Palms on the Brink: Conservation Status of the Threatened Palms *Dypsis saintelucei* and *Beccariophoenix madagascariensis* in the Littoral Forests of Sainte Luce, Southeastern Madagascar

SAM HYDE ROBERTS[1,2], STEPHANIE HARRIS[1], KATHRYN STRANG[1], JASON ALEX GUY[1], RETSIRAIKY JEAN ROSSIZELA[1], AND LUCIA CHMUROVA[1]

[1] *SEED Madagascar. Studio 7, 1A Beethoven Street, London, W10 4LG, UK.*

[2] *Oxford Brookes University, Headington Road, Gipsy Lane. Oxford, 0X3 0BP, UK.*

Corresponding author: samhyderoberts@gmail.com

Initial population assessment of the palms *Dypsis saintelucei* and *Beccariophoenix madagascariensis* in the littoral forests of Sainte Luce between 2008 and 2011 revealed that despite their integral role as community resources, local populations were under significant pressure. Given their low abundance in the area, high utility and an increasing demand for resources driven by a rapidly expanding human population, these threatened species warranted systematic and rigorous monitoring. Eight years later, we reassessed the subpopulations of each species

across five forest fragments. All previously recorded individual palms (n=239) were revisited, and additional individuals (n=38) were identified. Results indicate that *D. saintelucei* has experienced a substantial decline, with a total mortality of 64% over an 8-year period, whilst *B. madagascariensis* has experienced more modest but still substantial losses (25%). The majority of palm losses (63%) can be attributed to anthropogenic factors. Our findings underline the need for urgent conservation intervention, and in this paper, we offer several suggestions to mediate further losses and potentially reverse the trend.

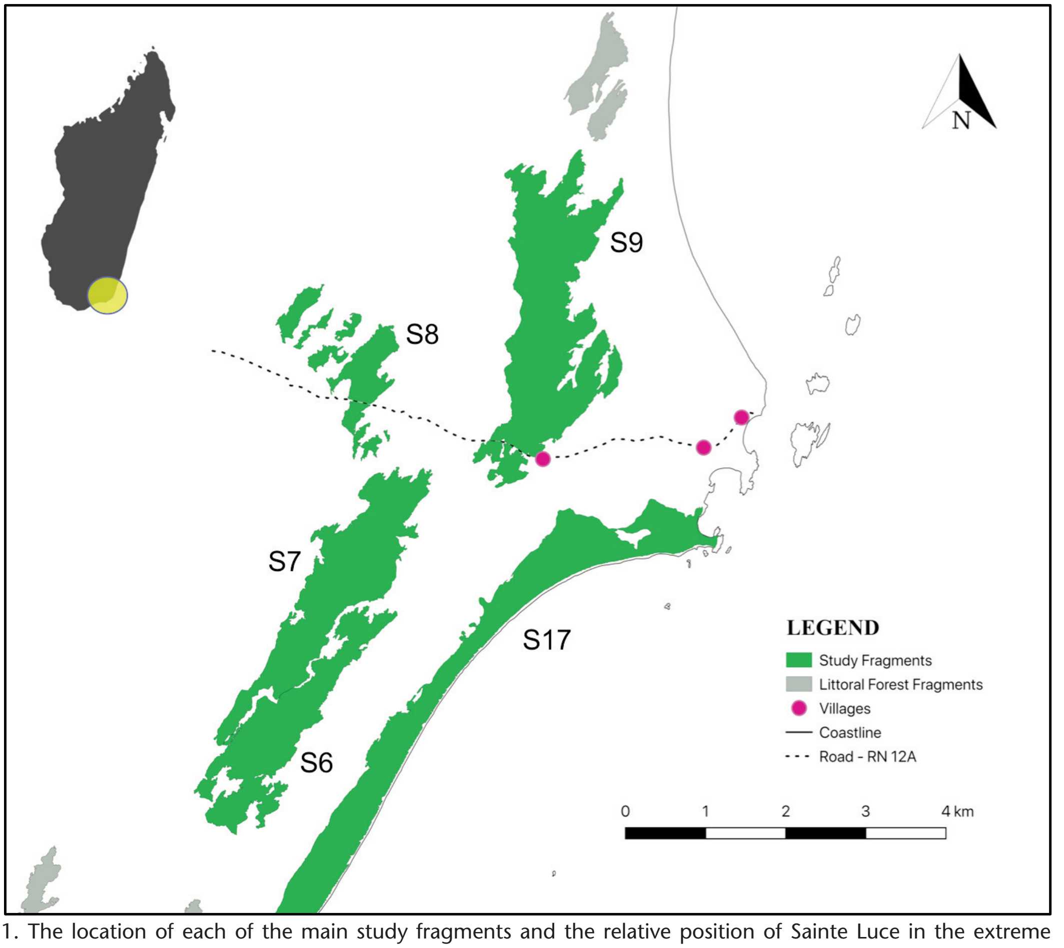
Madagascar supports a grand and globally important palm flora (Arecaceae) characterized by high phylogenetic clustering and morphological diversity (Dransfield & Beentje 1995, Callmander et al. 2011, Kissling et al. 2014). The vast majority of described species (+208) belong to the subendemic genus *Dypsis*, with most being distributed along the eastern margins of the island within the humid rainforests. Numerous new species have been described since the comprehensive monograph compiled by Dransfield and Beentje was published in 1995 (summarized in Eiserhardt et al. 2018), with increased field work and wider expedition coverage indicating that the discovery phase for Malagasy palms is incomplete. Furthermore, many species are considered range-restricted and as a result, further discoveries are anticipated in the highly fragmented and remote areas of the island (Eieserhardt et al. 2018). Such species, however, are inherently at higher risk of extinction through destructive processes on a local scale, and indeed, many of the newly described taxa are classified as Threatened by the International Union for the Conservation of Nature (IUCN, 2020).

Palms are regarded as Madagascar's most endangered plant group, with a comprehensive assessment concluding that 83% of species are threatened with extinction (Rakotoarinivo et al. 2014). An array of anthropological threats including deforestation, unsustainable harvesting practices, and fire, are considered the leading causes for concern (Rakotoarinivo et al. 2014). Palms play key ecological roles in tropical ecosystems but are also regarded as being amongst the most important plant families to humans (Couvreur & Baker 2013, Bennett 2001). They provide numerous highly valued resources from food and medicinal products to materials for construction and weaving, and their economic value is particularly important in impoverished countries such as Madagascar (Dransfield et al. 2008). The socio-economic importance of palms is most significant at local and rural levels where reliance on forest products and natural resources is most pronounced. As a result, many palm species are susceptible to unsustainable harvesting as human populations continue to grow and demands for finite forest resources increase (Dransfield & Beentje 1995, Johnson 1996, Ratsirison et al. 1996, Byg & Baslev 2001, Hogg et al. 2013a).

The monitoring of palm populations, therefore, is critical from both a biological and economic perspective. In this study, we assess the population status of two palm species, *Dypsis saintelucei* and *Beccariophoenix madagascariensis*, within the littoral forests of Sainte Luce over a period of eight years.

Study Site

Sainte Luce (Fig. 1; 24°46'52"S; 47°10'28"E) lies within Madagascar's humid bioclimatic zone in the southeastern coastal lowlands, ca.45 km north of Tolagnaro/Fort Dauphin (the Anosy regional capital). The area receives an average annual rainfall of 2690 mm, with temperatures relatively constant with a mean annual temperature of 28°C (Goodman et al. 1997, Vincelette 2007). The area supports an estimated 10% of the island's remaining littoral forests (Bollen & Donati 2006). These specialized humid evergreen woodlands are adapted to low altitude (0–50 m a.s.l), sandy coastal substrates and support high levels of diversity and endemism. Approximately 13% of Madagascar's total indigenous flora is known to exist within this habitat type and over a quarter of the species supported by littoral forests are considered endemic (Du Puy and Moat 1998, Dumetz 1999, Consiglio et al. 2006).



1. The location of each of the main study fragments and the relative position of Sainte Luce in the extreme southeast of Madagascar. Villages from left to right: Ambandrika, Ampanasatomboky, Manafiafy. Fragments S6 + S7 constitute the Community Resource Zones (CRZ) and S8, S9 and S17 constitute Conservation Zones (CZ).

Nationwide, only an estimated 10% of original littoral forest cover remains (Moat & Smith 2007) and the remaining forests are now heavily fragmented and degraded (Ingram & Dawson 2006). The littoral forests of Sainte Luce are no exception yet are considered amongst the most intact examples of this habitat remaining (Rabevohitra et al. 1996, Dumetz 1999, Bollen and Donati 2006). The Sainte Luce formations currently comprise 17 disconnected forest fragments, ranging in size from ca. 6 ha to 350 ha, and cover a total estimated 1500 ha (Ramanamanjato 2007, Vincelette et al. 2007). The human community of Sainte Luce comprises three hamlets – Ambandrika, Ampanasatomboky and Manafiafy – with a combined total population of approximately 2500 (Berina, Chef de Fokontany, pers. comm., January 2020), who all rely to some extent on natural forest resources. As a result, significant pressure is exerted on the surrounding littoral forests for food, construction materials and livelihoods, and palms are regularly utilised (Vincelette 2003, Bollen & Donati 2006, Rasolofoharivelo 2007, Hogg et al. 2013a). The area is also subject to a proposed mining operation by QIT Madagascar Minerals (QMM), a subsidiary of the large international corporation Rio Tinto, who plan to exploit the heavy mineral sands to extract ilmenite, a titanium-iron oxide mineral (Temple et al. 2012). As a result of the mine's presence, the area has received a relatively extensive botanical assessment and the vegetation has been well characterised (Lowry & Faber-Langendoen 1991, Rabevohitra et al. 1996, Du Puy & Moat 1998, Dumetz 1999, Consiglio et al. 2006).

This study focuses on five of the most intact forest fragments (Fig. 1), positioned most proximally to the villages, named S6, S7, S8, S9 and S17 during the initial mining prospecting. Both S6 (170ha) and S7 (220ha)

2. A solitary adult *Dypsis saintelucei* in exposed swampy habitat near S8.

now represent the most degraded fragments, after designation as community resource zones (CRZs) in 2015 prior to their proposed future clearance for ilmenite extraction. Both S8 (90ha) and S9 (340ha) are now designated IUCN Category IV protected areas and are managed by QMM as part of their conservation offset target (Temple et al. 2012). Forest fragment S17 is currently under private ownership and exists outside of the mining zone.

Given the status of littoral forests as a whole in Madagascar, their importance for supporting biodiversity and their vastly diminished distribution, this habitat type is recognised as one of the nation's highest conservation priorities (Ramanamanjato et al. 2002, Ganzhorn et al. 2001, Bollen & Donati 2006). Until recently, very few patches of littoral forest were included within the existing protected areas network (Consiglio et al. 2006), and whilst this has increased over the past

3. A sub-adult *Beccariophoenix madagascariensis* at the boundary between forest and a cassava plantation near S8.

decade (Goodman et al. 2018), an accurate picture of littoral forest health and conservation status nationwide is still lacking. At present, there are 13 species of palm in the Sainte Luce area (Hogg et al. 2013a); however, this study focuses on just two species, both of which had been considered as being high conservation priorities in the past and remain locally threatened.

Study Species

Dypsis saintelucei (Fig. 2) had been formerly classified as Critically Endangered by the IUCN; however, upon the discovery of three additional subpopulations away from its type locality in Sainte Luce, its conservation status was downgraded to Endangered (B2ab(ii,iii)) in 2012 (Dransfield & Beentje 1998, Rakotoarinivo & Dransfield 2012). The wider distribution now includes Ampasimanolotra, Vondrozo and Tsitongambarika (Rakotoarinivo 2008, Rakotoarinivo & Dransfield 2012), a highly disconnected range spanning a total area of approximately 650 km^2 along the east coast. Rakotoarnarivo and Dransfield (2012) estimated 300 adults exist over the three sites, with approximately half occurring in Sainte Luce's littoral forests (Hogg et al. 2013b).

Beccariophoenix madagascariensis (Fig. 3) is another species whose conservation status has been downgraded in recent times, considered Critically Endangered up until 2012, it is now considered as Vulnerable (B1ab(iii)+2ab(iii)) after the discovery of two further populations. Its wider distribution now encompasses Vondrozo (where it is again sympatric with *D. saintelucei*) and the large protected area of Mantadia National Park. Similar to *D. saintelucei*, the distribution of *B. madagascariensis* is highly fractured with each population separated by hundreds of kilometres (Rakotoarinivo & Dransfield 2012). Population density is thought to vary greatly between the three localities, and the overall population is believed to comprise of approximately 900 mature individuals (Rakotoarinivo & Dransfield 2012). Sainte Luce is believed to support a little over 5% of the total of known adults (Hogg et al. 2013a).

Hogg et al. (2013a) identified the main uses of these two palm species in Sainte Luce. Both *D. saintelucei* and *B. madagascariensis* have been selectively harvested in the past and used in the manufacture of lobster pots. Lobster fishing has long been a major source of income within the Sainte Luce community (Holloway, 2013), and demand for these palms has been high. *Dypsis saintelucei* is also harvested for construction purposes and for its edible palm heart, whilst *B. madagascariensis* is also used for cultural purposes. Hogg et al. (2013a) noted that the unsustainable harvesting of palms, as well as land clearance for agricultural purposes, is driving dramatic population declines.

Methods

Between 2008 and 2011, a systematic search methodology was employed to identify and locate all adult and sub-adult *D. saintelucei* and *B. madagascariensis* palms in the forest fragments S6, S7, S8, S9 and S17 (Fig. 1). Surveying east to west with 100 m line spacing and following a zigzag search pattern, the sweep was designed to maximize forest coverage and the number of palms recorded in the study. In addition to the standardized search method, individual palms known to the local guides were visited and included in the dataset to provide a comprehensive baseline dataset that could be used for future monitoring. Once an individual was located, morphological data, GPS location and the health status of the palm were recorded, and each individual was given a unique ID code. Individual maturity was assessed following Hogg et al. (2013b) (Table 1). The early baseline studies found neither palm species in the large coastal fragment S17, and despite repeated expeditions in recent years, no individuals have been discovered.

In November and December 2018, all known sub-adult and adult *D. saintelucei* individuals across the four forest fragments were revisited. Similarly, between April and June 2019, all *B. madagascariensis* individuals were revisited. Over the course of the study, 18 inventories were carried out including the additional ad hoc surveys in fragment S17. Data collected in 2018 and 2019 mirrored that of the earlier studies and included a range of morphological characteristics as well as notes on the general condition (cut marks, fire damage, rot, etc.), habitat type and, crucially, its status as alive or dead. Each individual was retagged where necessary for future monitoring purposes. When an individual was found dead, the cause of death was determined as accurately as possible based on the available evidence. In instances where individual palms could not be located, either alive or dead, a further search for remains (stump, felled log, stripped bark) in the surrounding vicinity was conducted. Palms that were classified as "assumed dead" were those where no obvious evidence of the

Table 1. A basic description of the maturity classes for *D. saintelucei* used to assess individuals in the study.

Classification of individual maturity status	
Maturity Phase	**Description**
Seedling	Seedling leaves (<4) possess a single leaflet pair (<15 cm in length)
Juvenile	No visible trunk; Early juveniles possess leaves with 2 or more leaflet pairs; leaves grow to 2 m+ in length in older juveniles
Sub-adult	Development of the crownshaft and a short trunk, no visible signs of reproductive maturity.
Adult	Visible signs of reproductive maturity; trunk usually 4 m in height

palm remained, despite being previously recorded in relatively open areas with good visibility.

Results

Dypsis saintelucei

During the initial surveys, between 2008 and 2011, 147 adult and 34 sub-adult individuals of *D. saintelucei* were recorded across the four study fragments, along with 102 juveniles. The distribution of adult palms was heavily skewed with 116 adults identified in association with forest fragment S7 (78.4%), 26 in S8 (17.6%), four in S6 (2.7%) and just a single adult palm in S9 (0.7%). Of the sub-adult palms identified, 19 (55.9%) were located in S8 and the remaining 15 (44.1%) were found in S7. All 102 juvenile palms were recorded within S7.

In 2018, 49 adult and 10 sub-adult *D. saintelucei* were found alive. Seventy adult palms (47.6%) were confirmed as dead and 15 were assumed as being dead (10.1%). A further nine (6.1%) were missing and four individuals (2.7%) were inaccessible. Twenty (58.8%) sub-adult *D. saintelucei* palms were confirmed dead, one (2.9%) was assumed dead and three (8.8%) were missing. Overall mortality for both adult and sub-adult palms was very high over the survey period, at 63.4% and 67.7% respectively. The 16 individuals that could not be located due to accessibility issues and difficulties associated with locating the palm have not been included in population losses; however, those we "assumed as dead" are included as they were in locations with good visibility and some evidence of their presence could be expected if still alive. Total mortality for adult and sub-adult individuals combined is 64.2% across the four study fragments over the study period. The survival rate of juveniles was not assessed during this phase of the project due to time constraints.

Over the eight-year period, a minimum of 85 adults and 21 sub-adult *D. saintelucei* has been lost from the population, corresponding to a mean annual loss of 13.25 palms and a population decline of 8.0% per year. However, the discovery of a further 16 additional adult palms and 10 sub-adults during 2018 increases the known minimum population size in Sainte Luce to 65 adults and 20 sub-adult palms.

Beccariophoenix madagascariensis

During the initial surveys, 48 adult *B. madagascariensis* palms were located, with 30 individuals identified in S8 (62.5%), 11 in S6 (22.9%), five in S7 (10.4%) and two palms in S9 (4.2%). Of these, 36 were alive in 2019. Total mortality for the Sainte Luce population was 25.0% over the study period, with an average loss of 1.5 adult palms per year. However, an additional 14 adult palms were located in 2019, although two of these individuals were dead upon discovery. Therefore, despite the loss of 25.0% of the original study population, the current census of *B. madagascariensis* remains unchanged at 48 known adult individuals as of June 2019.

Palms in the Community Resource Zones (CRZ) – Fragments S6 + S7

Unfavourable weather conditions and flooding meant that access to large parts of S6, which

Table 2. A summary of *D. saintelucei* and *B. madagascariensis* population trends in Sainte Luce. The 300 juvenile *B. madagascariensis* juveniles estimated by Hogg et al. (2013) are not included as their distribution across Sainte Luce is unknown. * represents adjusted values based on missing palms that could either not be assessed during the follow-up study or could not be located but neither confirmed dead. ** represents the minimum number of surviving palms in 2016 from a project for which several hundred juveniles were transplanted in ca. 2013. CRZ = Community Resource Zone, CZ = Conservation Zone.

Palm demographics for each of the study fragments in the littoral forests of Sainte Luce							
		S6	**S7**	**S8**	**S9**	**CRZ**	**CZ**
Dypsis saintelucei	Total Adults 2011	4	116	26	1	120	27
	Total Adults 2018	1*	33	15*	0	34*	15*
	Mortality	0%*	69.45%	40%*	100%	68.81%	40%*
	New Adult palms 2018	0	16	0	0	16	0
	Min. population size	1*	49	15	0	50	15
	Total Sub-adults 2011	0	15	19	0	15	19
	Total Sub-adults 2018	0	9	1*	0	9	1*
	Mortality	0%	35.71%*	94.12%*	0%	35.71%*	94.12%*
	New Sub-adult palms 2018	0	9	1	0	9	1
	Min. population size	0	18	2	0	18	2
	Total juveniles 2011	0	102	222**	0	102	222**
Beccariopheonix madagascariensis	Adult palms 2011	11	5	30	2	16	32
	Adult palms 2019	7	4	23	2	11	25
	Mortality	36.36%	20.00%	23.33%	0.00%	31.25%	19.57%
	New palms 2019	5	2	5	0	7	5
	Min. population size	12	6	28	2	18	30

Table 3. A summary of presumed cause of death in assessed *D. saintelucei* and *B. madagascariensis* palms. *indicates that in some cases the cause of death is likely a combination of factors, with fire used as a tool to kill and clear trees in areas subsequently used for agriculture.

Inferred cause of death						
		Agriculture	**Felled**	**Fire**	**Natural causes**	**Unknown**
Dypsis saintelucei	Adult (n=80)	11*	30	8	15	16
	Sub-adult (n=20)	9	0	7	2	2
		20.0%	30.0%	15.0%	17.0%	18.0%
Beccariopheonix	Adult (n=14)	2*	3	2	0	7
madagascariensis		14.3%	21.4%	14.3%	0.0%	50.0%
Total	Combined (n=114)	22*	33	17	17	25
		19.3%	29.0%	14.9%	14.9%	21.9%

contains many swampy areas was limited. As a result, three of the four known adult *D. saintelucei* palms could not be monitored in December 2018. The one accessible individual was found alive. In S7, the fragment found to support the highest density of *D. saintelucei* palms in 2011, only 33 of the 108 monitored adults (30.6%) and nine of the 14 (64.3%) sub-adults remained alive. Eight adult palms were recorded as being missing, and one individual could not be accessed. The *D. saintelucei* subpopulation in S7 has experienced a total decline of 65.6% over the eight-year monitoring period, with an average loss of 9.38 adult palms per year. However, the majority of new *D. saintelucei* individuals were also discovered in S7, with 16 further adults and nine sub-adults added to the number of known individuals. Total mortality for adult and sub-adult *D. saintelucei* combined in the CRZs was 65.0% over the study period, whilst the minimum known population stands at 50 adults and 18 sub-adults (Table 2).

Similarly, total mortality for *B. madagascariensis* in the combined CRZ fragments stands at 45.5% over the eight-year period. During the follow up study, four of the 11 palms located in S6 were dead (36.4%), along with one of the five palms in S7 (20.0%). However, six of the newly discovered palms (five living individuals and a single dead palm) were found in S6, and two further living and healthy individuals were recorded in S7 along with an additional dead palm. The current number of known adult *B. madagascariensis* within the CRZ stands at 18 individuals (Table 2).

Palms in the Conservation Zones (CZ) – Fragments S8, S9 + S17

In the forest fragment S8 and its satellite remnants, ten of the previously recorded 26 adult and 16 of the 19 sub-adult *D. saintelucei* palms were found deceased. One adult and two sub-adults could not be located. Total losses correspond to a 61.9% overall decline in the number of known *D. saintelucei* in the area. A single sub-adult palm was discovered during the 2018 survey, leaving the minimum population of S8 at 15 adults and two sub-adults. The only known *D. saintelucei* in the largest protected forest fragment in Sainte Luce, S9, could not be found in 2018, and it is now highly likely that the S9 subpopulation stands on the brink of extirpation.

The forest fragment S8 supported the largest number of adult *B. madagascariensis* during the initial 2011 assessment, however seven of the 30 individuals (23.3%) had died during the intervening years. A further five individual adults were discovered during the 2019 surveys. Both of the known individual palms in S9 remained alive. The total number of known *B. madagascariensis* palms in the CZs stands at 30 adults (Table 2). To date, no palms of either species have been recored in fragment S17.

Threats

A breakdown of inferred cause of death for both species is provided in Table 3. When all cases are combined (for all assessed *D. saintelucei* and *B. madagascariensis* palms), the leading cause of palm mortality is deliberate felling (29.0%, n=33). However, the difficulties of post-mortem assessment are reflected in the number of palm deaths categorized as "unknown" (n=25), the second largest mortality category (21.9%). Agricultural practices and land conversion are a further substantial driver behind the decline of both species, accounting for the loss of 22 palms (19.3%), whilst 17 cases (14.9%) were each attributed to both fire and natural causes. However, it is difficult to disentangle fire and agricultural practice as the definitive cause of mortality as both are often linked, with fire utilized as a means of clearing ground for crops. Combined, anthropogenic factors (agriculture, felling and fire) account for 63.2% of overall palm mortality, natural causes were attributed to 14.9% of cases and 21.9% were unsolved. Whilst the inferred cause of death appears to be largely consistent for both adult and sub-adult *D. saintelucei* palms with regards to both fire and agriculture, the apparent lack of evidence for the deliberate felling of sub-adults may reflect differentiated harvesting practices associated with both age classes (Hogg et al. 2013a). In contrast, the seemingly disparate number of deaths attributed to natural causes may be age-related.

Discussion

The remaining littoral forests in the extreme southeastern corner of Madagascar are predicted to lose a number of plant and animal species in the coming decades as high levels of deforestation, forest fragmentation and an increasing pressure on forest resources exact their toll on the natural environment (Bollen & Donati 2006). The impact of the proposed ilmenite mine in the region provides a further overarching threat to endangered species in the region (Ganzhorn et al. 2001, Bollen & Donati 2006, Watson et al. 2010, Rakotoarinivo & Dransfield 2012, Goodman et al. 2018). The implications of the results presented here further signal the grave threat faced by many species over the coming decade. Whilst we resist the temptation to predict timeframes for the possible extirpation of both palm species, it is clear they face an uncertain future in Sainte Luce and the next few years could prove critical to the long-term future of both species. The limited number of adult palms remaining is a real concern, as is the realization that the majority of *D. saintelucei* exist outside of the recognized conservation zones and within the community resource zones, areas that are also under the proposed mining footprint (Temple et al. 2012, Hogg et al. 2013a).

Whilst it is highly likely that further undiscovered palms exist within the study fragments, the number is likely low given the intimate degree to which local forest guides know the area and individual trees within the forest, and also the time invested locating palms over the course of this study. It is also more likely that further individuals of both species may be found in the CRZs than in the CZs, since these forests are less explored and still maintain areas that are difficult to access. However, such new discoveries, although promising in the short term, provide no security for the future of either species if current mortality rates are unchecked and mining operations proceed as anticipated. Furthermore, whilst it may be obvious that resources in close proximity to human communities should be the most exploited, the current distributional pattern also raises questions as to the underlying ecological health of the forest fragments themselves, and it is plausible that different fragments have a differentiated capacity to regenerate certain species. Moreover, it is important to note that a further 12 forest fragments exist beyond the study forests, comprising an additional ca. 380 ha of unexplored habitat within the wider landscape. Although these smaller forest fragments are considered to be more degraded than the CRZ and CZ forests, they may still support a significant number of individual palms.

The population status of *B. madagascariensis* in Sainte Luce appears to be consistent with the estimates of Hogg et al. (2013a) with slightly fewer than 50 adult palms remaining in the area. However, this figure has remained stable only with the discovery of previously unknown individual palms and masks the steady decline in the number of persisting adults. The population estimate of approximately 85 adult and sub-adult *D. saintelucei* seems reliable; however, it is plausible that a relatively large number of the 102 juveniles discovered in 2011 remain alive and are developing. While Ellis (unpub. 2003) placed the number of adult palms at 130 in fragment S8 alone (Hogg et al. 2013b), the sub-population has been severely depleted, with our results indicating that as few as 15 adult palms may remain in the fragment despite its protected status. Even more worrying is that no known mature individuals persist in the largest protected fragment (S9).

The rapid loss of adult palms revealed in this study further highlights the unsustainable rate at which both palm species are being lost and emphasises the role of anthropogenic factors in the declines. Less than 15% of diagnosable palm deaths were attributable to natural causes, which is similar to findings reported by Hogg et al. (2013b). It is clear that conservation interventions are needed now if the species are to survive long-term. In saying this, the needs of the local communities must be addressed and preserving livelihoods must be a key consideration in any future conservation actions. Lobster fishing in particular is an important livelihood in Sainte Luce and commercial exports contribute substantially to the local economy (Sabatini et al. 2007). Although many species can be used in lobster pot construction, the durability of *Dypsis* rachis (represented locally by *D. saintelucei*, *D. scottiana* and *D. prestoniana*) mean that palms are a favored resource. Prior to ca. 1990, the vine *Flagellaria indica* was the preferred species locally for trap manufacture, but overharvesting has led to its near disappearance. Subsequent diversification of materials then led to the rapid depletion of the local *D. scottiana* population and has also placed increasing pressure on *D. saintelucei* (Hogg et al. 2013a). Local demands are evidently unsustainable and the pressure on these resources is having a serious detrimental impact on local populations.

This study found that in 56.7% of cases where the *D. saintelucei* had been felled, only the crown and leaves had been harvested. In such cases, the trunk remained at the site, indicating that the recovery of wood for construction or fuel was not the objective reason for the logging. This cutting technique and wasteful resource use was also observed by Donati and Bollen (2006). Amidst the crown of *D. saintelucei* is the edible palm heart, a vegetable commonly harvested by previous generations (prior to ca. 1985); however, this practice seems to have faded out over time and is considered unlikely to have influenced recent tree felling (Hogg et al. 2013b). Despite almost one in five adult *D. saintelucei* exhibiting axe wound damage to the trunk, a test of maturity and its readiness for construction purposes, we conclude that the felling of individual palms for their rachis and leaves at all life stages, presents the most damaging and direct threat to *D. saintelucei*. Furthermore, the non-lethal practice of harvesting the fibrous leaf rachis has been shown to render young trees in a quasi-juvenile state and stalls the development of affected palms (Dransfield & Beentje 1995, Hogg et al. 2013a).

Whilst the principal cause of death could not be determined in 50% of cases, adult *B. madagascariensis* palms are demonstrably still vulnerable to human activities. Adult palms were found to have succumbed to deliberate felling, fire and agricultural clearing. Whilst Hogg et al. (2013a) surmised that the species is infrequently used by local communities, despite utility in a diverse range of applications, any upsurge in its use could present significant population level problems given the low number of remaining palms.

In nutrient-depleted areas such as Sainte Luce, forested land often holds the most fertile soil and illegal slash and burn practices such as "*tavy*" can provide a quick fix of nutrients for growing crops and grass pastures for cattle grazing. Whilst there is no heavy dependence on agriculture in Sainte Luce, cassava – a hardy, drought-tolerant crop – is a staple in the local diet and is widely cultivated. Despite large areas of available open ground, the borders around some fragments (most notably S6 and S8 along with its satellite remnants) are being transformed into small-scale agricultural plots used almost exclusively for cassava cultivation. In some areas, these micro plots are rapidly encroaching into standing forest. Either through targeted removal or uncontrolled burning, 39 individual *D. saintelucei* and *B. madagascariensis* have been lost as a result of agricultural practices over the course of this study.

Conservation actions

A number of ambitious conservation initiatives have previously been introduced into Sainte Luce in an effort to counter the well acknowledged palm declines, with varying degrees of success. Both SEED Madagascar and QMM have fully operational plant nurseries and have in the past invested significantly in the cultivation of numerous palm species, including both *D. saintelucei* and *B. madagascariensis*. Previous work by SEED Madagascar growing *D. saintelucei* in the nursery had germination and first-year survival rates of over 90%. Similarly, a small number of transplanted *D. saintelucei* and *B. madagascariensis* saplings also show high survival rates after the first year (>70%) (SHR, pers obs. November 2019). Therefore, ex-situ cultivation in local nurseries and future palm transplantation initiatives may play an important role in future conservation planning and species management. Fragments S9 and S17 should be considered as priority recipient fragments, given their protected status and very low number of existing adult palms. However, the apparent absence of palms in S17 is curious and suitability trials should precede a fully committed trans-planting programme.

Whilst the threat posed by unsustainable harvesting is difficult to address, recent attemps to cultivate alternative resources (e.g. *Flagellaria indica* and *Bambusa multiplex*) in Sainte Luce should be supported. If successful and adequately scalable, these plantations could provide a sustainable solution for the construction of lobster traps, and relieve pressure on a number of local species (including *D. saintelucei*, *D. scottania* and *B. madagascariensis*). Similarly, they may provide a more environmentally acceptable option to other proposed alternatives such as gill-netting and plastic (Girlades et al. 2015). However, given the huge demand for such material locally and the slow growing nature of *F. indica* (Rabenantoanadro et al. 2007), meeting demand could be problematic.

Recommendations

The local threats faced by both palm species are well understood and have been adequately documented (Rakotoarinivo & Dransfield 2012, Hogg et al. 2013a, 2013b). Whilst the challenges associated with successfully overcoming these difficult problems are substantive, the limited success of past conservation efforts is reflected in the continual decline of both species over the past decade. In order to address this conservation problem, a dedicated, long-term and well-coordinated strategy must be developed focusing on several core aspects: the functional protection of remaining individuals across Sainte Luce, the provision of accessible alternative resources for community livelihoods, and the restoration of wild populations through supplementation. Whilst local projects have attempted to address the latter, follow up studies are now crucial in order to determine their success. Furthermore, a reliable and sustainable alternative source of materials for lobster trap construction is still required and the protection of the remaining adult palms needs urgent attention.

A potential short-term solution to abate the loss of threatened palms could be a locally enforced moratorium on the felling or exploitation of at-risk species. Such a dictate could effectively prevent the imminent loss of further palms but the timing of such an intervention would be crucial. A reliable supply of alternative resources, such as *F. indica* and *B. multiplex* (Rabenantoanandro et al. 2007) would be required to sustain livelihoods in the period whilst cultivated juvenile palms mature and prevent the harvesting pressure simply being shifted on to other palm species (Hogg et al. 2013a).

At the local level, the regulation of natural resources and the management of protected areas are the responsibility of COBA and FIMPIA respectively and both would need increased empowerment to ensure known palms and other valuable species are safeguarded. Working closely with NGOs, both entities could incorporate tailored monitoring regimes into existing patrols. Both bodies will be integral to the conservation of both palms; however, legal enforcement is a sensitive matter in impoverished rural communities, as compliance with regulatory frameworks and enforced financial consequences can endanger livelihood quality. This fundamental problem is demonstrated by the local use of tavy, which despite being nationally outlawed and prohibited locally around the protected areas, remains one of the most destructive environmental practices in Sainte Luce. Both community awareness and engagement will be critical to any successful scheme.

In the meantime, extensive cultivation and transplanting schemes must be reinvigorated, with local plant nurseries dedicating some proportion of their capacity to threatened species and prioritising those with high utility. Such schemes should dedicate a proportion of their output towards conservation and restorative purposes but also towards sustainable community use. The location of transplanted palms must also be very carefully considered, with the position of community resources informed by local stakeholders as well as the fundamental ecological requirements for optimal development. Finally, the opportunity to improve our understanding of both species through research should not be missed. Concurrent studies detailing the optimal growing conditions for both species *in situ* and *ex situ* will provide vital lessons for the future and a comprehensive monitoring programme should be developed to ascertain the success and survivorship rates of palms in different settings. Similarly, the refinement of cultivation and transplantation techniques is essential, building on the lessons learned during past projects (Azafady 2012). Finally, crucial ecological detail is still also lacking in terms of the natural pollinators, dispersers and predators of both palm species, and an understanding of these important natural history details will improve our collective ability to conserve these species long-term.

Acknowledgments

First and foremost, we are indebted to the kindness and expertise of the Sainte Luce community and the local guides on whom this project has relied so heavily – Babaly, Solo, Raziva and Altera. We would like to extend our gratitude to all of those who contributed to the field work over the duration of this project, including former SEED Madagascar (previously ONG Azafady) staff and volunteers, who each devoted their hard work and time. Special thanks to Dr. J. Dransfield who kindly helped us to improve the initial versions of the manuscript. Finally, our sincere respect goes out to all of those working to conserve the precious wildlife and ecosystems of Madagascar. *Misoatra betsaka*.

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