Two of Madagascar’s Most Threatened Palms: Voanioala gerardii and Lemurophoenix halleuxii

Madagascar has a high diversity of endemic palm species and the Masoala Peninsula is a hotspot for their diversity. Several species are critically endangered, and their populations are known to be in decline due to a combination of land clearance, destructive harvesting for heart of palm and potentially unsustainable commercial seed collection. The critically endangered Voanioala gerardii and the endangered Lemurophoenix halleuxii are two palm species from monospecific genera endemic to Madagascar that overlap in their distribution within this region.

Madagascar is known around the world for its unique flora and fauna. It contains 199 species of palms, 97 percent of which are endemic to the island (Rakotoarinivo & Dransfield 2010). Unfortunately, 145 species of the currently known palms of Madagascar are now threatened with extinction according to the IUCN Red List criteria (Rakotoarinivo & Dransfield 2011). Currently very little is known about the ecology or genetics of Madagascan palm species (Dransfield & Beentje 1995, Ratsirarson et al. 1996, Shapcott et al. 2007). The eastern escarpment region contains the greatest diversity of palms in Madagascar, many species being restricted to this area (Demetz 1999, Rakotoarinivo et al. 2007, Rakotoarinivo & Dransfield 2010). The Masoala Peninsula, which is partially protected within a National Park, is a hotspot for palm diversity where several species are critically endangered and their populations known to be in decline due to a combination of land
clearance, destructive harvesting for heart of palm and potentially unsustainable commercial seed collection.

Some of the most threatened species in this region are large and charismatic and have been sought after by palm enthusiasts around the world. Two such species are the critically endangered *Voanioala gerardii* (IUCN 2009) and the endangered *Lemurophoenix halleuxii* (IUCN 2009), both from monospecific genera that are endemic to Madagascar and overlap in their distribution within this region. *Voanioala gerardii* and *L. halleuxii* are known to exist only in small, isolated populations within rainforests on the Madagascan “vanilla coast” surrounding the Bay of Antongil in northeastern Madagascar. The palms are known to be found in the Masoala National Park, but new unprotected populations were discovered in 2005 during comprehensive palm inventory studies undertaken by Royal Botanic Gardens Kew/Madagascar (Rakotarinivo 2008).

*Voanioala gerardii*, a member of subfamily Arecoideae, tribe Cocoseae, subtribe Attaleinae (Dransfield et al. 2008) (Figs. 1–3) is a majestic palm known as the “forest coconut” and is sought after by palm enthusiasts around the world leading to a trade in the seeds of this species and a source of income for local people. It was CITES listed in an attempt to assist with its conservation in the wild. The heart of palm is also harvested by local people. *Lemurophoenix halleuxii*, the “red lemur palm,” belongs to subfamily Arecoideae, and tribe Areceae, subtribe Dypsidinae (Dransfield et al. 2008) (Fig. 4). The fruit grows to approximately 5 cm in diameter and is said by villagers to be eaten by lemurs (Dransfield et al. 2008).

Palm are an important resource for indigenous people in Madagascar, for food, fiber and construction (Dransfield & Beentje 1995, Byg & Balslev 2001a). Palm heart is widely harvested in the region, and the seeds of many palm species are collected for the ornamental trade (IUCN 2009, Rakouth & Roger 2011). However, this puts single stemmed species at risk as harvesting for seed or palm heart often results in trees being cut down leading to tree death (Byg & Balslev 2001a & b, Dransfield et al. 2008). Even though Madagascar has established numerous National Parks, less than 15% of Madagascar’s natural forests remains intact (Cadotte et al. 2002, Marie et al. 2009), and many species located within National Parks are still harvested. Recent political events have put even greater pressure on the existing protected areas, according to reports of logging and other illegal activities.

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1 (left). *Voanioala gerardii*, the forest coconut, growing in Masoala National Park. 2 (right). The distinctive trunk of an adult plant.
We undertook searches to find these palms in remote rainforest in eastern Madagascar shortly after the political upheavals in 2009. We aimed to document the population size and demographic structure and to collect samples for genetic studies in order to gain a better understanding of the species and its conservation requirements and to engage with the local ANGAP (Madagascar Protected Areas) staff and local villagers to raise their awareness of these species and their conservation. The detailed genetic results can be found in Shapcott et al. (2012).

Methods

*Lemurophoenix halleuxii* grows to 20 m tall; it has a distinct pink and grey crownshaft and red newly exposed leaves (Dransfield et al. 2008). It is monoecious and protandrous with flowers borne in triads; inflorescences grow to 2 m in length with over 100 flower-bearing branches (Dransfield et al. 2008). Nothing is known about its pollination biology. *Voanioala gerardii* grows to 15–20 m and is found in primary rainforest to an elevation of approximately 400 m (Dransfield & Beentje 1995, Dransfield et al. 2008). It is monoecious, with solitary inflorescences that are apparently protandrous; the pollinators are unknown (Dransfield 1989). The large single-seeded fruit (7–8 cm by 4–5 cm) is rich red-brown when ripe with a fibrous outer and fleshy inner mesocarp, and grows in large bunches at the crown (Dransfield 1989, Dransfield & Beentje 1995). The dispersal mechanisms are unknown; fruit is often found at the base of trees (Dransfield et al. 2008). It seems possible it could be dispersed by water or by large frugivores and it has been hypothesized it may have been dispersed by the now extinct giant elephant bird (Dransfield & Beentje 1995). *Voanioala gerardii* is one of only four palms known to be polyploid and has the highest number of chromosomes ($2n = 550–600 \pm 3$) of all the monocotyledons (Johnson 1989, Röser 1994).

The political upheavals at the time restricted air travel to this remote area. The first trip to revisit the newly discovered populations was taken after delays due to the closure of the main airport in Antananarivo due to political unrest. The second trip was undertaken overland due to uncertainty of air travel and luggage restrictions. This adventurous route, complete with multiple barge crossings and bridge repairs (bring your own planks!) (Fig. 5), took four days in either direction to the port town of Maroantsetra, from where a day long trip by speedboat through rice paddies took us to our base camp in a remote part of the Masoala National Park to survey *Lemurophoenix halleuxii*. We undertook day long surveys to each of the known populations in this area. After return to Maroantsetra, we headed out again to the Masoala peninsula on another day long speedboat trip where we set up another base camp from which to make our surveys. We were assisted by botanist Jao Aridy from ANGAP, who acted as an important liaison with the local villagers, who knew the location of all populations and who was able to lead us to a new previously unknown population of *V. gerardii* in the Masoala National Park. We were also assisted with our base camp set up and surveillance by ANGAP staff and local villagers as there had been reports of local poachers in the area. We also hired local guides to assist us navigate the forest at each location.

All known populations of *V. gerardii* (VG) and *L. halleuxii* (LH) were surveyed during this study to document population size and structure, reproductive activity and sample for genetic analysis (see Shapcott et al. 2012). There is an additional herbarium record of seedlings of *V. gerardii* (in Masoala Peninsula), but this was not visited due to difficulty of accessing this remote site. Populations at each site were systematically surveyed in their
entirety for either *V. gerardii* or *L. halleuxii* and the location recorded at the start and finish using a GPS. The relative locations of each plant were also recorded. The relatively large numbers of small sized plants of *L. halleuxii* meant some plants may have been missed in the steep, highly dissected terrain. Data recorded for each individual included trunk height to the crown shaft, or total height for plants without a trunk, trunk diameter at breast height (DBH) if present, and evidence of reproductive activity, such as presence of flowers, fruit or old inflorescences. Individuals were categorized according to life stage class as follows: seedlings with entire bifid leaves; juveniles with pinnate leaves but no apparent trunk; sub-adults with pinnate leaves and a trunk, but not yet reproductive; adults with pinnate leaves, a trunk and evidence of reproduction or a size shown to be capable of reproduction. Populations were systematically sampled for genetic analysis from across their spatial distribution (see Shapcott et al. 2012).

**Results**

We confirmed the largest population of *L. halleuxii* (LH01; from the Ampotaka region that was originally discovered in 2005) comprised only 10 adults (20–35 m tall and 30–50 cm DBH), 6 sub-adult trunked plants and dominated by seedlings (280 of 320 plants). This population is not currently protected, and only three plants retained evidence of recent reproductive activity. However, the large number of seedlings found indicates viable fruit has been produced recently and that germination is successful in the wild. We were not able to confirm the single historical recording of this species from the Masoala Peninsula (LH2) or indeed find any evidence of this species from that area. We found two populations close to each other (LH3, LH4) in another part of the Masoala National Park. These populations also had few trunked adult plants (LH3, 6 adults; LH4, 12 adults) and were conspicuous in their lack of sub-adult plants with only two of these present in LH3. However, these populations had higher reproductive output with 5 of the 6 adults in LH3, and 10 of the 12 adult plants in LH4 with fruits present. The large numbers of seedlings found indicate that the fruit produced in these populations is viable and germinates in the wild at these sites also. However, these populations had a greater number of juvenile plants indicating that recruitment to larger sizes has been taking place. It was hypothesized that the lack of sub-adult sized plants may be
a result of past harvesting of this size plant prior to National Park protection. We observed one dead fallen tree in our surveys (Fig. 6) and observed considerable evidence of human activity within close proximity of the National Park boundary. The total number of *L. halleuxii* recorded was only 28 adult plants and a total of 729 plants documented. The populations are quite compact and dense. The largest population, LH01, was the densest with the average distance between adult plants 4.7 m, the most sparse population was also the smallest, LH3, where adults trees were 14.2 m apart on average (see Shapcott et al. 2012). It is expected that this species is pollinated by insects. The close proximity of adult trees and high reproductive activity appears to have enhanced outcrossing, and the populations are generally not inbred; however, where the trees are further apart there was evidence of inbreeding suggesting fewer pollinators fly these distance between flowers (Shapcott et al. 2012).

While the populations were clumped there was clear evidence of localized dispersal away from adult trees. The large fleshy fruit is thought to be attractive to lemurs, and we saw evidence that *Daubentonia madagascariensis* (the Aye-Aye lemur) had fed on its fruit (Fig. 7). We documented a total of 135 *V. gerardii* plants from four populations. However, only seven adults plants and 13 sub-adults were recorded. The newly discovered and unprotected populations located in the Ampotaka region (VG1, VG2) had no adult plants present. These had apparently been felled between the time of original population discovery (in 2005) and the 2009 survey for this study (pers. obs. Rakotoarinivo). The relatively large number of seedlings and all life stages except adults in VG1 indicated that prior to the recent felling this is likely to have been the largest population of *V. gerardii*. In our survey VG1 consisted of 71 plants, of which 31 were seedlings, 33 juveniles and 7 sub-adult plants. The second population nearby (VG2) consisted of only six sub-adult plants (see Shapcott et al. 2012). The lack of small plants suggests either adults were felled much longer ago or it has arisen relatively recently from some multiple dispersal events. In the Masoala National Park we identified two populations (VG3, VG4). The newly discovered population (VG3) consisted of only four adult plants and 22

5. We brought our own planks to repair broken bridges along the Vanilla Coast of Madagascar en route to the Masoala National Park.
seedlings, 20 of these were located close to one tree. Three of the four adult plants were, or had recently been reproductively active with fruit present at the time of the study. Genetic results indicated that the 20 seedlings had not arisen due to self-pollination of the maternal tree and confirmed that another tree has pollinated at least some flowers of this tree (Shapcott et al. 2012). The adult trunked plants were of varying sizes/ages ranging from 4.5 m to 28 m to the base of the leaf sheath, and ranging from 50 to 120 leaf scars present. The second population in the Masoala National Park (VG4) was spatially clustered into two distinct sub-populations (VG4a, VG4b). The first sub-population (VG4a) with 25 plants consisted only of seedlings and immature non-trunked plants. There were 20 seedlings less than 1 m tall; 2 plants 1–3 m tall; and 3 non-trunked plants 4 m or taller, all located within a small area. Genetic studies found several seedlings and a sub-adult from the VG4a subpopulation contained an allele at one genetic locus that was not found in the neighboring VG4b or VG3 populations (Shapcott et al. 2012). This suggests that these seedlings arose from adults either recently felled or from an as yet undiscovered nearby population. In the second sub-population (VG4b) there were no seedlings present. It had seven plants in total, of which three were adult trunked trees 4, 8 and 15 m to the base of the leaf sheath respectively and ca. 20–25 cm in diameter, and four non-trunked plants 4 m or taller. Two of the three adult plants were reproductively active at the time of the survey. In the 1980s, ten V. gerardii adults were recorded in VG4 (Dransfield 1989), but now only 3 remain indicating population decline. The results provide some evidence that there may be more as yet undiscovered populations within the Masoala region, which is supported by evidence of seedlings reported from another site within the region.

Despite the smaller population sizes there was approximately twice as much genetic diversity found in populations of V. gerardii, compared with L. halleuxii (Shapcott et al. 2012). There was little difference in levels of diversity among populations in L. halleuxii, whereas, in V. gerardii allelic diversity was apparently correlated with increasing population size and was unexpectedly high given the extremely small population sizes, nevertheless all populations were inbred (Shapcott et al. 2012). We also found that the two groups of V. gerardii...
populations were surprising genetically similar given their isolation from each other. In contrast, *L. halleuxii* populations were genetically distinct between regions (Shapcott et al. 2012).

**Discussion and conclusions**

We found extremely small population sizes for both species; in particular, the number of trunked adults was very small for both species, especially *V. gerardii*. This is most likely a consequence of harvesting and fragmentation. A study of the palm *Astrocaryum mexicanum* revealed a major decline in adults in its populations due to fragmentation (Arroyo-Rodriguez et al. 2007). Other Madagascan palm species have had populations reduced to immature plants due to harvesting (Shapcott et al. 2007). Both species display evidence of active recruitment of seedlings and juvenile plants, but there is a noticeable lack of recruitment of trunked plants to sub-adult sizes in several populations. Both species are traditionally harvested for heart of palm; this practice targets sub-adults (pers. comm. local guides), which may account for some regeneration failure. Adult trees are also felled to obtain seeds for commercial sale, particularly to the overseas market. We encountered seed collectors claiming to be looking for these species during our surveys. Even if protected from harvesting, survival to reproductive maturity is variable among populations and only a small proportion of the current immature crop may reach maturity. Given the likely long time from seedling to reproductive maturity any harvesting of this species that leads to tree death is unsustainable for the foreseeable future and could lead to extinction of the species. Given their very small population sizes and slow maturation, these two species should be considered at great risk of extinction.

Low genetic variation was found in *L. halleuxii*, consistent with expectations (Shapcott et al. 2012). However, in contrast to expectations very high levels of genetic diversity, in comparison to other palm species, were found in *V. gerardii* (Shapcott et al. 2012). The relatively high levels of genetic diversity found within populations of *V. gerardii* are consistent with results found for some of its closest relatives, such as *Cocos nucifera* (Teulat et al. 2000) and *Beccariophoenix madagascariensis* (Shapcott et al. 2007; Shapcott et al. 2012). It has been suggested that high genetic diversity in rare and endangered species is an indication of historically larger populations (Shapcott et al. 2007) or populations linked by gene flow (Shapcott 1998). The results could indicate that more populations are located nearby that have yet to be found, or that the species had until recently been more abundant.

An active program involving local villagers and land managers in the conservation and restoration of these species would be required to prevent their extinction. Significant populations of both species are currently protected within the Masoala National Park but park managers need support to maintain their protection. Conservation should focus on conserving populations from both regions of *L. halleuxii* given their genetic distinctiveness, while in *V. gerardii* more focus could be placed on conserving the largest number of adults of this species and enabling smaller plants to mature. An active program to change methods of seed collection to stop the destructive seed harvesting practices replacing this with more sustainable approaches is important for these species. A reduction in demand for the seed of these species by palm enthusiasts internationally could greatly assist in reducing the pressure on wild harvesting of seeds of these species.

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**LITERATURE CITED**


