seed **madagascar**
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A Technical Report for

PROJECT PALMS

An Assessment of the Growth, Germination, and Survival Success of Threatened Palms in Sainte Luce

August 2023

Contents

Summary

The Sainte Luce Littoral Forest (SLLF), southeast Madagascar, supports a large variety of endemic and threatened species, including populations of threatened palm species. Many of these palm species are important natural resources used for construction materials, firewood, and local livelihood generation for communities surrounding the SLLF. Project Palms aims to expand existing knowledge of population size, distribution, microhabitat requirements, phenology, nursery growth, and the threats facing six threatened species: *Beccariophoenix madagascariensis* (VU), *Chrysalidocarpus prestonianus* (VU), *Chrysalidocarpus psammophilus* (EN), *Chrysalidocarpus saintelucei* (EN), *Dypsis brevicaulis* (CR) and *Dypsis scottiana* (VU).

To address the challenges of habitat loss, fire, mining, and increasing human dependence on natural resources, Project Palms aims to increasing understanding of the growth of these six species. A nursery for palm seedlings was established, and seeds from fruiting palms were collected, sown, and monitored regarding optimum soil composition, germination rates and times, growth, and survival. Through targeted supplementation and protection, utilising nursery generated seedlings, the project also aims to improve the long-term viability of each palm species within protected fragments of the SLLF.

Data was collected on target species between August 2021 and July 2023. Data analysis revealed the soil composition with the highest germination rates across all species was Natural/Compost soil. Germination rates varied considerably per species, whereby *C. saintelucei* had the highest germination rate (72.16%) and *C. prestonianus* had the lowest (12.97%). The mean germination rate across all species was 34.23% nine months after planting.[1] The mean time to begin germinating across all species was 12 weeks, however this also varied considerably per species. *C. saintelucei* seedlings germinated the fastest, with most germination beginning within week eight of sowing, and the majority having germinated by the third month of monitoring. *C. psammophilus* seedlings took the longest time to begin germinating, occurring after 15 weeks. *D. scottiana* seedlings took the longest time to germinate, with the majority germinating between month six and nine.

Monitoring of palm growth revealed a mean growth rate across all species of 0.53cm/week. *C. saintelucei* had the highest mean growth rate at 1.02cm/week, while *D. scottiana* had the lowest mean growth rate at 0.34cm/week. Post germination survival was above 95% for all target species, excluding *C. psammophilus*.[2] Nursery survival rates continue to be recorded so progress towards target palm numbers can be monitored.

In-situ palm planting trials begun with 66 *C. saintelucei* seedlings being planted in the protected SLLF fragment of S9. The palms had a 100% survival rate after three months, with 94% (*n* = 62) of seedlings described as Condition 4/Good (the highest ranking on the four-point palm condition scale). The monitoring of growth and survival rates of these *in-situ* seedlings is ongoing, and will inform future larger scale planting events, with the objective of bolstering palm populations of each of the six target species within protected fragments of the SLLF.

[1] *C. saintelucei* had not reached the nine month post sowing monitoring interval at the time germination rates were calculated, so germination from six months post sowing was used instead.

[2] Excluding *C. psammophilus* (56.79%) because it was affected by uncontrolled environmental conditions.

1 Introduction

1.1. Background

Madagascar is one of the world's highest conservation priorities (Myers et al., 2000). With 98% of palm species endemic to the island, it has one of the most unique and diverse palm collections in the world (Méndez et al., 2022). However, ecosystems across Madagascar are in decline, with 4.36 million hectares (25%) of Madagascar's forest cover lost to deforestation between 2001 and 2021 (Global Forest Watch, 2022). Littoral forests are one of the rarest and most threatened ecosystems in Madagascar, and considered a national conservation priority (Ganzhorn et al., 2001), with an estimated 90% loss of original forest cover (Krishnan et al., 2012).

The southeast Anosy region contains some of the few remaining viable littoral forests (Bollen & Donati, 2006). The Sainte Luce Littoral Forest (SLLF), comprising 17 fragments, is one of three larger fragmented littoral forests remaining in the region. Sainte Luce, with approximately 2,600 inhabitants, is just one of the local communities supported by the forest through the provision of natural resources for firewood, construction materials, and local livelihood generation (Bollen & Donati, 2006; Hyde Roberts et al., 2020; SEED Madagascar, 2021).

Although a critically important natural resource for the Sainte Luce community, most of the 13 species of palm supported by the SLLF are threatened[3] with extinction (Bennett 2011; Couvreur & Baker, 2013). The six target palm species for this study are all threatened and in decline locally, *Beccariophoenix madagascariensis* (VU), *Chrysalidocarpus prestonianus* (VU), *Chrysalidocarpus psammophilus* (EN), *Chrysalidocarpus saintelucei* (EN), *Dypsis brevicaulis* (CR), and *Dypsis scottiana* (VU) (Hyde Roberts et al., 2020; Rakotoarinivo & Dransfield, 2012a; 2012b; 2012c; 2012d; 2012e; 2012f).

Extant populations in the SLLF are threatened by habitat fragmentation and degradation, drought, increased vulnerability to fire, and proposed mining activities by QIT Madagascar Minerals (QMM) (Bollen & Donati, 2006; Vincelette et al., 2007; Krishnan et al., 2012; Ashraf et al., 2021). With 83% of endemic palm species threatened with extinction in Madagascar (Rakotoarinivo et al., 2014), it is crucial to understand the local pressures on palms, and map viable pathways for their conservation and continued availability. A previous study by SEED Madagascar (SEED) identified rapidly declining populations of *B. madagascariensis* and *C. saintelucei* in Sainte Luce (Hyde Roberts et al., 2020). While limited information exists on the current demography and distribution of the other four target species, it is believed that the local populations of these threatened species are in decline.

1.2. An Overview of Project Palms

Project Palms seeks to improve the conservation status of these six threatened palm species through increasing understanding of the distribution, microhabitat requirements, phenology, and nursery growth, which will inform *in-situ* planting efforts. This study aims to improve understanding of the growth requirements and conditions of each species, through the completion of nursery and planting trials, combined with regular monitoring. Research conducted in this study included: a soil trial, to assess the soil composition that produced the highest mean germination, survival, and growth rates for each species; germination monitoring, to reveal mean germination rate and time per species; and survival and growth monitoring which assessed mean post germination survival (%) and growth rates per week (cm) per species. The Palms Microhabitat Assessment provided a solid understanding of the environmental requirements needed for the sustainable growth and survival of each species and findings were used to inform *in-situ* planting efforts.

[3] Threatened is an umbrella term consisting of Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) species (IUCN Standards and Petitions Committee, 2022).

2 Methodology

2.1. Study Site

Seed collection was conducted in five littoral forest fragments (S6, S7, S8, S9, and S17) within the SLLF in the Anosy region of southeast Madagascar (24° 46’ S, 47° 10’ E) (Figure 1). S6 and S7 are designated as Community Resource Zones (CRZ), from which natural resource use is permitted. S8 and S9 are part of Madagascar’s National Protected Areas network, classified as conservation zones under IUCN Category V Protected Areas regime. S8 is comprised of two fragments, S8 North (S8N) and S8 South (S8S), and five remnants (S8R1-5). Much of S17 is privately owned land, with an area designated as a CRZ.

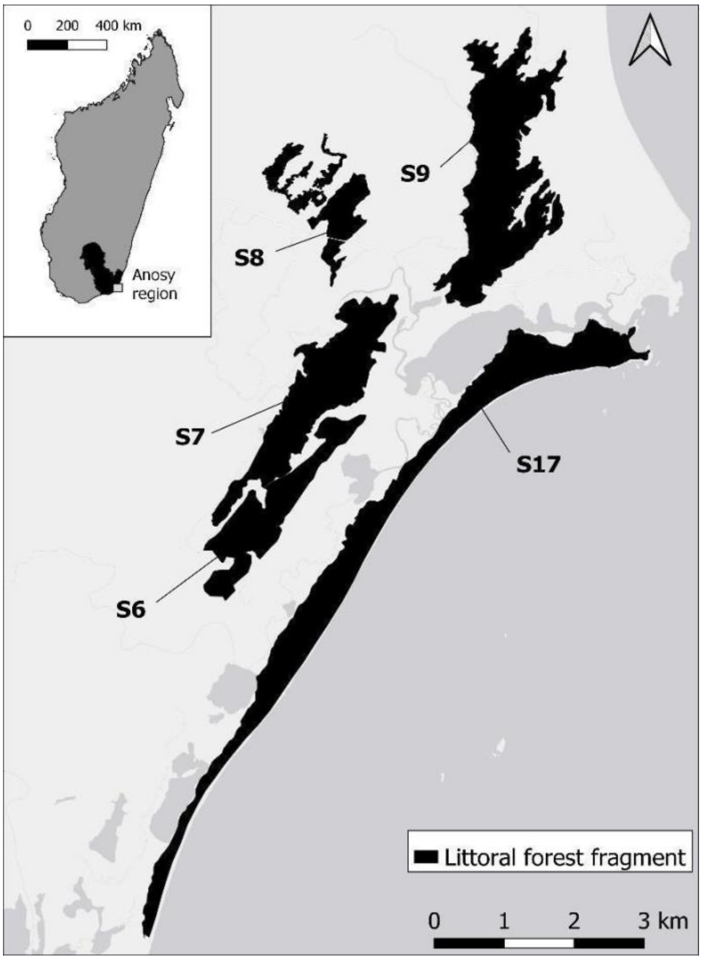

Figure 1: Study site.

2.2. Seed Collection, Preparation, and Sowing

Seeds were collected between December 2021 and July 2023 from reproductively mature individuals (as defined by Hogg et al. (2013)). These adult palms were identified as potentially suitable donor trees via visual observation of adults encountered during the Palm Population Census and using local expert knowledge. Never were more than 50% of the total fruits on an inflorescence harvested from the palm or collected from the vicinity, to prevent interference with natural seed dispersal.

SEED aimed to collect a minimum of 1,000 seeds per species. With an estimated 60% loss throughout the nursery growth period, factoring in seed mortality (unviable seeds), germination mortality (failure of the seed to germinate), and nursery growth mortality (death of the seedling post germination), it was estimated this would meet the target of 300 alive and healthy seedlings to be planted *in-situ*.

Seeds were washed with harvested rainwater, and the fibrous or fleshy epicarp and mesocarp (species-dependent) was removed, after which they were cleaned again and dried in direct sunlight for a period of six to eight hours. Seeds were soaked for 24 hours in clean rainwater and sown immediately afterwards. Time between seed collection and sowing was minimised to prevent seed mortality. Seeds were initially sown in large pots (20cm diameter), following the method utilised by Missouri Botanical Garden (MBG). However, several *B. madagascariensis* were sown in small pots (12cm diameter) in SEED's nursery for a different project. Approximately 80% of seeds sown in small pots germinated and were alive after 3 months. Comparatively, only 20% of seeds sown in large pots germinated. Following this observation, a local expert was consulted to confirm findings. Informed by both, Project Palms seeds were sown in small pots from 11th March 2023, for all species apart from *C. saintelucei* (because germination rates were considered high for this species). Due to the long germination times of palm species, these data have not been included in the Year 2 analysis.

All seeds were sown within the Project Palms nursery at the SEED Research Camp bordering the village of Ambandrika, within SLLF fragment S9. Seedlings were protected from harsh weather conditions by shade roofs made of *Ravenala madagascariensis* leaves. Seedlings were separated by species and labelled with species name, donor tree number, and sowing date. All seedlings were monitored on a weekly basis.

2.3. Soil Trials

Soil trials were conducted with 40 seeds per species, with 10 seeds each sown in 1) natural soil (mainly composed of sand, collected from nearby the SEED Research Camp in S9), 2) equal mixture of compost (50%) and manure (50%), 3) equal mixture of natural soil (50%) and compost (50%), and 4) equal mixture of natural soil (33%), compost (33%), and manure (33%). Germination success (Y/N) was monitored on a weekly basis. If successful, seedling height (cm) was recorded, using a ruler to measure from the soil surface to the highest point of the seedling (stretching to the top of the leaf tip). Initial height was measured on the recorded date of germination, which could be up to a week after actual germination occurred due to data being collected weekly.

2.3.1. Statistical Analyses

No statistical comparisons could be made for *C. psammophilus*. Seeds only germinated in Natural/Compost soil, and all germinated seedlings died of sunlight exposure when nursery shades broke in March 2023.

The germination time for each seed was calculated as the number of days between the sowing date and the date of the seedling's first emergence.[4]

Fisher's exact test was performed using the 'stats' statistical package in R (v4.1.2; R Core Team, 2021) to determine if there was a significant association between soil type and seed germination percentage across species.

The growth rate was calculated only for seeds that germinated and that were still alive on the date of the last measurement before conducting data analysis (12th May 2023). To calculate the growth rate, the difference between the last recorded palm height and the height on the date of germination was divided by the number of weeks between these two dates.

A Kruskal Wallis test[5] was performed using the *'stats'* statistical package in R (v4.1.2; R Core Team, 2021) to compare whether there was a statistically significant difference between the growth rates of the palms in the different soil types. Soil types which have statistically significant differences are not identified, therefore a post-hoc Dunn's test for more in-depth analysis was necessary.[6]

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[4] Seedling germination is referring to emergence of seedling, although for consistency seedling germination is used throughout.

[5] The Kruskal-Wallis test is a non-parametric hypothesis test that can be used to compare three or more independent groups, without assuming that the data are normally distributed, which these data are not. The test ranks the data from highest to lowest, and then averages the ranks assigned, of which the test compares the means.

[6] Dunn's test is usually performed if the null hypothesis is rejected in the Kruskal-Wallis test ($p < .05$). This was not the case for the germination time data ($p = .075$), but the test can be performed even if the null hypothesis is not rejected. Dunn's test was performed as a post-hoc analysis, although as the null hypothesis was not rejected and the Kruskal-Wallis test was not close to significant, pairwise comparisons for each soil types have not been reported.

Dunn's test[7] was performed using the '*FSA*' package in R (v0.9.3; Ogle et al., 2022) to identify whether seedlings had statistically significantly different germination times between soil types. It was necessary to adjust the *p*-value to control the total error rate across the tests following multiple pairwise comparisons. The Holm correction was used with Dunn's test using R Statistical Software (v4.1.2; R Core Team, 2021).

2.4. Germination Monitoring

Germination monitoring aimed to uncover germination rates of seeds from a variety of donor trees. Data was collected weekly. Each week, the number of germinated seedlings was recorded for all target species. For each seed sown, the donor tree number, germination (Y/N), and date of germination were recorded. For each donor tree number, locality information was kept, which included GPS coordinates, forest fragment, condition score, DBH, and height of the tree.

To calculate germination rates, the number of seedlings that had germinated per species (by the last day of measurement before analysis - 12th May 2023) was divided by the total number of seeds sown per species. The sowing date was counted as week zero. Week zero for one sowing batch does not necessarily represent the same date as weeks zero for another sowing batch. As such, monitoring periods vary depending on when seeds were sown, which varies by species and by donor tree.

2.5. Post-Germination Survival and Growth Monitoring

From the onset of data collection, a goal of 20 seeds from 10 donor trees for each of the target species was set (200 total seeds sown per species). This was not always possible due to the size of fruiting inflorescence and the availability of fruiting adults. A total of 20 to 300 seeds per species from one to 15 donor trees were collected and sown. Post-germination survival (Y/N) and seedling height (cm) were recorded weekly. Post-germination survival and growth rates were calculated using R Statistical Software (v4.1.2; R Core Team, 2021).

2.6. *In-Situ* Planting Trials

In February 2023, 66 *C. saintelucei* seedlings were planted in the protected fragment of S9.

2.6.1. Preparation

Seedlings were sown in October 2021. More than one seed was sown per pot, resulting in there being one to three seedlings per pot. The seedlings were separated prior to planting via one of three strategies: 1) separated one week before planting, 2) separated on the day of planting, or 3) not separated and multiple seedlings were planted together. Seedlings were watered and labelled according to separation strategy and designated planting site. Approximately an equal number of seedlings per separation strategy was planted at each site.

2.6.2. Location

S9 was chosen as pilot planting location due to its classification as a conservation zone, habitat suitability for *C. saintelucei*, approval from the *Direction Régionale de l'Environnement et du Développement Durable* (DIREDD; Regional Ministry of Environment and Sustainable Development) to plant on the site, and proximity to the SEED Research camp.

A range of locations and habitats were identified and investigated to test planting site suitability. Five sites were considered for the planting trials (Table 1), all agreed upon by local experts, members of the Forestry Police Association (FIMPIA), and SEED's Conservation Research Programme (SCRP). Site feasibility was determined by *C. saintelucei* habitat preferences and accessibility (Annex 1).

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[7] The Dunn's test was performed on the germination time data to check what the *p*-value was for the comparison between the Natural/Manure/Compost soil and the Manure/Compost soil, because there was a large difference in the germination times between the two soil types. The *p*-value for the pairwise comparison between the germination times in the Natural/Manure/Compost soil and the Manure/Compost soil was close to but slightly greater than .05.

Table 1: Description of potential sites for in-situ planting trial.

Potential Site	Description
Site 1	Many juveniles present. Wetland. Shaded but partially open canopy.
Site 2	Many juveniles present, up to 3m tall. Stream running through site, soil is more saturated than Site 1 and gentle sloping gradient away from stream. Open but low canopy.
Site 3	Few juveniles present. Stream running through site. Partially closed canopy at roughly 75% cover, and around 15m tall. Many Pandanus spp. and Bamboo spp. (*voliandroky*) within the vicinity. Close to bridge over stream and pathway, ensuring easier accessibility for monitoring and local forest users.
Site 4	Few juveniles present, few adults have grown here in the past. Stream runs through the site with steep slopes alongside each side of the site. Close to bridge over stream and pathway, ensuring easier accessibility for monitoring and local forest users. Open canopy, with canopy height around 10m tall.
Site 5	Very few juveniles present. Area is swampy, with soil consisting mainly of organic matter and little to no sand. Steep sides on either side of the site. Close to pathway, ensuring easier accessibility for monitoring and local forest users.

Four sites were chosen for the preliminary planting trials. Site 2 was excluded as it was very similar to Site 1. Planting locations can be seen in Figure 2. Sites had equal numbers of seedlings planted (n = 16), except Site 1 where 18 seedlings were planted.

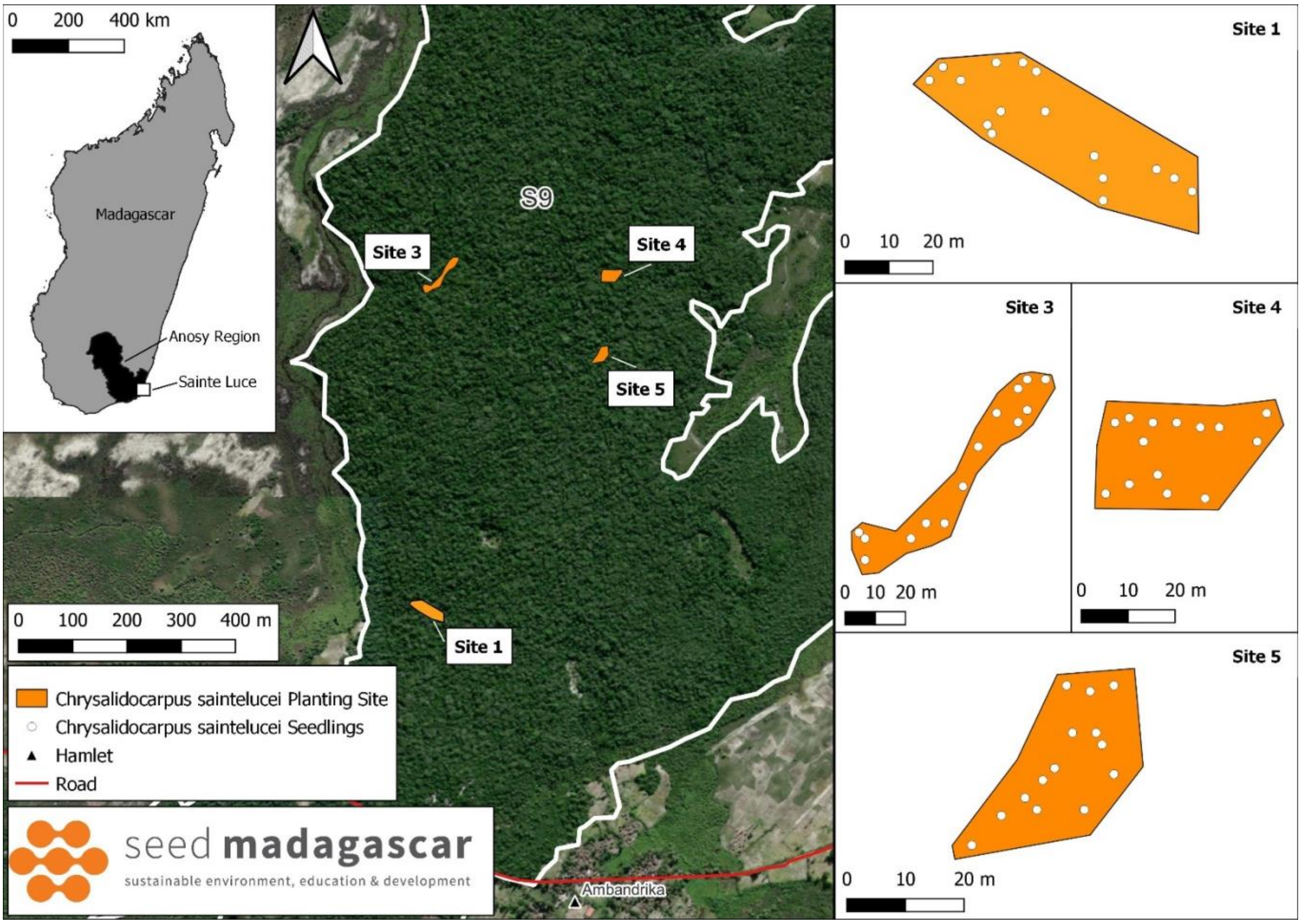

Figure 2: In-situ palm planting sites in S9.

2.6.3. Planting and Monitoring

Before the planting event, palms were labelled, and local stakeholders attended training on digging holes at the planting sites. Holes were dug one day before the event to 40cmx40cmx20cm with topsoil left to one side, as recommended by MBG. Despite the small size of seedlings, the large hole helps to loosen the soil for the seedlings and has been observed to improve survival rate.

At the start of the planting event, a planting demonstration was given. With the help of SCRP, members of FIMPIA, *Communautés de Base* (CoBA; forest management association), and *Polisin'ala* (local forest patrol) planted palms at each site.

Palms were planted in the centre of each hole, at a height where leaves were above the hole, with a handful of manure concentrated near the roots and the topsoil placed back over the top of the hole. Each seedling was watered and marked. Planting sites were mapped using the geographic information system Quantum GIS (QGIS) (QGIS Development Team, 2022). Once planted, the height of each palm was recorded, using the same method employed in the nursery. Condition was recorded on a scale of 1 to 4 (Table 2).

Fixed point photographs were taken of all seedlings at Site 4, one metre north of the seedling at a camera height of 30cm, facing south towards the seedling.

Table 2: Description of palm condition categories, developed with local guides and expert knowledge.

Condition	Description
1 - Dead	Palm has wilted, lost its leaves, and turned brown
2 - Poor	Severe signs of either: damage, pest infestation, discolouration, fungi, or abnormal growth
3 - Fair	Signs of either: damage, pest infestation, discolouration, fungi, or abnormal growth
4 - Good	Healthy palm, with green leaves showing no evidence of pests/disease, or human disturbance such as leaf removal or axe marks on trunk

3 Results

3.1. Seed Collection, Preparation, and Sowing

8,812 seeds were collected from five fragments within the SLLF and sown, comprised of 2,128 seeds from *B. madagascariensis,* 1,181 seeds from *C. prestonianus,* 1,512 seeds from *C. psammophilus,* 296 seeds from *C. saintelucei,* 1,959 seeds from *D. brevicaulis,* and 1,736 seeds from *D. scottiana*.

3.2. Soil Trials

Soil trials were conducted for target species between 25th June 2022 and 12th May 2023.

On average, palms had the highest mean germination rate in the Natural/Compost soil (50.0%) and the lowest mean germination rate in the Manure/Compost soil (26.0%) (Figure 3). There was a significant association between soil type and germination rate across species (Fisher's exact test, two-tailed $p = .048$). When analysing species individually, the relation between soil type and seed germination rate was only significant for *D. scottiana*, which achieved higher germination rates in Natural/Compost soil (Fishers exact test, two-tailed $p < .001$).

Differences in germination times between the soil types were not statistically significant (Kruskal-Wallis, H (3) = 6.91, $p = .075$). Overall, palms had the shortest mean ($\bar{x}$) germination time (T) in the Natural/Manure/Compost soil ($\bar{x}\ T = 105.3$ days) and the longest mean germination time in the Manure/Compost soil ($\bar{x}\ T = 192.6$ days) (Figure 4). A Dunn's test and Holm correction indicated that the difference between germination times in Natural/Manure/Compost soil and the Manure/Compost soil was not statistically significant ($p = .059$).

Differences in growth rates between the soil types were not statistically significant (Kruskal Wallis, H (3) = 3.73, $p = .292$) (Figure 5).

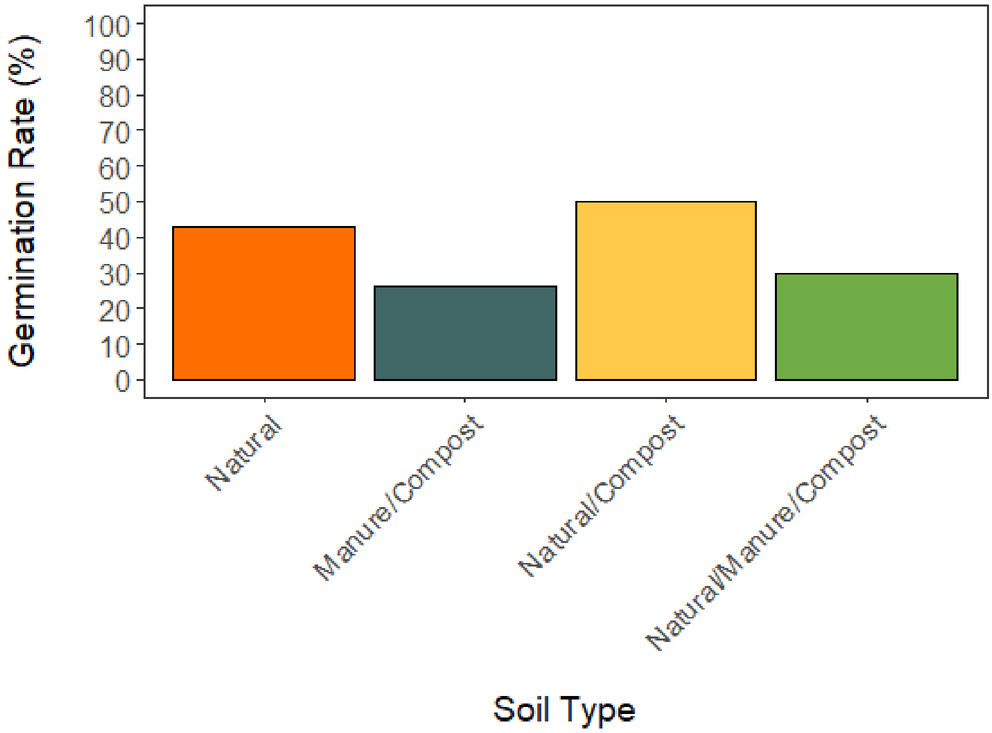

Figure 3: Germination rates of palm seeds in different soil types.[8]

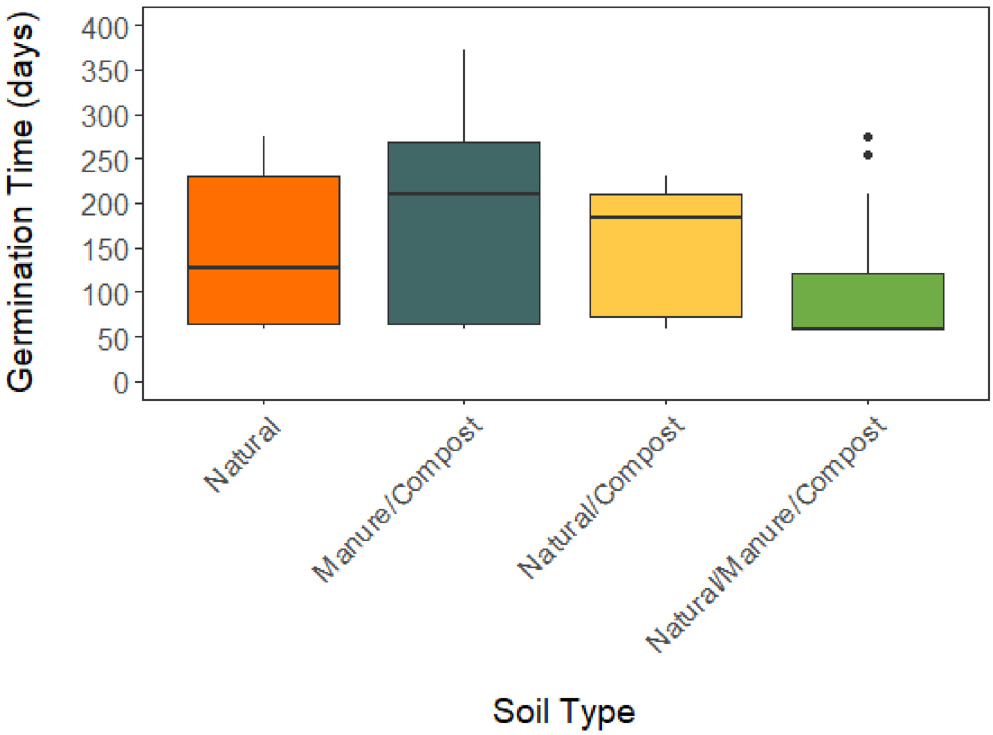

Figure 4: Germination time of palm seeds in different soil types.[9]

[8] Sample numbers for germination rate included: Natural soil (*n* = 49), Manure/Compost soil (*n* = 50), Natural/Compost soil (*n* = 50), and Natural/Manure/Compost soil (*n* = 50).

[9] Sample numbers for germination time included: Natural soil (*n* = 21), Manure/Compost soil (*n* = 13), Natural/Compost soil (*n* = 25), and Natural/Manure/Compost soil (*n* = 15). Germination time was calculated for all palm seeds that germinated, including three seeds that germinated but did not survive through the date of the last measurement (1 each in the Manure/Compost, Natural/Compost, and Natural/Manure/Compost soil).

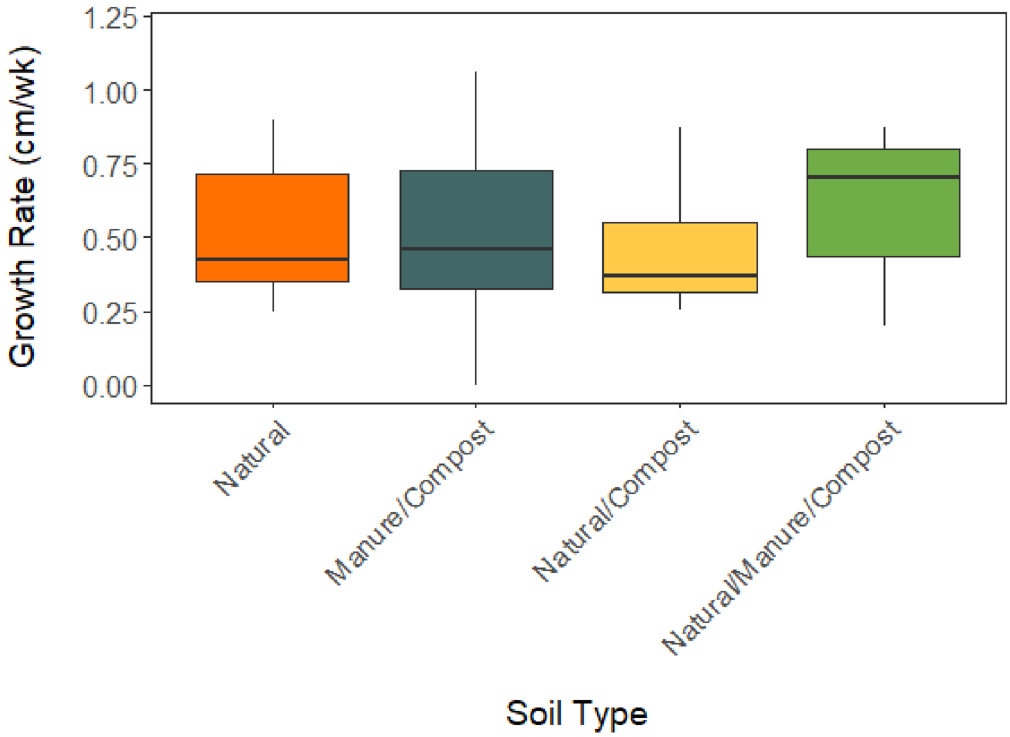

Figure 5: Growth rates across of palm seeds in different soil types.[10]

3.2.1. Observations per Species

B. madagascariensis had the highest germination rate in the Natural/Manure/Compost soil (40.0%) and the lowest germination rates in the Natural/Compost soil and Manure/Compost soil (20.0% each) (Table 3). It had the longest mean germination time in the Manure/Compost soil ($\bar{x}$ *T* = 251.0 days) and the shortest in the Natural/Compost soil ($\bar{x}$ *T* = 73.0 days). The mean germination times were similar in the Natural soil ($\bar{x}$ *T* = 111.5 days) and the Natural/Manure/Compost soil ($\bar{x}$ *T* = 111.2 days). *B. madagascariensis* had the highest mean ($\bar{x}$) growth rate (*G*) ($\bar{x}$ *G* = 0.95cm/week) in the Manure/Compost soil, while mean growth rates were similar in all other soil types ($\bar{x}$ *G* = 0.49-0.54cm/week).

C. prestonianus had a higher germination rate in the Natural soil (50.0%) than all other soil types (20.0%). *C. prestonianus* had the longest mean germination time ($\bar{x}$ *T* = 191.0 days), but highest mean growth rate ($\bar{x}$ *G* = 0.46cm/week) in the Manure/Compost soil. The mean germination times and growth rates were similar in all other soil types ($\bar{x}$ *T* = 121.0-156.0 days, $\bar{x}$ *G* = 0.31-0.38cm/week).

C. psammophilus only germinated in the Natural/Compost soil (70.0%).

C. saintelucei had the highest germination rates in the Natural soil and the Natural/Manure/Compost soil (70.0% each) and the lowest germination rate in the Manure/Compost soil (40.0%). The mean germination times and mean growth rates were similar in all soil types ($\bar{x}$ *T* = 50.3-58.0 days, $\bar{x}$ *G* = 0.72-0.79cm/week).

D. brevicaulis had a higher germination rate in the Natural/Compost soil (50.0%) than in the Natural soil (30.0%) or the Natural/Manure/Compost soil and Manure/Compost soil (10.0% each). The mean germination times and mean growth rates were similar in all soil types ($\bar{x}$ *T* = 203.6-231.3 days, $\bar{x}$ *G* = 0.37-0.50cm/week).

D. scottiana had the highest germination rate and shortest germination time in the Natural/Compost soil (100%; $\bar{x}$ *T* = 204.2 days) and the lowest germination rate in Natural/Manure/Compost soil (10.0%). The mean germination times and mean growth rates were similar in all other soil types ($\bar{x}$ *T* = 259.9-292.5 days, $\bar{x}$ *G* = 0.52-0.60cm/week).

Table 3: Germination rate, survival rate, mean growth rate, and mean germination time for each palm species in the four trialled soil types.

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[10] Sample numbers for growth rate included: Natural soil (*n* = 21), Manure/Compost soil (*n* = 12), Natural/Compost soil (*n* = 24), and Natural/Manure/Compost soil (*n* = 14).

Species	Soil Type	Germination Rate[11] (%)	Mean (SD) Germination Time (days)	Mean (SD) Growth Rate (cm/week)	Survival Rate of Germinated Seeds (%)
B. madagascariensis	Natural	22.2	111.5 (4.9)	0.49 (0.07)	100.0
	Manure/Compost	20.0	251.0 (24.0)	0.95 (0.16)	100.0
	Natural/Compost	20.0	73.0 (0.0)	0.51 (0.00)	100.0
	Natural/Manure/ Compost	40.0	111.2 (95.4)	0.54 (0.14)	75.0
C. prestonianus	Natural	50.0	135.0 (9.9)	0.38 (0.04)	100.0
	Manure/Compost	20.0	191.0 (0.0)	0.46 (0.04)	100.0
	Natural/Compost	20.0	156.0 (9.9)	0.36 (0.04)	100.0
	Natural/Manure/ Compost	20.0	121.0 (9.9)	0.31 (0.04)	100.0
C. psammophilus[12]	Natural/Compost	70.0	148.0 (18.0)	NA	0.0
C. saintelucei	Natural	70.0	60.0 (3.4)	0.79 (0.08)	100.0
	Manure/Compost	40.0	59.8 (3.5)	0.72 (0.03)	75.0
	Natural/Compost	60.0	60.3 (3.6)	0.79 (0.09)	100.0
	Natural/Manure/ Compost	70.0	58.0 (0.0)	0.79 (0.06)	100.0
D. brevicaulis	Natural	30.0	231.3 (20.5)	0.42 (0.07)	100.0
	Manure/Compost	10.0	211.0 (NA)	0.38 (NA)	100.0
	Natural/Compost	50.0	203.6 (29.6)	0.37 (0.08)	100.0
	Natural/Manure/ Compost	10.0	211.0 (NA)	0.50 (NA)	100.0
D. scottiana	Natural	40.0	259.5 (19.7)	0.29 (0.05)	100.0
	Manure/Compost	40.0	292.5 (54.4)	0.22 (0.15)	100.0
	Natural/Compost	100.0	204.2 (17.1)	0.30 (0.05)	90.0
	Natural/Manure/ Compost	10.0	275.0 (NA)	0.20 (NA)	100.0
Total	Natural	42.9	145.2 (80.8)	0.52 (0.21)	100.0
	Manure/Compost	26.0	192.6 (102.9)	0.52 (0.30)	92.3
	Natural/Compost	50.0	155.2 (67.6)	0.46 (0.21)	96.0
	Natural/Manure/ Compost	30.0	105.3 (77.3)	0.60 (0.23)	93.3

3.3. Germination Monitoring

The number of seeds sown and number of donor trees collected from varied between species (Table 4).

Table 4: Number of seeds sown from number of donor trees and the number of seeds that germinated by 12th May 2023.

Species	Seeds Sown	Number of Donor Trees	Seeds Germinated
B. madagascariensis	782	19	211
C. prestonianus	791	7	95
C. psammophilus	748	10	267
C. saintelucei	176	1	127
D. brevicaulis	977	62	219
D. scottiana	755	17	386

[11] Includes seeds that germinated but did not survive through the last measurement.

[12] The standard deviation for *C. psammophilus* is NA as only seedlings within Natural/Compost soil germinated. The values in the "Total" rows do not include any of the data for *C. psammophilus*.

Germination rates and times differed between species (Table 5 and Figure 6). Germination rates within the same species but on different sowing dates are shown in Annex 2. The mean time for any seeds to begin germinating across all species was 12.17 weeks. *C. saintelucei* seedlings began germinating the fastest after sowing, with seeds germinating from eight weeks of sowing. Germination times for seedlings of all the other species were longer, with germination beginning from 10 weeks for *D. scottiana,* 13 weeks for *B. madagascariensis* and *C. prestonianus,* 14 weeks for *D. brevicaulis,* and 15 weeks for *C. psammophilus.*

The largest percentage of seeds that had germinated by month three were C. saintelucei. For *C. psammophilus*, the majority of seeds that germinated did so between months three and six. *D. scottiana* germination appeared to be the slowest, with most individuals germinating between months six and nine. *C. saintelucei* seeds had the highest germination rate and also germinated within the shortest time period, 72.16% germinated within three months. *D. scottiana* showed the second highest percentage of seeds that germinated, at 44.60% nine months after sowing. While only 12.97% of *C. prestonianus* seeds germinated nine months after sowing. *B. madagascariensis, C. prestonianus, C. psammophilus,* and *D. brevicaulis* all had germination rates lower than 35% nine months after sowing.

Table 5: Percentage of seeds sown that have germinated by 3, 6, and 9 months after sowing per species.[13]

Species	Month 3	Month 6	Month 9
B. madagascariensis	0.06	16.06	22.25
C. prestonianus	0.22	13.59	12.97
C. psammophilus	0.00	31.04	34.79
C. saintelucei	72.16	72.16	NA
D. brevicaulis	0.00	15.11	18.62
D. scottiana	0.14	0.14	44.60

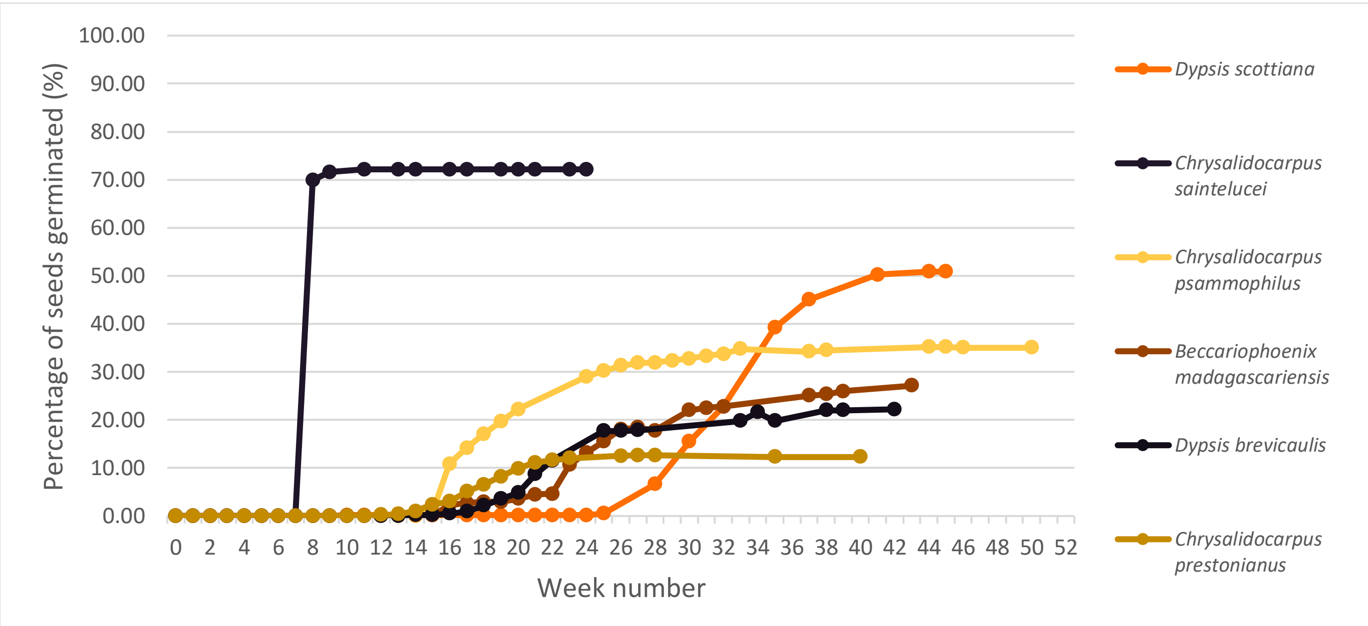

Figure 6: Percentage of seeds germinated over time per species.[14]

[13] NA indicates that it has not yet been 9/12 months since these seeds were sown.
[14] For each species, data have been omitted for all sowing periods where there are missing recordings for a particular sowing batch on one monitoring occasion.

3.4. Post-Germination Survival and Growth Monitoring

The survival and growth monitoring revealed differences in mean post-germination survival rate (%) and mean growth rates (cm) between species within the nursery.

3.4.1. Post-Germination Survival Rates

All species except *C. psammophilus* showed a post-germination survival rate of above 95% (Table 6).

Table 6: Post germination survival rates per species.

Species	Survival Rate (%)
B. madagascariensis	98.11
C. prestonianus	100.00
C. psammophilus	56.79
C. saintelucei	100.00
D. brevicaulis	98.78
D. scottiana	95.28

3.4.2. Growth Rates

Growth rates ranged between 0.26cm and 1.02cm per week (Table 7 and Figure 7). Seeds were sown upon their collection, therefore sowing and monitoring dates are not consistent within and across all species. The palm species with the fastest mean growth rate was *C. saintelucei* ($\bar{x}$ *G* = 1.02cm/week), over the shortest number of weeks (*n* = 13). *B. madagascariensis* were the second fastest growing palm ($\bar{x}$ *G* = 0.61cm/week), over the highest number of weeks (*n* = 38). The palm species with the slowest growth rate was *D. scottiana* ($\bar{x}$ *G* = 0.34cm/week). *D. brevicaulis*, *C. prestonianus*, *C. psammophilus*, and *D. scottiana* demonstrated a regular increase in growth. *C. saintelucei* showed rapid growth rate at initial germination, and then slows considerably at approximately five weeks. *B. madagascariensis* showed a regular increase in growth up to week 10, a plateau in growth between weeks 10 and 20, and a regular increase in growth again following week 20.

Table 7: Number of weeks growth was monitored for and mean growth rates per week per species.

Species	Total number of weeks growth was monitored for[15]	Mean growth per week (cm)
B. madagascariensis	38	0.61
C. prestonianus	28	0.39
C. psammophilus	35	0.47
C. saintelucei	13	1.02
D. brevicaulis	23	0.36
D. scottiana	18	0.34

[15] The number of weeks growth was monitored varies per species depending on the time of year seeds could be collected from fruiting adult palms and the germination time of each species.

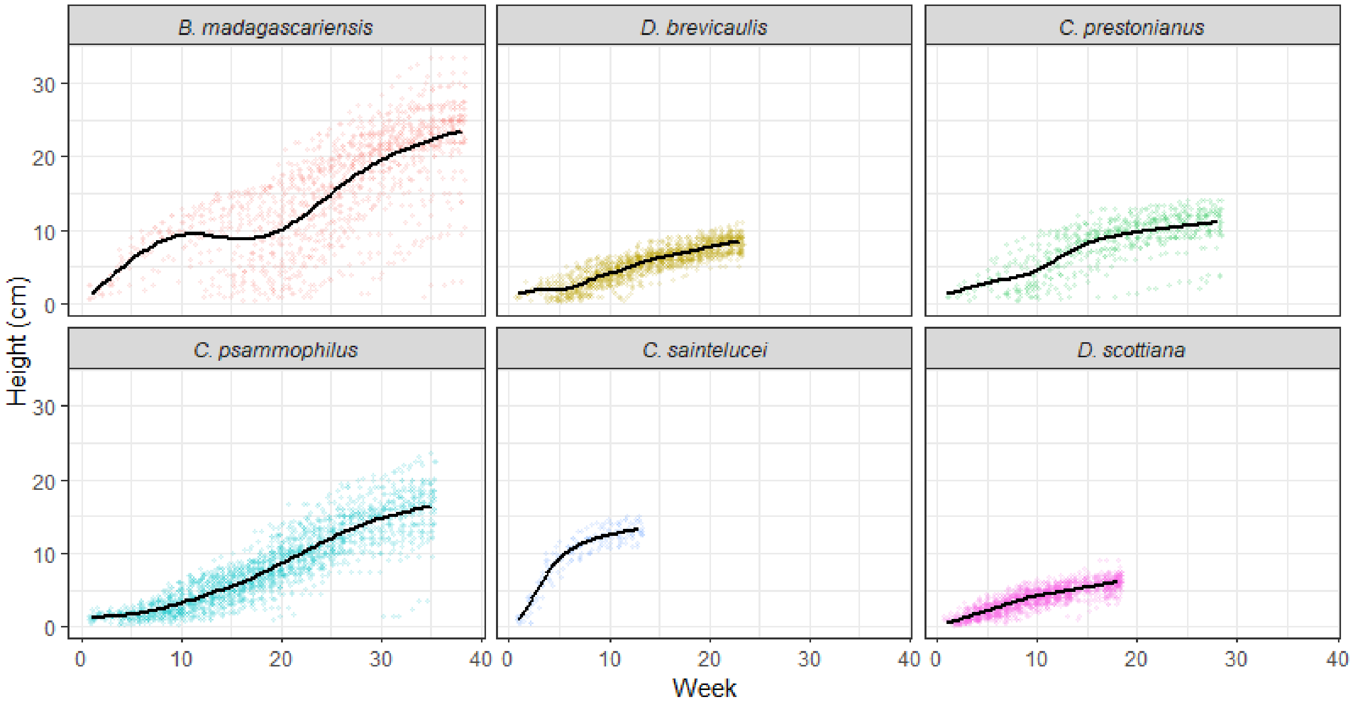

Figure 7: Growth rates per species over their individual growth periods. Coloured points show individual palms within each species.[16]

3.5. *In-Situ* Planting Trials

The *C. saintelucei* planted *in-situ* at planting sites 1 and 4 show an initial increase in mean height between month zero and month one, before a decrease in average height between month one and month three (Figure 8 and Annex 3). The seedlings planted at Site 3 show a continuous increase in mean height over time. At planting Site 5, seedlings showed an initial decrease in average height between month zero and month one, before increasing between month one and month three.

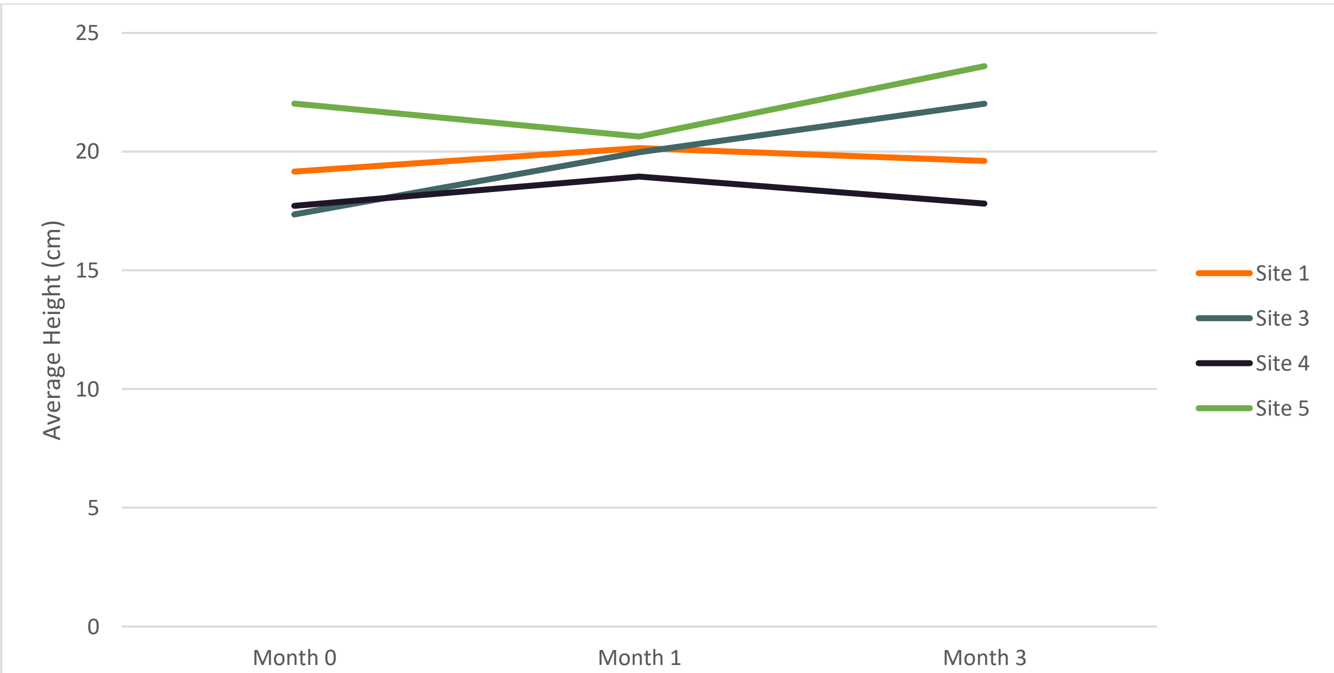

Figure 8: Mean height of seedlings at each planting site over time.

[16] Only seedlings which survived have been included in this plot. Trend lines were fitted as Generalised Additive Models for each species respectively to account for the non-linearity in growth trend. The models use adapting smoothing meaning that the line is permitted to vary in how closely it bends with the data.

Mean condition of seedlings after planting improved in all sites (Table 8, Annex 4). The seedlings in Site 5 increased the most in mean condition (3.56 to 4) and at month three were in the best condition overall.

Table 8: Mean and mode condition of seedlings at each planting site on the day of, one month, and three months after planting.

Planting Site	Day of Planting: Mode condition	Day of Planting: Mean Condition	Month One: Mode condition	Month One: Mean condition	Month Three: Mode condition	Month Three: Mean condition
Site 1	4	3.61	4	3.83	4	3.94
Site 3	4	3.63	4	3.81	4	3.88
Site 4	4	3.5	4	3.69	4	3.81
Site 5	4	3.56	4	3.88	4	4

4 Discussion

Research into palm germination, survival, growth, and most suitable soil composition has been completed, alongside *in-situ* planting trials. Results have provided insights into the best conditions for planting and survival for the six target threatened species of palm and demonstrate the feasibility of supporting local palm populations through supplementary planting into protected fragments. Some particularly important emergent findings are discussed in greater detail below.

4.1. Discussion of Findings

4.1.1. Soil Trials

Since no seeds germinated in three of the soil compositions for *C. psammophilus*, it is likely that there were factors affecting the viability of the seeds. For example, Cruz-Tejada et al. (2018) observed that palm seeds can be attacked by pathogens, resulting in their death. As *C. psammophilus* seeds planted in the soil trials were collected in March and April 2022 from different trees, there is potential that a collection of abiotic and biotic factors from collection, such as environmental conditions or infection with pathogens after planting, affected the viability of seeds.

Soil composition was shown to significantly affect the germination rate of *D. scottiana*, with 100% of seedlings germinating in the Natural/Compost soil, and *C. psammophilus*, for which seedlings only germinated in the Natural/Compost soil (70%).

Observational findings from nursery staff about the good condition and high growth rate of seedlings in Natural/Compost soil support the high germination rates found. Results from the soil trials will inform species specific soil composition when sowing seeds within the nursery from August 2023 onwards.

4.1.2. Germination Monitoring

The germination monitoring showed that the species all have different germination rates. They were highest for *C. saintelucei* and *D. scottiana,* and the lowest for *C. prestonianus*. For all other species, germination success rate was between 18-35% at nine months after sowing. Randriatakifa et al. (2008) commented on low germination rates observed within the littoral forests of the Taolagnaro region and suggested these could be explained by high relative humidity and temperatures within the area. Over 50% of the species in Randriatakifa et al. (2008) trial (*n* = 119) had germination rates of less than 50%. In this study, five out of six species had germination rates below 50% nine months after sowing. A high germination rate of 72.12% was observed for *C. saintelucei* in this study. This aligns with recordings by Hogg et al. (2013) of particularly high germination and first-year survival rates of *C. saintelucei* seedlings, of over 90%, within cultivation trials in Sainte Luce.

Palm species also varied by the time period at which they reached maximum germination success. This may be because some plants of the littoral forests are known to experience inhibition phenomena and seed dormancy (Randriatakifa et al., 2008). Inhibition phenomena, namely inhibition of seed germination, can be caused by phytohormones present in the palm (Wang et al., 2019). Morphophysiological seed dormancy can be caused by a thick endocarps or incomplete embryo development prior to fruit falling, which delays germination in seeds in order to enhance their survival rate (Soares et al., 2022). Some palms require high temperatures to break this dormancy and begin germinating (Hussey, 1958). This could explain why several target palms species, *D. scottiana* for example, have such long germination times, but the *C. saintelucei* that were planted in the hotter months (November to March) did not.

Nursery mortality rates were estimated at 60% of seeds sown, factoring in seed mortality, germination mortality, and nursery growth mortality. Germination mortality was higher than expected, with a mean germination rate of 34.23% across all species at nine months after sowing (except *C. saintelucei* which had not reached nine months, and data from monitoring interval six months after sowing was used instead). As such, seed collection targets were revised to ensure the target number of alive and healthy seedlings (n = 300 per species) could be met. Species with particularly low germination rates, such as *C. prestonianus* and *D. brevicaulis*, became greater priorities for seed collection and sowing as the project progressed.

4.1.3. Post-Germination Survival and Growth Monitoring

For all species, excluding *C. psammophilus,* post-germination survival rates were above 95%. This is similar to the first-year survival rates which Hogg et al. (2013) observed.

Jansen et al. (2012) found that individual *Chamaedorea elegans* palms grow at different rates. Growth differences were owed to factors such as spatial variation in soil fertility, soil texture, and water availability, as well as genetic variation between individuals. Figure 7 shows a varying growth rate between palms within the same species as well as between different species. The factors mentioned by Jansen et al. (2012) could explain some of the variation in trend lines of growth rates for *B. madagascariensis* and *C. saintelucei,* which increase rapidly after planting and then slow considerably. Further exploration into factors which could have influenced these growth trends of individual seedlings and of species is needed to develop a deeper understanding about growth patterns and support this study's novel findings for each species.

Due to *C. saintelucei*'s low seed availability, seeds from this species were sown later in the year (November) than other species (April to July). This could have affected observed growth rates, as on average the temperatures, humidity levels, amount of rainfall, and number of daylight hours are higher in November. These abiotic factors are known to have some of the most significant effects on plant growth (Robinson, 2010; Hong Xing et al., 2011). In this study, such abiotic conditions were not recorded, but it may be worthwhile to monitor how they affect growth rates in potential future studies. Abiotic factors could explain the observed rapid germination time and growth trend for *C. saintelucei* compared to the other species.

4.1.4. *In-Situ* Planting Trials

Hogg et al. (2013) predicted that *C. saintelucei* seeds are barochorous, meaning their dispersal mechanism is mainly through gravity of the seeds falling. Due to finding many seedlings within two meters of adult palms, juveniles experienced high levels of competition and showed signs of chlorosis (leaf yellowing), with few making it to adulthood. This supports the reasoning for planting *C. saintelucei* seedlings in S9 at least two meters away from other seedlings and or large trees. This helps to reduce competition, by increasing available growing area and favouring a more open canopy, where more light reaches the forest floor (Riegel et al., 1992).

4.2. Limitations

Ravenala madagascariensis leaves are used to provide 60-70% shade to the seedlings in the nursery. In March 2023, some of these shades were damaged, resulting in seedlings being exposed to direct sunlight and causing them to die. This primarily impacted the *C. psammophilus* seedlings in the soil trials.

During survival and growth monitoring, the study aimed to collect and sow 200 seeds from each species. This target could not be met for *C. saintelucei* and *D. brevicaulis* due to difficulties in finding seeds. Therefore, only one donor tree was used for the *C. saintelucei* survival and growth monitoring. For *D. brevicaulis*, the observed number of fruits on an inflorescence is fewer than for the other target species, so it was necessary to gather from more donor trees.

It was decided analysis of post-germination survival rate would draw the most accurate results from the survival and growth data set as the total number of seeds sown was occasionally inconsistently recorded. Results of whole nursery survival rates could therefore not be gathered for this dataset. In future, more consistent record keeping of seed sowing would enable an analysis of whole nursery survival to be conducted.

Monitoring of the *in-situ* planting sometimes showed a decrease in seedling height. When digging holes, soil was removed and placed to the side. In many cases, not all removed soil was placed back in the hole after palms were planted, due to the addition of manure and the seedling. Many of the palms were planted on a steep gradient. During the time of planting, in rainy season, earth was washed back into the holes, raising the level of the soil. This extra soil shortened the appearance of the stem, and therefore resulted in palms appearing to shrink. If excessive additional soil was observed covering the seedlings during monitoring intervals, it was dug out to ensure their survival. This resulted in decreases of height and inaccurate growth measurement for some of the planted seedlings, resulting in inability to track true growth rate of seedlings. In future, as the palms settle into their habitat, and time since planting increases, soil should compact more, loose soil will be washed into the holes, and the number of times that palms seem to decrease in height will reduce.

5 Conclusion

The findings of this report point to several key observations of current threatened palm populations in the SLLF. All target palms have low numbers of adult individuals, with broader concerns that local populations of each of these species may continue decreasing as a consequence of mining, habitat loss, and unsustainable natural resource use. A current understanding of the germination rates and time, post-germination growth rates and survival, as well as preferred soil requirements of the target species in the SLLF has now been achieved. *In-situ* planting trials have also been started, providing novel insight into survival and growth of transplanted *C. saintelucei* seedlings into the SLLF. The findings of this study improve the overall understanding of these palm species, by broadening the literature about their distribution, phenology, germination, growth and planting requirements and informing future *in-situ* planting events, aiding the ability to conserve them. By informing national and international understanding of these threatened species, the development of a community-driven conservation action plan can be contributed to, to ensure their long-term survival.

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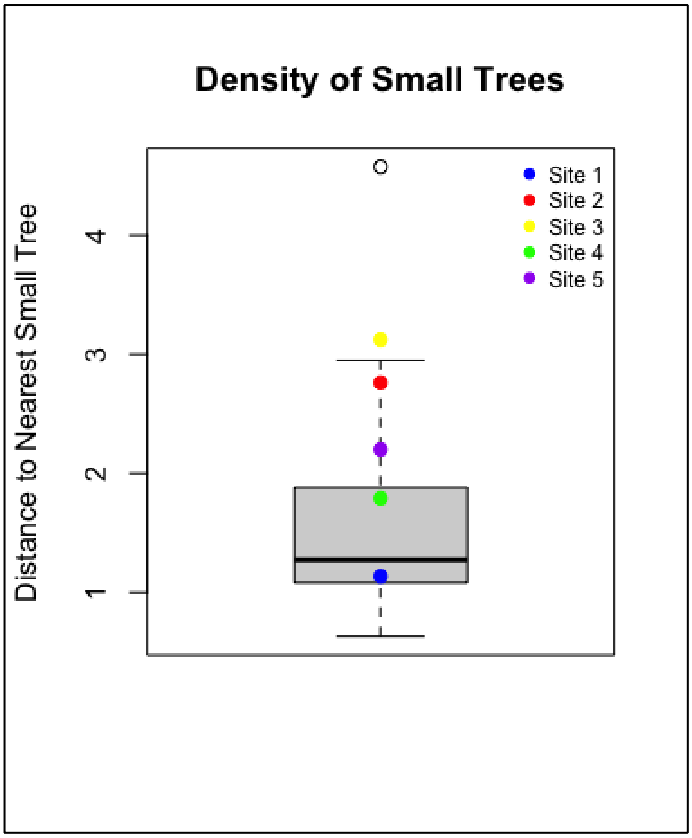
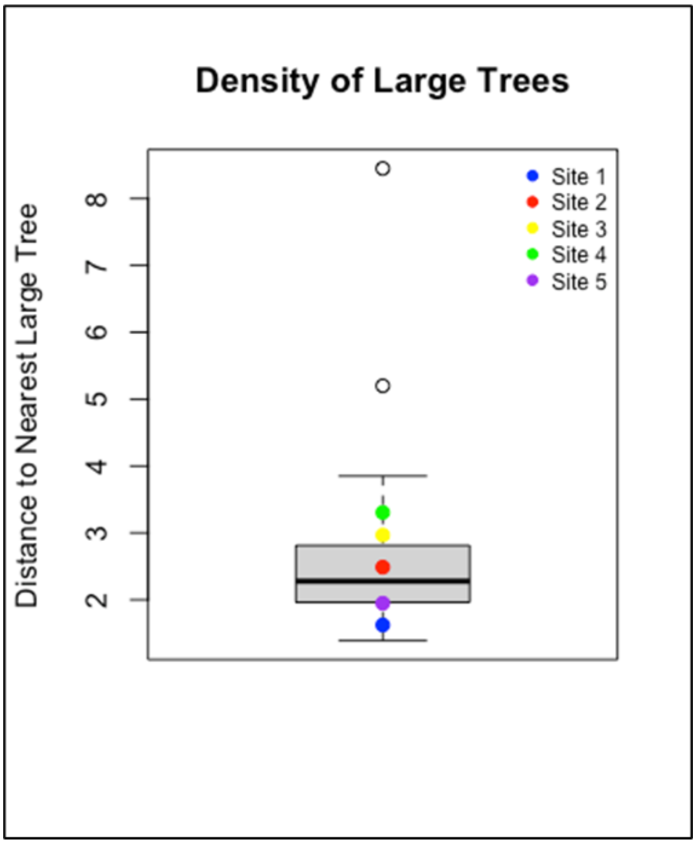
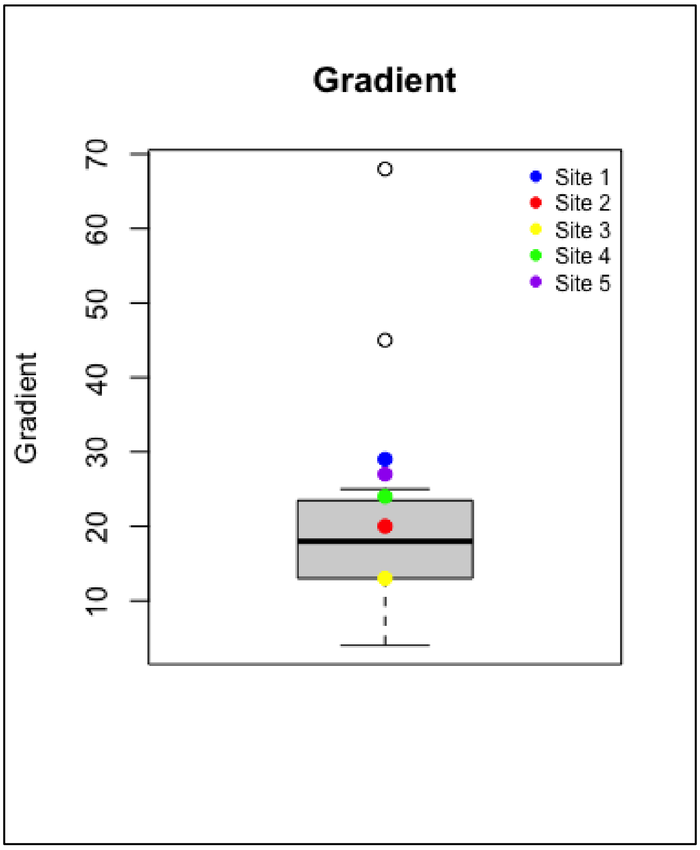
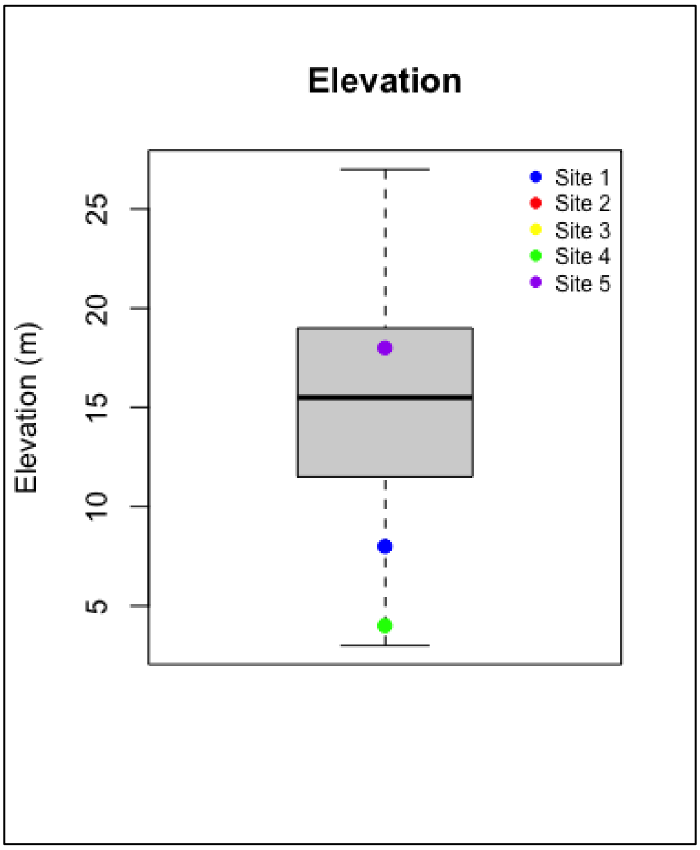
7 Annexes

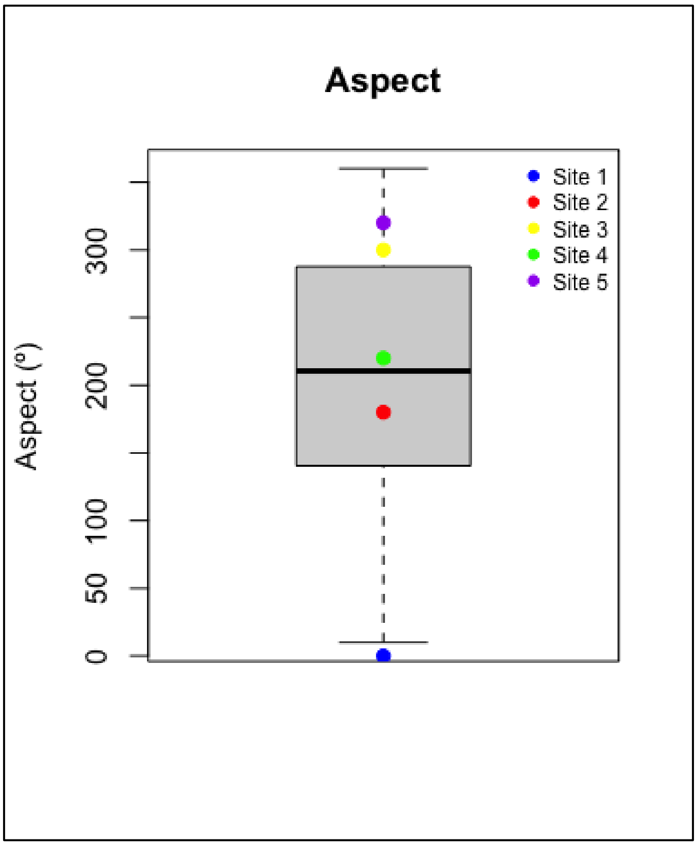
Annex 1 – Microhabitat results for planting site 1-5







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Aspect (°)
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100
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300
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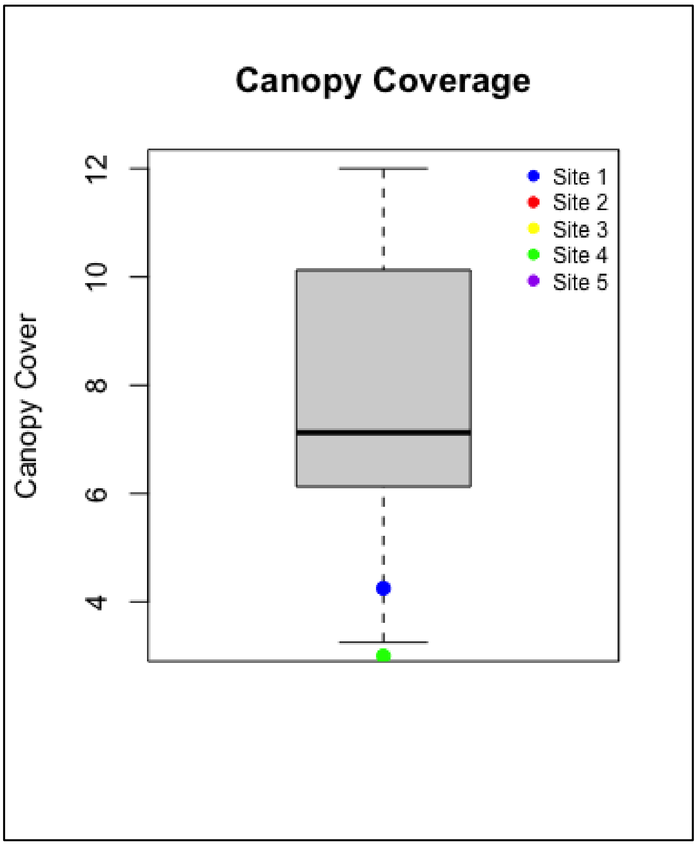
Site 2
Site 3
Site 4
Site 5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Canopy Cover
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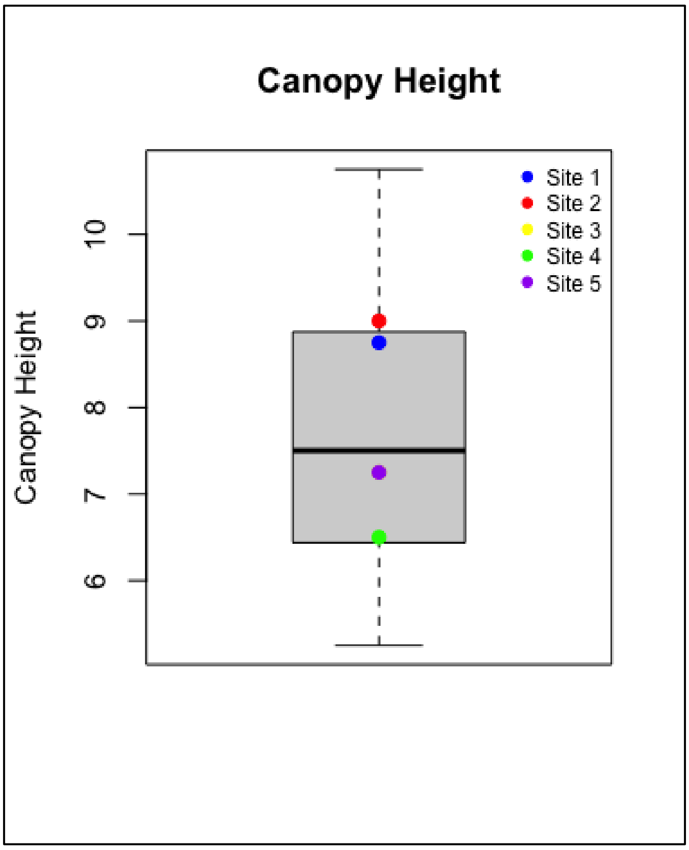
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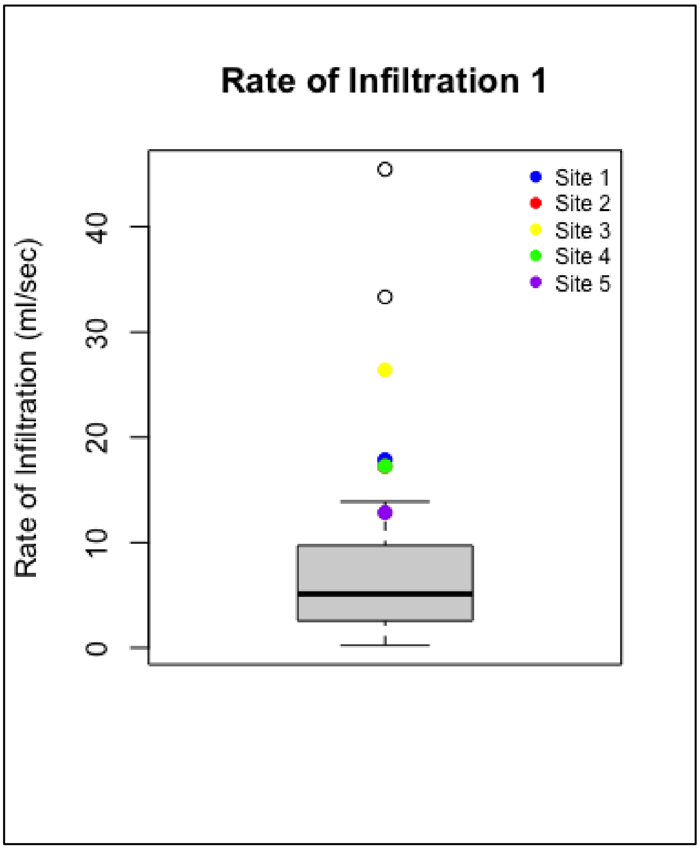
Rate of Infiltration 1
Rate of Infiltration (ml/sec)
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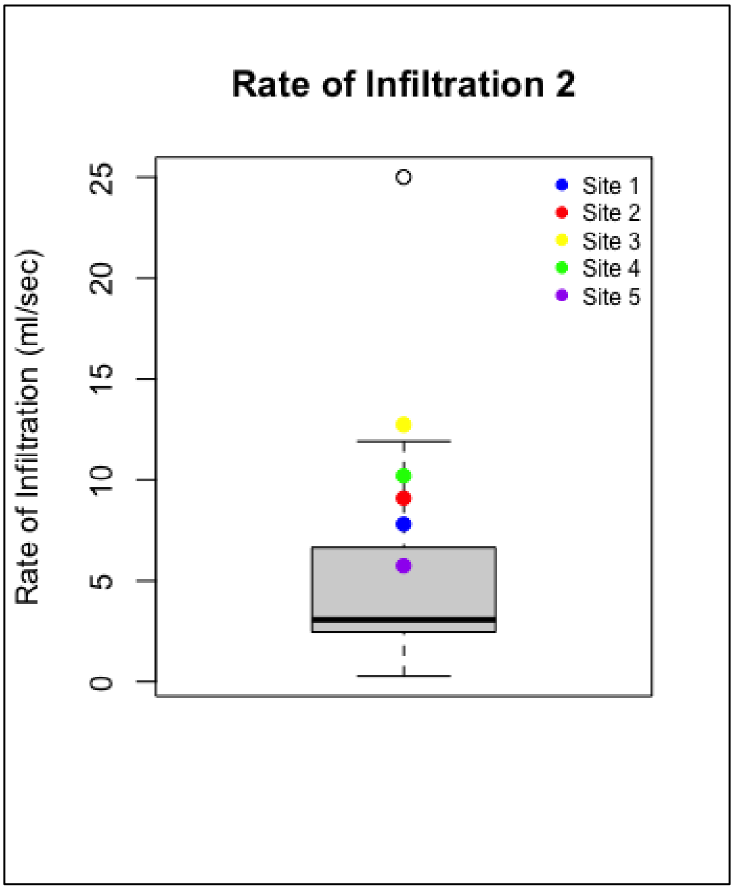
10
20
30
40
Site 1
Site 2
Site 3
Site 4
Site 5



Rate of Infiltration 2
Rate of Infiltration (ml/sec)
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5
10
15
20
25
Site 1
Site 2
Site 3
Site 4
Site 5

Annex 2 – Mean Germination percentage per sowing

	Sowing Batch	Month 3	Month 6	Month 9	Month 12
D. scottiana	Sowing batch 1	0.00	0.00	25.81	31.72
	Sowing batch 2	0.41	0.41	61.38	N/A
	Sowing batch 3	0.00	0.00	46.61	N/A
	total	**0.14**	**0.14**	**44.60**	**N/A**
C. saintelucei	Sowing batch 1	72.16	72.16	N/A	N/A
	total	**72.16**	**72.16**		**N/A**
C. psammophilus	Sowing batch 1	0.00	15.41	16.85	16.49
	Sowing batch 2	0.00	43.93	47.66	48.29
	Sowing batch 3	0.00	33.78	39.86	39.86
	total	**0.00**	**31.04**	**34.79**	**34.88**
B. madagascariensis	Sowing batch 1	0.00	9.05	20.81	24.43
	Sowing batch 2	0.00	2.50	5.00	N/A
	Sowing batch 3	0.25	23.94	31.92	N/A
	Sowing batch 4	0.00	28.75	31.25	N/A
	total	**0.06**	**16.06**	**22.25**	**N/A**
D. brevicaulis	Sowing batch 1	0.00	0.00	0.00	N/A
	Sowing batch 2	0.00	4.76	6.96	N/A
	Sowing batch 3	0.00	26.73	35.85	N/A
	Sowing batch 4	0.00	28.96	31.66	N/A
	total	**0.00**	**15.11**	**18.62**	**N/A**
C. prestonianus	Sowing batch 1	0.00	28.57	26.67	N/A
	Sowing batch 2	0.00	0.83	0.83	N/A
	Sowing batch 3	0.00	20.35	19.47	N/A
	Sowing batch 4	0.86	4.61	4.90	N/A
	total	**0.22**	**13.59**	**12.97**	**N/A**

Annex 3 – Mean growth of seedlings at each planting site over time. Negative values indicate a decrease in mean height.

Planting Site	Mean Growth: Month 0-Month 1 (cm)	Mean Growth: Month 1-Month 3 (cm)
Site 1	0.99	-0.55
Site 3	2.61	2.06
Site 4	1.23	-1.15
Site 5	-1.39	2.96

Annex 4 – Mean condition of seedlings at each planting site over time.