Journal of Tropical Resources and Sustainable Science
Website : http://journal.umk.edu.my/index.php/jtrss/
eISSN : 2462-2389
Vol: 14 Issue 2, 2026, 307-315
DOI: https://doi.org/10.47253/jtrss.v14i2.1726

RESEARCH ARTICLE

Optimizing reforestation: growth and survival of selected tree seedlings in different light and land-use conditions

Muhammad Azmil A.R.*, Farah Ain J.

Fakulti Perhutanan Tropika, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.

ARTICLE HISTORY
Received : 14 September 2025
Accepted : 26 November 2025
Online : 30 June 2026

KEYWORDS
growth rates,
natural forest,
plantation,
survival rates

☒ * CORRESPONDING AUTHOR
Muhammad Azmil Abdul Razak
Fakulti Perhutanan Tropika, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
Email: azmilrazak@ums.edu.my

ABSTRACT

Tropical forest degradation has resulted in biodiversity loss and diminished ecosystem services. Light strongly increases tree growth but its effect on survival depends on life stage, species and stressors. Urban and disturbed landscapes may enhance plant growth but are often associated with increased turnover rates. Effective management should align species selection with site-specific light conditions, mitigate environmental stressors, and implement targeted thinning or enrichment planting strategies to optimize restoration outcomes. This study examines the growth and survival rates of tree seedlings in Sapong Estate, Tenom, Sabah, through a comparative analysis of natural forest and plantation landscapes. Seedling growth rates were quantified based on height increments over time, while survival rates were determined by the number of seedlings remaining at the end of the experimental period. A randomized complete block design (RCBD) was employed, with four seedling species—*Rubroshorea cutrisii* (Dipterocarpaceae), *Dryobalanops aromatica* (Dipterocarpaceae), *Durio zibethinus* (Bombacaceae), and *Artocarpus odoratissimus* (Moraceae)—planted under different light exposure conditions. Growth and survival rates were measured over time, and statistical analysis was conducted using ANOVA. Seedlings in plantation areas exhibited significantly higher growth rates (0.36 cm/day) than those in natural forest conditions (0.22 cm/day), with statistical significance ($p < 0.05$). However, survival rates between the two landscape types did not differ significantly ($p > 0.05$). While light exposure had limited influence on growth performance, shaded microsites markedly improved seedling survival (99.5%) compared to open areas (77.08%) with significance of ($p<0.05$). The findings suggest that land-use type and environmental conditions influence seedling performance, providing insights for ecological restoration strategies. Notably, *D. aromatica* and *R. curtisii* emerged as the fastest-growing species, confirming their suitability as priority candidates for restoration initiatives. To enhance seedling establishment and long-term forest recovery, it is recommended that restoration efforts prioritize the replanting of these species in shaded areas, where survival rates are markedly higher. Integrating species-specific performance with microhabitat considerations will strengthen restoration success and support biodiversity conservation in disturbed tropical landscapes.

1.0 INTRODUCTION

Over 50% of the world's tropical forests has been replaced by different land uses, leading to a reduction in habitats and resources for both species and human communities that depend on these forest ecosystems. This trend has also put at risk the ecosystem services that are crucial for sustaining life on our planet. To prevent further losses in biodiversity and protect global carbon stocks, it is essential to establish conservation and management plans for the remaining old-growth forests (Berhanu et al., 2023).

One of the most effective nature-oriented approaches to prevent and reverse biodiversity loss while also mitigating the effects of climate change is the restoration of tropical forests through afforestation and natural regeneration techniques. Restoration initiatives are aim to bring back indigenous species and develop diverse landscapes that harmonize agricultural requirements with conservation objectives (Zedler & Lindig-Cisneros 2013).

Tree growth and survival rates in tropical regions are influenced by a complex interplay of environmental, biological, and climatic factors. Rising temperatures and vapor pressure deficits are significant drivers of increased tree mortality in moist tropical forests, often leading to carbon starvation and hydraulic failure (Miyamoto et al., 2021). The survival and growth of trees are also size-dependent, with different species exhibiting distinct survival strategies that are influenced by climate variables such as mean annual temperature and water deficit (Taccoen et al., 2021). In terms of biological factors, species with denser wood tend to have higher survival rates but lower growth rates, indicating a trade-off between growth and survival that is consistent over time (Tuck et al., 2016). A study investigating the spatial distribution of adult trees and seedling survivorship of *Pentaspadon motleyi* in the lowland rainforests of Peninsular Malaysia revealed that light gaps, characterized by approximately 4% sunlight penetration, significantly enhanced seedling survival and growth rates (Manokaran et al. 1992). Inter-species relationships significantly influence seedling growth and survival in forest restoration efforts. A study conducted in Peninsular Malaysia demonstrated that *Shorea roxburghii* is particularly well-suited for enrichment planting in secondary forest conditions. *Hopea odorata* thrives in areas previously dominated by *Acacia mangium*, while *Shorea leprosula* shows strong adaptability to regeneration in logged-over forest sites. (Parsada, 2013). These findings underscore the importance of both microhabitat conditions, such as light availability, and species-specific ecological compatibility in enhancing seedling survival and growth. Integrating light-gap dynamics and strategic species selection can substantially improve the effectiveness of forest restoration initiatives in Peninsular Malaysia.

The Sapong Estate in Tenom, Sabah, illustrates the ongoing conversion of native forests into oil palm plantations since 1916 (Abdullah & Nakagoshi 2020). The aim of this research is to examine the influence of land-use alterations on the establishment and growth of selected seedlings within the Sapong Estate, considering critical environmental variables that influence these phenomena. This study is designed with several specific objectives: (i) to assess and compare the growth dynamics and survival rates of seedlings established in natural forest ecosystems versus plantation environments; (ii) to analyse the influence of light availability by assessing seedling performance; (iii) to identify species with higher growth and survival rates in both natural forest and plantation settings; and (iv) to provide insights that guide silvicultural practices and management strategies for improving seedling establishment and ensuring sustainable forest regeneration. This study is essential to understand the effects of land-use change on the establishment of new seedlings in the Sapong Estate. The findings will provide valuable insights into the factors influencing seedling growth rates and survival. Understanding these dynamics is crucial for developing effective management strategies that promote biodiversity conservation while balancing agricultural productivity and economic development.

2. MATERIALS AND METHODS

2.1. Study Site

This study was carried out at Sapong Estate, situated in Tenom, Sabah, Malaysia. Sapong Estate is located at the southwestern region of Sabah (Figure 1). The estate is located at approximately 5°03'52.90" N and 115°56'56.80" E. The region is characterized by persistently high temperatures and substantial rainfall throughout the year, creating favorable conditions for plantation crops such as oil palm. The mean annual rainfall, estimated at 137.34 mm, is based on data collected from 2014 to 2023 (Shem, 2018). The estate was initially set up as a research location for tobacco farming around the year 1905. Frank Edward Lease served as the inaugural manager of the estate. Between the years 1916 and 1921, Sapong Estate expanded to emerge as one of the preeminent estates in North Borneo (John & Jackson 1973).

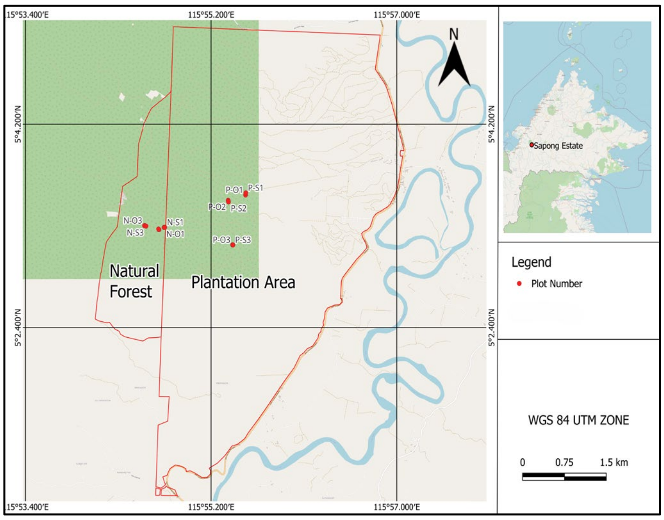

Figure 1: The location of Sapong Estate, Tenom, Sabah.

2.2. Experimental Design

This study employed a quantitative experimental design to investigate the factors influencing the growth and independence of seedlings planted under different conditions. This study focused on comparing the growth rate and survival of seedlings across two distinct environments: (i) natural forest areas, which are gazetted as protected zones by SD Guthrie Sapong and remain undisturbed, dominated by native forest tree species; and (ii) plantation areas, which are cultivated with *Elaeis guineensis* (oil palm) and subjected to routine management practices such as weeding and fertilization. Additionally, comparisons were made between open areas, characterized by high light exposure (100% light), as shown in Figure 2, and shaded areas with low light exposure (5% of light), as shown in Figure 3, within these landscapes. This design allowed for a thorough evaluation of the effects of environmental conditions and light exposure on the performance of the saplings.

Figure 2: Open area in plot P-01, Sapong Estate, Tenom, Sabah.

Figure 3: Shaded area in plot P-S2, Sapong Estate, Tenom, Sabah.

The study was conducted using a randomized complete block design (RCBD) to ensure the minimization of environmental variations within the landscape types (Harbur et al., 2023). Two landscape types were included in the study: natural forest and plantation. Each landscape type was further divided into two light exposure conditions: open areas, where seedlings were exposed to high levels of sunlight, and shaded areas, where seedlings received lower levels of sunlight. Each treatment combination was replicated three times, resulting in a total of 12 subplots, with six subplots located in the plantation areas and six in the natural forest areas (Figure 4).

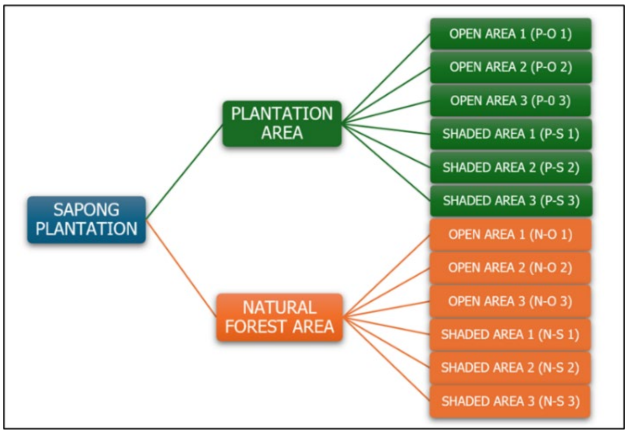

Figure 4: Layout of plantation and natural forest areas showing open and shaded study plots in Sapong plantation.

Four seedling species were selected for this study, comprising two dipterocarps *Rubroshorea cutrisii* (Seraya) and *Dryobalanops aromatica* (Kapur) and two fruit trees *Durio zibethinus* (Durian) and *Artocarpus odoratissimus* (Tarap). Each subplot was planted with 32 seedlings, approximately eight months old, with heights ranging from 80 to 100 cm. The planting design included eight individuals per species within each subplot. The seedlings were arranged in alternating rows, where the first row consisted of all eight seedlings of *R. cutrisii*, followed by a second row of eight seedlings of *D. zibethinus*. This pattern continued alternately between dipterocarp and fruit tree species, ensuring a systematic and balanced planting design within each subplot. In total, 384 seedlings were planted across all subplots. As shown in Figure 5, the seedlings of four species were arranged in rows with 1-meter spacing between them to ensure adequate growing space and minimize competition for light, water, and nutrients (Vänninen 2005). Initial measurements (t_0) were recorded on 23 October 2024, and subsequent measurements (t_1) were taken on 29 December 2024, representing an interval of 67 days between observations.

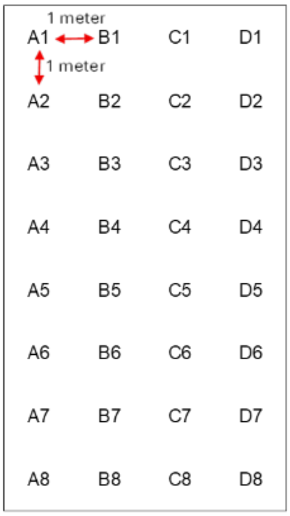

Figure 5: Arrangement of seedlings in experimental plot; A: *R. cutrisii* (Seraya); B: *D. zibethinus* (Durian); C: *D. aromatica* (Kapur); D: *A. odoratissimus* (Tarap).

2.3. Selected species

R. cutrisii (Seraya), is a tall tropical hardwood from the Dipterocarpaceae, reaching over 40 meters (Ashton & Heckenhauer, 2022). It has glossy, elliptical leaves, winged seeds for wind dispersal, and rough dark brown bark with shallow fissures. The species is native to the Peninsular Malaysia, Sumatra, and Borneo (Subiakto et al., 2017). *D. aromatica* (Kapur), a member of the Dipterocarpaceae family, grows in Sumatra, Peninsular Malaysia, and Borneo. It reaches up to 60 meters tall with a 3.4-meter bole and exhibits crown shyness. The tree flowers every 2 to 7 years, producing white to cream flowers. Its 5-winged fruit has wings up to 6 cm.

Seeds and seedlings are eaten by rodents and wild pigs (Syahida et al., 2020). *D. zibethinus* (Durian), belonging to the Bombacaceae family is a tall tree that has a straight trunk with rough, peeling bark and a large, irregular crown. Its oblong leaves are glossy green on top and silvery or bronze underneath, measuring 6-20 cm long and 3-9 cm wide. The bright yellow, bell-shaped flowers grow in clusters of up to 30, bloom at night (NParks 2022). *A. odoratissimus* (Tarap), classified under the Moraceae family, found mainly on Borneo Island, is an evergreen tree reaching 25 meters tall with a 40 cm trunk diameter. Its twigs are 4–10 mm thick with yellow to red hair. The large, dark green leaves are 16–50 cm long and 11–28 cm wide. Each fruit contains about 100 seeds, each weighing around one gram. The fruit is soft, flavourful, and considered superior to jackfruit and Cempedak (Abu Bakar 2018).

2.4. Analysis

In this study, the data analysis involved calculating the growth rate and survival rate of the seedlings to evaluate their performance under different treatments. These calculations were performed before conducting statistical analysis using JASP software to identify significant differences between experimental groups through ANOVA (Analysis of Variance).

Before performing the statistical analysis, two key metrics, growth rate and survival rate, were calculated to evaluate the performance of seedlings under different treatments. The growth rate was calculated to assess the rate of seedling height increase over the study period (Gardiner et al., 2019).

$$Growth\ Rate = \frac{Height\ t^1(cm) - Height\ t^0(cm)}{t^1 - t^0\ (day)}$$

Where,
Height t_1=The seedling height measured at the end of the experiment,
Height t_0=The height measured at the start of the experiment and,
t_1- t_0=The duration of the study in days.

This calculation provided the daily growth rate in centimeters per day, offering a precise measure of seedling performance. The results were organized based on species and treatment conditions to facilitate statistical analysis. Similarly, the survival rate was calculated to determine the percentage of seedlings that survived throughout the study period (Berhe et al., 2023). This percentage served as an indicator of the treatment's effectiveness in maintaining seedling viability.

$$Survival\ Rate\ (\%) = \frac{Number\ of\ surviving\ seedlings}{Total\ number\ of\ seedlings\ planted}\ x\ 100\%$$

Where,
Number of surviving seedlings = The count of seedlings still alive at the end of the study and,
Number of seedlings planted = The initial count at the start

After calculating both the growth and survival rates, the data were compiled into a spreadsheet categorized by treatment groups, including species, plantation area, and light conditions (open and shaded areas). These calculated values were used as dependent variables in the subsequent statistical analysis.

The data analysis method applied in this study was ANOVA (Analysis of Variance), a widely used statistical technique designed to determine whether there are statistically significant differences between the means of multiple groups. This method is particularly effective when there is one dependent variable being measured and one or more independent variables that are manipulated or categorized. By analyzing the variance both within and between groups, ANOVA helps identify whether the observed differences in the data are due to the experimental treatments or merely the result of random variation (Ostertagová & Ostertag 2013).

The statistical analysis was conducted using JASP software, employing a one-way ANOVA to test for significant differences in the mean growth and survival rates among the treatment groups. The dataset, containing the growth and survival rates, was imported into JASP. Treatment species groups, plantation areas, and light conditions were specified as independent variables. ANOVA was performed to detect whether the variations in the growth and survival rates were statistically significant. When significant differences were observed, post-hoc tests were applied to identify the specific treatment groups contributing to these differences. This approach provided a comprehensive evaluation of the factors influencing seedling growth and survival, allowing for meaningful interpretations of the treatment effects.

3. RESULT

3.1. Type of landscape influence towards seedling growth rate

The species selected for this study comprised two distinct groups: fruiting seedlings, represented by *D. zibethinus* (Durian) and *A. odoratissimus* (Tarap); and native forest seedlings, represented by *R. cutrisii* (Seraya) and *D. aromatica* (Kapur).

The seedling growth rate observed in plantation settings is greater (0.36 cm/day) in comparison to the natural forest ecosystems (0.22 cm/day) (Figure 6). The p-value is less than 0.05, thereby indicating that the comparison of the seedling growth rates between the natural forest and the plantation is significantly different. This leads to the conclusion that the seedlings in the plantation show a statistically significant higher growth rate compared to the seedlings in the natural forest.

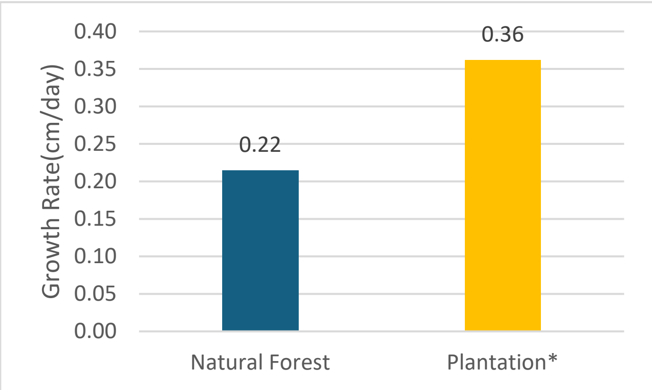

Figure 6: Seeding growth rate comparison with natural forest and plantation

3.2. Type of landscape influence towards seedling survival rate

The seedling survival rate observed in natural forest ecosystems is greater (95.31%) in comparison to the plantation setting (81.25%) (Figure 7). The p-value is more than 0.05; therefore, this study cannot prove statistically that the seedling survival rate in both natural forest and plantation is significantly different. This leads to the conclusion that the seedlings in the landscape are showing a similar survival rate.

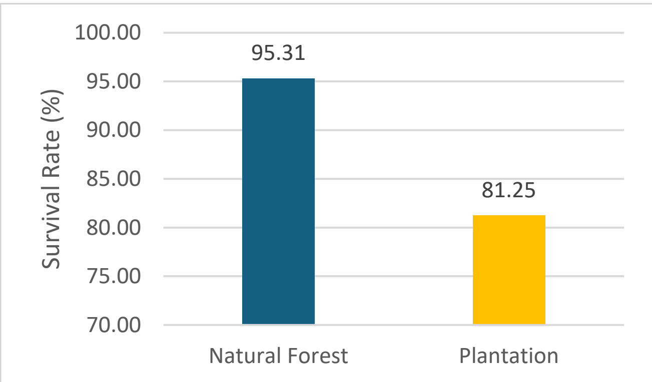

Figure 7: Seeding survival rate comparison with natural forest and plantation.

3.3. Effect of sunlight exposure influence towards seedling growth rate

The seedling growth rate observed in the open area is greater (0.30 cm/day) in comparison to the shaded area (0.28 cm/day) (Figure 8). The p-value is more than 0.05; therefore, this study cannot prove statistically that the seedling growth rate in both the open area and the shaded area is significantly different. This leads to the conclusion that the sunlight exposure did not affect the seedling growth rate.

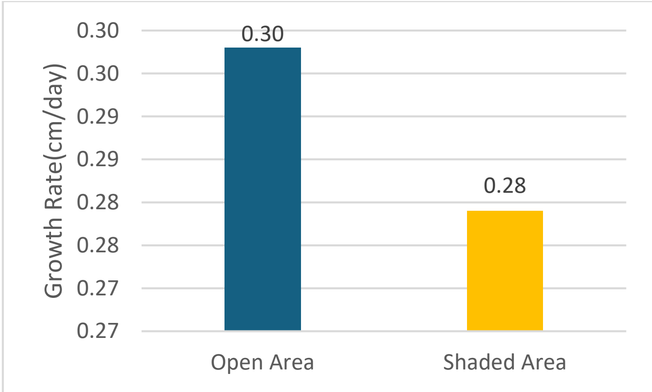

Figure 8: Seeding growth rate comparison with open area and shaded area

3.4. Effect of Sunlight Exposure Influence Towards Seedling Survival Rate

The seedling survival rate observed in the shaded area is greater (99.48%) in comparison to the open area (77.08%) (Figure 9). The p-value is less than 0.05, thereby indicating that the comparison of the seedling survival rates between the shaded area and the open area is a statistically significant difference. This leads to the conclusion that the seedlings in the shaded area show a higher survival rate than the seedlings in the open area.

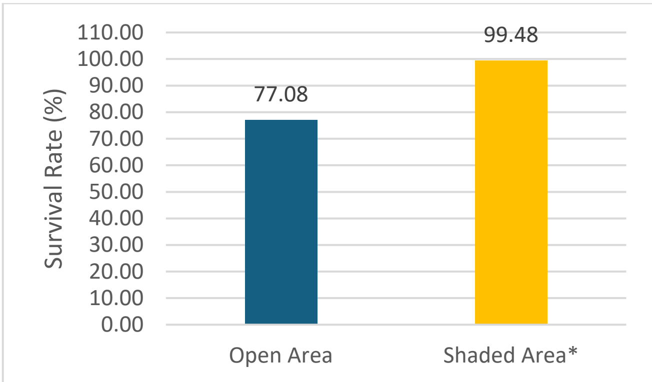

Figure 9: Seeding survival rate comparison with open area and shaded area.

3.5. Type of species influence towards seedling growth rate

D. aromatica showed the highest growth rate, which is 0.49 cm/day, followed by *R. cutrisii* (0.37 cm/day), *D. zibethinus* (0.21 cm/day), and *A. odoratissimus* (0.1 cm/day) (Figure 10). The p-value is less than 0.05, thereby indicating that the comparison of the seedling growth rates between the types of species is significantly difference. This leads to the conclusion that the *D. aromatica* and *R. cutrisii* seedlings show a higher growth rate compared to *D. zibethinus* and *A. odoratissimus*.

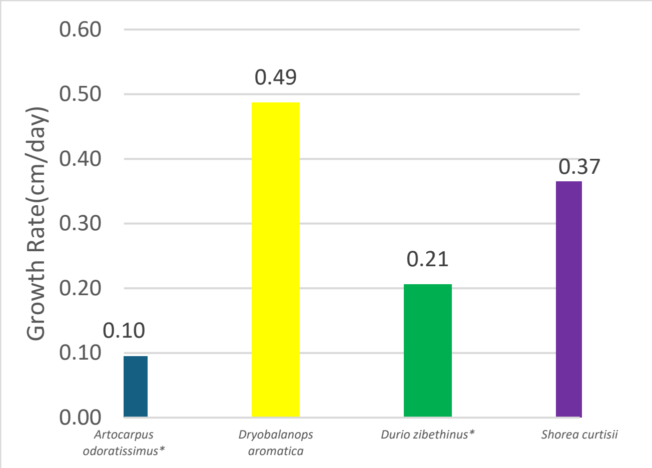

Figure 10: Seeding growth rate comparison with different species

3.6. Type of species influence towards seedling growth rate in a different landscape

Figure 11 shows the seedling growth rate between different species in natural forest ecosystems and plantation settings. There is a trend showing that seedling growth rate in each species in plantation settings is higher than in natural forest ecosystems. However, since the p-value is higher than 0.05, it cannot be proven that the different landscape is resulting in a significant difference in growth rate. This concludes that the difference in landscape did not affect the rate of growth in each species.

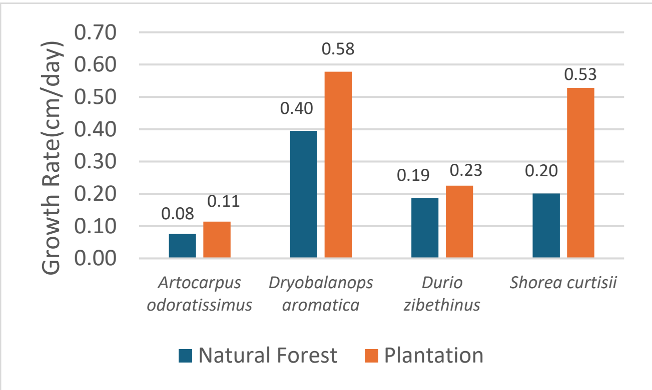

Figure 11: Seeding growth rate comparison of different species in response to type of landscape

3.7. Type of species influence towards seedling survival rate

A. odoratissimus showed the highest survival rate, which is 91.67%, followed by *R. cutrisii* (90.63 %), *D. aromatica* (89.58%) and *D. zibethinus* (81.25 %) (Figure 12). The p-value is less than 0.05, thereby indicating that the comparison of the seedling survival rates between the types of species is not statistically significant. This leads to the conclusion that the type of species did not affect the seedling survival rate.

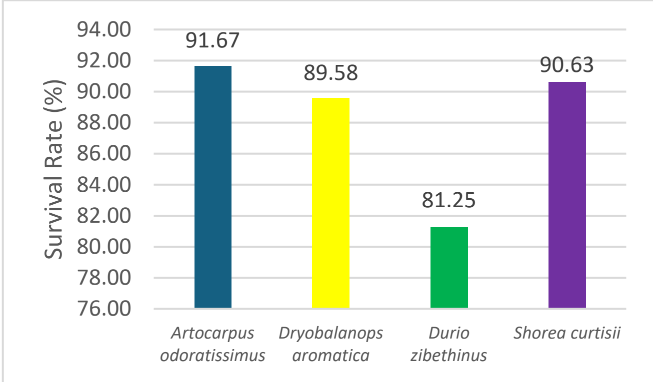

Figure 12: Seeding survival rate comparison with different species

3.8. Type of Species Influence Towards Seedling Survival Rate in a Different Landscape

Figure 13 shows the seedling survival rate between different species in natural forest ecosystems and plantation settings. There is a trend showing that seedling survival rate in each species in natural forest ecosystems is higher than in plantation settings. However, since the p-value is higher than 0.05, it cannot be proven that the different landscape is resulting in a significant difference in growth rate. This concludes that the difference in landscape did not affect the survival rate of each species.

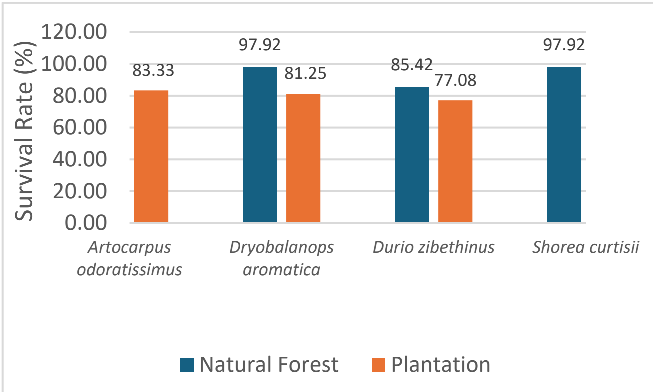

Figure 13: Seeding survival rate comparison of different species in response to type of landscape

4. DISCUSSION

4.1 Seedling survival: contexts and drivers

Seedling survival in natural forests and plantations is influenced by a complex interplay of environmental factors, including both abiotic and biotic elements. In natural forests, factors such as light availability, rainfall, and biotic interactions like density dependence play significant roles. This is supported by the finding where the survival rates were higher in natural forests (95.31%) than in plantations (81.25%). Light exposure had minimal impact on growth rates, but shaded areas significantly enhanced seedling survival (99.5%) compared to open areas (77.08%).

For instance, in North Queensland rainforests, seedling survival is higher in tree-fall gaps due to increased light, and protection from vertebrates significantly reduces mortality rates (Osunkjoya et al.,1992). Similarly, in a subtropical rainforest in Taiwan, seedling survival is influenced by rainfall and neighborhood density, with higher survival rates in years of greater rainfall and abundant recruitment (Staquet 2022).

Additionally, the density of the overstory in plantations can moderate microclimatic conditions, optimizing light and reducing herbivory, which enhances seedling survival (Paquette et al., 2006). In both settings, abiotic factors such as soil and air temperature and biotic factors like fungal infections can further influence survival, with fungal infections notably reducing survival in tropical forests (Chanthorn et al. 2013).

Overall, while natural forests rely heavily on the interplay of light, rainfall, and biotic interactions, plantations benefit from controlled conditions that favor specific seedling traits and sizes, highlighting the nuanced differences in seedling survival strategies across these environments.

The differences in seedling growth rates between natural forests and plantations are influenced by a variety of factors, including soil properties, species diversity, environmental conditions, and management practices. seedlings in plantation areas exhibited significantly higher growth rates (0.36 cm/day) compared to those in natural forests (0.22 cm/day). In natural forests, higher soil organic matter, nutrient levels, and microbial diversity, particularly fungi, contribute to better seedling growth compared to plantations, where these factors are often lower due to less diverse undergrowth vegetation and microbial communities (Hou et al., 2021).

4.2 Growth rates and species/ trait effects

Type of species do not influence towards seedling survival rate. Among species, *D. aromatica* and *R. cutrisii* exhibited the highest growth rates. In contrast, plantations often emphasize the importance of seedling size and species-specific traits. Larger seedlings generally have higher survival rates, especially in arid conditions, where stress-resistant traits like low specific leaf area and high wood density are advantageous (Andivia et al. 2021). Additionally, the size and functional traits of seedlings, such as specific leaf area and wood density, play a crucial role in their survival and growth, with larger seedlings generally having higher survival rates in plantations, especially when adapted to the specific aridity and stress conditions of the site (Andivia et al., 2021). Compared to current research, it has been recorded that while there are significant differences in survival rates between species, there is no significant difference within the survival rates of the same species. Lastly, the structural flexibility and adaptability of certain species, such as *Podocarpus falcatus*, allow them to thrive in both plantation and natural forest environments, although their growth patterns may differ based on the specific conditions of each setting (Tadele & Fetene 2013).

4.3 Additional determinants and ecosystem processes

Additionally, crown form and prior growth are critical factors affecting tree mortality, with mechanical damage and other stresses playing a significant role (Zuleta et al., 2021). Nutrient availability, particularly in relation to soil age, also affects tree growth, with younger soils supporting higher growth rates due to better nutrient availability (Sardans & Peñuelas 2013). Furthermore, wind exposure influences tree growth strategies, with species having lower wood density being more susceptible to wind mortality (Wang et al., 2022). The role of biodiversity is crucial, as diverse species mixtures can stabilize forest functioning and enhance resilience against environmental changes (Tuck et al., 2016). Lastly, leaf physiological traits and spectral changes can serve as indicators of tree health and impending mortality, providing a potential tool for monitoring forest dynamics (Kopačková et al., 2014). Overall, these factors collectively shape the growth and survival of trees in tropical regions, highlighting the need for integrated management approaches that consider both biotic and abiotic influences.

4.4 Site conditions and management implications

In terms of environmental conditions, natural forests often provide more suitable substrates for seedling establishment, such as rotten wood, which is less abundant in plantations (Gagné et al., 2019). Light availability is another critical factor, with natural forests often having more optimal light conditions for seedling growth compared to dense plantations, where light can be limited (Park et al., 2022). The current study has shown that different light conditions resulted in significantly different seedling survival rates; however, there is no significant difference in the growth rates.

Furthermore, the presence of endomycorrhizal fungi, which is often reduced in plantations, particularly under certain pine species, can significantly affect nutrient uptake and seedling growth (Tobiessen & Werner 1980). Management practices such as soil preparation and canopy opening can enhance seedling density and growth in plantations by reducing competition and improving seed availability (Dassot & Collet 2015). Overall, these factors highlight the complex interplay between biotic and abiotic elements that influence seedling growth rates in natural forests versus plantations.

5. CONCLUSION

The seedlings demonstrated a notably higher growth rate in plantation environments when compared to those found in natural forest settings. These findings highlight the importance of understanding how land-use changes impact seedling dynamics, which is crucial for effective conservation and management strategies in the region.

Seedlings found in shaded areas have shown a higher survival rate compared to those in more exposed locations. These results underscore the necessity of implementing targeted management practices that consider light availability to enhance seedling survival rates in restoration efforts.

This study highlights species-specific differences in survival and growth, identifying *D. aromatica* and *R. curtisii* as optimal candidates for restoration due to their superior performance. Findings demonstrate that plantation environments promote faster seedling growth compared to natural forests, while shaded conditions enhance survival, underscoring the influence of microclimatic factors. These insights provide a practical framework for restoration strategies that integrate species selection and site conditions to support biodiversity conservation and ecosystem recovery in landscapes affected by land-use change.

ACKNOWLEDGEMENT

We would like to express sincere gratitude to SD Guthrie Berhad for sponsoring this research and allowing our team to conduct our study at Sapong Plantation. We also extend heartfelt thanks to the management of SD Guthrie Berhad Sapong branch for their continuous support in managing our research team and facilitating our on-site sampling.

REFERENCES

Abdullah, A. A. (2020). Dilema antara perburuhan dan perhambaan: analisis realiti di Ladang Sapong, Borneo Utara (1881-1941). *Jurnal Borneo Arkhailogia (Heritage, Archaeology and History), 5*(1). https://doi.org/10.51200/jba.v5i1.2847

Abu Bakar, F. I., (2018). Tarap— *Artocarpus odoratissimus*. Exotic fruits, 413–418. https://doi.org/10.1016/b978-0-12-803138-4.00041-1

Andivia, E., Villar-Salvador, P., Oliet, J. A., Puértolas, J., Dumroese, R. K., Ivetić, V., Molina-Venegas, R., Arellano, E. C., Arellano, E. C., Li, G., Ovalle, J. F., & Ovalle, J. F. (2021). Climate and species stress resistance modulate the higher survival of large seedlings in forest restorations worldwide. *Ecological Applications, 31*(6):e02394.10.1002/eap.2394. https://doi.org/10.1002/eap.2394

Ashton, P. S., & Heckenhauer, J. (2022). Tribe Shoreae (*Dipterocarpaceae* subfamily Dipterocarpoideae) finally dissected. *Kew Bulletin, 77*(4), 885–903. https://doi.org/10.1007/s12225-022-10057-w

Berhanu, Y., Dalle, G., Sintayehu, D. W., Kelboro, G., & Nigussie, A. (2023). Land use/land cover dynamics driven changes in woody species diversity and ecosystem services value in tropical rainforest frontier: A 20-year history. *Heliyon*, *9*(2). https://doi.org/10.1016/j.heliyon.2023.e13711

Berhe, D. H., Gidey, T., Gebregziabher, D., Tesema, T., Anjulo, A., Retta, A. N., Tefera, A. S., & Okolo, C. C. (2023). Seedling survival and plantation success in the drylands of Northern Ethiopia [Preprint]. https://doi.org/10.21203/rs.3.rs-3314359/v1

Chanthorn, W., Caughlin, T. T., Caughlin, T. T., Dechkla, S., & Brockelman, W. Y. (2013). The relative importance of fungal infection, conspecific density and environmental heterogeneity for seedling survival in a dominant tropical tree. *Biotropica, 45*: 587-593. https://doi.org/10.1111/btp.12044

Dassot, M. & Collet, C. (2015). Manipulating seed availability, plant competition and litter accumulation by soil preparation and canopy opening to ensure regeneration success in temperate low-mountain forest stands. *European Journal of Forest Research, 134:* 247–259. https://doi.org/10.1007/S10342-014-0847-X

Gagné, L., Sirois, L., & Lavoie, L. (2019). Seed rain and seedling establishment of *Picea glauca* and *Abies balsamea* after partial cutting in plantations and natural stands. *Forests, 10*(3), 221. https://doi.org/10.3390/F10030221

Gardiner, R., Shoo, L. P., & Dwyer, J. M. (2019). Look to seedling heights, rather than functional traits, to explain survival during extreme heat stress in the early stages of subtropical rainforest restoration. *Journal of Applied Ecology, 56*(12), 2687–2697. https://doi.org/10.1111/1365-2664.13505

Harbur, M. L., Moore, K., Mowers, R., Merrick, L., & Mahama, A. A. (2023). Chapter 11: Randomized Complete Block Design. Quantitative methods for plant breeding. https://iastate.pressbooks.pub/quantitativeplantbreeding/chapter/randomized-complete-block-design/

Hou, L., Zhang, Y., Li, Z., Shao, G., Song, L., & Sun, Q. (2021). Comparison of soil properties, understory vegetation species diversities and soil microbial diversities between Chinese fir plantation and close-to-natural forest. *Forests, 12*(5), 632. https://doi.org/10.3390/F12050632

John, D. W., & Jackson, J. C. (1973). The tobacco industry of North Borneo: A distinctive form of plantation agriculture. *Journal of Southeast Asian Studies, 4*(1):88-106. https://doi.org/10.1017/S002246340001643X

Kopačková, V., Mišurec, J., Lhotáková, Z., Oulehle, F., & Albrechtová, J. (2014). Using Multi-date High Spectral Resolution Data to assess the physiological status of macroscopically undamaged foliage on a regional scale. *International Journal of Applied Earth Observation and Geoinformation, 27*, 169–186. https://doi.org/10.1016/J.JAG.2013.09.009

Manokaran, N., Kassim, Abd. R., Hassan, A., Quah, E. S., & Chong, P. F. (1992). Short-term population dynamics of dipterocarp trees in a lowland rain forest in Peninsular Malaysia. *Journal of Tropical Forest Science, 5*(1), 97–112. http://www.jstor.org/stable/43581674

Miyamoto, K., Aiba, S., Aoyagi, R., & Nilus, R. (2021). Effects of El Niño drought on tree mortality and growth across forest types at different elevations in Borneo. *Forest Ecology and Management, 490*, 119096. https://doi.org/10.1016/J.FORECO.2021.119096

NParks. (2022). *Durio Zibethinus*. Flora & Fauna Web. https://www.nparks.gov.sg/florafaunaweb/flora/2/8/2865

Ostertagová, E., & Ostertag, O. (2013). Methodology and application of One-way ANOVA. *American Journal of Mechanical Engineering, 1*(7), 256-261.

Osunkjoya, O. O., Ash, J., Hopkins, M. S., & Graham, A. W. (1992). Factors affecting survival of tree seedlings in North Queensland rainforests. *Oecologia, 91,* 569–578. https://doi.org/10.1007/BF00650333

Paquette, A., Bouchard, A., & Cogliastro, A. (2006). Survival and growth of under-planted trees: A Meta-analysis across four biomes. *Ecological Applications, 16: 1575-1589.* https://doi.org/10.1890/1051-0761(2006)016[1575:SAGOUT]2.0.CO;2

Park, B. B., Ko, Y., Hernandez, J. O., Byambadorj, S.-O., & Han, S. H. (2022). Growth of deciduous and evergreen species in two contrasting temperate forest stands in Korea: An intersite experiment. *Plants, 11*(7):*841*. https://doi.org/10.3390/plants11070841

Parsada, N. B. (2013). Multi storied forest management system as an enrichment planting arrangement on poorly stocked inland forest: An experience in Peninsular Malaysia. *International Journal of Sciences*, *2*(11), 28–42. https://www.ijsciences.com/pub/article/326

Sardans, J., & Peñuelas, J. (2013). Tree growth changes with climate and forest type are associated with relative allocation of nutrients, especially phosphorus, to leaves and wood. *Global Ecology and Biogeography*, *22*(4), 494–507. https://doi.org/10.1111/GEB.12015

Shem, V. (2018). Sime Darby Plantation Berhad – Initial assessment report. BSI Group. https://www.bsigroup.com/globalassets/localfiles/en-my/mspo/psr-2018/sime-darby-plantation-berhad--sou-melalap-palm-oil-mill--melalap-estates--initial-assessment-7-march.pdf

Staquet, A. (2022). Variation in biotic interactions mediates the effects of masting and rainfall fluctuations on seedling demography in a subtropical rainforest. *Journal of Ecology, 110,* 762–771. https://doi.org/10.1111/1365-2745.13833

Subiakto, A., Rachmat, H. H., & Wijaya, K. (2017). Mapping shore a natural distribution in the last remaining forests in Riau as a baseline information for conservation strategy. *IOP Conference Series Earth and Environmental Science, 54:* 012045. IOP Publishing. https://doi.org/10.1088/1755-1315/54/1/012045

Syahida Emiza Suhaimi, A. N. Md. N. & L. S. S. (2020). *Dryobalanops aromatica* C.F. Gaertn. Malaysia Biodiversity Information System (MyBIS). https://www.mybis.gov.my/art/303

Taccoen, A., Piedallu, C., Seynave, I., Gégout-Petit, A., Nageleisen, L.-M., Bréda, N., & Gégout, J.-C. (2021). Climate change impact on tree mortality differs with tree social status. *Forest Ecology and Management, 489*, 119048. https://doi.org/10.1016/J.FORECO.2021.119048

Tadele, D., & Fetene, M. (2013). Growth and Ecophysiology of seedlings of *Podocarpus falcatus* in plantations of exotic species and in a natural Montane Forest in Ethiopia. *Journal of Forestry Research, 24,* 29–35. https://doi.org/10.1007/S11676-013-0322-4

Tobiessen, P., & Werner, M. B. (1980). Hardwood seedling survival under plantations of scotch pine and red pine in Central New York. *Ecology, 61:* 25-29. https://doi.org/10.2307/1937150

Tuck, S. L., O'Brien, M., Philipson, C. D., Saner, P., Tanadini, M., Dzulkifli, D., Godfray, H. C. J., Godoong, E., Nilus, R., Ong, R. C., Schmid, B., Sinun, W., Snaddon, J. L., Snoep, M., Tangki, H., Tay, J., Ulok, P., Wai, Y. S., Weilenmann, M., … Hector, A. (2016). The value of biodiversity for the functioning of tropical forests: Insurance effects during the first decade of the Sabah biodiversity experiment. *Proceedings of The Royal Society B: Biological Sciences, December 2016; 283 (1844):* 20161451. https://doi.org/10.1098/RSPB.2016.1451

Vänninen, I. (2005). Alternatives to pesticides in fruit and vegetable cultivation. In *Improving the Safety of Fresh Fruit and Vegetables* (pp. 293-330). Woodhead Publishing. https://doi.org/10.1533/9781845690243.2.293

Wang, H., Hua, J., Kang, M., Wang, X., Fan, X., Fourcaud, T., & de Reffye, P. (2022). Stronger wind, smaller tree: testing tree growth plasticity through a modeling approach. *Frontiers in Plant Science, 13*. https://doi.org/10.3389/fpls.2022.971690

Zedler, J. B., & Lindig-Cisneros, R. (2013). Restoration of biodiversity, Overview. In Encyclopedia of Biodiversity (Second Edition) (pp. 453-460). Elsevier. https://doi.org/10.1016/B978-0-12-384719-5.00297-5

Zuleta, D., Arellano, G., Muller-Landau, H. C., McMahon, S. M., Aguilar, S., Bunyavejchewin, S., Cárdenas, D., Chang-Yang, C.-H., Duque, A., Mitre, D., Nasardin, M., Pérez, R., Sun, I.-F., Yao, T. L., & Davies, S. J. (2021). Individual tree damage dominates mortality risk factors across six tropical forests. *New Phytologist, 233:* 705-721. https://doi.org/10.1111/NPH.17832

