.

Moutoni, L. 2019. Community forestry in Cameroon. An overview of the community perspective. Forest Peoples Programme. [Online] Available at: https://www.forestpeoples.org. [Accessed 17 October 2024].

Murphy, B. P. and Bowman, D. M. J. S. 2012. What controls the distribution of tropical forest and savanna? *Ecology Letters*, **15:748–758**.

Myklestad, A. 2004. Soil, site and management component of variation in species composition of Agricultural Grasslands Western Norway. *Grass forage Science*, **59:136-143**.

Naiman, R.J., Latterell, J., Pettit, N.E., Olden, J.D. 2008. Flow variability and the biophysical vitality of river systems. *Geoscience,* **340:629-643**.

Ndamason, S. 2016. Assessment of floristic diversity and carbon stocks in relation to stream. FASA, University of Dschang, Cameroon.

Nganwa, R. J. 2003. Contribution à l'étude de la diversité floristique dans deux villages du Sud Cameroun. Mémoire de DEA. Université de Yaoundé I. 52.

Njoya, I. 2016. National Community Drive Development Program (PNDP). [online] available at WWW.pndp.org/documents. [Accessed 17 May 2016

Ngougni, L. 2017 Floristic diversity, structure, biomass and uses of some sacred forests in the highlands of western Cameroon: implications in the conservation of biodiversity, Master's thesis University of Dschang 89.

Ngnignindiwou, M., Wouokoue, T.J.B., and Nguetsop, V. F. 2021. Woody species diversity and ecological characteristics of the Mawouon forest, in the Western highlands of Cameroon. *Cameroon Journal of Experimental Biology*, **15(1):28-34**.

Noumi, E. 2013. Floristic inventory of woody species in the Manengouba mountain forest, Cameroon. *Journal of Biology and Life Science*, **4 (2): 282**.

Odum, E. P. 1976. Fundamentals of ecology (3rd ed.). W.B. Saunders Company.

Onana, J. M and Cheek, M. 2011. Red Data Book: The flowering plants of Cameroon IUCN Global Assessments. Royal Botanic Gardens, Kew IRAD-National Herbarium of Cameroon

Raunkiaer, C. 1934. The life forms of plants and statistical plant geography. *Oxford University Press.*

Simpson, E.H. 1949. Measurement of Diversity. *Nature,* **163:688**.

Senbeta, F. and Denich, M. 2006. Effects of wild coffee management on species diversity in the Afromontane rainforests of Ethiopia. Forest Ecology Management, **232: 68-74**.

Solefack, M. C., Fedoung,F. E., and Temgoua, L. F. 2018. Factors determining floristic composition and functional diversity of plant communities of Mount Oku forests, Cameroon. *Journal of Asia-Pacific Biodiversity*, **11(2): 284–293**.

Stephenne, N. and Lambin, E.F. 2004. Scenarios of land use change in Sudano-Sahelian countries of Africa to better understand driving forces. *GeoJournal*. **61:365-379**.

Tiokeng, B., Koukeu, D.G., Etchike, A.D., Kenne, L.T., Nguetsop, V. F. and Mapongmetsem, P. 2024. Floristic diversity and carbon stock of woody stands in some sacred forests in the west Cameroon region. *Journal of Agriculture and Ecology Research International*, **25(2):42-52.**

Tsitoh, P. 2018. Floristic composition, diversity and analysis of forest cover change in the Kedjom-Keku community forest, N.W. Cameroon. *Open Journal of Ecology*, **9(8):15-117**.

Wouokoue, T.J.B., Nguetsop V.F. and Fonkou, T. 2017. Floristic diversity of Western Highlands savannas of Cameroon. *International Journal of Current Research in Biosciences and Plant Biology*, **4(4):7-13**.

Zeh, A. F., Nkwatoh, A. F., and Melle, E. M. 2019. Flora composition, structure and diversity in the Kimbi Fungom National Park, North West Region, Cameroon. *Journal of Ecology and The Natural Environment*, **11(1):1–13**.

Ziblim, I.A., Khan, A.T., Deo-Anyi, E.J. 2013. Exploitation and use of medicinal plants, Northern region, Ghana. *Journal of medical plant research*, **7(27):1984-1993**.

Appendix 1. Preliminary check list of woody plant species, distribution in gallery forests and conservation priority of Babessi subdivision

No	Botanical name	IUCN red list status	Locality
Anacardiaceae			
1	*Pseudospondias microcarpa* A. (Rich.) Engl.		BGN, BBA, BBS
Apocynaceae			
2	*Funtumia africana* (Benth.) Stapf		BGN
3	*Voacanga thouarsii* Roem. & Schult.		BGN, BBS, BBA, BBN
4	*Rauwolfia macrocarpa*		BGN
5	*Voacanga africana* (Scott-Elliot) Stapf.		BBS, BBN
Araliaceae			
6	*Polyscias fulva* (Hiern) Harms	NT	BGN, BBS, BBA, BBN
7	*Schefflera hierniana Harms*		BBA
	Arecaceae		
8	*Pheonix reclinata* Jacq		BBA
Asteraceae			
9	*Vernonia cinerea* (L.) Less		BBN
Bignoniaceae			
10	*Stereospermum personatum*		BBS
11	*Markhamiatomentosa* (Benth.) K.Schum. ex Engl.		BBN
12	*Spathodeacampanulata* P. Beauv.	en	BBN
Boraginaceae			
13	*Cordia platythyrsa* Bak.		BBS
Burseraceae			
14	*Canarium scheinfurthii* Eng.		BGN, BBS, BBA, BBN
Clusiaceae			
15	*Garcinia smeathmanii* (Planch. & Triana) Oliv.		BBS
Combretaceae			
16	*Terminalia glaucescens* Planch. ex Benth.		BBS
17	*Combretum molle* R.Br. ex G.Don		BBS
Euphorbiaceae			
18	*Antidesma chevalieri* Beille		BGN
19	*Macarangaoccidentalis* (Müll.Arg.) Müll.Arg.		BGN, BBS, BBA, BBN
20	*Macaranga spinosa* Müll.Arg.		BGN
21	*Bridelia ferruginea* Benth		BGN
22	*Spondianthus preussii* Engl.		BBA
23	*Neobourtonia glabescence* Prain.		BBA, BBN

24	*Bridelia micrantha* (Hochst.) Baill.	BBA
25	*Croton macrostachyus* Hochst. ex Del.	BBS
26	*Jatropha podagirca* Hook.	BBA, BBN
27	*Margaritaria discoidea* (Baill.) G.L.Webster	BBS
28	*Tragia benthamii* Baker	BBN
Fabaceae		
29	*Dalbergia sissoo* Roxb. ex DC.	BGN
30	*Pericopsis laxiflora* Benth Meeuwen	BGN
31	*Pterocarpus erinaceus* Poir.	BGN
32	*Entanda abyssinica* A. Rich.	BBA
33	Unidentified	BBA
34	*Albiziaadianthifolia* (Schumach.) W.F. Wight	BBA
35	*Sesbania sesban* (L.) merr.	BBA
36	*Albizia coriaria* Welw. ex Oliv.	BBS
37	*Xeroderris stuhlmannii* (Taub.) Mendonca & E.P.Sousa	BBS
38	*Albizia zygia* (DC.) J.F.Macbr.	BBS, BBN
Flacourtiaceae		
39	*Caloncoba glauca* (P. Beauv.) Gilg	BGN
40	*Flacourtia flavescens* Willd.	BGN
41	*Flacourtia indica* (Burm.f.) Merr.	BBS
42	*Oncoba spinosa* Forssk.	BBS
Gentianaceae		
43	*Anthocliestia djalonensis* A.Chevy	BGN, BBA, BBN
44	*Anthocleista procera* Lepr. ex Bureau	BBS
Gutiferae		
45	*Allanblackia floribunda* Oliv.	BBA, BBS
46	*Psorospermum senegalense* Spach	BBA
47	*Garcinia ovalifolia* Oliv.	BBS, BBN
Hymenocardiaceae		
48	*Hymenocardia heudelotii* Planch. ex Müll.Arg.	BBA
Hypericaceae		
49	*Harungana madagascariensis* Lam ex.Poir	BGN
Lamiaceae		
50	*Vitex doniana* Sweet	BGN, BBS, BBA, BBN
51	*Vitex welwitschii* Gurke	BBS
Lauraceae		
52	*Beilschmiedia tarairi* (A.Cunn.) Benth. & Hook.f. ex Kirk	BGN, BBS

Malpighiaceae			
53	*Alicia anisopetala*(A.Juss.)W.R.Anderson		BBA
Malvaceae			
54	*Cola acuminata - (P.Beauv.) Schott & Endl*		BGN
55	*Cola nitida* (Vent.) Schott & Endl.		BBA
Melastomaceae			
56	*Erythroxylum abyssinica*		BGN, BBS
Meliaceae			
57	*Khaya senegalensis* (Desr.) A.Juss.	VU	BGN
58	*Trichilia emetica* Vahl		BBA, BBS
59	*Swietenia mahogani* (L) Jacq.		BBA
Menispermaceae			
60	*Penianthus camerunensis*		BGN
Moraceae			
61	*Ficus vallis-choudae* Del.		BGN
62	*Ficus extrangulaire*		BGN, BBA
63	*Ficus elastica* Roxb. ex Hornem		BGN
64	*Ficus asperifolia* Miq		BGN, BBS, BBA, BBN
65	*Ficus lutea* Vahl		BBA
66	*Ficus exasperata* Vahl.		BBA
67	*Ficus mucuso* Welw. ex Ficalho		BBA
68	*Milicia excelsa* Welw.C.C.Berg		BBA
69	*Ficus thonninjii* Blume		BBS
70	*Ficus platyphylla* Del.		BBS
71	*Ficus aurea* Nutt.		BGN, BBS, BBA, BBN
72	*Ficus ingens* (Miq.) Miq.		BBS
73	*Ficus trichopoda* Baker		BBN
Mytaceae			
74	*Syzygium guineense* Var. macrocarpa (Eng)		BGN
Myristicaceae			
75	*Pycnanthus angolensis* (Welw.) Warb		BGN
Myrsinaceae			
76	*Maesa lanceolata* Forssk.		BBS
Olacaceae			
77	*Olax sp* indet. null		BGN
Oleaceae			
78	*Olea hochstetteri* Bak.		BGN
Phyllanthaceae			
79	*Uapaca guineensis* Mull. Arg.		BGN

80	*Fluggea virosa* (Roxb.exWilld) voight		BGN, BBS, BBA
81	*Bridelia micrantha* (Hochst.) Baill.		BGN, BBA, BBS
Proteaceae			
82	*Protea madiensis* Olive.		BGN
Rhamnaceae			
83	*Ziziphus abyssinica* Hochst		BGN
Rubiaceae			
84	*Mitragyna stipulosa* (DC.) O. Ktze	NT	BGN
85	*Macrosphyra longistyla* (DC.) Hook.f.		BGN
86	*Keetia cornelia* (Cham. & Schltdl.) Bridson		BGN
87	*Pavetta crassipes* K. Schum.		BGN
88	*Sarcocephalus latifolius* (Sm.) E.A.Bruce		BGN
89	*Hallea stipulosa* (D.C) Le Roy		BGN, BBS, BBA, BBN
90	*Canthium subcordatum* D.C.		BGN, BBA, BBN
91	*Psychotria djumaensis* De Wild.		BGN, BBA, BBS
92	*Craterispermum laurinum* (Poir.) Benth.		BGN
93	*Alchornea cordifolia* (Schumach. & Thonn.) Müll.Arg		BBA
94	*Psychotria peduncularis* (Salisb.) Steyerm.		BBA
95	*Breonadia salicina* (*Vahl*) Hepper et Wood		BGN
96	*Cremaspora triflora* (Thonn.) K Schum.		BBS
97	*Sericanthe chevalieri* (K Krause) Robbrecht		BBN
Rutaceae			
98	*Vepris heterophylla* (Engl.) Letouzey		BGN
Sapindaceae			
99	*Allophylus africanus* P. Beauv.		BGN, BBA
100	*Allophylus bullatus* Radlk.	VU	BBN
Sapotaceae			
101	*Vitellaria paradoxa* C.F.Gaertn.	VU	BGN
102	*Pachystela brevis*		BBA
103	*Afrosersalisia cerasifera* (Welw) Aubrev.		BBA
Sterculiaceae			
104	*Sterculia tragacantha* Lindl		BBS
Ulmaceae			
105	*Trema orientalis* Linn. Blume		BBA, BBN

BGN: Bangolan; BBS: Babessi; BBA: Baba I; BBN: Babungo; VU: Vulnerable; NT: Near threatened

Ethiopian Journal of Biodiversity

Guideline for contributors

1. Types of papers

- **Research papers -** Research papers should not exceed 8000 words in length, including Figures, Tables and References. Moreover, they should not contain more than 10 Figures and/or Tables
- **Review papers -** Critical and comprehensive reviews that provide new insights into or interpretations of the subject through a thorough and systematic evaluation of available evidence that should not exceed 10,000 words including Figures, Tables and References
- **Short communications -** Short communications such as opinions and commentaries should not exceed 1500 words and they must be brief definitive reports which need not be divided into Materials and Methods, Results and Discussions
- **Book Reviews -** Book review which is a critical evaluation of published books in any discipline of biological sciences/biodiversity will be published under this column

2. Manuscript preparation

2.1 Article style and structure

Manuscripts should be written in American English, typed double-spaced, on A4 size, with margins of 1.5 cm on top and bottom sides of the paper, 2 cm on left and 1.5 cm on the right. A font size of 12 points (Times New Roman) should be used throughout the manuscript. The major sections of the manuscript include title, abstract, keywords, introduction, materials and methods, results, discussion, conclusion and recommendation, acknowledgements and references. Those sections having headings and sub-headings should not have more than three levels. All pages and lines should be numbered with the title page being page1

2.2 Title page

- **Title:** The title should be clear, short and precise and it should not exceed 20 words.
- **Author name and affiliations:** Full name(s) of the author(s) and address (es) including institution(s) in which the research was carried out and affiliation(s) of the author(s) if more than one shall be indicated. Where there is more than one affiliation, match authors and their appropriate affiliations with superscript numbers
- **Corresponding author:** The corresponding author (identified with a superscript asterisk) and his/her email should also be shown on the title page
- **Authors' contribution:** if the arrangement of authors list is not in accordance with their contribution, the authors' contribution should be mentioned separately below the corresponding author section. For example if all authors equally contributed, it can be stated "all authors are equally contributed"

2.3 Manuscript format

- **Abstract:** The abstract of the manuscript should not exceed 250 words. It should give the reader the objectives of the study, how the study is conducted, the main findings and major conclusions. There should be no reference citations and abbreviations
- **Keywords:** Four to six words and/or phrases should be listed in alphabetical orders at the bottom of the abstract
- **Introduction:** provides an adequate background, states the objectives of the work avoiding a detailed literature survey or a summary of the results
- **Materials and methods:** Provide sufficient detail to allow the work to be reproduced, methods already published should be indicated by reference; only relevant modification should be described
- **Results:** Should describe the result of the study clearly and concisely
- **Discussion:** explores the significance of the findings without repeating the results. Avoid extensive citations and discussions of published literature.

- **Conclusion and recommendation:** presented in a short form and appears after a discussion section. It highlights the implications of the key findings.
- **Acknowledgements:** appear in a separate paragraph before the reference, and should be as brief as possible. All sources of funding should also be declared.

2.4 References style

EthJBD follows referencing style described below. Unpublished results and personal communications are not recommended on the reference list, but maybe mentioned in the text and indicated in footnotes. Citation of a reference as 'in press' implies that the item has been accepted for publication. Moreover, citation in the text should follow the same referencing style. The citation styles described below is also applicable for Ethiopian Authors' work.

2.5 Citation in the reference list

For books with one author includes the following:

Example: One author AND first edition:

Acquaah, G. 2012. Principles of plant genetics and breeding. Oxford: Wiley-Blackwell.

Example: One author AND NOT the first edition

Dahl, R. 2004. Charlie and the chocolate factory. 6^{th} ed. New York: Knopf.

Books with Two or More Authors:

Example:

Desikan, S. and Ramesh, G. 2006. Software testing. Bangalore, India: Dorling Kindersley.

For Chapters in Edited Books:

Harlan, J. R. 1971. On the origin of barley: a second look. In: R. A. Nilan, ed., Barley Genetics vol. II Proc. 2nd Barley Genetics Symposium. Washington State Univ. Press, Pullman, pp. 45 - 50.

Multiple Works by the Same Author:

Start from the oldest publication

Example:

Brown, D. 1998. Digital fortress. New York: St. Martin's Press.

Brown, D. 2003. Deception point. New York: Atria Books.

For Print Journal Articles:

The standard structure of a print journal citation includes the following components:

Last name, First initial. Year published. Article title. *Journal*, **Volume (Issue number): Page(s).**

Examples:

Engels, J. M. J. 1994. Genetic diversity in Ethiopia in relation to altitude. *Genetic Resources and Crop Evolution*, **41: 61-73**.

Lemessa, D., Hylander, K. and Hambäck, P. 2013. Composition of crops and land use types in relation to crop raiding pattern at different distances from forests. *Agriculture Ecosystems and Environment*, **167:71-78**.

Mewded, B., Negash, M. and Awas, T. 2020. Woody species composition, structure and environmental determinants in a moist evergreen Afromontane forest, southern Ethiopia. *Journal of Forestry Research*, **31(4): 1173-1186**.

For Journal Articles Found on a Database or a Website:

When citing journal articles found on a database or through a website, including all of the components found in a citation of a print journal, but also include the medium ([online]), the website URL, and the date that the article was accessed.

Structure:

Last name, First initial. Year published. Article Title. *Journal*, [online] **Volume (Issue number): page(s).** Available at: URL [Accessed Day Mo. Year].

Example:

Raina, S. 2015. Establishing Correlation Between Genetics and Nonresponse. *Journal of Postgraduate Medicine*, [online] **61(2):148**. Available at: http://www.proquest.com/products-services/ProQuest-Research-Library.html [Accessed 8 Apr. 2015].

For Websites:

When citing a website, use the following structure:

Last name, First initial. Year published. Page title. [online] Website name. Available at: URL [Accessed Day Mo. Year].

Bejiga, G. and van der Maesen, L.J.G. 2006. *Cicer arietinum* L. [online] PROTA. Available at: https://uses.plantnet-project.org/en/Cicer_arietinum_(PROTA) [Accessed 1 Mar. 2020].

When no author is listed, use the following structure:

The website name, Year published. *Page title*. [online] Available at: URL [Accessed Day Mo. Year].

Example:

Avogel.com, 2015. *A. Vogel plant encyclopaedia.* [online] Available at: https://www.avogel.com/plant-encyclopaedia/ [Accessed 20 Apr. 2015].

6.2.6 Citation in text

One author: The last name of the author followed by year of publication will be cited in the text.

Example: ……..(Brown, 2005).

Two authors: The last name of the authors are joined by "and" followed by year of publication.

Example: ……….. (Tesfaye and Girma, 2019).

More than two authors: The last name of the first author followed by "et al., " and year of publication

Example :…………(Adugna et al., 2019).

2.7 Tables

Tables should be as editable text and be placed on a separate pages at the end of the manuscript. Number tables consecutively (i.e. Table 1, Table 2, etc.) in accordance with their appearance in the text and avoid vertical lines and shading in the table cells. Table captions should be descriptive and appear above the table. Footnotes and sources to tables should be placed under the table. Larger datasets can be uploaded separately as Supplementary Files

2.8 Figures

Figure should be prepared in formats like JPEG, TIFF and JPG, with the resolution of 300 dpi or higher. Captions should be numbered consecutively (Figure 1, Figure 2, etc.) and placed below the figure. Figures from other sources should be used with the permission of the publishers of the articles. Figure citations in the text should always be with capital "F" as follows:

One figure (e.g. Figure 1), and more than one figure (e.g. Figures 1–3, Figures 2A–E.)

2.9 Abbreviations and symbols – All abbreviations used in the text should be defined in their first use. Abbreviations used only in tables and figures can be defined in the table foot note or figure legend

2.10 Units – All measurements should be in the metric system. Geographic coordinates should be written as degree, minute and second. Example: 36°31'21"N; 114°09'50"W

2.11 National Administration units– At initially, all administration units such as Woreda, Kebele, Zone etc. should be described in a bracket at the first mention of the word.

3. Manuscript submission and checklist

Manuscripts should be submitted to the EthJBD via e-mail or online submission system in word format (.doc, .docx). The submission should be accompanied by a cover letter stating the novelty of the finding and the manuscript was neither submitted nor published elsewhere

The author(s) should ensure that the entire checklist stated in the guide for authors are present; and these include:

- Title and corresponding author with contact details (email and postal addresses)
- Abstract and Keywords
- Main text
- All figures with captions
- All tables with captions
- All figures and tables are cited in the main text
- A reference section containing all sources cited in the text
- Declaration and conflict of interest statement
- Referee suggestions and their contact details (optional)

8. Proofreading

PDF proofs are to be sent by email to the corresponding author for correction. Authors are responsible for the final proofreading of their manuscripts and no corrections are accepted after re-submission. The corrected version should be returned to the editor-in-chief/associate editor within a week.

Editorial office contact: ethjbd@ebi.gov.et

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