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Fostering Green Legacy Initiative: Sustaining Seed Production for Scarce Indigenous Tree Species by Identifying, Characterizing, and Mapping of Mother Trees in Awi Zone, Northwestern Ethiopia

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ABSTRACT

The aim of this study was to identify, characterize, and map mother trees of selected indigenous tree species to tackle shortage of high quality and quantity tree seed provision for massive plantation program by providing both temporal and spatial distribution of mother trees in the study area. This study identified 90 mother trees across seven indigenous tree species through stratified purposive sampling, treating each tree as an individual sampling plot to ensure localized data precision. Data on height, girth, and *X*- *Y* coordinates of each mother tree, as well as nearby trees within 10 m. Radius from selected mother trees were recorded. Descriptive statistics and coefficient of variance were calculated for the collected data. Following the statistical analysis, the spatial distribution of the mother tree was mapped using ArcGIS software. *Juniperus procera* in Banja District shows the largest mean both in terms of DBH (116.21 ± 37.3 cm) and height (33.82 ± 4.07 m) while *Podocarpus falcatus* in Guangua District score the second largest mean for DBH (94.83 ± 15.1 cm) and height (32.28 ± 14.3 m). *Prunus africana* in Banja District 2 were the third largest from the characterized seed sources by scoring average DBH (91.98 ± 19.71 cm) and height (29.16 ± 6.27 m). The coefficient of variance of selected mother trees both by species and by forest name also indicate the suitability of selected forest for the production of high quality and quantity of tree seed. Spatial mapping and local knowledge were combined to point out specific seed collection sites, such as Ziqe Forest, and to determine optimal collection times. This research provides a data-driven framework for developing targeted seed sourcing strategies that enhance the genetic resilience of restoration efforts, directly supporting Ethiopia's national and international reforestation and afforestation commitments.

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1 | Introduction

Production of quality tree seed is very crucial to achieve Ethiopia ambitious aim of restoring 15 million hectares of degraded land by 2030 which is aligned with the commitment to the Bonn challenge as well as billions of seedling produced every year by Green Legacy initiative (Ministry of Agriculture) [1].

Recently, the government of Ethiopia plan and implement huge restoration and afforestation program known as green legacy initiative [1]. The objective of green legacy campaign aligned with the international initiative on ecosystem restoration signed by the government of Ethiopia such as the Bonn challenge and the United Nation Decade ecosystem restoration [2]. Availability of high quality and sufficient quantity of tree seed is a vital component of restoration and reforestation; however, shortage of seeds of indigenous tree species remains critical bottleneck for the success of forest restoration effort [3]. The quality of tree seed mainly affected by the processes of seed collection, processing, and storage. Furthermore, the genetic quality of seed also impacted by its natural habitat, edaphic, and environmental condition; thus, proper documentation is vital for ensuring tree seed quality [4]. Tree seed can be sourced from either natural forest or plantation forest mostly single species. Collecting tree seeds from well-known and accurately documented sources not only improve seed germination but also play a critical role in stabilizing restored ecosystem by increasing the survival of planted seedlings.

Even if huge seedling production require sufficient and efficient seed provision, the seed system is unable to provide the required quantity and quality of tree seed, especially in the Amhara region [5]. Limited research was conducted especially in quantifying structural parameter and distribution mother tree in the Amhara region. Banja and Guangua districts endowed with tree species such as *Albizia gummifera*, *Croton macrostachyus*, *Prunus africana*, and *Millettia ferruginea*. Some species, such as *Podocarpus falcatus*, *Cordia africana,* and *Juniperus procera*, are found in fragmented and isolated patches [6]. Moreover, natural forests in the Amhara region are highly exploited, but in some places, such as Banja and Guangua districts, natural forests are untouched and can be used for sourcing tree seed. Indigenous tree species provide both ecosystem service and high quality timber as well as medicinal services for local communities; thus, to sustain, this function restoration of degraded forest land is important but the concern on propagation material is vital for the success of restoration effort [5].

C. africana is used in furniture and musical instrument production, while *J. procera* is also widely utilized and preferred for pole and sawn timber due to its decay resistance and durability [7]. The demand for indigenous tree species is increasing substantially on one hand, and the growth and natural regeneration of the species are very low on the other hand [8]. Farmers and timber traders are reluctant to plant indigenous tree species for several reasons: slow growth rates and long time to financial return, limited propagation and management knowledge, and lack of access to quality seed. Land scarcity for large-canopy species further reduces adoption, while harvest restrictions on indigenous trees discourage commercial planting [9].

To fill this gap, the provision of tree seed is mandatory; thus, this research was conducted [3, 10]. Moreover, natural forest degradation is aggravated by cropland expansion, population growth, and illegal logging. Forest degradation also causes the loss of mother trees which lead to genetic erosion [11, 12]. To help forestry investment effective and tree seed system coast effective, information on the location, species type, and expected quantity of seed that can be collected is very crucial [13]. Assessing and locating mother tree to facilitate tree seed collection is the objective of this study. Further study needed to manage the identified seed sources to improve them to sustainable seed production area (Figure 1).

2 | Materials and Methods

2.1 | Study Area

This study was carried out in Guangua and Banja districts of Awi zone, Amhara region, Ethiopia (Figure 2). The Guangua district is geographically located at $10^0 52'$ to $11^0 3'$ N and $36^0 38'$ to $37^0 8'$ E [6].

The study area mainly characterized by mountainous topography and the rainfall ranging from 1200 to 1800 mm, the annual temperature range from 16°C to 22°C. The study area is purposefully selected based on the endowment of intact forest and underutilized for collection of tree seed [14]. The Awi district selected due its endowment with intact natural forest which have a great potential for seed sources establishment.

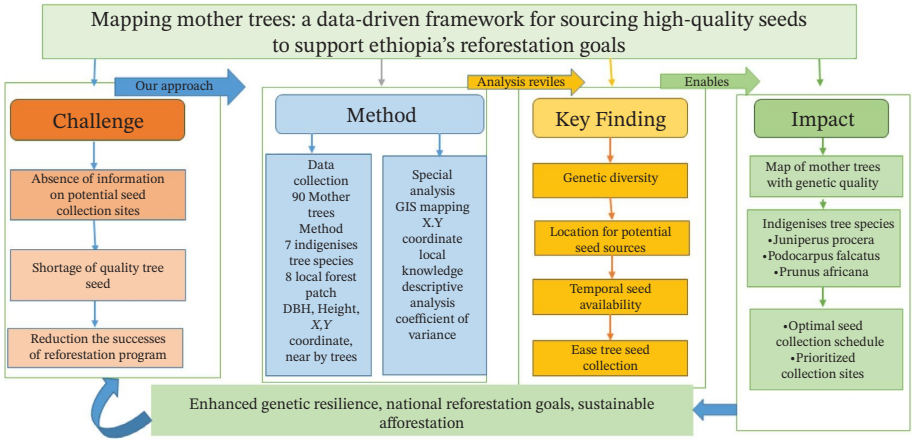


FIGURE 1 | Conceptual framework of the study.

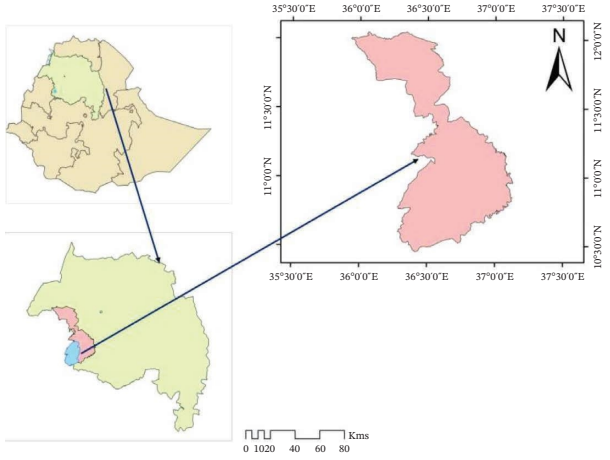


FIGURE 2 | Map of the study area.

2.2 | Sampling and Data Collection

Seed sources from natural forest were selected by following purposively stratified sampling method and mother trees of *A. gummifera* (10 trees) from two districts, *Prunus africana* (10 trees) from two sites, *C. macrostachyus* (10 trees), *Millett ferruginea* (10 trees), *Podocarpu falcatus* (10 trees), *C. africana* (10 trees), and *J. procera* (10 trees) were selected. Mother trees were carefully selected based on phenotypical characteristics and reproductive potential, and we also considered availability of seed and level of IUCN vulnerability while following guidelines of [4, 15]. Targeted tree species were selected for their ecological and economic importance. For example, *C. africana* produces high-quality timber and provides valuable shade for coffee agroforestry, *J. procera* yields termite-resistant wood preferred for church construction, and *M. ferruginea* and *A. gummifera* contribute to nitrogen fixation and soil rehabilitation [16]. Additionally, the critical shortage of quality seeds for these species informed their prioritization. First, 10 individual trees were selected for each of seven target species (70 trees). An additional 20 trees, 10 *A. gummifera* and 10 *P. africana*, were sampled from Askuna Abo and Senkesa forests to better represent these particularly valuable and common species across different spots. The forests in the Awi Zone cover an extensive and continuous landscape across varied topography, so selecting suitable forest patches as seed sources required clear criteria such as accessibility and population dynamics. With these criteria in mind, four seed sources (*A. gummifera, M. ferruginea, C. africana*, and *P. falcatus)* were selected from Guangua District, while five seed sources (*C. macrostachyus, J. procera, A. gummifera,* and two *P. africana* patches from different spots) were selected from Banja District. The decision to sample 10 individual trees per species was made to capture structural variability while working within practical constraints of time, budget, and available labor. Finally 90 mother trees were selected and marked from Guangua and Banja districts. Ninety single trees used as sample plot within 9 parallel transect line separated 500 m. Each transect line include 10 single tree spaced 200 m. And for nearby (Nt) tree enumeration, all trees of the same species were counted within 10 m radius (10-m radius, reflecting typical pollen dispersal distances for Afromontane species) [17], from selected mother tree, Total height (m), diameter at breast height (DBH) (cm), total number of nearby trees of the same species, and *X* and *Y* coordinates of all mother trees and nearby tree were recorded. The selection of mother trees followed established criteria for each species. The data underwent descriptive analysis and were presented narratively to provide comprehensive information on the timing and location of seed collection sites, supplemented by a detailed seed source map. Intensive focal group discussions (FGD) and key informant discussions (KID) were conducted, following the methodology outlined by [18]. Three FGDs were organized, comprising forest guards, tree seed collectors, and youths. Based on the information gathered, forests were identified, the time and expected quantity of seed can be collected were estimated, and intensive field observations were conducted to triangulate the information obtained during FGDs and KIDs with ground data. Additionally, data on the expected quantity and timing of seed collection were collected, using Dataset 1 for supplementary information.

2.3 | Data Analysis

The data collected subjected to descriptive analysis to figure out structural diversity among mother trees of different species and forest type. Mean, standard deviation, number of trees observed, computed at 5% critical value coefficient of variance (CV) also used to understand the structural diversity of the species by using Equation (1). For local density analysis, we used simple fixed radius neighborhood by following procedure of [19]. While for spatial distribution analysis generation RStudio (Version 2024.12.1, RStudio Team, 2024) with the dplyr, ggplot2, and ggpubr packages where used finally for a spatial mapping of important mother trees of mother tree distribution QGIS Desktop 3.42.3 was used by integrating a digital elevation model (SRTM 30 m), hillshade, and geographic coordinates. Visual distribution characterized by using the process of data in to QGIS along with cropping digital elevation model to fit the Amhara region and projected in to geographic coordinates of(EPSG:4326). Finally, the map exported with high-resolution image.

$$\text{CV of (DBH)} = \frac{\text{Standard Divation of DBH}}{\text{Mean of DBH}} * 100, \quad (1)$$

$$\text{CV of (Height)} = \frac{\text{Standard Divation of Height}}{\text{Mean of Height}} * 100. \quad (2)$$

3 | Results and Discussion

3.1 | Genetic Diversity of Selected Indigenous Mother Tree Species in Identified Seed Sources

J. procera in Banja District shows the largest mean both in terms of DBH (116.21 ± 37.3 cm) and height (33.82 ± 4.07 m), while *P. falcatus* in Guangua District scores the second largest mean of DBH (94.83 ± 15.1 cm) and height (94.83 ± 15.1 m). *P. africana* in Banja District 2 was the third largest from the characterized

TABLE 1 | Structural diversity and density class of tree species in selected seed sources sites in Awi Zone.

Mother trees selected from different natural forest	Location by districts	Mean DBH (cm)	Mean height (m)	Mean number of nearby trees:	Structural diversity class	Local density class
Albizia gummifera	Banja	40.93 ± 12.6	12.89 ± 1.77	11 ± 5.03	Moderate	Low
Croton macrostachyus	Banja	35.91 ± 9.34	14.41 ± 3.72	8 ± 2.71	Small	Low
Albizia gummifera	Guangua	50.96 + 22.93	17.48 ± 9.40	12 ± 4.04	Moderate	Moderate
Cordia africana	Guangua	42.1 ± 12.26	13.83 ± 3.27	12.±8.73	Small	Moderate
Juniperus procera	Banja	116.21 ± 37.3	33.82 ± 4.07	4.±1.32	Moderate	Very low
Millett ferruginea	Guangua	15.87 ± 3.14	10.78 ± 2.14	13 ± 4.76	Small	Moderate
Podocarpus falcatus	Guangua	94.83 ± 15.1	32.28 ± 15.1	6 ± 3.25	Small	Low
Prunus africana	Banja	84.54 ± 17.6	29.71 ± 6.82	4 ± 1.41	Small	Very low
Prunus africana	Banja2	91.98 ± 19.71	29.16 ± 6.27	6 ± 1.87	Small	Low

seed sources by scoring average DBH (91.98 ± 19.71 cm) and height (29.16 ± 6.27 m). Our findings were consistent with the study conducted by Brocheman et al. [20, 21] on natural forest in Awi Zone. Even if these species score the largest average girth and height, the number of neighboring trees species recoded were 4, 6, and 6, respectively, for each species mentioned above which indicates low local density (Table 1).

Generally, CV used to characterize the stand structure and evaluate the status of forest in terms of ecological importance and growth condition [22, 23]. The result of our analysis supports utilization of selected tree species in the designated forests as seed sources for scarce indigenous tree species. Tree species with a higher CV value indicate greater structural diversity. According to [23] classification, a CV of less than 30% is considered small, 30%–50% is moderate, and greater than 50% reflects higher structural diversity. Our result fall within the small and moderate structural diversity categories, suggesting that seeds collected from identified mother trees will be reproductively mature and genetically diverse. This is due to the possibility of seed collection form diverse age class. Furthermore, seeds collected for prolonged period due to variation in fruiting times within the same species. Additionally collecting seeds from identified seed sources enables the collection of seeds from different tree species within the same forest.

Higher CV mostly associated with low local density which supports less completion for resources and production of vigorous and large quantity of seed. Availability of high quality and quantity of seed in specific place reduce time and budget invested in tree seed collection. Thus, collecting tree seeds from the selected seed sources are not only effective but also efficient. Furthermore, forest site with high local density leads to higher coopetition and trigger trees to allocate more energy for growth which results in reduction of seed production. Additionally, tree species with a very low local density can cause shortage of pollen which hider seed development and also favors inbreeding leading to reduction of genetic diversity [24] (Figure 3).

Some species such as *Albizia gummifera* and *C. africana* showed intermediate DBH and height values, with high local densities. While *A. gummifera* in Guangua and Banja districts had an average height of 17.5 and 12.89 m, and diameter of

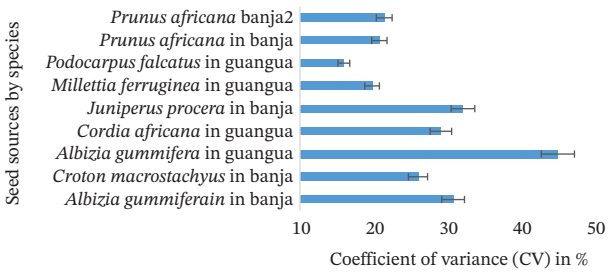


FIGURE 3 | Coefficient of variance for selected mother tree species in different districts of Awi Zone.

50.96 cm and 40.93 cm with 12 and 11 nearby trees, respectively (Figures 3 and 4). *C. africana* shows good population connectivity with the record of 12 average nearby trees finally small sized tree species *(C. macrostachyus and M. ferruginea)* in the study area showed low and moderate local density with 8 and 13 average nearby trees, respectively, the result also aligned with the result of [25]. For local density categorization by mean of nearby trees, we follow the method used by different scholars such as [26, 27] average nearby trees categorized as 0–4 *very low*, 5–9 *low*, 10–18 *moderate*, 19–30 *high*, and > 30 *very high* local density tree species. Importantly, the study highlights urgent on site conservation, and seed source establishment is needed for tree species with very low nearby trees.

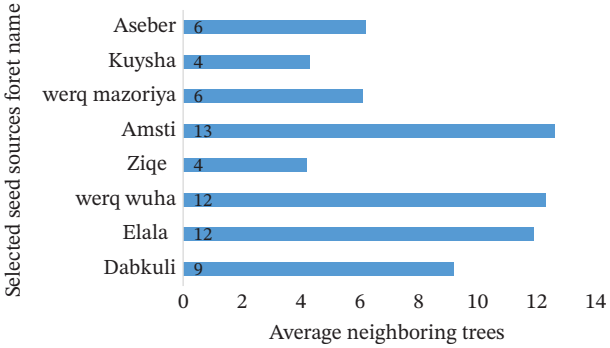


FIGURE 4 | Average nearby trees of selected seed sources from local forests.

3.2 | Expected Quantity of Seed Production From Selected Natural Tree Seed Sources Sites

Seed sources in Elala, Werq Wuha, and Amsti forests are moderately dense while Dabkuli and Werq Mazoria show low local density, and finally forests in Ziqe and Kuysha staked very low level (Table 2). Forests with very low local density may reduce the quantity of seed produced from a specific forest due to small number of same species trees. We highly suggest collecting tree seeds from Elala, Werq Wuha, and Amsti forests to ensure high quality and quantity of seed production. To sustain natural forest tree seed sources in Dabkuli, Werk Mazoria, and Asber forests, urgent enclosure and enrichment planting is needed [24]. Moreover, the forest in this site indicates animal encroachment and selective cutting [28], and intensive management of natural forest will require to enhance the capacity of the forest for tree seed production [29].

Local forest classified with the help of local forestry expert and using indigenous knowledge from elders, tree seed dealers, and youth to provide refined information for tree seed collectors from different stakeholders. Based on the findings from the FGD and KID summary, we provide a comprehensive analysis of the optimal timing for tree seed collection, the anticipated quantity of seeds available for harvest, and the precise locations of the mother trees. Our results align with those documented by the authors in [30–32].

The seeds of *A. gummifera*, *C. macrostachyus*, and *P. africana* can be collected from March to June at a specific location known as Askuna Abo. Up to 200 kg of *C. africana* can be harvested from a particular forest called Yecheraqa. Additionally, *J. procera* and *M. ferruginea* can be collected from the areas of Ziqe and Amsti Kebele (Table 3).

Selected mother tree in Elala, Werq Wuha, and Amsti forests score moderate average nearby trees which favor production of genetically divers and vigorous tree seed, our result is consistent with other studies conducted in Canada [33]. Moderately, dense forest not only produce high quantity of tree seed but also high quality seeds due to low competition for resources and availability of relatively good number of nearby tree which can produce additional seeds.

3.3 | Spatial Distribution of Mother Trees by Species

In the Awi Zone of the Amhara region, mother trees were charted to show where mother trees are located (Figure 5). The area is rich in species such as *A. gummifera, C. africana*, *C. macrostachyus*, *Juniperus procer*, *Militia ferruginea*, *Podocarpus falcatu*, *and P. africana*, as noted by Masresha and Melkamu [34]. Below is a description of the spatial distribution of mother trees of various trees.

TABLE 2 | Local density of selected tree seed sources in different forests.

Selected seed sources local forest name	Mean DBH (Cm)	Mean height (m)	Structural diversity class	Coefficient of variance (cv)	Local density class
Dabkuli	38.42 ± 11.10	13.65 ± 2.94	Small	28.89	Low
Elala	50.96 ± 22.94	17.48 ± 9.41	Moderate	45.02	Moderate
Werq Wuha	42.1 ± 12.26	13.83 ± 3.27	Small	29.12	Moderate
ZIQE	116.21 ± 37.31	33.82 ± 4.07	Moderate	32.11	Very low
AMSTI	15.87 ± 3.14	10.78 ± 2.14	Small	19.79	Moderate
Werq Mazoriya	94.83 ± 15.13	32.28 ± 4.49	Small	15.95	Low
Kuysha	84.54 ± 17.56	29.71 ± 6.82	Small	20.77	Very low
Aseber	91.98 ± 19.71	29.16 ± 6.27	small	21.43	low

TABLE 3 | Estimated amount and time of indigenous tree seed collection in Awi Zone.

Selected mother trees for indigenous tree seed production	Local name of selected tree species	Best time for seed collection	Quant. seed (kg)	District	Kebele (specific location)
Albizia gummifera	Sesa	May - June	200	Banja	Askuna Abo
Albizia gummifera	Sesa	Nov.- Jan.	250	Guangua	Ambiki
Cordia africana	Wanza	Sep.- Nov.	200	Guangua	Yechereqa
Croton macrostachyus	Bisana	Mar. - May	100	Banja	Askuna Abo
Juniperus procera	Yehabesha tid	Jan.- May	300	Banja	Ziqe
Millettia ferruginea	Birbira	Nov.- Jan.	300	Guangua	Amsti
Podocarpus falcatus	Zigba	Dec.- Jan.	150	Guangua	Yechereqa
Prunus africana	Tikur Inchet	Mar.- May	400	Banja	Askuna Abo
Prunus africana	Tikur Inchet	Mar.- may	300	Banja	senksa

Note: Source (FDG and KID).



FIGURE 5 | Spatial distribution of mother trees by species in the Awi Zone.

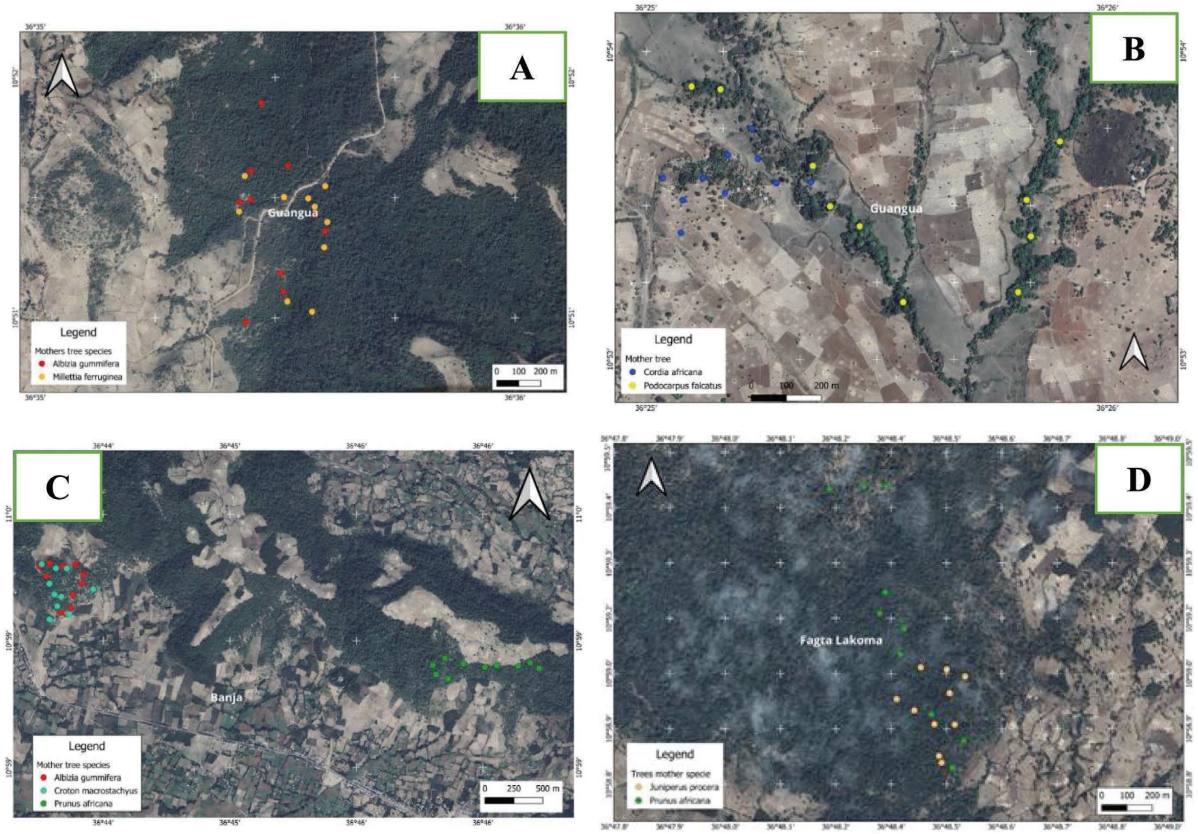


FIGURE 6 | Special distribution of mother trees by districts.



FIGURE 7 | (A) Partial view of identified seed sources, (B) mother trees of *Prunus africana* in Banja District.

In various districts of the Awi Zone, mother trees of different species were mapped (Figure 6) to facilitate the collection of tree seeds by indicating the locations of these specific trees.

A: The spatial distribution of *A. gummifera* (denoted by a red dot) and *M. ferruginea* (represented by a yellow dot) in the Guangua District. B: *C. africana* (indicated by a blue dot) and *P. falcatus* (marked with a yellow dot) in the Guangua District. C: *A. gummifera* (red dot), *C. macrostachyus* (cyan), and *P. africana* (green) in the Banja District. D: *J. procera* (yellow dot) and *P. africana* (Green dot) mother trees in the Banja District (Figure 6). The selected forests were intact and divers (Figure 7).

4 | Conclusions and Recommendation

This study highlights the suitability of identified seed sources for production of scare indigenous tree species in Banja and Guangua districts of Amhara Region. Seed sources of *A. gummifera*, *M. ferruginea*, *C. africana*, *P. falcatus*, *A. gummifera*, *C. macrostachyus*, *P. africana*, *J. procera*, and *P. africana* can be established and managed for production of genetically diverse and huge quantity of seeds to support multimillion seedling production to achieve the green legacy initiative massive planting program. The girth and height of *J. procera, P. falcatu*s, and *P. africana* were among the top largest tree species which indicate the potential of mature tree seed production on one hand, and the low level of local density of the species faces the challenge of sustainability on the other hand. Most identified natural tree seed sources show from low to moderate local density which favor production of genetically vigor tree seed. Thus, to ensure the sustainability of the forest and guaranteeing sustainable tree seed production enrichment planting, livestock management and controlling illegal cutting play a crucial role. The local density of selected seed sources range from very low to moderate which is very good for tree seed collection. The special distribution of mother trees was located, and the expected amount of tree seed produced from the selected seed sources tells that genetically good and economically efficient tree seed production can be ensured if stakeholders in tree seed system focused to collect identified tree species in Banja and Guangua districts.

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Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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