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A Case Study on the Growth and Restoration of Native Plant Species in Formerly Utilized Areas: The Gunung Gede Pangrango National Park

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Abstract. The success of forest restoration relies on factors such as the extent of damage, environmental constraints, and restoration objectives. When restoring conservation areas, it is crucial to carefully select and cultivate indigenous species to ensure their successful establishment. This study addresses important aspects of restoration outcomes by evaluating the survival rate, diameter growth, height growth, and natural regeneration of eight native tree species: Altingia excelsa, Decaspermum fruticosum, Elaeocarpus sphaericus, Litsea angulata, Manglietia glauca, Schima wallichii, Swietenia mahagoni, and Syzygium polyanthum, which were planted 13, 14, and 15 years ago. Data were collected from five plots measuring 20m x 50m, focusing on individuals of these ages. The results revealed a high overall survival rate of 86.25% to 96%. The diameters of the trees ranged from 13 cm to 29.2 cm, while the heights varied from 10.94 m to 18.99 m. Additionally, the stand volume ranged from 62.8 m3 to 126.0 m3 per ha. All eight species demonstrated the ability to flower and bear fruit, and six species exhibited natural regeneration. Only Altingia excelsa and Toona sureni did not show evidence of progeny generation. These findings underscore the suitability of these native species for forest restoration projects, considering their high survival rates, growth characteristics, and natural regeneration potential.

1. Introduction

A National Park is a nature reserve area that has a native ecosystem. These parks are managed through zoning systems and serve multiple purposes, including research, education, support for cultivation, tourism, and recreation. However, these conservation areas often face disturbances caused by human activities such as deforestation, land use changes, and the introduction of invasive species, as well as natural disturbances like drought, fire, and climate change. Therefore, efforts are necessary to restore the original ecosystems within these conservation areas, particularly forests that closely resemble their natural state.

In 2003, Gunung Gede Pangrango National Park (TNGGP) expanded its conservation area by 300 hectares, which was previously a production forest. Several areas covering a total of 7,655 hectares had suffered significant damage or lacked vegetation due to encroachment and other activities. The local community had cultivated these damaged areas for generations, and some individuals depended on the forest for their livelihoods.

The expansion of the conservation forest by 300 hectares has become a model for the Green Wall program, an ecosystem restoration initiative launched in 2008. This program encompasses socio-economic surveys of local communities, biodiversity assessments, planting activities, community empowerment, educational efforts, conservation awareness programs, and ongoing monitoring to assess the success of the restoration efforts. Forest restoration aims to restore, maintain, and enhance the functionality of forests and land, thereby increasing their capacity, productivity, and role in sustaining life support systems [1]. Restoration can take a variety of forms, including physical, biotic, or functional restoration, depending on the extent of damage. In cases where a production forest area is converted into a protected area, as in parts of Gunung Gede Pangrango National Park, it is crucial to consider not only the technical aspects of restoration but also the socio-economic aspects involving the local community, especially those who were previously involved in the management of the production forest.

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The success of restoration can be assessed by evaluating the success of the planted vegetation and the community's perception of the forest. Community perception refers to the process of forming impressions and opinions about various aspects, including rehabilitation programs, in the field [2,3]. Mobilizing the potential and culture of the community in implementing forest and land rehabilitation programs is essential to ensure their active participation and support for the program [4].

Periodic monitoring of plant success is conducted to gather data and information on the progress achieved. Evaluations of restoration activities are carried out at specific intervals, such as every five years, including the five-year, ten-year, fifteen-year, and twenty-year milestones after planting. The evaluation includes assessing ecological trends or developments towards the desired ecosystem, regeneration or natural succession, the presence of animals, the success of plants, and the community's perception of ecosystem restoration activities [5].

Previous research on plant growth has primarily focused on plants younger than 5 years old. Therefore, conducting research on the growth of plants aged 13, 14, and 15 years is crucial. The selected restoration plants are local native species that have demonstrated their ability to grow and adapt, aligning with the conservation objectives of preserving native species. The eight selected plant species include *Altingia excelsa, Decaspermum fruticosum, Elaeocarpus sphaericus, Litsea angulata, Manglietia glauca, Schima wallichii, Syzygium polyanthum,* and *Toona sureni*, with *Swietenia mahagoni* being one of the species included.

2. Materials and Methods

2.1 Location

This study was conducted in a national park restoration area as part of the ”Green Wall” program. This research was conducted in a national park forest area implementing forest restoration under the Green Wall program. The study was conducted as part of the Green Wall program. This program is a collaborative initiative between the Gunung Gede Pangrango National Park (TNGGP), Conservation International (CI), and Daikin Industries—the program aims to restore a 300-hectare damaged forest area within the TNGGP conservation area. Originally a production forest, the area was later designated as a conservation forest. From 2008 to 2010, plants were planted, with a resultant population of plants of various ages. The oldest plants were observed to be 15 years of age at the time of the research.

The research site, located at Nagrak Resort within the TNGGP conservation area, was characterized by yellowish-brown latosol soil based on the West Java Province Soil Map and the Bogor Regency Soil Map. The soil was acidic but relatively fertile, with a high capacity for nutrient retention and fixation. The physiographic condition of the area consisted of volcanic hills with relatively steep topography and slopes reaching up to 30%. The elevation of the study site ranges from 500 to 600 meters above sea level. The climate is classified as type A, with average annual rainfall ranging from 3000–4000 mm, average air temperature ranging from 5–9 degrees Celsius, and air humidity ranging from 80%–90%.

The restoration area was located within the rehabilitation zone, encompassing the Pasir Buntu, Pasir Kuta, Panyusuhan, and Cilondong blocks. The total area of the rehabilitation zone was 300 hectares, with 190.8 hectares utilized for agriculture, mainly cultivating cassava (95%) and some vegetables. The restored area covered 109.2 hectares and consisted of stands of *Agathis dammara* with irregular density and distribution.

This study aimed to assess the suitability of species selected for restoration in conservation forests. The study focused on four main aspects: (1) plant survival, (2) diameter growth, (3) height growth, and (4) natural regeneration.

2.2 Plotting and Observation

The study encompassed three different plant ages: 13, 14, and 15 years. Each age group consisted of five plots measuring 20 m x 100 m. Within these plots, all plants were evaluated for survival rate, diameter growth, height growth, and the presence of natural seedlings. The restoration plants under observation included eight species: *Altingia excelsa, Decaspermum fruticosum, Elaeocarpus sphaericus, Litsea angulata, Manglietia glauca, Schima wallichii, Syzygium polyanthum,* and *Toona sureni*. Additionally, *Swietenia mahagoni* was included in the Green Belt.

Immediate replanting was conducted in cases of plant mortality to maintain the desired restoration plant density of 400 seedlings per hectare. This approach ensured a balanced growing space and minimized competition among the plants. The planting patterns were designed to mimic the natural distribution of species in forests, avoiding the clustering of species. Consequently, the number of plants varied for each species within the research plots.

The observed variables included plant survival, diameter, height, and natural regeneration. The percentage of surviving plants was calculated based on the initial number of seeds planted. Tree diameter was measured at a height of 1.3 meters (DBH, cm), while tree height was measured as the total height. The presence of natural seedlings within the plot, including their names and numbers, was recorded, while those outside the plot were not documented. The collected data was analyzed using a T-test [6].

3. Results

Case studies on the growth and recovery of native plant species show impressive survival rates. The average survival rate for plants aged 13 years was 94.0%, with plants aged 14 years showing an average survival rate of 96.3%. At 15 years of age, the average survival rate for plants was 86.3% (Table 1).

Table 1. Average plant survival

Age	Plot					Means	St.Dev
	1	2	3	4	5		
	.... %						
13 Year	100	86.25	92.5	100	91.25	94.0 a	6.0
14 Year	85	100	100	100	96.25	96.3 a	6,5
15 Year	82.5	71.25	83.75	93.75	100	86.3 b	11.1

Based on Table 1, restoration plants at each plant age show different survival rates. Among the different age categories, plants aged 13 years exhibited the highest average survival rate, with plants aged 14 years and 15 years closely following. The survival rates for 13-year-old plants ranged from 86.25% to 100%, while 14-year-old plants had a survival range of 85% to 100%. Plants aged 15 years showed a survival range from 71.25% to 100%.

The diameter growth of trees can be influenced by various factors, including age, size, species, and competition with other plants. When trees reach the age of 13, their average diameter ranges from 7 cm to 45 cm. At 14 years old, the range expanded to 8 cm to 46 cm, and at 15 years old, it further increased to 8 cm to 48 cm. Overall, the average diameter across all types of plants fell between 13.02 cm and 29.18 cm (Table 2).

Table 2. Recapitulation of average diameter growth of various plant species

Species	N	Min	Max	Mean	Stand. dev
13 Years					
Elaeocarpus sphaericus	47	7	45	19.07	7.08
Litsea angulata	17	11	29	16.94	4.69
Decaspermum fruticosum	23	8	25	16.11	4.21
Manglietia glauca	132	7	32	13.02	4.25
Schima wallichii	45	9	36	19.33	5.84
Syzygium polyanthum	74	9	34.5	20.55	6.18
Toona sureni	70	7	37	21.43	6.48
14 Years					
Elaeocarpus sphaericus	22	8	46	25.52	7.56
Swietenia mahagoni	23	10	45	22.00	9.25
Manglietia glauca	50	8	44	17.32	7.39
Schima wallichii	21	9.5	35	23.36	5.92
Altingia excelsa	19	9	25.5	20.24	4.36
Syzygium polyanthum	227	9	38	20.44	5.85
Toona sureni	38	14.5	42	29.18	6.87
15 Years					
Elaeocarpus sphaericus	21	9	40	22.24	8.03
Decaspermum fruticosum	22	9	35	16.48	6.31
Swietenia mahagoni	13	13	40	28.58	8.87
Manglietia glauca	151	8	48	26.05	7.47
Schima wallichii	13	10	30	22.54	5.50
Syzygium polyanthum	141	9	33.5	19.64	5.34

Based on Table 2, the average diameter growth of 13-year-old plants ranged from 13.02 cm to 21.43 cm, 14-year-old plants ranged from 17.32 cm to 29.18 cm, and 15-year-old plants ranged from 16.48 cm to 28.58 cm.

The growth of the restoration plants varied from 11.61 m to 18.99 m (Table 3).

Table 3. Recapitulation of average height growth for various types of plants

Age	N	Min	Max	Mean	Stand. dev
13 Years					
Elaeocarpus sphaericus	47	8	34	14.98	4.52
Litsea angulata	17	8	20	13.24	3.61
Decaspermum fruticosum	23	6	18	11.61	3.37
Manglietia glauca	132	4	23	12.63	3.55
Schima wallichii	45	5	19	13.11	3.12
Syzygium polyanthum	74	6	31	14.14	3.70
Toona sureni	70	9	32	15.24	4.39
14 Years					
Elaeocarpus sphaericus	22	7	22	14.86	3.41
Swietenia mahagoni	23	6	16	10.96	253
Manglietia glauca	50	6	22	12.04	3.51
Schima wallichii	21	9	20	14.10	2.53
Altingia excelsa	19	5	21	14.53	3.44
Syzygium polyanthum	227	7	21	13.63	2.29
Toona sureni	38	11	25	15.71	3.72
15 Years					
Elaeocarpus sphaericus	21	7	39	17.10	7.03
Decaspermum fruticosum	22	7	19	12.00	3.30
Swietenia mahagoni	13	9	25	14.54	4.07
Manglietia glauca	151	5	37	18.99	6.47
Schima wallichii	13	12	30	17.46	4.59
Syzygium polyanthum	141	7	35	16.06	5.03

The average height of plants at 13 years of age ranged from approximately 4 cm to 34 cm, while at 14 years of age, it ranged from about 5 cm to 25 cm. For plants at 15 years of age, the average height fell within the range of5 cm to 39 cm.

Stand potential is closely related to density, diameter growth, height, and timber production. A stand is a group of trees occupying an area, including species composition, horizontal structure (diameter), and vertical structure (height). Diameter and height data are essential components in calculating standing potential.

Stand potential includes tree density (N/ha) and stand volume potential (m^3ha^{-1}) [9]. Stand potential presentation is differentiated based on age group, diameter, height, and stand volume (Table 4).

Table 4. The average diameter, free branch height and stand volume in the restoration area at Gunung Gede Pangrango National Park

Age	Stand density (Trees/ha)			Diameter (cm)			Branch free height (m)			Stand Volume (m^3 ha^{-1})		
	Mean		StDev	Mean		StDev	Mean		StDev	Mean		StDev
13 Year	408	A	68	17.7	B	1.8	7.8	A	1.7	62.8	A	23.1
14 Year	400	A	41	21.4	AB	2.1	7.2	A	0.8	78.6	A	22.9
15 Year	361	A	74	22.4	A	3.0	10.3	A	2.9	126.0	A	81.4

Note: The same letters in the same column are not significantly

Based on Table 4, plant age did not significantly affect plant density, height, or volume. However, plant age did affect plant diameter. Plant diameter at 13 years of age was significantly different from that at 15 years of age but not significantly different from that at 14 years of age.

Growth rates such as diameter, free branch height, total height, and stand volume are presented in Table 5.

Table 5. The average annual increase in diameter, free branch height, total height and stand volume in the restoration in Gunung Gede Pangrango National Park, West Java.

Age (Year)	MAI of diameter (cm y^{-1})			MAI of branch-free height (m y^{-1})			MAI of total height (m y^{-1})			MAI of stand Volume (m^3 $ha^{-1}y^{-1}$)		
	Mean		StDev	Mean		StDev	Mean		StDev	Mean		StDev
13	1.36	A	0.14	0.60	A	0.13	1.04	A	0.11	4.83	A	1.78
14	1.53	A	0.15	0.51	A	0.05	0.97	A	0.07	5.61	A	1.64
15	1.49	A	0.20	0.69	A	0.20	1.10	A	0.27	8.40	A	5.43
Average	1.46			0.60			1.04			6.28		

Note: The same letters in the same column are not significantly

Table 5 shows that age has no significant effect on MAI diameter, free branch height, total height, or stem volume. An annual increment is a measure of the growth or increase of a plant in a single year. It includes aspects such as increases in stem diameter, plant height, and wood volume. MAI is defined as the volume of stands that can be traded divided by the age of the stand [14]. MAI also describes the dimensions of a forest stand over a specific time interval [15]. Increased tree growth can be used to estimate forest productivity.

Restoration for 13 to 15 years can support natural regeneration. The term "natural regeneration" refers to the process by which plants naturally replace themselves, offering a cost-effective approach to the restoration of vegetation and the maintenance of genetic identity and diversity. [22]. Enhancing natural tree regeneration and establishing self-sustaining communities are crucial for successful restoration efforts [23].

Through interviews and information gathered from the local community and forest area managers, it was discovered that nine planted species demonstrated the ability to flower and produce fruit. Field surveys further identified nine species of naturally occurring seedlings (Table 6).

Table 6. Ability to flower, bear fruit and natural regeneration

Species	flower and bear fruit (Years)	Natural regeneration
Altingia excelsa	9	No
Toona sureni	9	No
Elaeocarpus sphaericus	7	Yes
Syzygium polyanthum	5	Yes
Schima wallichii	5	Yes
Litsea angulata	7	Yes
Manglietia glauca	7	Yes
Decaspermum fruticosum	5	Yes

Based on Table 6, the restoration plants started flowering and fruiting at the age of 5 to 9 years. Six plant species performed natural regeneration, while the other two species did not perform natural regeneration.

4. Discussion

Plant survival is one of the indicators of restoration success. Among the different species, *Toona sureni* exhibited the highest diameter growth at 13 years of age, followed by *Syzygium polyanthum, Schima wallichii, Elaeocarpus sphaericus, Litsea angulata* BI, and *Decaspermum fruticosum*. The species with the lowest diameter growth at this age was *Manglietia glauca*. At 14 years of age, *Toona sureni* again showed the most remarkable diameter growth, followed by *Elaeocarpus sphaericus, Schima wallichii, Swietenia mahagoni, Syzygium polyanthum,* and *Altingia excelsa*. *Manglietia glauca* exhibited the lowest diameter growth at this age. Finally, at 15 years of age, *Swietenia mahagoni* demonstrated the highest diameter growth, followed by *Manglietia glauca, Schima wallichii, Elaeocarpus sphaericus,* and *Syzygium polyanthum. Decaspermum fruticosum* exhibited the lowest diameter growth at this age (Figure 1).

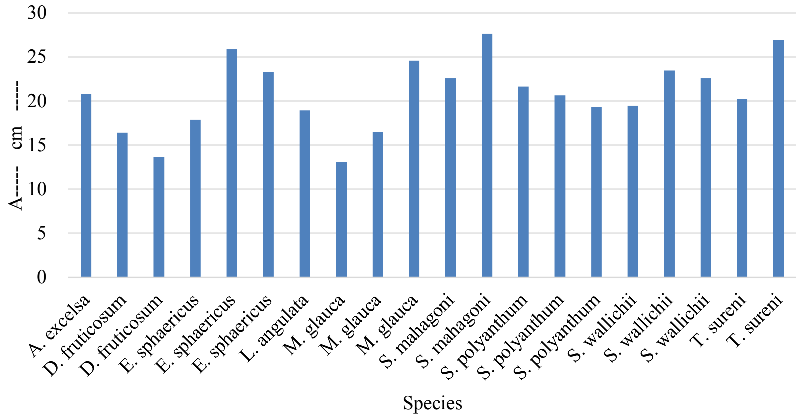

Figure 1. Diameter growth at 3 years of age

The variation in diameter growth among species is influenced by internal factors specific to each species as well as environmental factors. Tree diameter growth is influenced by factors such as tree size, species characteristics, and other factors that affect tree growth [7]. Additionally, weather conditions, which are difficult to control, can also impact growth responses [8]. The diameter distribution of plants at 13 years of age exhibited a range from 7 cm to 45 cm, while at 14 years of age, it exhibited a range from 8 cm to 46 cm. At 15 years of age, the diameter distribution ranged from 8 cm to 48 cm (Figure 2).

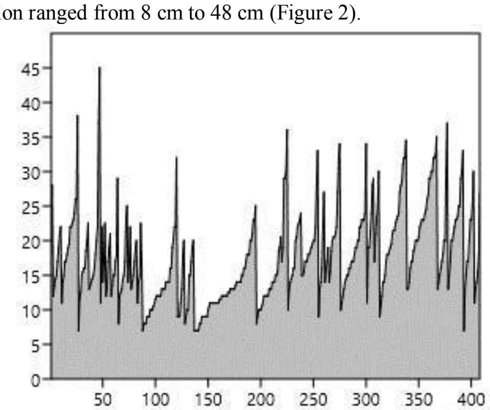

Figure 2. Diameter distribution of plant species

Restoration plant species have variable height growth. Among the different species, Toona sureni exhibited the tallest height at 13 years of age, followed by *Elaeocarpus sphaericus, Syzygium polyanthum, Litsea angulata*, *Schima wallichii, Manglietia glauca,* and *Decaspermum fruticosum* with the lowest height. At 14 years of age, *Toona sureni* once again demonstrated the most excellent height, followed by *Elaeocarpus sphaericus, Altingia excelsa, Schima wallichii, Syzygium polyanthum, Manglietia glauca*, and *Swietenia mahagoni* with the lowest height. For plants at 15 years of age, *Manglietia glauca* achieved the most excellent height, followed by *Schima wallichii, Elaeocarpus sphaericus, Syzygium polyanthum, Swietenia mahagoni*, and *Decaspermum fruticosum* with the lowest height (Figure 3).

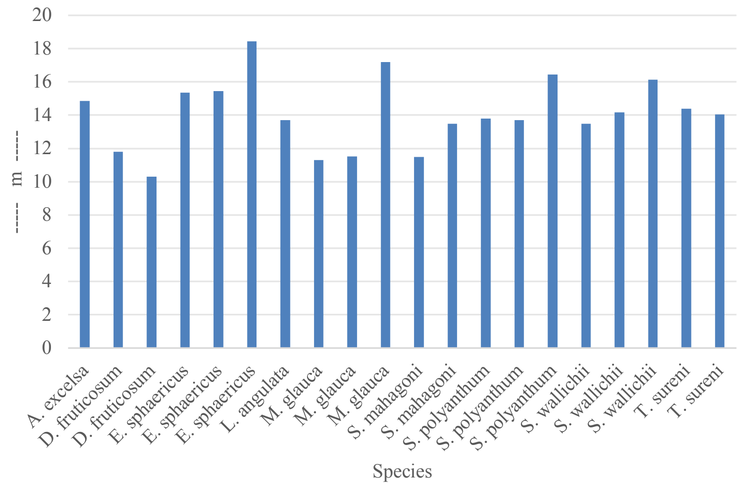

Figure 3. Tree height at 3 plant ages

The growth of plant height varies among species, influenced by internal factors specific to each species and environmental factors. Tree diameter growth rates vary, influenced by factors such as tree size, species characteristics, and other factors impacting tree growth [7]. Moreover, tree height growth is influenced by weather conditions that are difficult to control, which in turn affect growth responses. Diameter growth rates depend on tree characteristics (age, size, competition status), microenvironmental factors (light and nutrient availability), and species traits [8]. The height distribution of plants at 14 years of age ranged from 4 m to 34 m, while for plants at 15 years of age, the distribution ranged from 5 m to 25 m. Plants at 16 years of age exhibited a height distribution ranging from 5 m to 39 m (Figure 4).

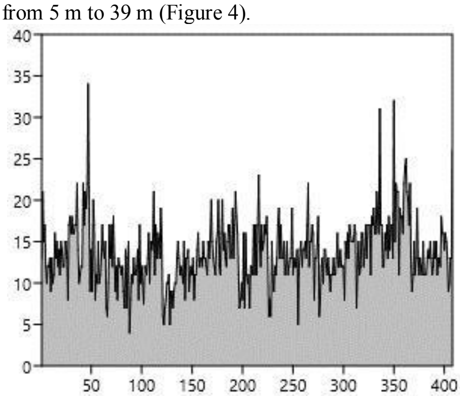

Figure 4. Tree height distribution

The growth of plants at ages 13, 14, and 15 had a notable impact on stand diameter, but it did not significantly affect stand density, free branch height, or stand volume. Variations in diameter and height growth among tree types are influenced by the unique characteristics of individual trees and species diversity [10].

The stand density for 13-year-old plants is 408 trees per hectare; for 14-year-old plants, it is 400 trees per hectare; and for 15-year-old plants, it is 361 trees per hectare. Plants aged 15 years are typically introduced at the start of restoration activities involving the study of planting techniques, and some areas may still retain connections to previously utilized spaces. This situation could potentially impact plant survival rates.

The age of the trees influences the diameter of a tree stand. The initial stand diameter at 13 years of age was 17.7 cm, which increased to 21.4 cm at 14 years of age and slightly further to 22.4 cm at 15 years of age. It can be observed that there is a tendency for stand diameter to increase with age. Additionally, the stand diameter can be affected by the density of the stand. The greatest diameter was recorded in stands aged 15 years, with the lowest stand density compared to stands aged 13 and 14 years. Plant density, determined by plant spacing, significantly influences both plant survival and stand diameter growth, whereas it does not impact stand height growth. [11]. The spacing between plants plays a crucial role in competition, influencing diameter growth [11].

At 13 years old, the stand volume reached 62.8 m^3ha^{-1}, slightly increasing to 78.6 m^3ha^{-1} at 14 years and further to 126 m^3ha^{-1} at 15 years. Stand volume is dependent on the growth of diameter and height without branches, where diameter is influenced by stand density. The highest stand volume achieved at 15 years is attributed to larger tree diameters and lower tree densities, specifically 361 trees/ha. Plant spacing affects diameter growth, with closer spacing indicating higher competition but no impact on height growth [11]. Stand volume increases with narrower planting distances [12]. Wider spacing between individuals is believed to enhance radial growth, particularly in the lower stem [13].

Forest productivity can be assessed by the annual stand volume per hectare ($m^3ha^{-1}y^{-1}$), which is calculated based on the diameter and height of branch-free trees. An analysis of variance indicated that the diameter, free branch height, and volume of plants aged 13, 14, and 15 years did not show significant differences. The mean annual increment (MAI) diameter of stands aged 13 years was 1.36 cm y^{-1}, 1.53 cm y^{-1} at 14 years, and 1.49 cm y^{-1} at 15 years. The MAI free branch height at 13 years was 0.60 m y^{-1}, 0.51 m y^{-1} at 14 years, and 0.69 m y^{-1} at 15 years. The total height of MAI at 13 years was 1.04 m y^{-1}, 0.97 m y^{-1} at 14 years, and 1.10 m y^{-1} at 15 years. Additionally, the MAI stand volume at 13 years was 4.83 $m^3ha^{-1}y^{-1}$, 5.61 $m^3ha^{-1}y^{-1}$ at 14 years, and 8.40 $m^3ha^{-1}y^{-1}$ at 15 years.

The restoration plants achieved an MAI diameter of 1.46 cm y^{-1}, surpassing the 21-year-old Ampupu stands' MAI diameter of 1.2 cm y^{-1} [16], but slightly below the MAI diameter of Gmelina species, precisely at 1.52 cm y^{-1} [17]. The MAI diameter can be enhanced by planting specific species through species and genetic testing. Intensive planting of superior species identified through type and genetic tests can lead to increased diameter growth, such as *S. parvifolia* at 1.86 cm y^{-1}, *S. leprosula* at 1.82 cm y^{-1}, and *S. dasiphylla* at 1.70 cm y^{-1} [18].

There were no statistically significant differences in mean annual increment (MAI) height without branches or total height at ages 13, 14, and 15 years. Light factors mainly influence the height of MAI. Planting at regular spacing and simultaneous planting in one area allows each plant to have a relatively uniform canopy, ensuring sufficient light. Light is a vital resource for plants, as it influences their growth and survival [19]. The MAI height of *Gmelina moluccana* is 1.49 m y^{-1} [20].

Stand volume in the restoration area after 13, 14, and 15 years did not show significant differences. The average tree volume reached 62.8 $m^3ha^{-1}y^{-1}$, higher than the 21-year-old Ampupu, which stands at 3.51 $m^3ha^{-1}y^{-1}$ [16]. Former agricultural forests exhibit higher tree productivity compared to natural forests by planting fast-growing and adaptable species [21]. At 13 years old, the tree volume reached 4.83 $m^3ha^{-1}y^{-1}$, slightly increasing to 5.61 $m^3ha^{-1}y^{-1}$ at 14 years and further increasing to 8.40 $m^3ha^{-1}y^{-1}$ at 15 years, following an exponential trend.

The average MAI diameter at 13 years was 1.36 cm y^{-1}, 1.53 cm y^{-1} at 14 years, and 1.49 cm y^{-1} at 15 years. The analysis of variance indicates that age does not have a significant influence on the MAI diameter. The MAI diameter of Gmelina species is 1.49 cm y^{-1} [17]. The MAI of TPTJ plants aged 5 years for *S. parvifolia* is 1.86 cm y^{-1}, *S. leprosula* is 1.82 cm y^{-1}, *S. dasiphylla* is 1.70 cm y^{-1}, and *D. lanceolata* is 1.05 cmy^{-1} [18].

The mean annual increment (MAI) height of branch-free trees at 13 years old is 0.6 m y^{-1}, 0.51 m y^{-1} at 14 years, and 0.69 m y^{-1} at 15 years. The analysis results of various age factors showed that there was no significant influence on the branch-free MAI of plants aged 13, 14, and 15 years.

Plant success can be seen in its growth. Plant growth stands out as a critical determinant of forest restoration success, with observable and measurable increases in plant diameter and height serving as critical indicators [24]. Success indicators for plants include survival rate, diameter and height growth, flowering and fruiting capabilities, and natural regeneration. Among the nine types of restoration plants meeting these criteria and deemed successful are *Altingia excelsa, Decaspermum fruticosum, Elaeocarpus sphaericus, Litsea angulata, Manglietia glauca Bl, Schima wallichii, Swietenia mahagoni, Syzygium polyanthum,* and *Toona sureni*.

The stability and success of plants can be assessed through their age, with mature plants showcasing their ability to adapt to the environment and access vital resources like nutrients, light, water, and varying climates. Plants that cannot adapt will perish, while adaptable ones thrive and continue to grow. All plant species studied have demonstrated survival and growth over 13, 14, and 15 years, indicating effective adaptation and stability. This success highlights the effectiveness of utilizing native plant species for restoration projects. Notably, planting native trees does not present significant obstacles in terms of growth, even under conditions of limited water availability [25].

The growth of restoration plants displays variations in both diameter and height, with differences in growth attributed to individual tree growth factors and species characteristics [26]. At 13 years of age, the diameter growth range for different tree species was as follows: *Toona sureni* ranged from 7 cm to 47 cm, *Syzygium polyanth*um ranged from 9 cm to 34.5 cm, *Schima wallichii* ranged from 9 cm to 36 cm, and *Elaeocarpus sphaericus* ranged from 7 cm to 45 cm. Similarly, the height growth range at 13 years of age was as follows: *Toona sureni* ranged from 9 cm to 32 cm, *Syzygium polyanthum* ranged from 6 cm to 31 cm, *Schima wallichii* ranged from 5 cm to 19 cm, and *Elaeocarpus sphaericus* ranged from 8 cm to 34 cm.

At 14 years of age, the diameter growth range for *Toona sureni* was 14.5 cm to 42 cm, *Syzygium polyanthum* ranged from 9 cm to 34.5 cm, *Schima wallichii* ranged from 9.5 cm to 35 cm, and *Elaeocarpus sphaericus* ranged from 8 cm to 46 cm. Correspondingly, the height growth range for Toona sureni was 11 m to 25 m, *Syzygium polyanthum* ranged from 7 m to 21 m, *Schima wallichii* ranged from 9 m to 20 m, and *Elaeocarpus sphaericus* ranged from 7 m to 20 m.

At 15 years of age, *Elaeocarpus sphaericus* showed a height range of 9 cm to 40 cm, *Decaspermum fruticosum* ranged from 9 cm to 35 cm, *Swietenia mahagoni* ranged from 13 cm to 40 cm, *Manglietia glauca* ranged from 8 cm to 48 cm, *Schima wallichii* ranged from 10 cm to 30 cm, and *Syzygium polyanthum* ranged from 9 cm to 33.5 cm. The height growth for these plants at 15 years of age varied from 7 m to 39 m for *Elaeocarpus sphaericus*, 7 m to 19 m for *Decaspermum fruticosum*, 9 m to 25 m for *Swietenia mahagoni*, 5 m to 37 m for *Manglietia glauca*, 12 m to 30 m for *Schima wallichii*, and 7 m to 35 m for *Syzygium polyanthum*.

Plants that are well-adapted to local environmental conditions, such as soil, climate, and interactions with other organisms, have a greater chance of survival and natural regeneration. Forest regeneration is a multifaceted process influenced by various factors. This study's focus is limited to the plant's ability to flower, bear fruit and the presence of naturally occurring tree seedlings. Information on flowering and fruiting was gathered through interviews with the local community and area managers, while data on natural tree seedlings was collected through field observations.

Field assessments revealed the presence of naturally occurring saplings of restoration plant species, with variations in quantity and distribution. Natural regeneration was observed in the 15-year-old forest for species like *Elaeocarpus sphaericus*, *Sizygium polyanthum*, *Decaspermum fruticosum*, *Schema wallichii*, and *Manglietia glauca*. Similarly, the 14-year-old restoration forests contained natural saplings of *Sizygium polyanthum*, *Elaeocarpus sphaericus*, *Schema wallichii*, *Decaspermum fruticosum*, *Maesopsis emenii*, *Swietenia mahagoni*, and *Manglietia glauca*. The 13-year-old restoration forest displayed natural saplings of *Sizygium polyanthum*, *Schema wallichii*, *Elaeocarpus sphaericus*, *Agathis dammara*, *Decaspermum fruticosum*, and *Litsea angulata* (Figure 5).

E. sphaericus *S. fruticosum* *S. polyanthum* *M. glauca* *S. wallichii*

Figure 5. Natural regeneration species

In general, natural saplings were observed to thrive in open areas, with fewer saplings found in densely vegetated regions. The scarcity of saplings in bushy areas may be attributed to the phenomenon of seeds becoming trapped within the bushes, which impedes their ability to reach the ground and sprout. Several factors, including tree, shrub, herbaceous, litter, and stand age, have been identified as playing a significant role in influencing natural regeneration. [27].

Conclusion

This document presents a comprehensive study that focuses on the development of restoration of plant species in previous plant areas, with a specific focus on the Gunung Gede Pangrango National Park. The study explores various dimensions of forest restoration, including plant survival rates, diameter and height growth, and natural regenerative abilities. The study evaluates the performance of eight indigenous species throughout 13 to 15 years, emphasizing the importance of selecting native species for restoration projects.

1. The research highlights impressive survival rates for restoration plants, ranging between 86.3% and 96.3% for different age groups.

2. Across the different species and age groups, significant variations were observed in both diameter and height growth, indicating robust growth patterns over the years. The standing volume of plants at 13 years old reached 67.91 $m^3ha^{-1}y^{-1}$; at 14 years, it reached 85.01 $m^3ha^{-1}y^{-1}$, and at 15 years, it reached 136.29 $m^3ha^{-1}y^{-1}$. The diameter of stands at 13 years old was 1.36cm y^{-1}; at 14 years, it was 1.53cm y^{-1}, and at 15 years was 1.49cm y^{-1}. The volume of stands at 13 years old was 5.22 $m^3ha^{-1}y^{-1}$; at 14 years, it was 6.07 $m^3ha^{-1}y^{-1}$, and at 15 years was 9.09 $m^3ha^{-1}y^{-1}$.

3. Out of the eight species analyzed, six exhibited successful natural regeneration, demonstrating their potential for effective restoration practices. A substantial number of the studied species showcased the ability to flower and bear fruit, contributing to the diversity and vitality of the ecosystem.

4. The study highlights the crucial role of long-term research on plant growth in restoration projects and confirms the effectiveness of native species in such endeavours. It provides detailed insights into the potential benefits of utilizing native plant species in forest restoration efforts, focusing on their survival, growth patterns, and natural regenerative abilities.

Research Limitations

There are certain limitations to take into account in this research. Firstly, the number of plants examined may be limited, potentially affecting the generalizability of the findings. Furthermore, the emphasis on local native species may restrict the applicability of the results to other regions or ecosystems.

Author Contributions

All authors played an equal role in the research process, contributing to the conceptualization of ideas, the development of methodology, the validation of findings, the conduct of formal analysis, the preparation of initial drafts of the written work, and the review and editing of the manuscript. Moreover, all authors have reviewed and approved the final version of the manuscript for publication.

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Conflicts of Interest

The author asserts that there is no conflict of interest.

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