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Short Note

Differences in Seed Germination and Seedling Survival of Selected Dipterocarpaceae Species Collected from Contrasting Forest Types in Brunei Darussalam

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The Dipterocarpaceae family is prevalent in the lowland forests of Borneo, accounting for 21.9% of all tree species in these forests (Slik et al., 2003; Atmoko et al., 2025). This species-rich family occurs as trees that dominate the canopy and emergent layers (Ghazoul, 2016) and are important to the ecological functioning of Bornean forests. One key characteristic of the Dipterocarpaceae family is mass flowering and mast fruiting, which occurs at irregular intervals ranging from two to ten years (Appanah, 1993). During these events, Dipterocarps produce seeds that are predominantly gravity-dispersed, resulting in short seed dispersal distances, usually near parent trees (Osada et al., 2001). The seeds of the Dipterocarpaceae family are recalcitrant (Ekasari & Oktaviani, 2024), able to germinate quickly after dispersal, but are typically not viable for long periods in the seed bank due to their high-water content and sensitivity to desiccation (Tweddle et al., 2003). The biological traits of Dipterocarpaceae, including irregular fruiting, short seed dispersal distances, and recalcitrant seeds, limit their natural regeneration potential. When compounded by external threats such as logging and deforestation, populations may fail to recover adequately, leading to long-term declines (Pang et al., 2021).

Of the 162 Dipterocarpaceae species native to Borneo, 99 species are designated as either Vulnerable, Endangered, or Critically Endangered in the IUCN Red List (2025). To date, only 32 threatened Dipterocarpaceae family species are protected *ex-situ* (Bartholomew et al., 2021). *Ex-situ* conservation of Dipterocarpaceae species is done by collecting recalcitrant seeds and seedlings from forests after masting events and growing them outside of their natural habitats (Ghazoul, 2016). This strategy helps protect threatened tree species by minimizing the environmental impacts caused by overexploitation and loss of their natural habitat (Susilowati et al., 2021). Successful *ex-situ* conservation programs can also produce seedlings or saplings that can eventually be replanted into natural habitats to reforest degraded areas (Mestanza-Ramón et al., 2020). However, successful *ex-situ* conservation efforts require information on seed and seedling growth to enable appropriate treatments to be developed.

The present study focuses on the assessment of seeds and seedlings survival of selected Dipterocarpaceae species in Brunei Darussalam, Northwest Borneo. The lowland forests in Brunei Darussalam are dominated by the Dipterocarpaceae family (Sukri et al., 2012) with 153 species (Ashton, 1964). The country retains a high percentage of intact forests, particularly lowland mixed dipterocarp forests (Bryan et al., 2013). This provides an ideal setting to collect seeds and seedlings by the Botanical Research Centre, Universiti Brunei Darussalam (UBD BRC) for *ex-situ* conservation efforts. This pilot study aims to evaluate *ex-situ* seed germination and seedling survival of selected Dipterocarpaceae species collected from three contrasting forest types, i.e. mixed dipterocarp, heath and peat swamp forests, in Brunei Darussalam. We chose the Dipterocarpaceae family due to its ecological importance and diversity in Bornean forests, where it is also facing increased anthropogenic threats that necessitates urgent conservation action. Our primary research question was how do seed germination and seedling survival rates vary among selected Dipterocarpaceae species and across different forest types in Brunei Darussalam? We hypothesised that (1) species-specific differences in seed germination and seedling survival will be recorded, and (2) seedling survival will differ between the three forest types. Knowledge gaps in seed germination and seedling survival of these high conservation value species to enhance their *ex-situ* conservation strategies still exist. Through this pilot study, our goal is to present much needed species-specific information to better tailor species recovery and forest restoration efforts across the region.

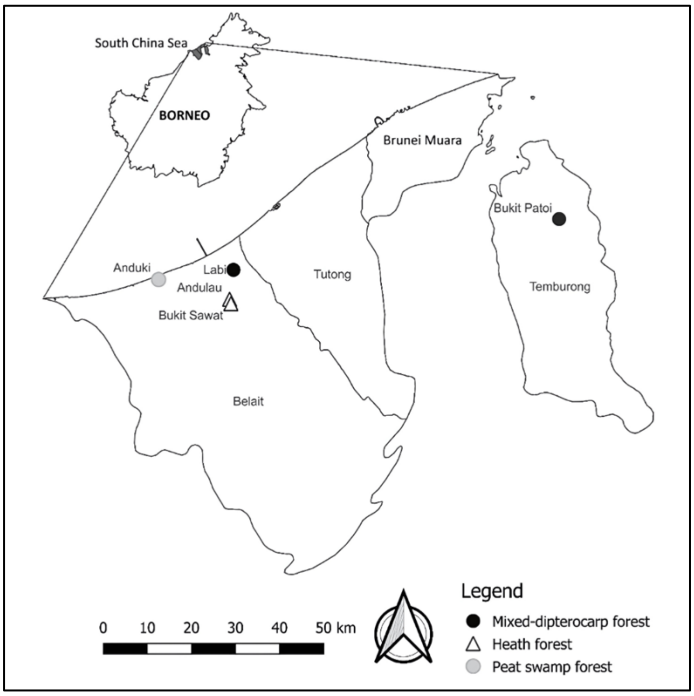

Figure 1: Location of the study sites consisting of five different locations in three forest types within the Belait and Temburong districts, Brunei Darussalam.

The study was conducted in five locations within the Belait and Temburong districts of Brunei Darussalam, encompassing three distinct forest types: mixed dipterocarp forest (MDF), heath forest (HF), and peat swamp forest (PSF; Fig. 1). All locations consisted of intact, primary forests: Bukit Patoi (4°45'0.60"N 115°11'0.04"E) in Temburong and Labi

(4°27'34.13"N 114°28'36.20"E) in Belait are MDFs, Andulau (4°36'18.69"N 114°30'30.41"E) and Bukit Sawat (4°34'18.10"N 114°30'42.91"E) are both HFs, and Anduki (4°37'32.57"N 114°21'53.45"E) is a PSF site.

At each of the five study locations, intensive surveys for Dipterocarpaceae seeds and seedlings were conducted along an accessible forest trail covering a distance of 2.0 km per location throughout May 2021 during a localised masting episode. Surveys were conducted with the assistance of botanists from the Brunei National Herbarium (BRUN).

From the surveys, two Dipterocarpaceae species were recorded as seeds: *Dipterocarpus borneensis* Slooten and *Dryobalanops rappa* Becc., and five species were recorded as seedlings: *Cotylelobium burckii* (F.Heim) F.Heim, *Hopea pentanervia* Symington ex G.H.S.Wood, *Hopea vacciniifolia* Ridl. Ex P.S.Ashton, *Richetia laxa* (Slooten) P.S.Ashton & J.Heck., and *Rubroshorea scaberrima* (Burck) P.S.Ashton & J.Heck. Field identification of these species was conducted by locating and identifying the parent trees, with the support of botanists from BRUN. Voucher specimens from the parent trees were also collected, and taxonomic identification was confirmed by cross-checking with BRUN collections, including type specimens where available. Representative photographs of all the seven species collected are provided in Fig. 2.

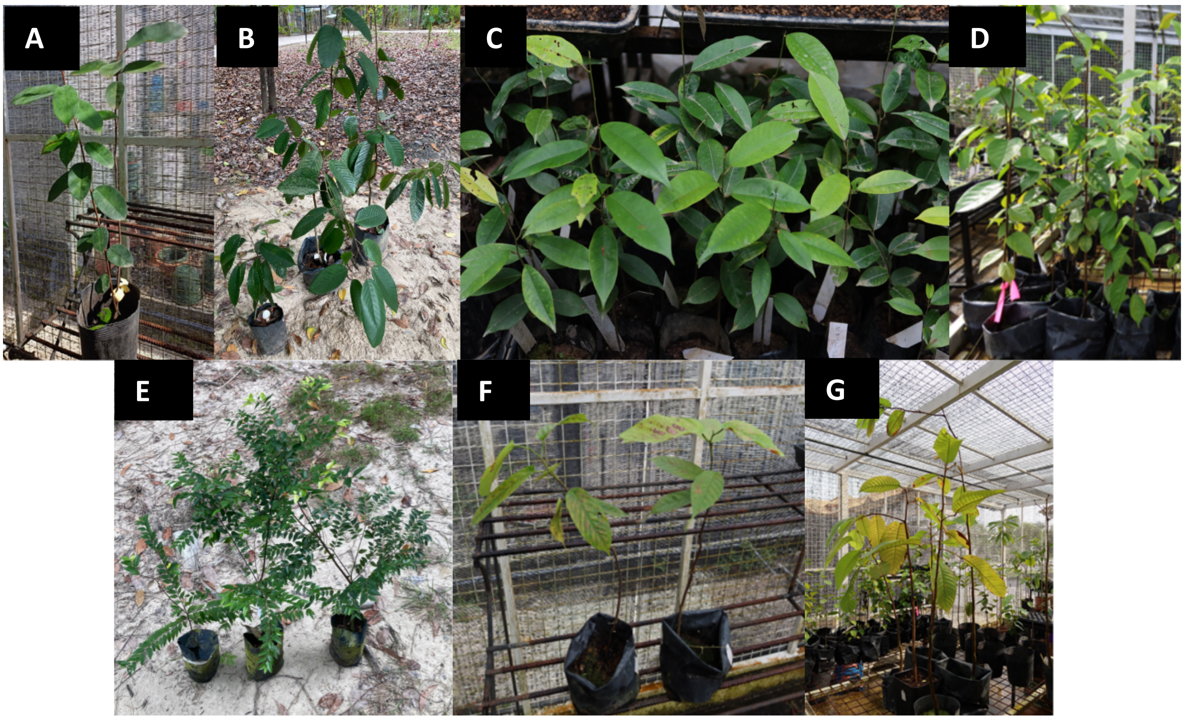

Figure 2: Representative photographs of the seven Dipterocarpaceae species collected in this study. The images show seedlings of: **A.** *Cotylelobium burckii*, **B.** *Dipterocarpus borneensis*, **C.** *Dryobalanops rappa*, **D.** *Hopea pentanervia*, **E.** *Hopea vacciniifolia*, **F.** *Richetia laxa*, and **G.** *Rubroshorea scaberrima.*

Seeds of *D. borneensis* and *D. rappa* were collected from among undamaged and non-germinating winged seeds on the forest floor within an area of 4 m^2 under at least three parent trees. This standardised plot size was chosen to ensure consistency in sampling effort and spatial coverage across all sites. Falling seeds were also obtained by shaking the tree branches following Velazco et al. (2018). Seedlings (height of 10 – 80 cm only) of *C. burckii*, *H. pentanervia*, H. *vacciniifolia*, *R. laxa* and *R. scaberrima* were collected within an area of 4 m^2 of at least three parent trees. Seedling heights were decided based on advice from the Brunei Forestry Department and was chosen to target healthy, naturally regenerating individuals that had progressed beyond the earliest seedling stage but had yet to reach the sapling phase. Selecting seedlings within this range ensured they were robust enough to tolerate transplanting stress during *ex-situ* relocation, while still representing the early growth stages appropriate for survival monitoring. Individual seedlings were extracted with care from the forest floor, ensuring the root system and root ball remained intact, following Susilowati et al. (2021).

The collected seed count comprised 153 seeds of *D. borneensis* from Labi (MDF) site and 306 seeds of *D. borneensis* from Bukit Sawat (HF) site, and 231 seeds of *D. rappa* collected from Anduki (PSF) site. For seedlings, a total of 40 *C. burckii* and 80 *H. vacciniifolia* were collected from Labi (MDF) site, 44 *R. laxa* were collected from Bukit Patoi (MDF) site, 51 *H. pentanervia* were collected from Bukit Sawat (HF) site, and 43 *R. scaberimma* were collected from Andulau (HF) site.

The collected seeds and seedlings were sorted according to species and carefully placed in labelled, resealable bags with moisture to preserve their condition. Seedlings were tagged with labels attached to their stems, indicating their species codes and respective collection sites. To minimize transpiration, about two-thirds of each leaf on all seedlings was carefully trimmed (Papuangan et al., 2014). Seeds and seedling collections were conducted in the mornings (from 8.00 am to 11.00 am) and all collected seeds and seedlings were transported on the same day to the UBD shade house for planting and re-potting.

For re-potting purposes in the shade house, forest soils from the same location as the parent tree species were also collected. General soil characteristics of the three forest types are summarised in Table 1 to provide environmental context for the forest soils from each forest type. Approximately 50 kg of forest soil within an area of 4 m^2 from each parent tree per location was collected using shovels. Forest floor litter was first removed by hand and an area of 1 m^2 was excavated for soil collection to a depth of 15 cm from the topsoil. Collected soils were then placed into appropriately labelled large bags, corresponding to their respective collection site.

Table 1: General soil characteristics of the three forest types studied in Brunei Darussalam (adapted from Jaafar et al., 2016).

Forest type	Soil Texture	pH Range	Nutrient Availability	Water-Holding Capacity
Mixed dipterocarp forest (MDF)	Well-drained	5.0 – 5.5	Moderate	Good
Heath forest (HF)	Sandy	~4.0 – 4.5	Low	Low
Peat swamp forest (PSF)	Organic-rich	~3.5 – 4.5	Low	High

Prior to sowing, a simple water flotation test was used to assess seed viability (Tiansawat et al., 2016). Collected seeds were placed in a container of water; seeds that sank were considered viable, while floating seeds were considered as non-viable and discarded. All viable seeds were cleaned with tap water, and their wings were manually removed. De-winged seeds were then sown into individual planting cells (depth of 5 cm, a top diameter of 5.8 cm, and a bottom diameter of 4.3 cm, containing soil mixture) within a black plastic tray (50 × 30 cm). All cells contained a mixture of the forest soil from the collection site that corresponds to the planted species and commercial potting soil (Bio-Root Medium; K.N. Nursery (B) Sdn Bhd, Brunei Darussalam) in a 1:1 ratio. Individual cells were labelled with the corresponding specimen code, name, number and collection site.

Individual seedlings were re-potted in individual polybags (0.7 L to 1.2 L volume). All polybags contained a mixture of the forest soil from the collection site that corresponds to the planted species and commercial potting soil (Bio-Root Medium; K.N. Nursery (B) Sdn Bhd, Brunei Darussalam) in a 1:1 ratio. Individual seedlings were labelled with the corresponding specimen code, number and collection site. All seeds and seedlings were maintained in the UBD BRC shade house under controlled conditions throughout the monitoring period. The shade house was covered with 50% black shade netting to reduce light intensity and simulate tropical understory conditions. An automated misting system was programmed to release fine water mist for 10 minutes at 7:00 am, 12:00 pm, and 5:00 pm daily. Environmental conditions were monitored throughout the study, with temperature ranging from 26°C to 33°C and relative humidity ranging from 75% to 95%, representing typical lowland tropical conditions.

After one month following the field collections, all planted seeds (n = 690 seeds; 2 species) were censused for seed germination, while all planted seedlings (n = 258 seedlings; 5 species) were censused for survival. Seed germination was characterized by signs of radical development and the appearance of cotyledons on the soil surface (Sasaki, 2008). Seedling death was confirmed by gently scraping stems of withering plants to determine whether plant tissue had died. The census was conducted monthly over a seven-month period, until December 2021.

All the statistical analyses were conducted in R 4.3.1 (R Core Team, 2023). Differences in final mean percentage seed germination at the end of the census period (December 2021) between forest types were determined using one-way ANOVA. In a separate analysis, final mean percentage seedling survival at the end of the census period (December 2021) was initially subjected to two-way analysis of variance (ANOVA) tests to determine differences between species, between forest types (MDF or HF), and species by forest type interaction. The two-way ANOVA however did not record any significant interactions between species and forest type. Therefore, two separate one-way ANOVA tests were conducted for the final mean percentage seedling survival to determine between-species differences and between-forest type differences. Multiple comparisons using Tukey's HSD test were also conducted. Data for the mean percentage seed germination and mean percentage seedling survival were arcsine-transformed after checking their normality of residuals and homogeneity of variances. Differences were considered significant when $P < 0.05$.

Seeds were observed to begin germinating within the first two months after planting. *Dryobalanops rappa* exhibited the most significant monthly increase in seed germination percentage, reaching a peak of 47.2% in July 2021. Conversely, *D. borneensis* from both MDF and HF collection sites consistently displayed lower monthly germination percentages (< 10%) throughout the census period.

At the end of the census period (December 2021), *D. rappa* seeds collected from the PSF recorded significantly higher final mean percentage germination (21.5 ± 2.70%) compared to *D. borneensis* seeds collected from HF (3.27 ± 1.02%) and MDF (3.92 ± 1.57%; $P < 0.001$; F-value: 62.96; df: 2, 687; Fig. 3). However, the final mean percentage survival of *D. borneensis* seeds did not significantly differ between HF and MDF collection sites.

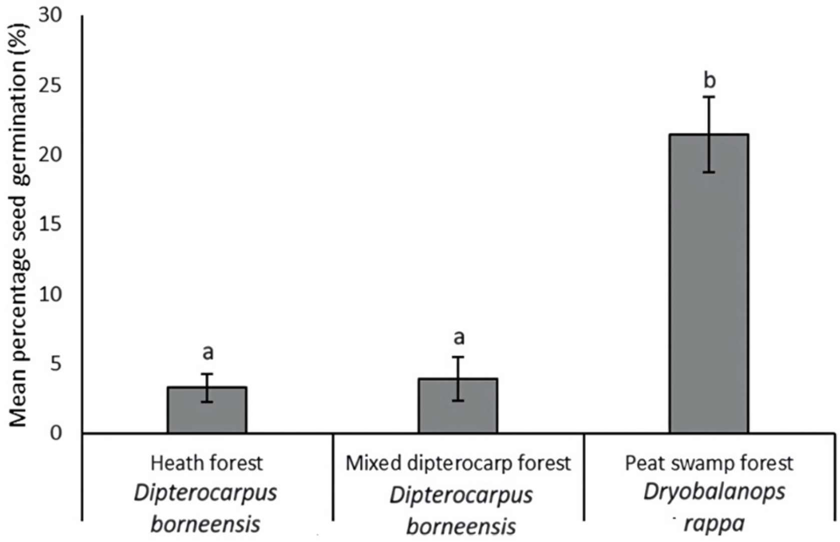

Figure 3: Final mean percentage seed germination at the end of the census period (December 2021) for *Dipterocarpus borneensis* seeds collected from the heath forest in Bukit Sawat and mixed dipterocarp forest in Labi, and *Dryobalanops rappa* seeds collected from the peat swamp forest in Anduki. Data values for mean percentage seed germination were arcsine-transformed, but untransformed data of mean percentage and error bars representing standard errors (SE) were used in the presentation. Different letters within a panel indicate significant differences at P < 0.05 as obtained from Tukey's HSD after one-way analysis of variance (ANOVA).

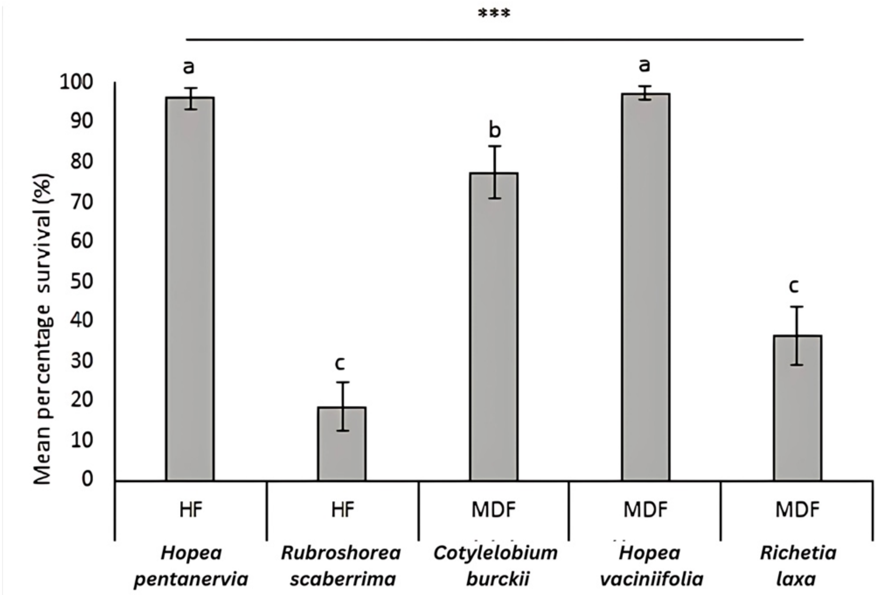

Figure 4: Final mean percentage seedling survival at the end of the census period (December 2021) for *Hopea pentanervia* and *Rubroshorea scaberrima* seedlings collected from heath forest sites and *Cotylelobium burckii*, *Hopea vaciniifolia* and *Richetia laxa* seedlings collected from mixed dipterocarp forest sites. Data values for mean percentage survival were arcsine-transformed, but untransformed data of mean percentage and error bars representing standard errors (SE) were used in the presentation. Different letters within a panel indicate significant differences at $P < 0.05$ as obtained from Tukey's HSD after one-way analysis of variance (ANOVA). Significant differences between forest types were detected after a two-way analysis of variance (ANOVA) test at $\alpha = 0.05$ level (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

The two-way ANOVA test revealed significant differences in final mean percentage seeding survival between the five study species and significant differences between the two forest types ($P < 0.001$; Fig. 4).

No significant interactions were detected between species and forest types for final mean percentage seeding survival. Seedlings of *H. vaciniifolia* collected from the MDF and *H. pentanervia* collected from the HF recorded significantly highest mean percentage survival (97.5 ± 1.76% and 96.1 ± 2.75%, respectively), while seedlings of *R. laxa* from MDF and *R. scaberrima* from HF recorded significantly lowest mean percentage survival (36.4 ± 7.34% and 18.6 ± 6.00%, respectively; $P < 0.001$; Fig. 4). Regardless of species, seedlings collected from MDF recorded significantly higher mean percentage survival compared to seedlings collected from HF (MDF: 75.6 ± 3.36%; HF: 60.6 ± 5.07%; $P < 0.001$; Fig. 4).

At the end of the monitoring period, *D. rappa* recorded significantly higher percentage seed germination than *D. borneensis*. This is consistent with field observations by Din et al. (2018) that *D. rappa* seedlings were 10 times more abundant than *Rubroshora albida*, suggesting that *D. rappa* had a greater chance of survival after successful mast fruiting. In contrast, the percentage of seed germination of *D. borneensis* collected at both HF and MDF sites was much lower. As *D. borneensis* is well-known as a generalist species (Bell & Sultan, 1999), we had expected higher germination success. Our results may be partly due to differences in seed viability between these two species (Naito et al., 2008). Seeds of *D. rappa* seeds were much larger in length and width than those of *D. borneensis*, and larger seeds often have longer seed viability and thus higher germination success (Daws et al., 2008). The comparatively smaller seeds of *D. borneensis* may be more prone to drying, thus lowering their viability and hampering seed germination (Appanah & Turnbull, 1998).

Our findings have shown that three Dipterocarpaceae species, *H. vaciniifolia*, *H. pentanervia* and *C. burckii*, recorded the highest percentage seedling survival. Seedlings of Dipterocarpaceae species are known to prefer varying light intensities (Paine et al., 2012; Widiyatno et al., 2020). *Hopea vacciniifolia* are treelets and mid-storey trees, while *H. pentanervia* and *C. burckii* are classified as canopy and mid-storey trees (Coode et al., 1996), and each species likely show different degrees of shade tolerance throughout their early growth stages. In contrast, *Richetia* and *Rubroshorea* species are less shade tolerant and more light-demanding in their early growth stages (Appanah & Weinland, 1993). Both *R. laxa* and *R. scabberima* seedlings exhibited larger leaf areas and thinner leaves than *H. vacciniifolia*, *H. pentanervia* and *C. burckii* (Fig. 2) which could have resulted in greater transpiration and leaf wilting affecting seedling growth of *R. laxa* and *R. scaberrima*.

Our pilot study revealed species-specific differences in seed germination and seedling survival of selected Dipterocarpaceae species collected from three contrasting forest types in Brunei Darussalam. Notably, *D. rappa* exhibited higher seed germination rates, while *H. vacciniifolia*, *H. pentanervia*, and *C. burckii* showed high seedling survival over a seven-month period. These results indicate that these species hold strong potential as candidates for *ex-situ* conservation. In contrast, lower germination in *D. borneensis* and reduced seedling survival in *R. scaberrima* and *R. laxa* suggest that additional treatments or alternative approaches such as targeted specimen collection or *in-situ* conservation interventions, may be required to support their conservation.

One limitation of the study was the relatively small sample size for species collected as seedlings. Our field collection was conducted during a localised Dipterocarpaceae masting episode and initially focused on seed collections. However, the presence of naturally regenerating individuals resulted in opportunistic collections of available Dipterocarpaceae seedlings for our study. Limited availability of seedlings during these field collections and a deliberate effort to minimise disturbance to forest ecosystems necessitated a lower sample size. Notably, rare or threatened species were encountered infrequently, making it difficult to obtain larger, more representative samples. Nevertheless, the data provide valuable baseline insights, and future studies should expand sampling across multiple sites and time periods to enhance statistical robustness.

Another key limitation is the relatively short monitoring period of seven months, which likely did not fully capture long-term survival trajectories, especially for slow-growing tropical tree species. While our study provides insights into early-stage establishment under *ex-situ* conditions, longer-term monitoring is essential to assess seedling growth into saplings, evaluate their developmental success, and refine conservation protocols. Future research should include extended observation periods to better determine species-specific growth responses and the sustainability of *ex-situ* conservation efforts.

In addition, this pilot study focused on quantifying differences in *ex-situ* seed germination and seedling survival across species and forest types. Experimentally assessing the factors, both biotic and abiotic, that directly influence seed germination and seedling survival was beyond the scope of our work. A critical extension to our study should therefore focus on these underlying factors, through controlled modifications of *ex-situ* environmental conditions and quantification of biotic factors, such as signs of seed damage and seedling herbivory, that are complimented by field assessments of *in-situ* environmental conditions and biotic influences.

Our results focus on *ex-situ* performance of the study species, to better inform ongoing conservation practices at the UBD BRC. A parallel comparison with *in-situ* monitoring of seed germination and seedling survival, although not logistically feasible for our pilot study, would have enabled an evaluation of the extent to which *ex-situ* conditions replicate natural environments in the species' habitats. This approach would help identify potential mismatches in environmental cues or resource availability that can then be modified to improve seed germination and seedling survival under controlled nursery conditions.

Despite a focus on *ex-situ* seed germination and seedling survival, we highlight the important practical implications of our findings upon *in-situ* conservation planning. Species that performed well under *ex-situ* conditions, such as *D. rappa*, *H. vacciniifolia*, and *H. pentanervia*, may exhibit strong natural regeneration potential and can be prioritised for restoration projects in degraded areas and enrichment planting in forest plantations or secondary forest areas. Meanwhile, species with lower performance may benefit from targeted *in-situ* conservation measures such as habitat protection, population reinforcement, or assisted natural regeneration. These insights can inform species selection and site-specific planning for forest restoration initiatives across Borneo and the broader Southeast Asian region, where Dipterocarpaceae forests face increasing ecological pressure.

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DECLARATIONS

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Generative AI use. We declare that generative AI was not used in this study nor in the writing of this article.

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