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A Technical Report for

PROJECT PALMS

An Assessment of the Phenology of Threatened Palms and their Associated Pollinators in Sainte Luce, Southeast Madagascar

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. Project Palms aims to expand existing knowledge of population size, distribution, demographic structure, phenology, and associated pollinators of six threatened species in five fragments of the SLLF.

Multiple aspects of Project Palms, including the Population Census Report, Microhabitat Assessment, phenology surveys and pollinator surveys, seed collection, and interviews with local experts were collated to determine the phenology of threatened species, *Beccariophoenix madagascariensis* (VU), *Chrysalidocarpus prestonianus* (VU), *Chrysalidocarpus psammophilus* (EN), *Chrysalidocarpus saintelucei* (EN), *Dypsis brevicaulis* (CR), and *Dypsis scottiana* (VU). These data were combined to produce a seasonality calendar for each of the target species.

These phenology data informed pollinator surveys conducted on flowering individuals of four target palm species. Composition and order of pollinators has been described for the first time for some of these species. Hymenoptera make up 85% of all observations during these studies, and are the main pollinator observed on every species of palm. Other palm visitors, such as Araneae, were only observed on *D. scottiana,* and *Phelsuma spp.* were only observed on *C. psammophilus* and *C. saintelucei.*

With limited quantitative data collected and published on the flowering and fruiting periods of these palms and their associated pollinators and visitors, phenology observations and pollinator surveys have provided novel insight into the natural history of these threatened palms.

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[1] 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, population, phenology, and natural history of each species, which will inform *in situ* planting efforts. Although Hogg et al. (2013a) has described insect visitation for *C. saintelucei*, and Shapcott et al. (2007) for *B. madagascariensis*, there is no literature on what pollinates the other four species of threatened palm, leaving a gap in their natural history. This study aimed to improve understanding of the phenology and associated pollinators of each species, to inform local reforestation efforts, and contribute to the sustainable growth and survival of the six threatened palm species within the SLLF.

2 Methodology

2.1 Study Site

Research was conducted in five littoral forest fragments (S6, S7, S8, S9, and S17) within the SLLF in the Anosy region of 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

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

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.

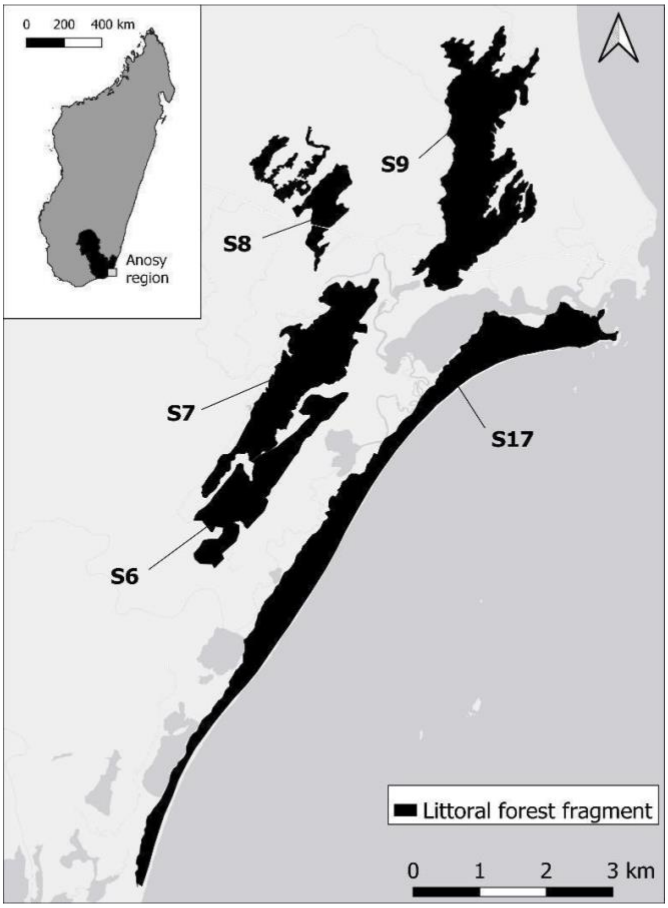

Figure 1: Study site.

2.2 Phenology Observations

2.2.1 Data Collection

Phenology data was collected between October 2021 and July 2023. Surveys aimed to collect novel data on the fruiting and flowering periods of the six target palm species, of which previously there was little recorded information.

During Year 1, phenology data was collected through population census surveys (as described in the Population Census Report) and local expert interviews. However, this only yielded limited information, leading to the targeting of specific forest fragments with phenology surveys in Year 2.

Few observations were made of *C. saintelucei* in Year 1 and consequently seed collection was limited, due to their small local population size in S8 and S9, which is where population census surveys were being conducted at the time (Annex 1). From January 2023, targeted phenology surveys of *C. saintelucei* were conducted across all forest fragments in which adults had been recorded (S6, S7, S8, and S9). From May 2023, due to its low germination rate within SEED's palm nursery, targeted phenology surveys and seed collections for *C. prestonianus* were conducted within S9, where most adult *C. prestonianus* occur.

Only adult palms were included in the survey, which were identified by local experts following descriptions by Hogg et al. (2013a). Adults were defined as having visible signs of reproductive maturity (flowers and/or fruit), where the trunk is taller, and bark is established. For each individual, the GPS location, trunk circumference (cm), palm height (m), condition, and phenology (flowering, fruiting, and emergence of new leaves) were recorded.

Location measurements were made using a Garmin 62S Global Positioning System (GPS). Trunk circumference (cm) was measured at chest height using a tape measure. Palm height (m) was estimated through visual observation. Palm condition was measured on a scale of 1 to 4, with criteria to differentiate between each category (Table 1).

Phenology was observed through the combined use of binoculars and a digital camera to observe the presence of inflorescences. If observed, these inflorescences were identified as consisting of either flowers or fruits through combined botanical and local knowledge. The stage of flowering (percentage of the flowers that were open) was interpreted by numbers of flowers on the inflorescence and whether these looked fresh or were brown or damaged.

Additional notes were recorded, including evidence of human activity (e.g. axe marks on trunk, removal of fronds from crown, evidence of fire), the condition of fruits and flowers (e.g. dead flowers, early fruiting), locality notes, whether any follow up visits were necessary, and timelines for potential follow up visits (e.g. good suitability for pollinator surveys and/or seed collection).

Table 1: Description of palm condition categories, developed with expert local guides.

Condition	Description
1 - Dead	Palm has wilted, lost its leaves, and turned brown.
2 - Poor	Severe signs of damage, pest infestation, discolouration, fungi, or abnormal growth.
3 - Fair	Signs of 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.

2.2.2 Seasonality Calendar

Data from the Population Census Report, phenology and pollinator surveys, and seed collection were incorporated into the seasonality calendar. For all datasets apart from the population census surveys, a logical value of “1” was assigned for each half-month (i.e. first and second 15 days in a 30-day month) if flowering and/or fruiting palms were observed or collected from, irrespective of number of recordings.

For the population census surveys, presence of flowering and/or fruiting on adult palms were assigned a logical value (e.g. “0” or “1”), from which the proportion of flowering and/or fruiting adults per half-month interval was calculated. Half-months in which more than 20% of observed adults were flowering and/or fruiting were assigned a greater numerical weight (“2”), than half-months in which fewer than 20% flowering and/or fruiting adults were observed (“1”).

Knowledge of four local experts gathered during interviews was also incorporated into the seasonality calendar. Months in which each species were said to be flowering and/or fruiting were given a logical value of “1”.

Palm seasonality conclusions for each half-month were then based on agreement between these sources.

2.3 Pollinator Observations

2.3.1 Data Collection

Between December 2022 and May 2023, 30 pollinator observation surveys were conducted on flowering adult palms within S7 and S8. Surveys aimed to collect novel data on the taxonomic orders of pollinating insects associated with target palm species and the frequencies of visitations. There are no previous studies on pollinator visitation rates for the six threatened palms in this study.

The original aim was for pollinator surveys to be conducted in all forest fragments, but due to presence of adults, accessibility, and ease of surveying, surveys were concentrated in S7 and S8. The fragment of S9 has a particularly tall canopy height, therefore surveys were not successfully completed in this fragment.

Before survey start, locality information on observed palms was recorded, including GPS location, Palm ID number, and forest fragment. Metrics for palm height (m), condition (Table 1), and phenology (flowering, fruiting, and emergence of new leaves) were recorded as described in the Phenology Data Collection section (2.2.1). Flowering percentage was visually estimated to give a rough indication of where the palm was in its flowering cycle (Figure 2). Inflorescence height (m), surrounding canopy height (m), and canopy cover (%, in 25% increments) were recorded through visual observation.

The date and start and end time (HH/MM) of the survey were also recorded, along with weather (sunny, no clouds; sunny, with clouds; overcast) and percentage of cloud cover. Surveys were conducted in the morning to increase chance of observing pollinators on the palms, following a study detailing visitation rates throughout the day by Fijen and Kleijn (2017). Pollinator surveys were not conducted during rain, as this influences the behavioural patterns and appearance of visitors (Yamaji & Ohsawa, 2016).

During each survey, flowering palms were observed for 16 minutes to balance research needs with time constraints. Fijen and Kleijn (2017) found that a mean observation time of 11.7 minutes was necessary to capture a representative sample of visiting pollinators on crops, given a mean visitation rate of 0.6 pollinators per minute. 16-minute survey periods were selected to enable a representative set of pollinators to be recorded assuming lesser visitation rate than 0.6/minute. One member of the survey team recorded data and kept time, whilst two trained researchers watched the palm inflorescence, using binoculars and a digital camera to spot invertebrates and take photos of species landing on the flowers for later identification and reference. Observations of invertebrates that could not be identified down to order were removed during data cleaning.

The number of invertebrates visiting the flowers where recorded every two minutes during the 16-minute period, with invertebrates categorised into taxonomic order. Ideally, floral visitors were only counted as pollinators if they were observed touching the sexual reproductive organs of a flower (Benadi & Pauw, 2019; Yamaji & Ohsawa, 2016). However, due to many of the palms being tall and having small flowers, it was not always possible to see whether invertebrates were touching the anthers or stigmata. Therefore, all visitors observed on the flowers or between landing and taking off were recorded as pollinator individuals.

Additional notes were recorded, including whether rain had fallen within 24 hours of the survey taking place, whether *tavy*[2] *h*ad occurred within the vicinity recently or at the time of survey, and anything morphologically valuable about the palms' phenology or pollinator behaviour.

Figure 2: A C. psammophilus flowering inflorescence with roughly 25% flowering.

[2] *Tavy* is a swidden agricultural practice which involves setting intentional fires to clear land for agriculture.

2.3.2 Data Analysis

Palm pollinator order and frequency data were analysed using R Statistical Software (v4.2.2; R Core Team, 2022) in Rstudio (Posit team, 2023). One Way ANOVA tests were conducted to determine whether there were any statistically significant differences in pollinator visitation rates between target palm species using the '*stats*' and '*base*' R packages (v4.2.2; R Core Team, 2022). The effect of different weather conditions on pollinator presence was assessed through logistical models subject to a likelihood ratio (LR) test performed using the '*lmtest*' R package (Zeileis & Hothorn, 2002). The Wald statistic calculated with the '*base*' R package was used as a general test to determine the effect of flowering percentage on pollinator presence (v4.2.2; R Core Team, 2022).

3 Results

3.1 Phenology Observations

Learnings from the Population Census, seed collection, Phenology and Pollinator Report, and local expert interviews suggest that flowering and fruiting periods vary between species and within species. Triangulation of data collected enabled identification of a broad time period in which flowering and fruiting takes place for each species (Figure 3, Annex 2).

B. madagascariensis has been observed flowering from November to June with a continuous flowering window from November to February. Fruiting has been recorded between February and September.

C. prestonianus was mainly observed flowering between February and April, with observations also recorded in June, August, and November. Fruiting has been observed between April and August, with local experts also identifying November as a fruiting month.

C. psammophilus has been recorded flowering from July to February. Much of the fruiting has been observed between February and May, with some observed between July and September.

C. saintelucei has been observed flowering between January and October, with most recordings between April and September. Fruiting takes place between April and December, with most adults producing fruit between July and September.

D. brevicaulis was primarily observed flowering from January to June with additional observations in October and November. Two distinct fruiting periods have been recorded, April to June and from October to January.

D. scottiana has been observed flowering year-round, with most concentration from January to April. Fruiting is concentrated between April and July, with observations recorded from February to December.

3.1.1 Seasonality Calendar

The seasonality calendar gives a visual representation of when flowering and fruiting was recorded in the SLLF. Through collating multiple data sources, there are varying levels of support for flowering and fruiting periods depending on species (Figure 3, Annex 2). Months where data from multiple data sources agree are shaded darker.

Key	
	No data sources
	1 data source
	2 complementary data sources
	3 complementary data sources
	4 complementary data sources
	5 complementary data sources
	6 complementary data sources

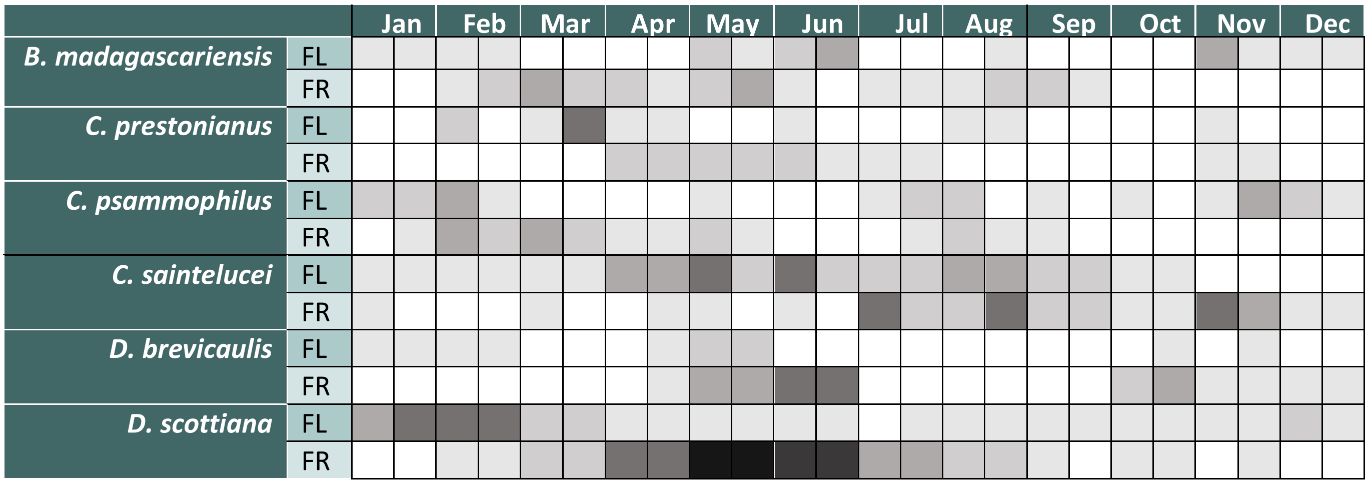

Figure 3: Calendar showing times of year when the six target species are flowering (FL) and/or fruiting (FR).

3.2 Pollinator Observations

Pollinator surveys started between 08:12am and 11:35am. The number of surveys per palm species varied, depending on which species were flowering and whether they could be observed due to environmental conditions and biotic factors. For example, if the palm was very tall or the surrounding canopy was too dense, visibility of the inflorescence was poor. The number of surveys conducted per palm species were *C. psammophilus* (*n* = 10), *C. saintelucei* (*n* = 5), *D. brevicaulis* (*n* = 11), and *D. scottiana* (*n* = 4). Surveys on *B. madagascariensis* and *C. prestonianus* were not conducted due to a lack of observed flowering palms.

Of all pollinators observed, 85.37% were in the Hymenoptera order (*n* = 945), which includes bees and wasps. Coleoptera were the second most observed order (*n* = 110, 9.94%), while Squamata (*n* = 20, 1.81%), Araneae (*n* = 18, 1.63%), and Diptera (*n* = 14, 1.27%) were recorded the least. No pollinators were recorded during three of the 30 surveys, or during 60 of the 270 two-minute observation intervals (24.44%).

3.2.1 Pollinators per Palm Species

C. saintelucei had both the greatest number and greatest diversity of pollinators. Squamata and Coleoptera were only observed on *C. saintelucei* (*n* = 18, *n* = 77) and *C. psammophilus* (*n* = 2, *n* = 16) (Figure 4). Two observations of *Phelsuma antanosy* (Squamata) were recorded on *C. psammophilus* (*n* = 1). Araneae were only observed on *D. scottiana* (*n* = 18) (Table 2).

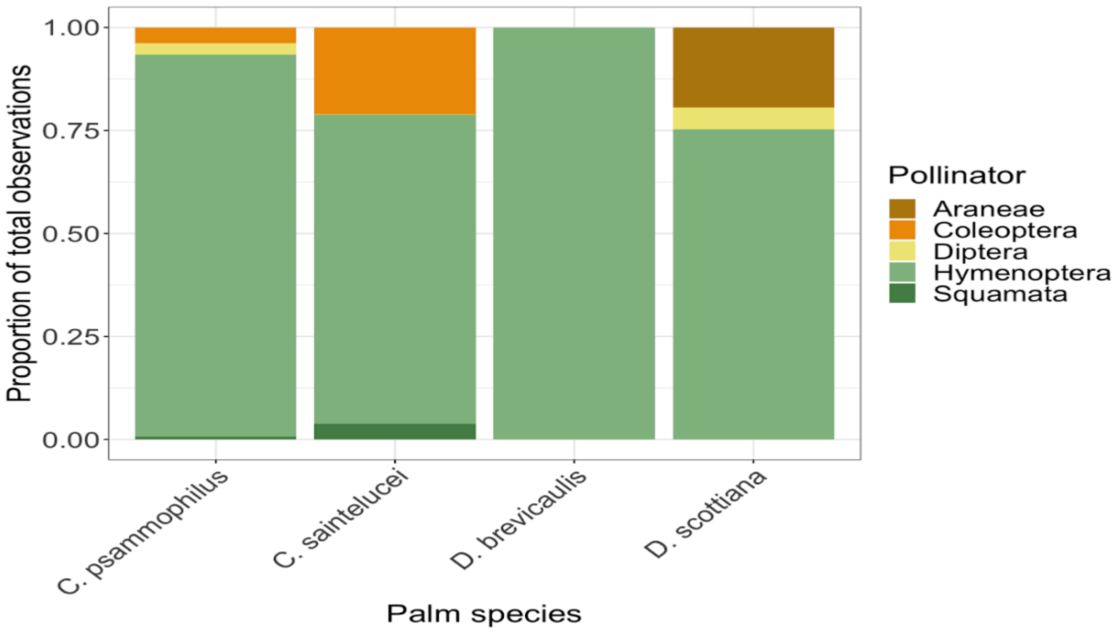

Figure 4: Proportion of pollinator orders encountered for each surveyed palm species. Graph doesn't account for number of observations where no pollinators were observed.

Table 2: Mean pollinator encounter rates per palm species, broken down by pollinator order.

	Araneae	Coleoptera	Diptera	Hymenoptera	Squamata
C. psammophilus	0.00	1.60	0.80	26.80	0.20
C. saintelucei	0.00	15.40	0.20	70.60	3.60
D. brevicaulis	0.00	0.00	0.00	23.09	0.00
D. scottiana	4.50	0.00	1.25	17.50	0.00

3.2.2 Factors Affecting Pollination

The mean number of visitors per survey were calculated accounting for the forest fragment (location) of the survey. The number of visitors per location and number of surveys per location were S7 (n = 340, 14 surveys) and in S8 (n = 767, 16 surveys) (Figure 5).

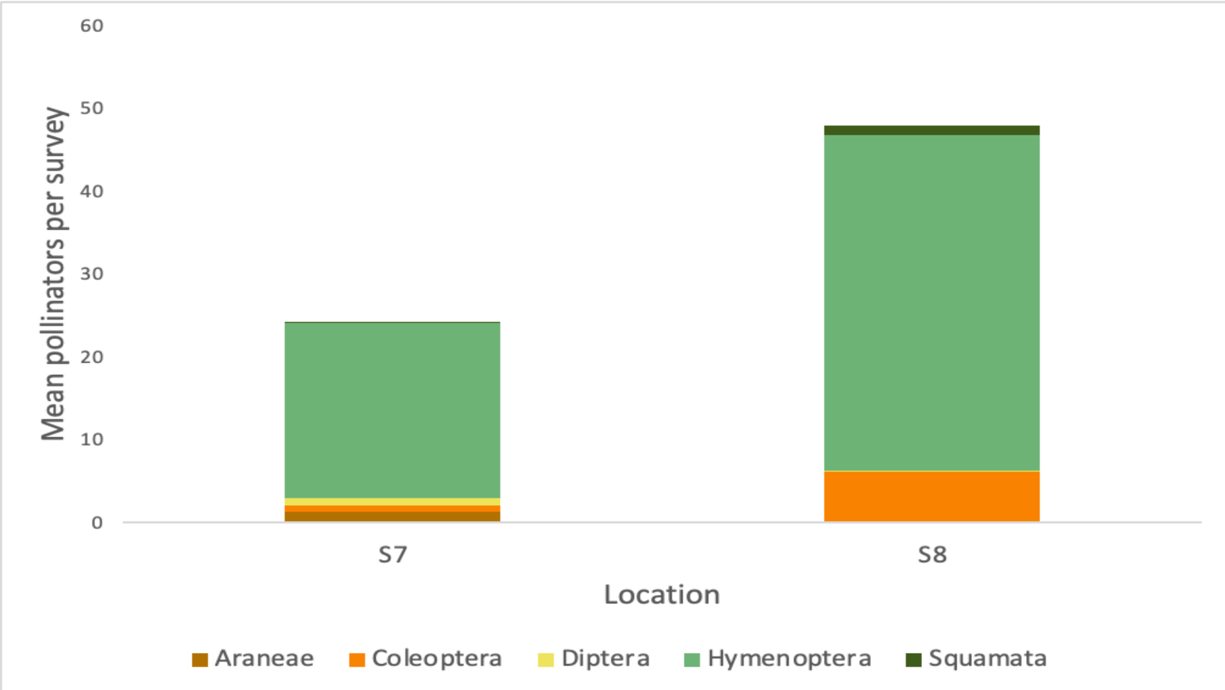

Figure 5: Mean pollinator count per survey by location (forest fragment).

A Wald Test confirmed that the presence or absence of flowering (z = 6.348, p < .001), along with estimated percentage of flowering has a significant positive effect on the likelihood of pollinator presence on a palm (z = 2.630, p = .00854).

Pollinator encounter rate is not correlated with flowering percentage (ANOVA, $F_{1,452}$ = 0.162, p = .687). However, there is a statistical relationship between pollinator encounter rate by order and flowering percentage (ANOVA, $F_{1,384}$ = 1.317, p = .007). Due to the small sample size, it was not possible to distinguish between the relationships of each pollinator order and flowering percentage. Hymenoptera observations are strongly overrepresented in the data (85.4% of total observed pollinators), possibly causing the identified relationship between pollinator encounter rate by order with flowering percentage.

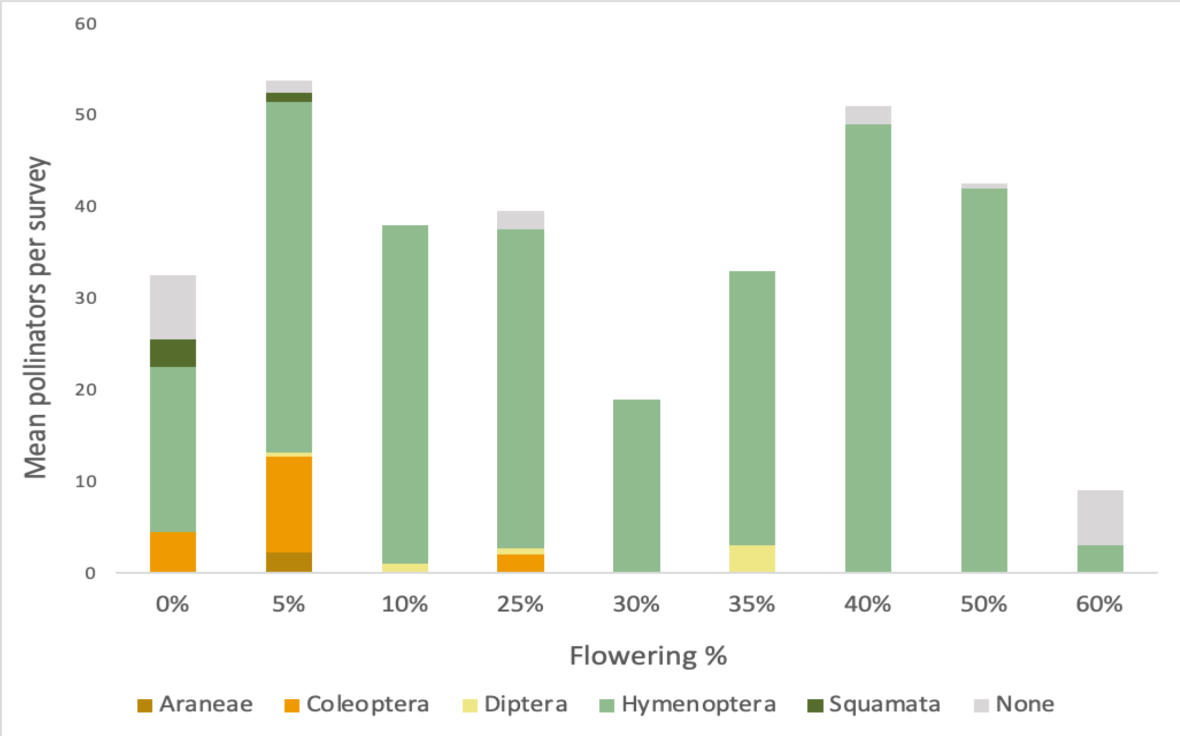

Figure 6: Mean pollinator rate per survey by flowering percentage.

Weather conditions (as defined by the three categories, sunny with clouds, sunny without clouds, and overcast) individually assessed using a Wald test to check for significance with overcast as a reference category indicated that the significance of category; sunny with clouds (z = -2.550, p = .011) and sunny without clouds are not significant (z = -2.179, p = .029). However, a likelihood ratio (LR) test showed that weather as a singular variable significantly affects the likelihood of pollinator encounters (LR Test χ^2 (2) = 15.241, p < .001).

4 Discussion

4.1 Discussion of Findings

4.1.1 Phenology Observations

Long periods of fruiting and flowering were identified for the six species of target palm.

For *C. saintelucei,* Randriatafika et al. (2008) recorded collection of mature fruits in April, whilst Hogg et al. (2013a) recorded fruit collection in March, April, August, and October, concluding that fruit production may occur year-round. This literature supports the seasonality calendar, as fruiting has been observed mainly from April to December but with observations also in January and March.

C. prestonianus has the most incongruence between phenology within the seasonality calendar, with only one to two sources supporting observations that fruiting was identified per month. Bollen and Donati (2006) recorded red collared brown lemurs (*Eulemur collaris)* feeding on *C. prestonianus* fruit in Sainte Luce in April, which aligns with the finding from this study that *C. prestonianus* fruiting primarily occurs between April and July.

There is very little published information and local knowledge on the phenology of *D. brevicaulis,* including seed collection times. This could be because *D. brevicaulis* has no known local uses, and therefore seed collection is not conducted by locals (Hogg et al., 2013b).

Randriatafika et al. (2008) recorded collection of *D. scottiana* seeds between April and July and in September. This aligns with the findings from this study and supports multiple congruent observations (four to six) of fruiting from April to June, therefore increasing certainty in the calendar's accuracy for this species.

B. madagascariensis has been observed producing green fruits in January which ripen to yellowish or purple in March with most fruits falling by June (Shapcott et al., 2007). During Project Palms, fruiting of *B.*

madagascariensis has been recorded from February until September, with most support for fruiting observed in March and May. Variation and long fruiting periods are supported in published literature; Randriatafika et al. (2008) recorded collection of *B. madagascariensis* seeds in August. Shapcott et al. (2007) identified asynchronous flowering between *B. madagascariensis*, with only 12% of palms having open flowers at any point over a six-month period. Asynchronous flowering, coupled with so few observations of adult individuals within the SLLF (*n* = 44, Annex 1), could explain the long flowering window of *B. madagascariensis*.

Long flowering windows have also been recorded for other target species of palm. For example, *D. scottiana* has been observed flowering every month (except within the beginning of July), whilst the observed flowering period recorded for *C. saintelucei* is from January to October. Barford et al. (2011) explains that many palm species flower asynchronously as a way of attracting different pollinators and limiting gene flow between species within the same locality. This supports the possibility of asynchronous flowering in the target palms and explains long flowering periods identified within the seasonality calendar.

When updating the seasonality calendar, incongruences in data from the previous and current years arose, with differences in flowering observed through local expert interviews and phenology and pollinator surveys. For example, local experts identified the fruiting period of *C. saintelucei* starting from July, whereas during phenology and pollinator surveys, and seed collection, trees were found fruiting as early as March and April. Flowering periods in palms are strongly affected by climatic variations, which could contribute to these incongruences and explain these as annual shifts in phenology (Barford et al. 2011). Phenology surveys will continue in Year 3 to help identify shifts in seasonality, as well as improve confidence in identified fruiting and flowering periods.

4.1.2 Pollinator Observations

Palms are entomophilous (Henderson, 1986), which supports the result that pollinators were present when palms were flowering during pollinator surveys. There are three major pollination syndromes in palms relating to three different insect orders: beetle pollination (cantharophily), bee pollination (melittophily), and fly pollination (myophily) (Henderson, 1986). Henderson's study (1986) thus supports the methodological approach of this research, in identifying pollinators to order and concluding the dominant pollination syndrome of the target palm species within the SLLF.

C. psammophilus has been interpreted as a microhabitat for the Critically Endangered *Phelsuma antanosy* (Hogg et al., 2013b). SEED also observed *P. antanosy* on *C. psammophilus* palms during pollinator surveys. These observations could be interpreted as *P. antanosy* foraging, as at the moment of observation, palms were between 0-5% flowering. In a comprehensive review of palm pollination by Barford et al. (2011), which took into account more than 60 studies, neither Geckos nor Squamata are mentioned as pollinators. Therefore, it is likely that *P. antanosy* has a foraging association with the microhabitat of *C. psammophilus* palms, as opposed to being a pollinator of this species.

Araneae are not traditionally referred to as pollinators (Barford et al., 2011). Araneae were recorded during two *D. scottiana* surveys*.* Due to the small size of flowers and inflorescence of this palm, it is possible that Araneae may have been present on the palm flowers, without aiding pollination. Future research should therefore only be recording organisms unambiguously in contact with open receptive flowers in order to establish the identity of true pollinators (Benadi & Pauw, 2019), although information on receptive timings on threatened palms within the SLLF has not currently been collected or recorded.

In other studies, weather conditions have been found to be major factors influencing pollinator visitation rates (Listabarth, 2001). This includes many abiotic factors including temperature, wind, rain, and cloud cover (Benadi & Pauw 2018; Fijen & Kleijn, 2017). This supports the findings in this study that weather was found to significantly affect frequency of pollinator encounter.

During pollinator surveys, mostly palms of lower flowering percentage were observed, with no palms of high flowering percentages encountered. The highest flowering percentage recorded was 60%. The data is therefore skewed in favour of lower flowering percentages, despite the aim to observe palms of all flowering percentages. This could mean that flowering occurs asynchronously within the inflorescence, and higher rates of flowering would not occur. Shapcott et al. (2007) observed that within *B. madagascariensis* inflorescences, flowers grow in triads, with two male flowers growing either side of a female flower. These staminate flowers open first and last for roughly 10 days, before female flowers open. This could explain why inflorescences of a greater than 60% flowering percentage were not observed.

4.2 Limitations of the study

4.2.1 Phenology Observations and Seasonality Calendar

Some species have long periods where no observations of flowering or fruiting have been recorded within the seasonality calendar. For example, between July and September there are no observations of flowering or fruiting for *D. brevicaulis*, therefore seasonality of reproductive phases can more confidently be said to occur outside of these months. Flowering of *C. prestonianus* was observed scattered through the year. Between these times, it is more likely that there were no observations recorded rather than flowering not actually occurring. *C. prestonianus* could have multiple flowering periods or one long flowering period per year, but data collected so far is inconclusive. Additional targeted phenology surveys throughout the year for this species are needed to give a clearer indication of true phenology.

One possible explanation for no observations being made in certain time periods, is that there are gaps in the data gathered through the population census and the phenology and pollinator surveys. Data collection was limited to the months SEED's Conservation Research Programme (SCRP) was present in Sainte Luce. Two to five-week breaks in research occur four times per year.

Phenology observations recorded during the census are skewed due to surveys being conducted in different forest fragments at different times. For example, *D. brevicaulis* were only observed within S8 (Annex 1). The population census took place in S8 for two months, from mid-April to mid-June, so the census only contributed to the *D. brevicaulis* seasonality calendar during those two months. Similarly, the greatest populations of *B. madagascariensis* were recorded within S8, and so the seasonality knowledge for this species derived from the census is also limited.

Data from pollinator surveys is also skewed, due to these surveys only taking place during each species' specific flowering period. For example, *D. brevicaulis* surveys only occurred in April and May. Pollinator surveys for each species were also targeted in specific fragments, due to species' presence or absence in certain areas, as well as accessibility and observability. For example, *C. saintelucei* were primarily observed within S8 during pollinator surveys, as many of the other adults for this species occur in the very south of S7, an area more difficult to access. As S8 was visited often for other research, flowering trees could be noted and revisited during a targeted survey.

To address these limitations and supplement data, SEED relied on knowledge from local palm experts, including forest guides and Forestry Police Association (FIMPIA) committee members. They have both current and historical knowledge on fruiting and flowering seasons for each species, so their knowledge informs not only current seasonality, but also how this may vary annually. These limiting factors emphasise the importance of local knowledge in creating the seasonality calendars, whilst also combining multiple sources of information. Therefore, to further mitigate limitations, the triangulation of data sources was used to enable identification of flowering and fruiting periods for each species.

4.2.2 Pollinator Observations

A limitation of this study was the ability to find suitable flowering target palms to conduct pollinator observations. Surveys were targeted during months and in locations where flowering individuals were known to occur, but there are few adults of certain target species within the SLLF. For example, only 44 adult *B. madagascariensis* were identified during the census (Annex 1), of which no flowering adults were observed between December 2022 and May 2023. Consequently, it was only possible to complete pollinator surveys for four out of the six target species. Further surveys encompassing a selection of adult individuals from all the fragments in which they occur could show important differences between visitation frequency or proportion of pollinator orders.

Height and observability were major barriers during pollinator surveys. As height of observed trees increased, the accuracy of pollinator and fruiting or flowering identification decreased. The view was not always clear and could be obscured by other trees in the canopy. Using binoculars and camera lenses to identify pollinators at great heights proved extremely difficult. Due to limited numbers of flowering adults of *C. saintelucei*, one very tall tree (17m) was observed and recorded. Certain flowering individuals, including one *C. prestonianus,* were observed but proved unsuitable for pollinator surveys due to their extreme height.

Due to the difficulties in surveying tall trees, as well as the increased apparency of shorter flowering palms, there was a selective bias for surveying shorter trees. For the taller species of palm, *C. saintelucei* and C*. psammophilus*, this could have affected abundance and type of pollinators recorded. Due to their smaller overall height, *D. brevicaulis* and *D. scottiana* would not have been affected by this selection bias.

A total of 30 pollinator surveys were conducted, with four to 10 surveys per observed species. Small sample sizes decrease the probability that the samples are representative of actual pollinator numbers, as fewer observations will contain significant environmental factors that could influence pollinator groups and abundance. Fijen and Kleijn (2017) observed that pollinator visitation rates varied considerably between different days, whilst surveying the same plants. Conducting pollinator surveys during May to September, when pollinator surveys were not conducted during Year 2, will improve accuracy of the data, as well as enable pollinator identification for the other two species of palms (*B. madagascariensis* and *C. Prestonianus*). Observations of flowering have been recorded for these two target species during these months, therefore pollinator surveys would rely on finding suitable flowering palms for observations within this timeframe.

In future studies, to increase detail of pollinator associations, identifying pollinators down to family, genus, or species would be more informative about the specific pollinators associated with the target palm species. This would provide novel research into specific pollinators of target species. For example, bees were named as potential pollinators of *C. saintelucei* but specific species are unknown (Hogg et al., 2013a). To achieve increased taxonomic detail, a future study would require pollinator collections and sending specimens for specialist identification.

5 Conclusion

The findings of this research point to several key observations of current threatened palm populations in the SLLF. Phenology of all target species has been observed and recorded, creating a seasonality calendar of all fruiting and flowering periods during the year. Observations of associated pollinators of four target palm species have been recorded, of which Hymenoptera comprise the majority or pollinators across all observed species. The findings of this study improve the overall understanding of these palm species, by broadening the literature about their distribution, demographics, and phenology and associated pollinators, 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 – Number of adult palms encountered in each fragment during the Palm Population Census

Species	S6	S7	S8	S9	S17	Total
B. madagascariensis	11	8	23	2	0	44
C. prestonianus	0	1	2	67	13	83
C. psammophilus	0	584	251	269	0	1,104
C. saintelucei	6	22	10	2	0	40
D. brevicaulis	0	0	382	0	0	382
D. scottiana	105	368	156	685	3	1,317
Total	**122**	**983**	**824**	**1,025**	**16**	**2,970**

Annex 2 – Seasonality calendar with original source information

	Phenological stage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec
B. madagascariensis	Flowering	2	2	2	2					1C	1	1C	1CC				C					3CC	3	3	3
	Fruiting			3	3X	23X	23	XC	X	XC	XCC	X		1	1	1	1C	1C	1						
C. prestonianus	Flowering			CC		2	2PC C	C	C			C				1	1					C			
	Fruiting							CC	CC	XC	XH	XH	X	2	2							1	1		
C. psammophilus	Flowering	2P	2P	1PC	1					C				4	4C	CC		C		C		2	2C C	2P	2
	Fruiting		C	2XC C	2X	1XC	1X	1	1	1C	1				C	4C	4	C							
C. saintelucei	Flowering	H	H	P	H	3	3	23P	23H	23PH	23	23HC C	23	23	23	13 4	134	34	3 4	3	3				
	Fruiting	H				X			H	H		H		23C C	23	23	23C C	23	2 3	2	2	14C C	14 X	X	X
D. brevicaulis	Flowering	1	1	1	1				P	PC	CC										C		C		
	Fruiting								X	XCC	XCC	14XC	14XC							23	23 C	2	2	2	2
D. scottiana	Flowering	13 C	13P C	13P C	13X C	2C	2C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	3C	3
	Fruiting			C	C	1C	1C	13X C	13X C	1234X C	1234X C	124X C	124X C	12C	12 C	2C	2C	C		C	C		C		

Key	Information source	Value
1	Local Expert Interview 1 - Palm expert	1
2	Local Expert Interview 2 - Palm expert	1
3	Local Expert Interview 3 - Forest guide	1
4	Local Expert Interview 4 - Local guide	1
X	Seed collection data	1
P	Pollinator survey	1
H	Phenology survey	1
C	Palm Census (<20% of total observations)	1
CC	Palm Census (>20% of total observations)	2