Fall 2014

Palm Reading: Predicting the Future of Four Threatened Palm Species at Pointe À Larrée, Eastern Madagascar

Eva Colberg
SIT Study Abroad

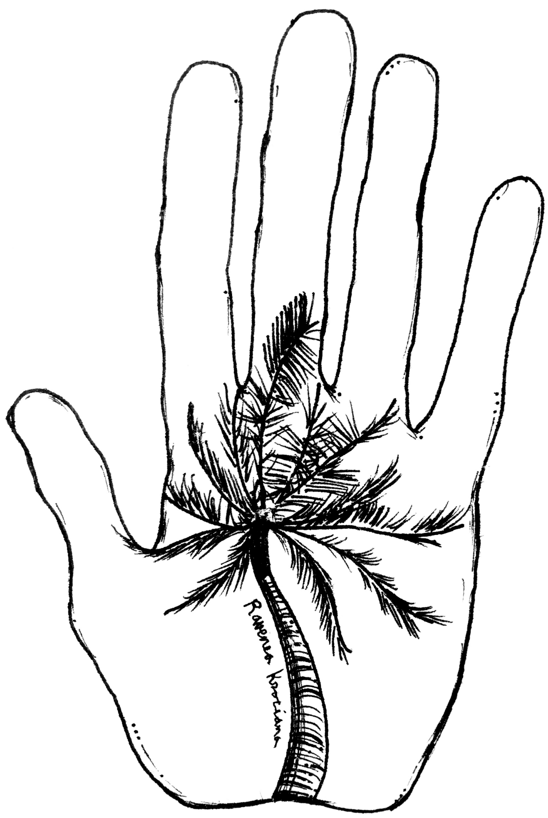
Palm Reading: Predicting the Future of Four Threatened Palm Species at Pointe À Larrée, Eastern Madagascar

Eva Colberg

Project Advisor: Adolphe Lehavana

Academic Director: Jim Hansen

Fall 2014



Acknowledgements

The first thanks must go to my **dear parents**: I am forever grateful to you for giving me the choice to come here even when you wanted me to refuse, and then for supporting my decision (albeit rather begrudgingly). I know the ISP period was particularly difficult for you (and for me as well!) because I couldn't contact you.

Barry: You made the initial contact with MBG for me, and then subsequently guided me through every other step of the process. Also, your visit was very welcome and very much needed.

Adolphe: Je suis arrivée à Fenerive Est sans aucune idée de votre personnalité ni capacité, mais vous m'avez accueillie et guidée plus que j'ai attendu, donc merci beaucoup. J'apprécie tous que vous m'avez appris, pas juste du sujet de mon projet mais aussi des sujets de l'agroforesterie, de la vie Malagasy, et de la botanique en générale. De plus, vous m'avez bien préparée pour mon séjour à Manjato ; je n'aurais pas pu le faire sans votre aide.

Mamy: Sans vous, je suis sûr que je serais encore perdue à Tana, sans aucune idée comment trouver une taxi-brousse. Merci beaucoup.

Francine: Mahandro tena tsara hanao, namako. Misaotra mba nanazavako ahoana manao tsihy sy mikarakara gironfle sy mahandro.

Thresis & Joshin: Misaotra betsaka. Mahay tsara ny ala hanareo, sy mpianatra tsara hanareo, mampianatrako malagasy sy mpianatrako englisy sy fransais.

COBA of Manjato: Merci beaucoup pour m'avoir permis d'étudier votre forêt, et de m'avoir accueillie si bien. J'espère que votre village et foret restent beaux et que votre communauté reste contente.

Guy: Votre présence dans les derniers jours de mon étude était vraiment appréciée, pour la traduction, l'aide, et la compagnie. Vous êtes si gentil pour m'avoir aidée sur terrain et puis en trouvant un bateau après, merci beaucoup.

Glossary

AOO: Area of Occupancy

COBA: *communauté de base*; the community organization in charge of setting up and maintaining forest management rules

CR: Critically Endangered, "facing an extremely high risk of extinction in the wild," an IUCN Red List classification (IUCN 2014)

EN: Endangered, "facing a very high risk of extinction in the wild," an IUCN Red List classification (IUCN 2014)

EOO: Extent of Occurrence

IUCN: International Union for the Conservation of Nature

Kona be: *Ravenea lakatra*

Lafaza: local name for *Dypsis psammophila*; also refers to several other *Dypsis* species

Mature: a plant with evidence of fruiting or flowering

MBG: Missouri Botanical Gardens

NT: Near Threatened, an IUCN Red List classification (IUCN 2014)

PAPC: priority area for plant conservation in Madagascar, as considered by MBG

Polisin'ala: Forest rangers, employed by COBAs but paid by MBG

Rabedona: *Dypsis carlsmithii*

Sinkara: *Dypsis sanctaemariae*

Tavy: traditional burning of the land for agricultural use

Threatened: CR, EN, or VU classification on the IUCN Red List (IUCN 2014)

VU: Vulnerable, "facing a high risk of extinction in the wild," IUCN Red List classification (IUCN 2014)

Table of Contents

Title Page	1
Acknowledgements	2
Glossary	3
Table of Contents	5
Abstract	6
Introduction & Background	7
Methods	11
Results	15
Discussion	20
Conclusion	23
Literature Cited	25
Appendix I: IUCN Red List Threat Levels	29
Appendix II: Species Images	30
Appendix III: GPS Coordinates	33
Appendix IV: Projected Overall Populations for *D. psammophila* and *D. sanctaemariae*	35

Abstract

Madagascar has one of the highest concentrations of palm diversity in the world, with 195 species, 192 of which are endemic, but just as for the rest of the island's natural resources, the future of these palms is at stake. In fact, 83% of the country's endemic palms qualify as threatened following the most recent version of IUCN Red List criteria, version 3.1, yet 28 are not even found within protected areas. One area awaiting government protection, MBG's Pointe à Larrée project, is home to 18 different palm species, 11 of which are threatened. This study took sample counts to find the minimum population, density, and maturity of four threatened species in the area (*Ravenea krociana, Dypsis carlsmithii, Dypsis psammophila,* and *Dypsis sanctaemariae*) in order to categorize their local future survival. These species were chosen because of their rarity, novelty, human use, and role as keystone indicator species in the forest, so their population statuses can indicate the overall state of their habitat and its conservation, to be considered in future conservation decisions. Additionally, this information adds to the knowledge of their distribution, helping with future studies and IUCN classifications, and adds to the knowledge of the site as it awaits governmental protection.

Introduction & Background

In terms of its amount of endemic plant and vertebrate species, both in quantity alone and as compared to the country's area, as well as the amount of primary vegetation left, Madagascar is one of the worlds "hottest" biodiversity hotspots (Myers et al. 2000). Although the unique, charismatic megafauna often get the most attention, the flora is equally fascinating, with over 9,700 endemic plant species, a count that continues to grow (Myers et al. 2000). The palm family, *Arecaceae,* is one of the more immediately recognizable families, and possesses an extremely high rate of endemism to the island. Out of Madagascar's 195 native palm species, 192 are endemic to the island (Rakotoarinivo et al. 2013), and 163 are of "elevated conservation concern" (Rakotoarinivo et al. 2014). Their threatened status is due to a multitude of reasons, including habitat degradation, reduction, and fragmentation as the country's growing population needs land for agriculture and wood for charcoal and construction. Direct human use also plays a role, due to palms' ethnobotanical importance in providing fibers for weaving, medicinal properties, edible palm hearts or other parts, and construction materials (Rakotoarinivo et al. 2014; personal observation).

Although palms can be found in every region of the country, but the highest levels of palm species richness occur in the more precipitous northeastern part of the island (Rakotoarinivo et al. 2013). This study took place from November 4-19, 2014, in the classified forests of Pointe à Larrée, a peninsula in one of Madagascar's northeastern regions, Analanjirofo, in the District of Soanierana-Ivongo. Missouri Botanical Garden (MBG) works in conjunction with four local community associations (COBAs) and Conservation International (CI) for the protection and conservation of three parcels of forest. Pointe à Larrée makes up part of MBG's country-wide effort to actively conserve Madagascar plant diversity, begun in 2002 and now spanning projects at eleven priority areas for plant conservation (PAPCs) (Birkinshaw 2013). MBG's end hope is for the Malagasy government to designate the Pointe à Larrée area as a category VI protected area, a protected area with sustainable use of natural resources under Madagascar's new protected areas network (*Nouvelles Aires Protégées, NAP*) (Lehavana et al. 2014). The most recent previous study of the peninsula's palms found 18 endemic species of palm in the area, 11 of which are threatened according to the IUCN's Red List (Razafitsalama 2009). These classifications (see appendix I) are based on a range of criteria, but all measure in some way the risk of extinction of the species.

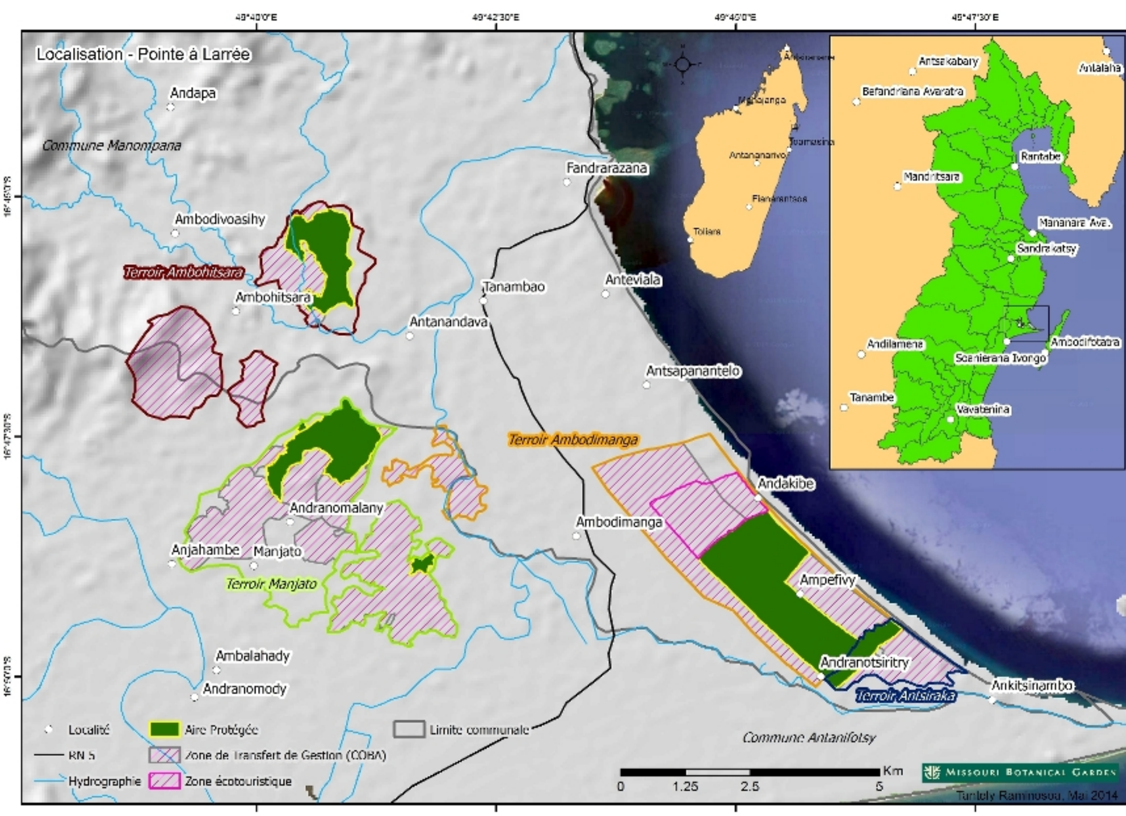


Figure 1: Map of the protected forests of Pointe à Larrée

The forests of Pointe à Larrée include three distinct habitats: littoral forest, swamp forest, and low-altitude rainforest (Razafitsalama 2009). There are both designated-use and no-entry zones of forest; *polisin'ala* from four of the local *fokotany* patrol the no-entry zones against cutting and hunting, but both activities still happen, albeit at reduced rates (personal observation). The surrounding villages are rural and access to the rest of the country is limited, forcing the people to rely heavily on their own agriculture, agroforestry, and the resources of their forests. In the areas where the communities do not participate in the conservation efforts, deforestation and *tavy* are freely committed.

Any information on threatened species in the area will increase its chances of being a government-protected land and will add to the knowledge base of the species in general and to MBG's work in particular. Given the importance of palm conservation in Madagascar, this study focuses on the populations of four threatened palm species in the area surrounding Terroir Manjato, one of Pointe à Larrée's four community-protected forests (see Fig. 1). The first target species, *Ravenea krociana,* locally referred to as *kona be*, is a dioecious palm mostly found in southeastern Madagascar that has been uplisted from vulnerable (VU) to endangered (EN) since its first Red List classification in 1995 (Rakotoarinivo et al. 2014). The justification for this uplisting is its small area of occupancy (AOO), which is 450 km^2, as well as the fact that its habitat is being degraded and lost. Its EOO is only at the Vulnerable threshold, at 10,241 km^2, but Pointe à Larrée is further north than its known range between Andohahela and Ampasimanolotra (Rakotoarinivo & Dransfield 2012). Pointe à Larrée locals use the leaf sheaths to make a tea that promotes the growth of infants (anonymous local, personal communication, 5 November 2014), but as of 2009, only a single individual was recorded in the Pointe à

Larrée area. It was located outside of the protected forest in the middle of a rice field, so this study aimed to determine if there are any more individuals, and if they are close enough to form a reproductive population.

The second species, *Dypsis carlsmithii*, first noted in 2002, is more recently described than the other palm species (TROPICOS). It currently qualifies for CR Red List designation, with an EOO of 2041 km^2 and an AOO of merely 8 km^2. In fact, recorded mature individuals amount to fewer than 15, at only two sites, although both sites are protected (Rakotoarinivo & Dransfield 2012). During this study's preliminary scouting, several individuals were found, and after talking with the guides, *rabedona* as the locals call it, exists to some extent in the Pointe à Larrée area. They eat the hearts of the young ones and use the trunks of the larger ones for construction wood (Thresis & Joshin, personal communication, 20 November 2014).

The third species, *Dypsis psammophila*, was downlisted from CR to EN in 2012, but is still of conservation concern, with an EOO of 4234 km^2 and an AOO of 112 km^2. Its range spans only five locations, none within protected areas and thus all facing habitat loss and degradation, with the entire population amounting to fewer than 200 clumps (Rakotoarinivo & Dransfield 2012). It is, however, present but not yet thoroughly recorded at Pointe à Larrée, where the locals refer to it as *lafaza.* Local uses include eating the palm heart and using the stalks as arches for special events such as weddings (Thresis & Joshin, personal communication, 20 November 2014).

The final species considered, *Dypsis sanctaemariae*, remains classified as CR, with an EOO and AOO of both 7 km^2. The only recorded population exists on Ile Sainte Marie, 8 km off the coast of mainland Madagascar (IUCN 2014, Lonely Planet).

However, MBG has known about a population on Pointe à Larrée, and the villages are plastered with *sinkara* posters, although no official counts have been made. The guides noted that people used to use the stalks for house building, but since MBG's involvement the locals have shifted towards using *Ravenala* instead (personal communication, 20 November 2014).

Considering the lack of recorded knowledge of the presence of all four species at Pointe à Larrée, information on their population distribution will add to their respective EOOs and AOOs, to be considered in future IUCN evaluations. Additionally, being able to conclusively show the presence of endangered species within the protected area gives the communities and MBG more credibility to gain funding and attract attention to the site. Finally, knowledge of how many mature individuals are present in protected areas can give the plant science and conservation communities an idea as to the future of their survival. Thus, in order to help with future classification of the species and the conservation of the area, this study aimed to answer the question: What are the sizes, distributions, and locations of the populations of *Ravenea krociana, Dypsis carlsmithii, Dypsis psammophila,* and *Dypsis sanctaemariae* at Pointe à Larrée, and their reproductive potential in terms of mature individuals?

Methods

Before any methods were decided upon, the first two days on-site were dedicated to reconnaissance work. Local guides were asked for directions to known individuals of *Ravenea krociana,* a species of whom only one mature individual had been previously recorded in the area, and locations and rough distribution of other endangered palms were noted along the way. From the observations of these two days, three additional target species were decided upon to be studied using the methods described below: *Dypsis carlsmithii, Dypsis psammophila,* and *Dypsis sanctaemariae.*

Two local guides, *polisin'ala* employed by MBG, assisted with fieldwork during the study. It should be noted that in communications with the guides, the target species were always referred to by their vernacular names, but photos were shown for clarity of species. Species were identified during the preliminary period using Dransfield and Beentje's *The Palms of Madagascar* 1995 and 2006 versions. Location coordinates were taken using the GPS device Garmin Etrex, entered into GoogleEarth for visualization. In the field, distances 50 m and under were measured using a 50 m measuring tape, while longer distances were measured using the Garmin Etrex device's pre-existing interface. Post-field analysis used CSGNetwork.com's GPS Latitude and Longitude Distance Calculator.

Both mature and immature individuals were noted; for classification, the IUCN counts only consider individuals capable of reproduction, but the amount of juveniles in a population can prove useful for future studies of reproduction rates and survivorship. The counts were also used to find local population densities, to give an idea of distribution, judged for reliability using the standard deviation and coefficient of variance.

Ravenea krociana

The two guides employed for this study, as well as other *polisin'ala* in the area, COBA members, and some individuals in the local communities were asked to find any *Ravenea krociana* individuals. Every possible lead was followed; if the tree in question really was *R. krociana,* GPS coordinates and state of maturity were recorded, maturity defined as the presence of inflorescence or infructescence. From the gathered data, distances between each individual were calculated and considered along with maturity in order to determine the population's chances of producing offspring.

Dypsis carlsmithii

MBG's standard method for determining population size and density of less abundant species is to count individuals in at least three 20x500 m transects (A. Lehavana, personal communication, 5 November 2014). The original plan for counting *D. carlsmithii* was to take GPS coordinates at the starting point, measure 10 m out on either side, and then walk forward, using the guides' judgment to maintain the 20 m width. We would then note every individual's presence and maturity for 500 m as measured by the GPS. The ending GPS point was also noted to ensure that transects did not cross, although not visually represented here. Starting points were chosen in areas of known habitat according to the guides' judgment. This method proved impossible to carry out for the expected transect length and amount of repetitions, however, due to fragmentation of habitat. Additionally, the initial plan of noting the GPS coordinates of every individual seen was soon nixed due to lack of feasibility, reverting to simply noting the number of individuals in the given area.

The first transect was performed according to these procedures, but the second came across a hill and slashed forest midway through, both clearly not *D. carlsmithii* habitat, necessitating a turn in the transect. Even after turning, however, habitat was still not the same. The point of turning and its distance from the beginning was noted.

For the subsequent three transects, habitat simply ended too soon before the 500 m; nevertheless, in order to have a population count and search for any mature individuals, each transect was carried out to its maximum possible length given habitat limitations, the shortest being 200 m.

Dypsis psammophila

Given the thick clustering habit of *D. psammophila,* MBG's standard for more abundant plants was used: at least three plots of 20x50 m. In fact, we counted eight 20x50 m plots of *D. psammophila* populations in the forest between Manjato and Tanambao. For each plot, GPS coordinates were taken at every corner. Boundaries were marked by the pathway, landmarks, the guides' recognition, and in the thickest forest by leaving out the 50 m tape. Within these plots, transects of varying width and repetition were made in order to count the mature and immature individuals. The width and repetition of these transects varied according to terrain and thickness of vegetation; in areas where vegetation was thicker, distance of visibility for counting was reduced, and thus more numerous and narrower transects were made.

Dypsis sanctaemariae

Methods were similar to those for *D. psammophila*: 20x50 m plots with transects of various width and frequency dependent no vegetation thickness, with GPS coordinates of each corner taken. In addition to simply recording maturity or not, however, a distinction between seedling under chest height and seedling over chest height was recorded. For under chest height individuals, a clump was counted as a single individual, but for anything higher than chest height, single trunks were counted. Due to the inconsistency of counting between the two juvenile sizes, juveniles below chest height were disregarded in analysis.

The location of the study also differed from that of *D. psammophila*; six plots were done in the forest to the east of Manjato and two were performed in Ambohitsara; seedlings under chest height were not recorded in Ambohitsara, due to the incredible thickness of population.

Results

Ravenea krociana

We were notified of four different *kona be* individuals; only three turned out to be *Ravenea krociana*, although the last one was *Dypsis carlsmithii* and thus still beneficial to our study. Using the GPS coordinates of the 2009 Razafitsalama study, one of our individuals was confirmed to be the same one that the 2009 study had found. As Razafitsalama found, this one was mature, with a dry male inflorescence still attached. The other two were both juveniles; one was also in a rice field, and the other in someone's backyard, thus all outside the protected areas. The two juveniles were 3.22 km apart, and respectively 5.98 km and 8.43 km away from the mature tree.

Figure 2: The three *R. krociana* individuals present at Pointe à Larrée. *R. krociana* 2, furthest from the other two individuals, is the sole adult.

Dypsis carlsmithii

We found a total of 124 individuals; none, however, showed any evidence of neither inflorescence nor infructescence, and thus were not considered to be mature even when their trunks looked fully developed. The average density of *D. carlsmithii* came out to be 34.11 individuals/ha, with a standard deviation of 23.36 individuals/ha and a coefficient of variance of 68.48%.

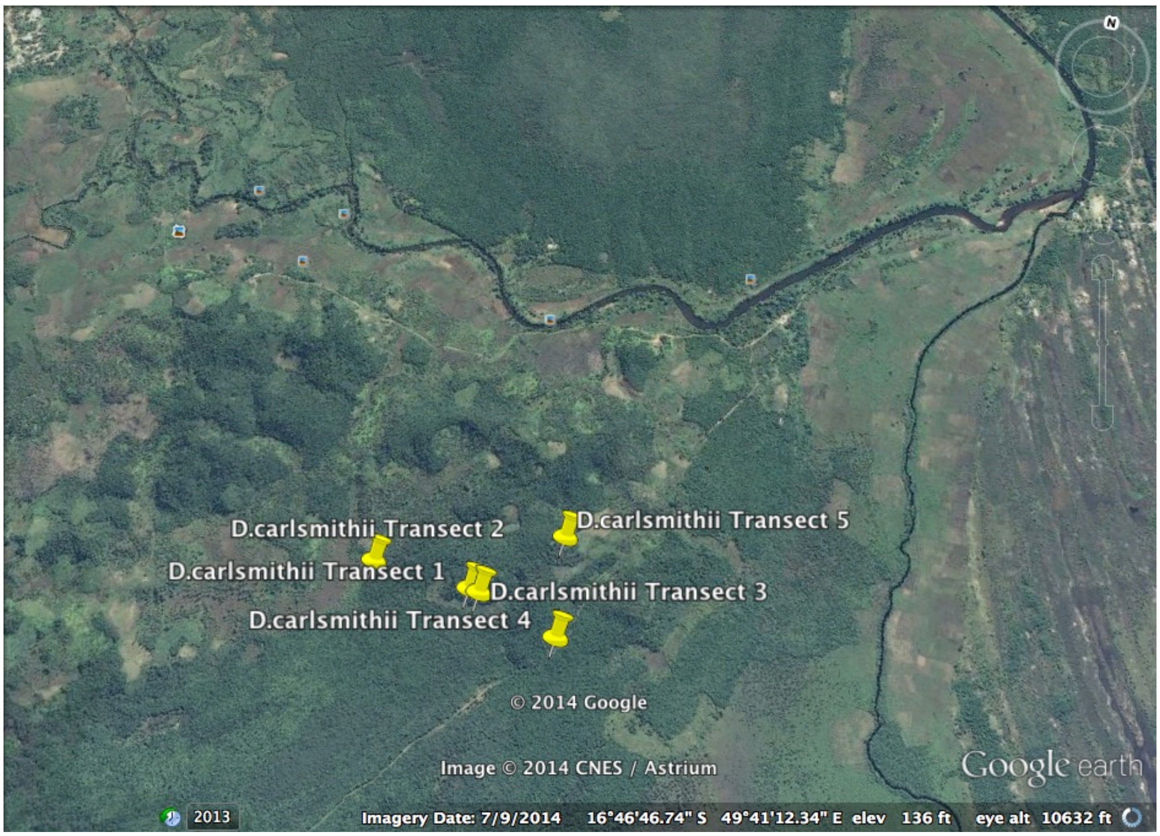


Figure 3: Starting points for *D. carlsmithii* transects.

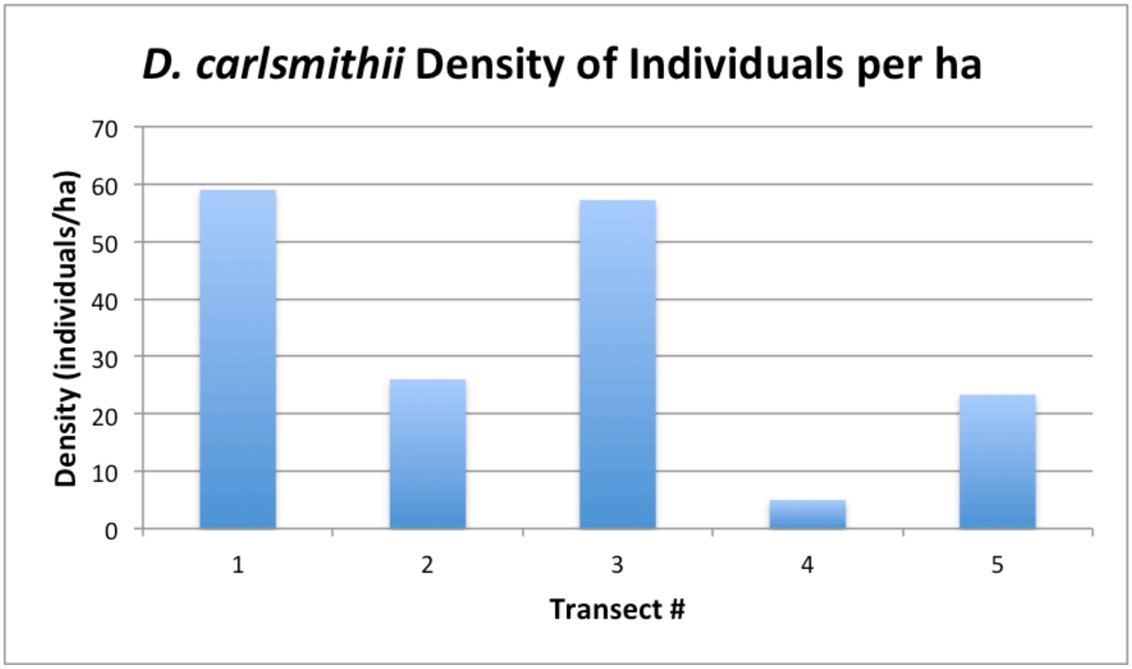


Figure 4: Distribution of *D. carlsmithii* throughout the transects.

Dypsis psammophila

Not previously recorded at Pointe à Larrée, this study counted eight 20x50m plots containing *D. psammophila*, adding 8000 m^2 to its AOO. We found a total of 1840 individuals, 254 of which were mature, although this may be an overestimate due to the clumping nature of the palm. However, using these counts, the average density per plot came out to 2300 individuals per ha with a sample standard deviation of 778.90 individuals per ha and a coefficient of variance of 33.87%. The densities ranged from a low of 1280 up to 3290 individuals per ha. When only considering the mature individuals, the average density is 317.5 individuals per ha, with a sample standard deviation of 136.46 individuals per ha, a coefficient of variance of 42.99%, and a range between 190 and 620 individuals per ha.

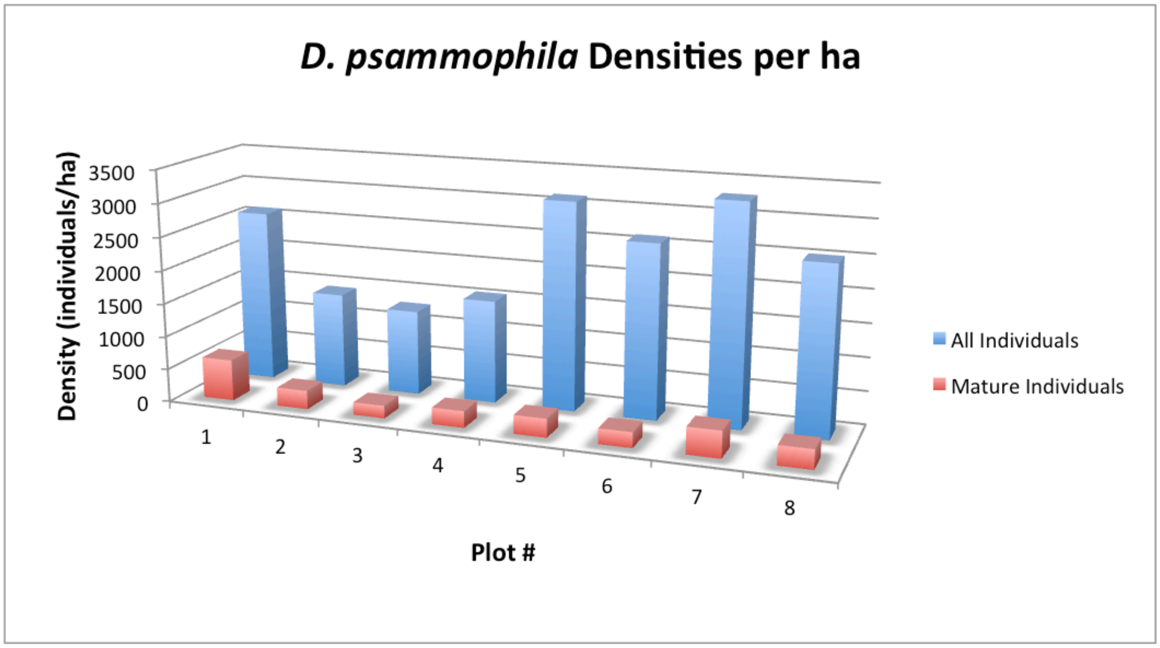


Figure 5: Densities of each plot of *D. psammophila* for all individuals and mature individuals in particular.

Dypsis sanctaemariae

As with *D. psammophila,* a total of 8000 m^2 was covered by the plots, thus adding that amount to the AOO of *D. sancatemariae* as well. We found a total of 20481 individuals, 738 of which were mature, although as with *D. psammophila*, this could be an overestimate due to the clumping nature of the palm. However, using these counts, the average density was 922.5 adults per ha, with a standard deviation of 1100.2305 adults per ha, and a coefficient of variance of 119.27%. The average density of individuals of all life stages was 25601.25 individuals per ha, with a standard deviation of 11490.9622 individuals per ha and a coefficient of variance of 44.88%.

No data about surrounding forest composition was recorded, but *D. sanctaemariae* seemed thickest in areas where there were not any larger trees or shrubs to compete with.

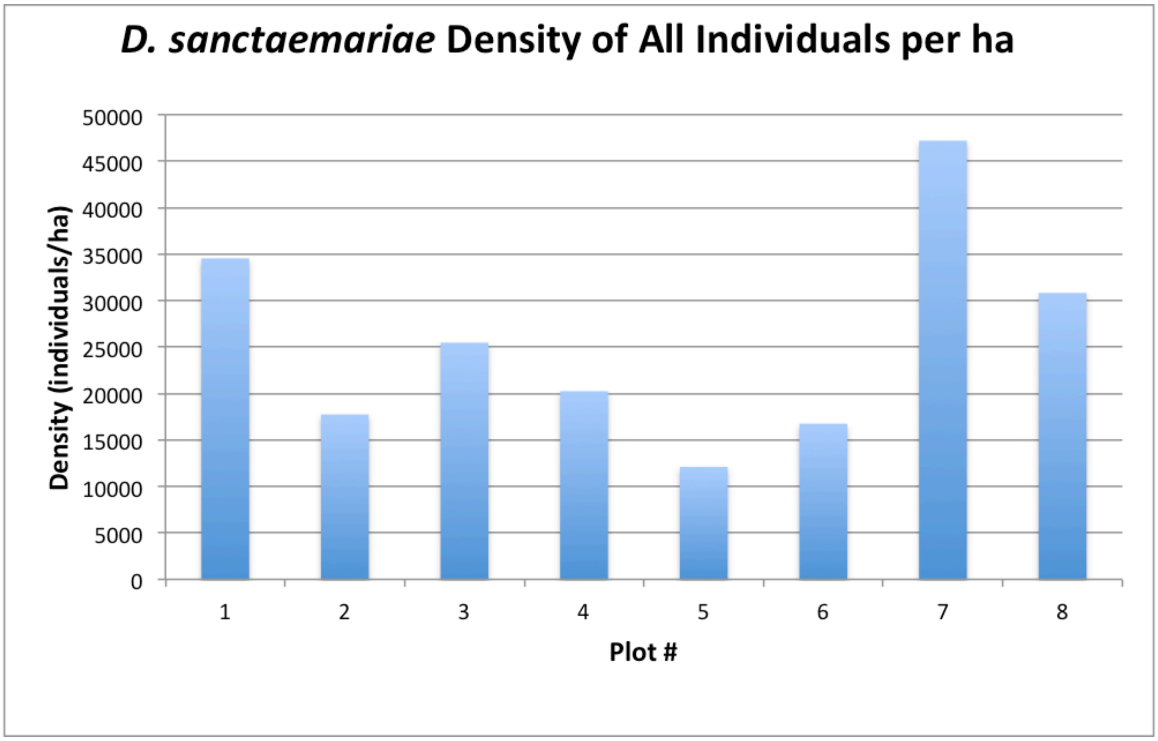


Figure 6: Densities of each plot of *D. sanctaemariae* when considering all individuals.

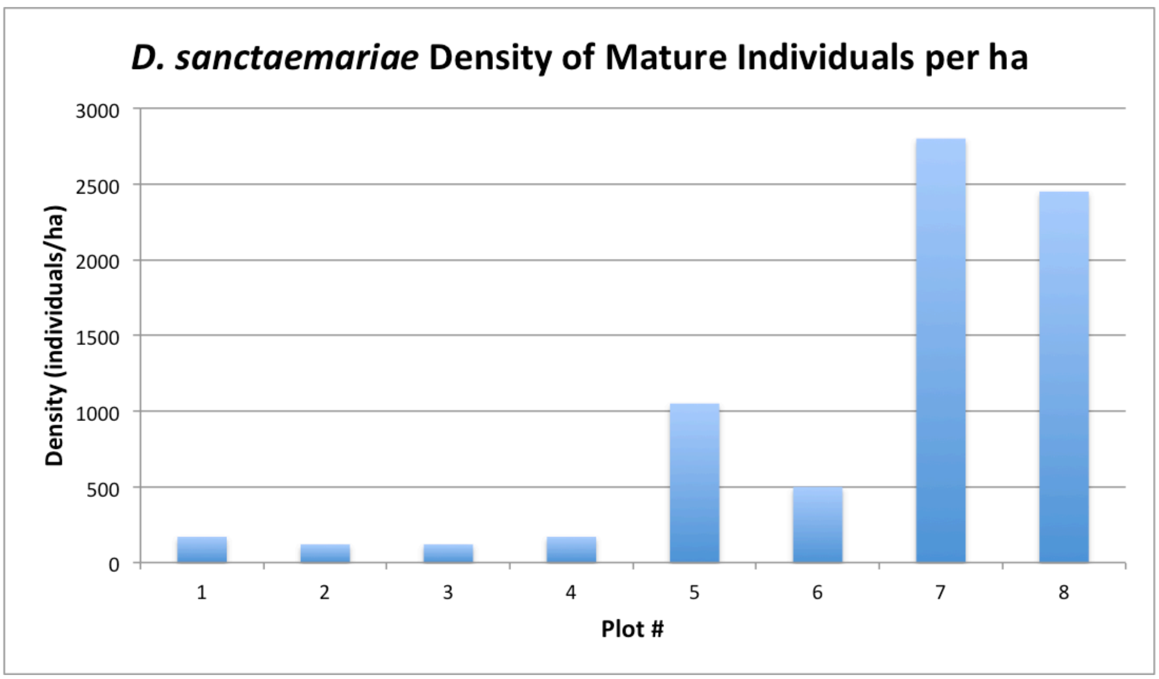


Figure 7: Densities of each plot of *D. sanctaemariae* when considering mature individuals only.

Discussion

The population of *Ravenea krociana* at Pointe à Larrée is minimal and has low reproductive potential, with two of the three individuals still juveniles. Even if one of the remaining two is compatible with the others, the distances between all three are great enough that pollination is improbable. As such, the lone male does not qualify to be counted under IUCN 3.1 criteria, due to the density being too low for fertilization. Beyond the lack of a reproductive future, all three individuals are found on private property, such that the fate of each tree depends upon the decision of the landowners. If their owners wish to cut them down or burn them, they can, although at the moment they have been left standing. Thus, although it is interesting to find *R. krociana* individuals further north than their usual southern range, the likelihood that this subpopulation will survive and produce offspring is too low to be counted in any IUCN ranking. Considering the fact that four of the five other known sites of *R. krociana* are within protected areas, and that the populations within them are abundant, resource and efforts at Pointe à Larrée would better be focused on the threatened but more abundant species, those more likely to benefit from the conservation of the area.

The densities of *D. carlsmithii* have a high standard deviation, derived from disparate densities found between transects, most likely due to the lack of standardized lengths and variations in habitat quality. Nevertheless, discovering *D. carlsmithii*'s presence in the area has the potential to expand its known AOO and EOO, although this population cannot be considered by the IUCN until mature individuals are found. The current absence of adults could simply be due to out-of-season observation; continued monitoring could potentially reveal the floraison season, when the mature individuals could finally be counted.

Regardless of maturity, the location bodes ill for the current population, as it is outside the protected area. The habitat is not under any sort of protection and is already fragmented and reduced as a result; several of our transects were cut short by swaths of slashed forest. Given the dearth of any other recorded *D. carlsmithii* populations, this discovery brings a new incentive to place the habitat under protection, at least partially, whether it means altering township boundaries or simply trying to secure the cooperation of the local community. Protection, however, is complicated by the fact that the local COBA was not selected as one to continue participation during MBG's reevaluation of the peninsula's protection scheme (Lehavana et al. 2014).

For *Dypsis psammophila* and *Dypsis sanctaemariae,* densities are again too unevenly dispersed, with high standard deviations. This is due to a small sample size and unevenly chosen sample locations. The coefficient of variance for mature *D. sanctaemariae* individuals was exceptionally high, indicative of a widely distributed dataset. Location seems to have played a large part in this; the first four plots were clustered together, whereas the last four plots were in different areas, and the counts of mature individuals significantly changes between the clustered and more distant ones. Thus, the average densities found for both species are not reliable, and extrapolating overall area of occupancy from them will not be representative until a better count is done, one with randomized sample locations and more repetitions. Extent of occupancy can be safely added to, however, thanks to the minimal population counts. For MBG and the local communities as they await the government's decision, the presence of these two threatened species within the protected area, one endangered and the other critically endangered, adds conservation value to the site. For a true estimate of their populations over their habitat in the entire area, however, and to add a significant swath of land to their AOO, further and more rigorous study is needed.

The current study lacked any randomization method to gain an understanding of the distribution over the entire habitat area, instead focusing on known clusters for a minimum population count. Even when considering known clusters, however, the chosen plots were not evenly spaced out enough, resulting in skewed data. A better approach would choose an equal number of plots in both Ambohitsara and Manjato forest areas, as the distribution patterns between the two already appear remarkably different for *D. sanctaemariae*. The same might be done for *D. psammophila* as well, since a small population was noted but not counted in the Ambohitsara area. At any rate, simply expanding the range of forest studied to encompass the entire protected area would provide more even and representative results.

The plots themselves could also be standardized, simply by marking with tape the boundaries and counting by following the same transect size and amount every time. Furthermore, standard convention could be followed by counting the clumps, not the individual stalks, for both species. Likewise, the *D. carlsmithii* transect methods were also not standardized, with the 20 m width becoming a rough estimate after the first few meters, and the lines turning and ending short due to fragmentation of habitat. If not enough habitat is available for 500 m-length transects, the better strategy would be to uniformly make every transect smaller, perhaps even reducing it to the 20x50 m plots of *D. psammophila* and *D. sanctaemariae.*

Conclusion

The target species *Ravenea krociana, Dypsis carlsmithii, Dypsis psammophila,* and *Dypsis sanctaemariae* are all presenct in the area of Pointe à Larrée; only *D. psammophila* and *D. sanctaemariae*, however, were found to have reproductive populations and to exist within the protected forest. *Ravenea krociana*'s fate in the area seems limited; only three individuals are known to exist, all outside of the protected zone. Furthermore, the distance between the three preclude any likely natural reproduction, and only one of the individuals has reached maturity. The palm's presence this far north is noteworthy, but its conservation efforts will be more productive in the southeastern areas where it occurs in greater abundance and in officially protected areas. Although monitoring the two juvenile Pointe à Larrée individuals for signs of maturity and then eventually breeding them is a possibility, MBG and the local communities' conservation efforts would be better spent on other species. One possibility is *Dypsis carlsmithii*, a critically endangered species with only two other known locations. Its presence at Pointe à Larrée is noteworthy, but its future in the area looks bleak unless its habitat is swept back into the protected portions, which would require opening up dialogue again with a community that no longer participates in conservation. At the moment, its habitat is fragmented and threatened by ever more deforestation; on top of this, no mature individuals have been found. Further studies to determine its floraison season and then count the sexually mature individuals would add to the overall knowledge of this newly described species.

The futures of *D. psammophila* and *D. sanctaemariae* both seem more positive. Both are threatened, but are locally abundant in the protected areas of Pointe à Larrée.

Furthermore, efforts by MBG to bring awareness about *D. sanctaemariae* seem to be successful reaching and impacting the local communities. *D. sanctaemariae* has not been officially recorded outside of Ile Sainte Marie, so this conservation achievement is especially significant. The presence of both of these threatened species within the protection of MBG and the local communities adds importance to the site already significant for conservation, and this record of their Pointe à Larrée populations will hopefully add to the qualifications to designate the site as an official protected area. Additionally, the information recorded in this study can serve as a basis for future researches in determining the reproductive rate of the area's populations of these species, which could aid with planning future management and protection strategies.

Literature Cited

Birkinshaw, C. "Restoration activities associated with Missouri Botanical Garden's site-based conservation program in Madagascar: annual report 2013.http://www.rncalliance.org/WebRoot/rncalliance/Shops/rncalliance/532E/4587/6584/A5FA/9700/C0A8/D2F8/87B5/RestorationMBG2013.pdf

Birkinshaw, C., Lowry II, P.P., Raharimampionona, J., & Aronson, J. (December 2013). Supporting target 4 of the Global Strategy for Pant Conservation by integrating ecological restoration into the Missouri Botanical Garden's conservation program in Madagascar. *Annals of the Missouri Botanical Garden.* 99(2):139-146. Web-accessed : http://www.rncalliance.org/WebRoot/rncalliance/Shops/rncalliance/52B6/7B4F/05A5/54B8/D6B0/C0A8/D2F8/F0D9/Birkinshaw2013MadagascarProgramContribGSPC.pdf

Birkinshaw, C. (2012). Over-view of Missouri Botanical Garden's restoration activities in Madagascar 2012. *Missouri Botanical Garden.* http://www.rncalliance.org/WebRoot/rncalliance/Shops/rncalliance/51FA/E7A5/E158/047D/B770/C0A8/D2F8/4760/Restoration_0020_MBG_0020_2012.pdf

CSGNetwork. 2014. GPS Latitude and Longitude Distance Calculator. Web accessed: http://www.csgnetwork.com/gpsdistcalc.html

CSGNetwork. 2014. GPS Latitude and Longitude Convertor. Web accessed: http://www.csgnetwork.com/gpscoordconv.html

Dransfield, J. & Beentje, H. (1995). *The Palms of Madagascar.* Kew Publishing.

Dransfield, J., Beentje, H., Britt, A., Ranarivelo, T., & Razafitsalama, J. (2006). *Toro-lalan'ireo Satrapotsy (Palmier) eto Madagasikara.* Kew Publishing.

Fathman, E. "Missouri Botanical Garden in Madagascar." Web accessed: http://www.academia.edu/7596866/Missouri_Botanical_Garden_in_Madagascar

Ganomanana, T., Hervé, D., & Randriamahaleo, S. (June 2011). "Dynamique institutionnelle des transferts de gestion dans le corridor Fandriana-Vondrozo." *Madagascar Conservation & Development.* 6(1):15-21.

Hockley, N.J., & Andriamarovololona, M.M. (5 June 2007). "The economics of community forest management in Madagascar: is there a free lunch?" *USAID.* Web accessed: http://pdf.usaid.gov/pdf_docs/PNADL290.pdf

IUCN. (2012). *IUCN Red List Categories and Criteria: Version 3.1.* Second edition. Gland, Switzerland and Cambridge, UK: IUCN. iv + 32pp.

Lehavana, A., Birkinshaw, C., & Raharimampionona, J. (Juillet 2014). *Document Strategique de Gestion de la Nouvelle Aire Protégée de Pointe à Larrée (Antsiraka).* Missouri Botanical Garden.

Missouri Botanical Garden. (1995-2014). "Deforestation and plant diversity of Madagascar's littoral forests." Web accessed: http://www.mobot.org/MOBOT/research/littoral/supplementary_material.shtml

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., & Kent, J. (24 February 2000). "Biodiversity hotspots for conservation priorities." *Nature.* 403: 853-858. Web accessed: http://www.nature.com/nature/journal/v403/n6772/pdf/403853a0.pdf

Rakotoarinivo, M., Blach-Overgaard, A., Baker, W.J., Dransfield, J., Moat, J., & Svenning, J. (20 February 2013). "Palaeo-precipitation is a major determinant of palm species richness patterns across Madagascar: a tropical biodiversity hotspot." *Proceedings of The Royal Society B.* 280(1757). Web accessed: http://rspb.royalsocietypublishing.org/content/280/1757/20123048

Rakotoarinivo, M. & Dransfield, J. (2012). "*Dypsis carlsmithii*." The IUCN Red List of Threatened Species. Version 2014.3. <www.iucnredlist.org>. Downloaded on 21 November 2014.

Rakotoarinivo, M. & Dransfield, J. (2012). "*Dypsis psammophila*." The IUCN Red List of Threatened Species. Version 2014.3. <www.iucnredlist.org>. Downloaded on 21 November 2014.

Rakotoarinivo, M. & Dransfield, J. (2012). "*Dypsis sanctaemariae*." The IUCN Red List of Threatened Species. Version 2014.3. <www.iucnredlist.org>. Downloaded on 21 November 2014.

Rakotoarinivo, M. & Dransfield, J. (2012). "*Ravenea krociana*." The IUCN Red List of Threatened Species. Version 2014.3. <www.iucnredlist.org>. Downloaded on 21 November 2014.

Rakotoarinivo, M., Dransfield, J., Bachman, S.P., Moat, J., & Baker, W.J. (30 July 2014). "Comprehensive Red List Assessment Reveals Exceptionally High Extinction Risk to Madagascar Palms." PLoS ONE 9(7): e103684. doi:10.1371/journal.pone.0103684. Web accessed: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0103684#pone.0103684-Rakotoarinivo1

Razafitsalama, J.L. (Septembre 2009). "Resultat des travaux d'inventaire des palmiers menés dans le complexe forestier de Pointe à Larrée." Missouri Botanical Gardens.

Tropicos.org. Missouri Botanical Garden. 27 November 2014. Web accessed : http://www.tropicos.org/Name/50216112?projectid=17

United States Department of Agriculture: Research, Education & Economics Information System. 2014. VA Poly Institute & State University. "Biodiversity Conservation and Drug Discovery in Madagascar." http://portal.nifa.usda.gov/web/crisprojectpages/0215326-biodiversity-conservation-and-drug-discovery-in-madagascar.html

WWF. (19 November 2014)."Celebrating parks, the planet and people." Web accessed: http://wwf.panda.org/wwf_news/?233454/Celebrating-parks-the-planet-and-people

Appendix I: IUCN Red List Threat Levels

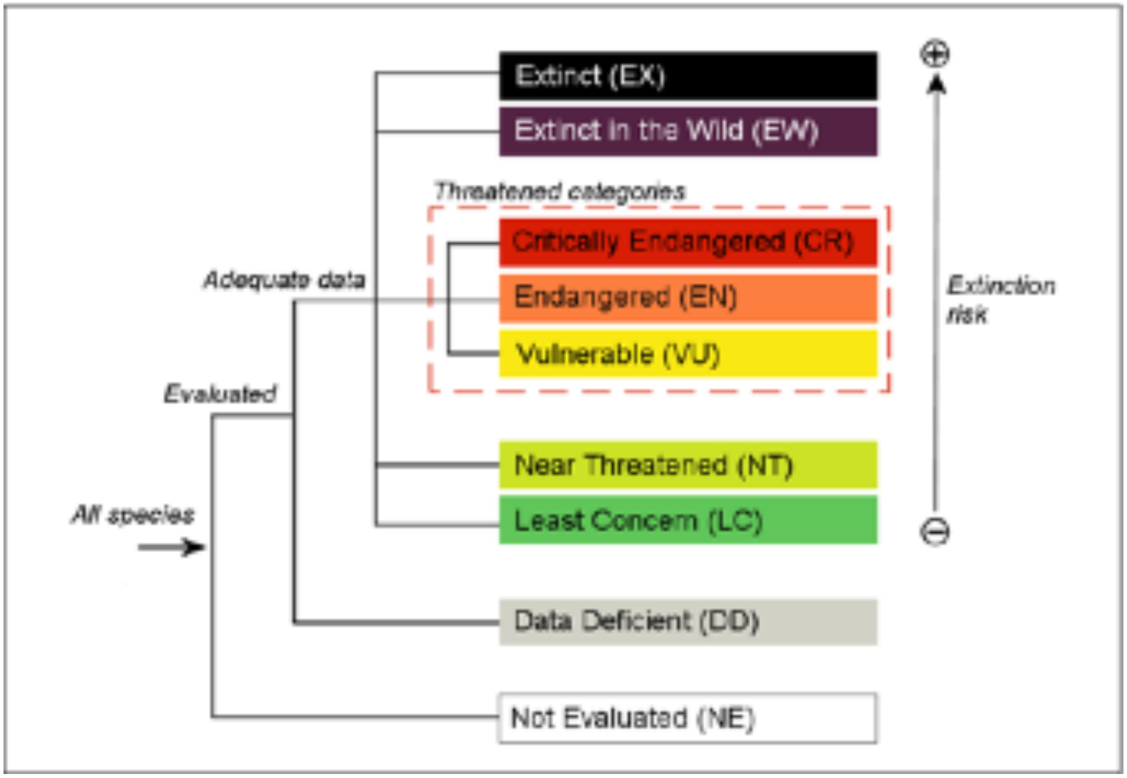


Figure I.1: Structure of IUCN's categories for risk of extinction (Image source: IUCN 3.1)

In 2012, all of Madagascar's palms were reevaluated for "extinction risk under current circumstances" according to IUCN 3.1 criteria, the most recent set of criteria published by the IUCN. All for of the target species for this study fall into "Threatened" categories. The preamble to the criteria is quick to point out that this classification is not a list of conservation priorities, but rather simply another factor to consider when determining conservation action plans.

Appendix II: Species Images

Figure II.1 (left): Juvenile *Ravenea krociana* found in rice field
Figure II.2 (right): Mature male *Ravenea krociana* found in rice field

Figure II.3 (left): Juvenile *Dypsis carlsmithii*
Figure II.4 (right): More developed *Dypsis carlsmithii,* but still no signs of inflorescence

Figure II.5: Medium-density area of *Dypsis sanctaemariae*

Figure II.6: Closer look at *Dypsis sanctaemariae* with remnant inflorescences


Figure II.7 (left): *Dypsis psammophila* fronds
Figure II.8 (right): *Dypsis psammophila* inflorescence

Appendix III: GPS Coordinates

***R. krociana* GPS Locations**

Individual #	S	EO
1	16°48.868'	49°38.493'
2	16°45.560'	49°41.755'
3	16°48.451'	49°40.258'

Figure III.1: The coordinates of each *R. krociana* individual found. Individual #2 was the adult, in the middle of a rice field. Individual #1 was also located in a rice field, and #3 was in someone's yard.

***D. carlsmithii* Transect Starting and End Locations**

Transect #	Start S	Start EO	End S	End EO	Start Elevation (m)	End Elevation (m)
1	16°47.165'	49°41.071'	16°47.230'	49°40.797'	25	2
2	16°47.149	49°40.886'	16°47.097'	49°41.094'	19	36
3	16°47.168'	49°41.090'	16°47.266	49°41.156	14	21
4	16°47.218	49°41.243'	16°47.199'	49°41.357'	11	N/A
5	16°47.044'	49°41.223'	16°36.843	49°41.283'	29	42

Figure III.2: The coordinates and elevation of each *D. carlsmithii* transect's beginning and end. Transects #1 and #2 were 500 m long each, #3 and #4 were 200 m long each, and #5 was 300m long.

***D. psammophila* Plot Corner GPS Coordinates**

Plot #	Corner 1 S	Corner 1 EO	Corner 2 S	Corner 2 EO	Corner 3 S	Corner 3 EO	Corner 4 S	Corner 4 EO
1	16°47.313'	49°41.121'	16°47.306'	49°41.114'	16°47.335'	49°41.106'	16°47.327'	49°41.4095'
2	16°47.333'	49°41.105'	16°47.357'	49°41.088'	16°47.352'	49°41.079'	16°47.330'	49°41.095'
3	16°47.290'	49°41.095'	16°47.267'	49°41.087'	16°47.271'	49°41.078'	16°47.291'	49°41.085'
4	16°47.025'	49°41.131'	16°47.334'	49°41.136'	16°47.344'	49°41.109'	16°47.349'	49°41.115'
5	16°47.349'	49°41.098'	16°47.368'	49°41.083'	16°47.351'	49°41.104'	16°47.373'	49°41.094'
6	16°47.288'	49°41.138'	16°47.311'	49°41.123'	16°47.308'	49°41.116'	16°47.284'	49°41.133'
7	16°47.275'	49°41.101'	16°47.270'	49°41.104'	16°47.269'	49°41.131'	16°47.077'	49°41.139'
8	16°47.306'	49°41.112'	16°47.302'	49°41.102'	16°47.326'	49°41.097'	16°47.321'	49°41.088'

Figure III.3: For each *D. psammophila* plot, the GPS coordinates were recorded at each corner.

***D. sanctaemariae* Plot Corner GPS Coordinates**

Plot #	Corner 1 S	Corner 1 EO	Corner 2 S	Corner 2 EO	Corner 3 S	Corner 3 EO	Corner 4 S	Corner 4 EO
1	16°47.463'	49°40.445'	16°47.465'	49°40.438'	16°47.483'	49°40.447'	16°47.486'	49°40.486'
2	16°47.427'	49°40.517'	16°47.425'	49°40.511'	16°47.447'	49°40.511'	16°47.449'	49°40.514'
3	16°47.458'	49°40.451'	16°47.469'	49°40.456'	16°47.455'	49°40.474'	16°47.457'	49°40.485'
4	16°47.412'	49°40.535'	16°47.419'	49°40.542'	16°47.393'	49°40.555'	16°47.398'	49°40.565'
5	16°48.210	49°39.655'	16°48.207'	49°39.677'	16°48.197'	49°39.677'	16°48.196'	49°39.656'
6	16°48.215	49°39.598'	16°48.213'	49°39.609	16°48.193	49°39.584'	16°48.188'	49°39.593'
7	16°45.573'	49°40.503'	16°45.554'	49°40.485'	16°45.561'	49°40.449'	16°45.582'	49°40.500'
8	16°45.250'	49°40.454'	16°45.458'	49°40.444'	16°45.227'	49°40.466'	16°45.225'	49°40.460'

Figure III.4: For each *D. sanctaemariae* plot, the GPS coordinates were recorded at each corner.

Colberg 34

Appendix IV: Projected Overall Populations for *D. psammophila* and *D. sanctaemariae*

Plots were not randomized but rather targeted known populations, thus this is not a scientifically rigorous estimate, especially considering the large size of the standard deviations. Additionally, keep in mind that the counts go off of individual stalks, not clusters. However, in the interest of trying to form some sort of overall population estimate, this appendix still uses the densities found. From personal observation, the percentage of habitat actually containing these species can be used to very roughly estimate the overall population in the area. Habitat areas are estimates from Adolphe Lehavana, an MBG botanist familiar with the area, while average densities are for mature individuals only.

For *D. psammophila*, the surface area covered by its habitat is estimated to be 150 ha. I estimate that it is present in about 30% of its habitat, or 45 ha. Using its average population density converted to ha, 922.5 individuals per ha, and multiplying that by the amount of land it is estimated to inhabit, we get an estimated population of 41512.5 mature individuals.

Performing the same operation for *D. sanctaemariae*, its habitat is estimated at roughly 6 ha. I estimate that it is present in 20% of this, or 1.2 ha. Its average population density in ha, 317.5 individuals per ha, applied to the estimated inhabited land, brings an estimated population of 381 ha.