



# Effectiveness of Vegetative Propagation of *Ficus fistulosa* and *Macaranga tanarius* for Ecosystem Restoration of Gunung Ciremai National Park, West Java, Indonesia

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## Abstract

Understanding propagation techniques for native species is essential to support conservation area restoration. This study investigates the factors influencing the success rate of twig cuttings of *Ficus fistulosa* and *Macaranga tanarius* in Gunung Ciremai National Park, as both species are capable of adapting to degraded sites. The research was conducted in two stages. The first stage was carried out in a greenhouse using a factorial randomized design involving different types of protective covers and growth regulators. The second stage was conducted under tree shade using a completely randomized design, with treatments involving various growth regulators applied only to *F. fistulosa*. Data were analyzed using ANOVA and the Mann-Whitney test to compare stem diameters between growing and dead cuttings. Greenhouse results showed that shoot emergence occurred only in *F. fistulosa* cuttings (22.50%), with protective covers having a significant effect ( $F = 6.38$ ;  $F_{(0.05)} = 4.49$ ), while growth regulators had no significant influence ( $F = 0.22$ ;  $F_{(0.05)} = 3.24$ ). In the shade experiment, *F. fistulosa* cuttings grew only in a medium composed of cocopeat, soil, and compost, and growth regulators showed no significant effect on cutting growth ( $F = 1.68$ ;  $F_{(0.05)} = 3.24$ ). A significant difference in diameter was observed between cuttings that produced shoots and those that died ( $P < 0.001$ ). The results indicate that *F. fistulosa* and *M. tanarius* require different treatments. Protective covers, growing media, and twig size are key factors determining the success of propagation in *F. fistulosa*, which is useful for ecosystem restoration.

Keywords: conservation area, ecosystem restoration, *Ficus fistulosa*, *Macaranga tanarius*, propagation.

## 1. Introduction

National parks play a crucial role in conserving biodiversity [1–5], offering outdoor experiences to the public [6,7], and regulating hydrological systems [8]. Given the importance of these roles, national parks must be maintained. Today, there are 2,411 national parks worldwide, located in various countries [9] and spanning the Americas, Europe, Africa, Asia, and Australia [10–12]. However, many national parks face various management challenges, including the spread of invasive species and ecosystem degradation due to multiple factors [13–16]. Ecosystem degradation has negative impacts, such as a decrease in biodiversity [17] and wildlife populations, including keystone animals [18]. These challenges must be addressed to ensure the sustainability of the functions and benefits of national parks.

Managers and related parties have made efforts to overcome the threats and degradation of national park ecosystems, including conducting preliminary studies on the status of biodiversity [11,19,20]. For example, in Gunung Palung National Park, which is the habitat of several protected wildlife species (such as *Pongo pygmaeus wurmbii*, *Nasalis larvatus*, *Helarctos malayanus*, *Pardofelis marmorata*, and *Neofelis diardi*), restoration has been carried out in areas of former illegal logging [21]. In Alta Murgia National Park, efforts have been made to improve habitat quality by eradicating the invasive species *Ailanthus altissima* [22]. In Bunaken National Park, ecosystem restoration has been carried out in mangrove forests damaged by the creation of shrimp ponds [23]. Another example is Shiretoko National Park in Japan, where restoration efforts have been carried out using various planting methods [24].

The decline in habitat quality also occurred in Gunung Ciremai National Park (TNGC) due to various factors such as fire [25], encroachment [26], and excessive land use/cultivation [27,28]. Another cause of habitat degradation in this national park is the change of forest cover from natural forest to *Pinus merkusii* plantation forest in some areas [29]. Encroachment, overuse, and land cover conversion occurred when Gunung Ciremai was still functioning as a production forest [27,29]. Wildfires still occur frequently, even though their function has changed to that of a nature reserve [30]. Restoration efforts on former fire and encroachment areas have been carried out, although they still reach only 67% [31]. However, ecosystem restoration of pine forests to conditions like those of natural forests has not yet been achieved.

Ecosystem restoration in *Pinus merkusii* stands within conservation areas, such as the TNGC, cannot be initiated by cutting pine trees during planting, even though pine is not a native species in the TNGC. This is because logging is not permitted in conservation areas. Therefore, a more feasible approach to restoration is to plant local tree species among the pine trees. However, not all local tree species can grow in pine stands because pine produces allelopathy [32], which can inhibit the growth of other species [33,34]. Local tree species, especially pioneer species, that can grow and dominate in pine stands include *F. fistulosa* and *M. tanarius* [35]. Due to their adaptive capacity, these two species are expected to accelerate vegetation recovery and improve habitat quality within pine stands. Meanwhile, planting requires a certain number of seedlings, which can be obtained through breeding. However, breeding information for pioneer tree species adapted to pine stands is limited. Therefore, this article presents the results of research on the breeding of *F. fistulosa* and *M. tanarius*. This information should be considered for ecosystem restoration in pine stands, especially in the TNGC.

## 2. Materials and Methods

This research is an experimental study conducted in a greenhouse (for 50 days) and under the shade of trees (for 119 days), with a total duration of 169 days. The research in the shade is a continuation of the research in the greenhouse, aimed at comparing the percentage of cutting growth under two different air temperature conditions. Air temperature in the greenhouse was higher than under tree shade. This temperature difference was presumed to affect the number of cuttings that successfully developed roots. It was expected that the percentage of cuttings that grew under shade would be higher than in the greenhouse.

### 2.1. Research in The Greenhouse

The materials used in this study included twig cuttings of *F. fistulosa* and *M. tanarius*, polybags, growing media, and root growth-promoting agents. Since the experiment was conducted in a greenhouse, the environmental conditions were considered homogeneous, ensuring that all individual cuttings were exposed to the same environmental influences. The polybags used measured 15 × 10 cm and served as containers for the growing medium. The growing medium consisted of sandy soil, compost, and cocopeat in a 2:2:1 ratio. The root-stimulating substances included: (a) natural ingredients, namely coconut water and onion extract, and (b) the synthetic hormone NAA, which is widely available on the market. The coconut water used was pure, with a volume of 1 liter. Pure coconut water was chosen because previous studies found that diluted coconut water did not yield significant results [36]. Onion extract was obtained by blending 150 grams of shallots and mixing the resulting paste with 500 ml of water. Water was added to dilute the solution and ensure even distribution, as the extract used was a crude extract. Growth regulators derived from synthetic hormones were dissolved in 1000 ml of water for every 2 ml of the substance, following the usage instructions on the packaging.

This study employed a two-way classification experimental design with interaction [37] or a factorial completely randomized design [38]. The first treatment factor involved the application of different types of growth regulators (R), namely: pure coconut water (R1), onion extract (R2), synthetic growth regulator (R3), and no growth regulator (R0). The second treatment factor was the use of protective covers (C), which included covered (C1) and uncovered (C0) conditions. The experiment was repeated three times, with each replication

consisting of 10 cutting samples to determine the percentage of successful growth. Thus, the total number of twig cuttings used as samples for each species, *F. fistulosa* and *M. tanarius*, was  $4 \times 2 \times (3 \times 10) = 240$  samples. Therefore, the total number of samples for both species was 480 (**Table 1**). Each cutting sample was 25 cm in length. Both *F. fistulosa* and *M. tanarius* underwent the same experimental treatments; however, the experiments were conducted separately for each species, and the data analysis was also performed independently.

In this experiment, 60 individual cuttings of *F. fistulosa* and *M. tanarius* (**Table 1**) were soaked in each growth regulator for 30 minutes and then transferred to polybags filled with planting medium. In addition, 30 cuttings from each treatment were covered with clear plastic and 30 cuttings were not covered (**Table 1**). Watering was performed when the planting media appeared to be drying out, generally every two days. Observations of all cuttings were made on day 20. The number of cuttings that germinated and the number of cuttings that died were recorded for each treatment.

**Table 1.** Number of cuttings that were sampled for each treatment of *M. tanarius* and *F. fistulosa* in the greenhouse experiments. The treatments consisted of cutting cover treatments (covered and uncovered) and different types of growth regulators, namely a control, coconut water, onion extract, and a synthetic hormone. Each treatment was replicated three times, with 10 cuttings per replicate. A total of 60 cuttings were used for each growth regulator per species.

Treatment		<i>M. tanarius</i>				<i>F. fistulosa</i>			
		Control (R0)	Coconut Water (R1)	Onion Extract (R2)	Synthetic Hormone (R3)	Control (R0)	Coconut Water (R1)	Onion Extract (R2)	Synthetic Hormone (R3)
Covered (C1)	Replication 1	10	10	10	10	10	10	10	10
	Replication 2	10	10	10	10	10	10	10	10
	Replication 3	10	10	10	10	10	10	10	10
Uncovered (C0)	Replication 1	10	10	10	10	10	10	10	10
	Replication 2	10	10	10	10	10	10	10	10
	Replication 3	10	10	10	10	10	10	10	10
Total		60	60	60	60	60	60	60	60

## 2.2. Research in the Shade of a Tree

The experiment conducted under tree shade was a continuation of the greenhouse study. This follow-up research was carried out because the success rate of cuttings in the greenhouse was relatively low, likely due to high air temperatures in the greenhouse. High air temperatures can increase evaporation and accelerate the drying of cuttings, which may eventually lead to their death. In contrast, the temperature at the follow-up research site was lower, as it was in a highland area near one of the potential planting sites in the TNGC. Since only *F. fistulosa* cuttings successfully grew in the greenhouse experiment, this study also used *F. fistulosa* cuttings. The experimental design employed a one-way classification design [37] or a completely randomized design [38], with treatments consisting of different types of growth regulators (R), namely: pure coconut water (R1), onion extract (R2), synthetic growth regulator (R3), and no growth regulator (R0). The dosage and soaking duration were the same as in the greenhouse experiment. The study consisted of two separate experiments based on the growing media used, and the data analysis was also conducted separately. This separation was necessary because the collection of cuttings and the preparation of the growing media were carried out at different times. The first experiment used a growing medium composed of soil, compost, and coco peat in a 2:2:1 ratio. The second experiment used a medium consisting of soil and coco peat in a 2:1 ratio. Each treatment was repeated five times, with each replication consisting of five cuttings to determine the percentage of successful growth. Thus, the total number of samples for each type of growing medium was  $4 \times 5 \times 5 = 100$  cuttings (**Table 2**). The sample handling process followed the same procedures as in the greenhouse experiment. Data recording was conducted on the 119th day after the cuttings were placed in the growing media. The recording was carried out after confirming that the non-sprouting cuttings were dead, ensuring that no further increase in the number of sprouted cuttings would occur.

**Table 2.** Number of *F. fistulosa* cuttings that were sampled for each treatment in the shade experiment. This table presents two experiments using different growing media (soil + compost + coco peat and soil + coco peat) with growth regulator treatments, a control, five replicates, and a total of 25 cuttings per treatment in each medium.

Media		Control (R0)	Coconut Water (R1)	Onion Extract (R2)	Synthetic Hormone (R3)
Soil + compost + cocopeat	Replication 1	5	5	5	5
	Replication 2	5	5	5	5
	Replication 3	5	5	5	5
	Replication 4	5	5	5	5
	Replication 5	5	5	5	5
Soil + cocopeat	Replication 1	5	5	5	5
	Replication 2	5	5	5	5
	Replication 3	5	5	5	5
	Replication 4	5	5	5	5
	Replication 5	5	5	5	5
Total		50	50	50	50

### 2.3. Data Analysis

Data analysis of the experimental results, both two-way classification with interactions and one-way classification, followed Walpole's formula [37]. Data for *F. fistulosa* and *M. tanarius* in the two-way classification experiment were analyzed separately. Similarly, data analysis from the one-way classification experiment for the cocopeat + sandy soil + compost planting medium was performed separately from the cocopeat and sandy soil planting medium study. The hypotheses used for the two-way classification or factorial completely randomized design are as follows:

Growth Regulator Factor (M)

Ho:  $M_1 = M_2 = \dots = M_m$ , indicating no difference in the average percentage of cutting growth across different growth regulators.

H<sub>1</sub>: At least one pair of  $M_i \neq M_{i'}$ , where  $i \neq i' = 1, 2, \dots, m$ , meaning that at least one pair of growth regulator treatments has a significantly different average percentage of cutting growth.

Protective Cover Factor (S)

Ho:  $S_1 = S_2$ , meaning that the average percentage of cutting growth between covered and uncovered treatments is the same.

H<sub>1</sub>: The average percentage of cutting growth between covered and uncovered treatments is different.

Interaction

Ho: There is no interaction between the application of growth regulators and the use of protective covers.

H<sub>1</sub>: There is an interaction between the application of growth regulators and the use of protective covers.

The hypotheses for the completely randomized design are as follows:

Ho:  $M_1 = M_2 = \dots = M_m$ , indicating no difference in the average percentage of cutting growth across different growth regulators.

H<sub>1</sub>: At least one pair of  $M_i \neq M_{i'}$ , where  $i \neq i' = 1, 2, \dots, m$ , meaning that at least one pair of growth regulator treatments has a significantly different average percentage of cutting growth.

At the conclusion stage, a confidence level of 95% was used. The decision-making criteria, applicable to both the factorial and completely randomized designs, are as follows:

If  $F < F_{0.05}$ , then Ho is accepted

If  $F \geq F_{0.05}$ , then Ho is rejected

The data analysis also included the Mann-Whitney median difference test [39]. This test was conducted to identify the difference in diameter between cuttings that developed shoots and those that did not survive. The Mann-Whitney test was selected due to the relatively small sample size (n = 14) in one group. Spearman’s rank correlation test was performed to examine the relationship between cutting diameter and several leaf parameters, including the number of leaves, average leaf width, and average leaf length [40]. Spearman’s rank correlation test was used because the paired sample size was small (n = 14).

### 3. Results and Discussion

#### 3.1. Results

##### 3.1.1. Percentage of Cuttings Grown in a Greenhouse

Experiments were conducted to determine the percentage growth of *M. tanarius* and *F. fistulosa* cuttings. The percentage of growth was recorded on the 20th day after the cuttings were placed in polybags. A total of 480 cuttings were used, consisting of 240 cuttings each of *M. tanarius* and *F. fistulosa*. The result of this study showed that only *F. fistulosa* cuttings remained alive or developed shoots, amounting to 22.50%, while all individual cuttings of *M. tanarius* died. The study also noted that the *F. fistulosa* cuttings that were given a cap had more germination (37.50%) than the cuttings that were not given a cap (7.50%) (Table 3). Based on the results of the analysis of variance, the provision of hoods had a significant effect on the percentage of cuttings that experienced shoot growth (Table 4).

**Table 3.** Percentage growth of *F. fistulosa* twig cuttings for each treatment and replication. This table illustrates the percentage of cutting growth for each replicate under treatments involving the application of growth regulators and a control, as well as cutting cover treatments. The application of synthetic hormones resulted in the highest average percentage of cutting growth among the growth regulator treatments. In addition, the use of covers produced higher growth percentages compared to uncovered treatments.

Treatment		Control (%)	Coconut water (%)	Onion extract (%)	Synthetic hormones (%)	Average (%)
Covered	Replication 1	50	40	60	50	37.50
	Replication 2	20	40	30	30	
	Replication 3	20	20	40	50	
Uncovered	Replication 1	10	10	0	10	7.50
	Replication 2	0	0	0	20	
	Replication 3	0	20	0	20	
Average		16.67	21.67	21.67	30.00	

The study also found that the percentage of cuttings that grew when treated with growth regulators ranged from 21.67-30.00%. The growth regulator that gave the highest percentage of growth was a synthetic growth regulator belonging to the NAA hormone group. Meanwhile, cuttings that received no growth regulators (control) had the lowest percentage of growth (Table 3). Although the provision of synthetic growth regulators tends to provide a higher percentage of growth, based on the results of the analysis of variance, the provision of different growth regulators does not have a significant effect (Table 4).

**Table 4.** Analysis of variance of *F. fistulosa* twig cuttings with two treatments. This table illustrates the effects of cutting cover application and growth regulator treatments, as well as the interaction between these two factors, on shoot growth of twig cuttings in the greenhouse experiment. The treatment that showed a significant effect on shoot growth was the application of cutting covers.

Source of Variation	DF	Sum of Squares	Mean Square	Computed F	F (5%)
Row means (Cover)	1	5,400.00	5,400.00	6.38*	4.49
Column means (Growth regulator)	3	550.00	183.33	0.22	3.24
Interaction	3	366.67	122.22	0.14	3.24

Error	16	13,543.33	846.46
Total	23	19,680.00	

For 30 days after the cover was removed, *F. fistulosa* was still observed to determine the growth of the shoots in the next period. This follow-up observation resulted in the death of all germinated cuttings. Likewise, the cuttings that germinated in the uncapped treatment all experienced the same thing, namely death and desiccation at a later stage.

### 3.1.2. Percentage of Cuttings Grown under Shade

This study was conducted at an altitude of about 800 meters above sea level and an air temperature of 26.6°C, lower than that in the greenhouse. Based on the observation results, the percentage of cuttings that grew on the planting media of cocopeat and composted soil at the end of the observation (day 119 after the cuttings were transferred to polybags) was 14.00% (Table 5). Meanwhile, all the cuttings placed in the planting media from a mixture of cocopeat and soil without compost did not show any shoot growth and even died. Based on the observations, the planting media consisting of cocopeat and uncomposted soil experienced compaction when watered or exposed to rainwater, so it had a denser condition than the planting media consisting of cocopeat and composted soil.

**Table 5.** Percentage growth of *F. fistulosa* cuttings for each treatment on mixed media of cocopeat, sandy soil, and compost. The application of coconut water as a growth regulator resulted in the highest average percentage of cutting growth compared with the other growth regulator treatments, including the control, in the shade experiment. The average percentage of cutting growth across all treatments was 14%.

Replication	Control (%)	Coconut Water (%)	Synthetic Hormones (%)	Onion Extract (%)	(%) Total
1	0	20	20	20	
2	0	0	0	0	
3	20	60	0	40	
4	0	20	20	40	
5	0	20	0	0	
Average	4	24	8	20	14

The treatment that gave the highest percentage growth value in this study was the use of coconut water, followed by onion extract and synthetic growth regulators. The control gave the lowest value (Table 5). Based on the results of the analysis of variance, the treatment did not have a significant effect on the percentage growth of cuttings (Table 6).

**Table 6.** Analysis of variance of *F. fistulosa* twig cuttings with media consisting of cocopeat, sandy soil, and compost. This table presents the test results for the effects of growth regulator treatments on shoot growth of twig cuttings in the shade experiment. The application of growth regulators did not have a significant effect on shoot growth.

Source of variety	Df	Sum of Squares	Mean Square	Computed F	F(5%)
Treatment (Growth regulator)	3	1,360	453.33	1.68	3.24
Error	16	4,320	270.00		
Total	19	5,680			

### 3.1.3. Relationship between cutting diameter and shoot growth and some leaf parameters

The Mann-Whitney mean difference test was performed to determine if there was a relationship between growing cuttings and cutting diameter. The test was a comparison of diameter between cuttings that experienced shoot growth and dead cuttings. Based on the measurement results, the average diameter of the cuttings that grew shoots was 1.15 cm, while the average diameter of the dead cuttings was 0.80 cm. The t-test results indicated that there was a difference in diameter between cuttings that grew shoots and dead cuttings ( $P < 0.001$ ). This study also showed that the diameter of the cuttings was not correlated with the

number of leaves ( $p = 0.097$ ;  $P = 0.740$ ), average leaf width ( $p = -0.189$ ;  $P = 0.517$ ), or average leaf length ( $p = -0.341$ ;  $P = 0.232$ ).

### 3.2. Discussion

#### 3.2.1. Percentage of Cuttings Grown in the Greenhouse

Ecosystem restoration of pine stands in protected areas (in this case, TNGC) to natural forests using a planting approach requires enough seedlings of a particular species. The required seedlings are local species that can adapt to the environmental conditions being restored. Therefore, it is necessary to collect information on adaptable species. To obtain information on adaptable species, previous research has identified local tree species that grow naturally in *Pinus merkusii* stands, one of the areas to be restored in TNGC [35]. This study is a follow-up to that research, which investigated the possibility of establishing nurseries using twig cuttings of *F. fistulosa* and *M. tanarius*, which are the dominant species in pine stands [35]. *Ficus* is one of the species often used in restoration in Asia because it is considered a keystone species [41]. *Macaranga* is a genus of trees that grows in secondary forests [42], can help improve soil fertility [43], and can be used for restoration [44].

The results of this study showed that the cuttings that were able to sprout were *F. fistulosa* cuttings, while all the cuttings of *M. tanarius* were unable to sprout. The average germination percentage of *Ficus* cuttings in this study was relatively higher than the results of Kuaraksa and Elliott [41], which was 15.1%. Although the exact cause of the difference is unknown (some *F. fistulosa* cuttings can grow and all *M. tanarius* cuttings die), the ability to grow cuttings, including root emergence, is different for each species [45] and is influenced by several factors such as growth hormones [46,47]. Although the percentage of growth is quite low [48], breeding of *Ficus* using the vegetative approach is more widely practiced than the generative approach [49].

In this study, the provision of hoods can induce *F. fistulosa* cuttings to produce shoots. The results of this study are consistent with the results of previous studies that indicate that the provision of hoods can increase the growth of plant cuttings or seedlings [50–52]. Hooding can regulate temperature, humidity, and reduce the intensity of sunlight, which triggers the auxin hormone to be more active in root formation [50,53].

The provision of growth regulators to *F. fistulosa* in this study resulted in a lower percentage of growth compared to the percentage of growth in cuttings of *F. auriculata*, *F. fulva*, *F. hispida*, *F. oligodon*, *F. semicordata*, an average of 66.1%, by previous researchers [41]. This study, which gave the results that the provision of synthetic growth regulators (belonging to the group of NAA hormones) tends to have the highest percentage of growth, in line with previous research on *F. benjamina*; the use of NAA hormones resulted in a higher percentage of growth of cuttings compared to IAA, IBA and GA3 [45]. The coconut water immersion treatment in this study yielded results comparable to those of previous research on the same species, which reported 20% [36]. In the case of Pulai cuttings, the application of shallot extract did not affect shoot growth [51]. Meanwhile, cuttings that were not treated with growth regulators (as a control) in this study had the lowest growth percentage value, which is consistent with previous research on *F. benjamina* species [45]. Although the application of growth regulators tended to result in a higher percentage of growth, it did not have a significant effect. On the other hand, the provision of a cover, which resulted in a significantly higher percentage of growth, suggests that the treatment is more important than the provision of growth regulators for the growth of *F. fistulosa* cuttings. This is because covering the plants can reduce evaporation and maintain environmental humidity.

The death of all *F. fistulosa* cuttings in the next observation period was probably related to the high air temperature in the greenhouse. The high ambient temperature led to increased evaporation from the plants. This result suggests that temperature and humidity are crucial factors in the vegetative propagation of trees [53,54]. For example, the optimum temperature for the growth of *Populus tremula* cuttings is 30°C [55].

The failure of *M. tanarius* cuttings to grow in this study is suspected to be influenced by multiple interrelated factors, including growth hormones, dosage application, growing media, and the plant parts used. Previous studies on other species have stated that cuttings

will develop roots if they contain enough auxin hormones [56–58], and vice versa. The optimal application of growth hormones can enhance root growth and development [59,60]. However, excessively high hormone concentrations and prolonged soaking can inhibit root formation and even cause toxic effects [61]. The choice of growing media also significantly affects rooting success; for instance, a mixture of peat moss and sand is highly effective for *Ficus* growth [62]. Additionally, different plant parts exhibit varying levels of success in rooting. In *Ficus* cuttings, the middle stem section has been reported to have a higher root growth percentage compared to the tip section [61,62]. Based on these findings, the failure of *Macaranga* cuttings to grow and their eventual death in this study is suspected to be due to low auxin content, inappropriate dosage and soaking duration of growth regulators, unsuitable growing media, and composition, as well as improper selection of plant parts.

Humidity, temperature, and light can also significantly impact root growth [61]. Air humidity of around 70% and a temperature of approximately  $20\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$  strongly support root formation [63]. Excessively high temperatures ( $>30^{\circ}\text{C}$ ) can inhibit root growth and trigger plant death [53]. Since the temperature in the greenhouse can reach  $32^{\circ}\text{C}$ , the excessively high environmental temperature is also suspected to be a factor in the failure of *Macaranga* cuttings to develop roots. According to previous studies, the presence of tannins can hinder plants from absorbing nutrients [64,65] and inhibit root growth [66]. *Macaranga* bark is also known to contain tannins [67]. Although this study did not conduct direct measurements, it also observed that *Macaranga* bark is relatively thin, which makes the stems dry out more quickly. Therefore, the failure of *Macaranga* cuttings is suspected to be related to the thickness and availability of tannins in the bark.

The successful propagation of *Macaranga* through stem cuttings plays a crucial role in restoration efforts. Conversely, the failure of propagation due to a lack of knowledge can negatively impact its success rate. Although the generative approach or tissue culture [66] can serve as alternatives for propagating *M. tanarius*, the use of stem cuttings should also be explored to meet seedling demands for restoration purposes. Therefore, further research on propagation through cuttings is necessary to determine the optimal plant parts, temperature, humidity, hormone dosage, and media composition.

### 3.2.2. Percentage of Cuttings Grown under Shade

The research in the shade is a continuation of the research in the greenhouse, using the species *F. fistulosa*, because the species based on the results of the research in the greenhouse was able to produce shoots but died in the next period. Cuttings that grow only on media with the composition of coco peat + composted soil, but not on media with the composition of coco peat and soil without compost in this study, indicate that the planting medium affects the growth of cuttings [68]. However, according to Aghdaei et al., cuttings placed in a medium that is a mixture of coco peat and peat moss compost tend to have better growth compared to other media mixtures. Based on the observations in this study, the planting medium with the composition of coco peat + soil without compost has a denser condition, so there are fewer pores compared to the media with the composition of coco peat + composted soil. Planting media with many pores can increase the percentage of cuttings growth because it can store a lot of air and water [45]. Therefore, the lack of pores is thought to be the cause of the non-growth of shoots on *F. fistulosa* cuttings placed on coco peat + uncomposted soil media.

Composted soil contains a significant amount of organic matter. The organic matter plays an important role for soil microorganisms [69], such as a source of nutrients. In addition, some soil microorganisms can form symbioses with plants, which is beneficial for plant growth, including root development [70,71]. The presence of microorganisms around plants can increase the availability of mineral nutrients such as nitrogen, phosphorus, and sulphur [69,72]. Therefore, the presence of microorganisms is also suspected to be a factor influencing the growth of cuttings on compost-treated planting media, or the cause of non-growth of cuttings on non-compost-treated media.

Regarding treatment with growth regulators, the research conducted in the shade was also consistent with the research conducted in the greenhouse. The application of growth regulators had no significant effect. The results also showed that sprouted cuttings placed

under shade did not experience any mortality until the end of the study, in contrast to those placed in the greenhouse. This study demonstrates that certain factors, including the type of growing medium and environmental humidity, are more important than the application of growth regulators in the cultivation of *F. fistulosa* cuttings.

### 3.2.3. Relationship between cutting diameter and shoot growth and some leaf parameters

The relationship between cutting diameter and shoot growth in this study is consistent with previous research on *P. thunbergii* species [73]; large-diameter cuttings have a greater chance of growing shoots than small-diameter cuttings. In the research of Waniatri et al. [36], although not significantly different, *F. fistulosa* cuttings from the base of the branch (generally larger diameter) tended to have a higher percentage of growth compared to cuttings from the middle and tip (generally smaller diameter). This study also demonstrates that branch diameter should be considered when propagating seedlings by cuttings. However, the results of this study cannot explain the optimal diameter for propagation of *F. fistulosa* cuttings. This was due to the limited number of samples in each diameter class and the relatively narrow range (from the smallest to the largest). Therefore, further research is needed to determine the optimal cutting diameter for sprout growth.

The size and number of leaves together are often key considerations in determining the readiness of a seedling to be planted in the field. Seedlings with larger leaf size and more leaves are more ready for planting than those with smaller leaf size and fewer leaves. Suppose diameter has a positive correlation with leaf size and number over the same period. In that case, larger diameter cuttings will be preferred to speed up (shorten) the establishment period to the planting period. The lack of correlation between cutting diameter and the number of leaves, average leaf width, and average leaf length may be since these leaf parameters are more closely related to the time since emergence. The longer the time since germination, the more the number and size of leaves increase. Therefore, this study suggests that cutting diameter selection may not be a reliable basis for reducing the budding time in *F. fistulosa*. Diameter selection can only be used to increase the chances of successful cutting growth.

### 3.2.4. Implications for conservation

Given the importance of an intact ecosystem for biodiversity conservation [74], degraded areas within conservation zones need to be restored [75]. In the case of TNGC, restoration efforts in pine stands involve planting native species among the existing pine trees. Planting will help accelerate the increase of local species populations and reduce the dominance of pine. One crucial aspect of ecosystem restoration is understanding propagation techniques for species that can adapt to the planting site.

Based on the results of this research, *F. fistulosa* is a pioneer tree species that can be propagated through stem cuttings, whereas *M. tanarius* requires further study. Although the optimal diameter has not yet been determined, it is recommended to select cuttings with a relatively large diameter, greater than 1 cm, typically taken from the base of a branch. The propagation medium used should have high porosity, such as a mixture of coco peat, humus, and topsoil. Porous media can retain more water and air, which are beneficial for the growth of cuttings, particularly in terms of root development. In addition, porous media provide a suitable environment for soil microorganisms that can help stimulate root growth in cuttings. Research results also indicate that cuttings placed in elevated areas near the planting site germinated better than those placed in a greenhouse. This suggests that seedbeds should be established near the planting or restoration area, including parts of the TNGC. The advantages of locating nurseries close to the planting area include having similar environmental conditions, easier access to cuttings, reduced transportation needs for seeds, and the elimination of the need for protective covers during the seeding process. This approach is more practical and cost-effective. It is essential to note that the proximity of the cutting source to the planting area significantly enhances these benefits compared to greenhouse propagation.

The areas requiring restoration are spread across multiple locations. Therefore, nurseries should not be established in a single location but in several places. The involvement of various stakeholders, such as local communities, village governments, district governments, private

companies, and universities, is crucial for conservation efforts [76], including seedling production, planting, and maintenance. Community involvement is particularly important in fostering conservation awareness and a sense of ownership in protecting the area [77]. The participation of private companies is also essential, as many businesses depend on conservation areas, particularly for water resources. Companies can contribute by providing funding for nursery development and field maintenance through their social responsibility programs. Similarly, the engagement of local governments is necessary, as regional development is closely linked to conservation areas within their jurisdiction. The local government can play a role as a funding provider and policy supporter in regional restoration, while the local community can act as nursery managers. Universities can play a crucial role in conducting research on seedling propagation and offering support to local communities in nursery management. In addition to the roles, these parties can collaboratively carry out planting activities in the restoration areas of TNGC, under the coordination of the site managers. Other potential participants in the planting efforts include students from schools and universities located around TNGC.

*Macaranga* species can be propagated through seed germination and tissue culture [66]. However, tissue culture requires relatively costly equipment, making seed germination a more practical alternative. While seed germination can be performed using simple equipment and at a relatively low cost, seeds are only available in certain seasons, and knowledge of phenology is also required [78]. Therefore, research on *Macaranga* cuttings should continue to develop an effective propagation method that facilitates seedling production. Moreover, research should not be limited to *Macaranga* but should also include other species that have adapted to the characteristics of the restoration area. This would increase the diversity of species planted and contribute to enhancing biodiversity in the pine stands of TNGC in the coming years following the restoration activities.

#### 4. Conclusions

This study concludes that each tree species requires specific propagation conditions. Temperature, humidity, and growing media are more critical factors than the application of growth regulators in the propagation of *F. fistulosa* through branch cuttings. As an implication of this study, the characteristics of the nursery site for *F. fistulosa* seedling production should include relatively low temperatures and high humidity. Therefore, nurseries should ideally be established near restoration sites. Additionally, the seedling medium should have high porosity, and the branch cuttings should be of sufficient size. The findings of this study offer valuable insights for conservationists and conservation area managers in restoration efforts, both within TNGC and in other conservation areas. However, for *M. tanarius*, this study provides limited information for guiding restoration efforts, highlighting the need for further research to identify key factors for stem cutting propagation. Further research is also needed to determine the ideal branch diameter for *F. fistulosa* propagation.

#### Author Contributions

**TS:** Conceptualization, Methodology, Investigation, Writing, Review & Editing; **YH:** Writing, Review & Editing; **DK:** Writing, Review & Editing; **IA:** Analysis, Review & Editing; **AN:** Analysis, Review & Editing; **RI:** Collecting data.

#### AI Writing Statement

During the preparation of this work, the authors used ChatGPT to assist with language editing and sentence refinement. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

### Conflicts of interest

There are no conflicts to declare.

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