

# Conservation status of vascular plant species from the QMM / Rio Tinto mining area at Mandena, Tolagnaro (Fort Dauphin) region, southeast Madagascar

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## ABSTRACT

A botanical inventory of the Mandena littoral forest, completed in 1991 as part of an environmental impact assessment study for a titanium oxide mining project being developed by QMM / Rio Tinto in the Tolagnaro (Fort Dauphin) region of southeastern Madagascar, identified 29 plant taxa as priorities for conservation, including 16 known only from the proposed mining path (Priority 1) and 13 restricted to the exploration zone (Priority 2). A re-evaluation in 2001 added 11 taxa from Mandena (the first of three sites targeted for mining, to be followed later by Petriky and then Sainte Luce) and removed 13 others, leaving a total of 27 taxa, five classified as Priority 1 and 22 as Priority 2. Using currently available data, we have removed four additional taxa from the list (three because populations were found outside the Tolagnaro area and one because its earlier inclusion on the list had been in error) and transferred four others from Priority 1 to Priority 2 as populations had been located within one or more of the newly-established conservation zones at Sainte Luce (747 ha), Mandena (230 ha) and Petriky (125 ha). Of the 15 currently recognized priority taxa present at Mandena, only two (an undescribed species in each of the genera *Canthium* and *Pseudocatha*) appear to be endemic there, but all remain a focus of QMM's environment, conservation and restoration activities. A total of 15 Mandena taxa are listed as threatened on the 2008 IUCN Red List (3 Critically Endangered, 7 Endangered, and 5 Vulnerable), most of which must be regarded as important for conservation; only three of these taxa also appear on the priority list, and none of the 12 remaining priority taxa from Mandena have been assessed for the Red List, underscoring the urgent need to expand evaluation to encompass the entire Malagasy flora and in particular range-restricted taxa.

## RÉSUMÉ

Un inventaire botanique de la forêt littorale de Mandena, clôturé en 1991 dans le cadre d'une étude d'impact environnemental portant sur un projet d'extraction minière d'oxyde de titane élaboré par QMM / Rio Tinto dans la région de Tolagnaro (Fort-Dauphin) au sud-est de Madagascar, a identifié 29 taxons de plantes prioritaires en matière de conservation, dont 16

taxons qui n'étaient connus que des seules parcelles à exploiter (Priorité 1) et 13 taxons dont la distribution était limitée à la zone d'exploration (Priorité 2). Une nouvelle évaluation en 2001 ajouta 11 taxons de Mandena (premier site qui fera l'objet de l'exploitation minière et qui sera suivi par Petriky puis Sainte Luce) et retira 13 autres taxons, ramenant ainsi la liste à 27 taxons dont cinq taxons de Priorité 1 et 22 de Priorité 2. En considérant les données actuellement disponibles, nous avons retiré quatre autres taxons de la liste (trois taxons pour lesquels des populations ont été localisées au-delà de la région de Tolagnaro et un dernier taxon car son inclusion initiale sur la liste n'était pas justifiée) et en avons déclassé quatre autres taxons en les passant de Priorité 1 à Priorité 2 avec des populations identifiées dans une ou plusieurs zone(s) de conservation nouvellement mise(s) en place à Sainte Luce (747 ha), Mandena (230 ha) et Petriky (125 ha). Sur les 15 taxons prioritaires actuellement reconnus et qui sont rencontrés à Mandena, seulement deux (une espèce non décrite dans chacun des genres *Canthium* et *Pseudocatha*) semblent y être endémiques mais tous sont concernés par les activités environnementales, de conservation et de restauration de QMM. Quinze taxons de Mandena figurent sur la Liste Rouge des espèces menacées 2008 de l'UICN (3 'en danger critique d'extinction', 7 'en danger' et 5 'vulnérable') dont la plupart doivent être considérés comme importants pour la conservation ; seuls trois de ces taxons apparaissent également sur la liste prioritaire alors qu'aucun des 12 autres taxons prioritaires de Mandena n'a été évalué pour la Liste Rouge, soulignant ainsi le besoin urgent d'étendre l'évaluation pour inclure l'ensemble de la flore malgache et plus particulièrement les taxons avec des distributions réduites.

KEYWORDS: IUCN Red List, littoral forest, plants, priority species, QMM / Rio Tinto.

## INTRODUCTION

The Mandena forest, located ca. 10 km NNE of Tolagnaro (Fort Dauphin) in southeastern Madagascar (for example Figure 1), has been the subject of botanical inventory work since the 1950s, when a forestry station was established and agents

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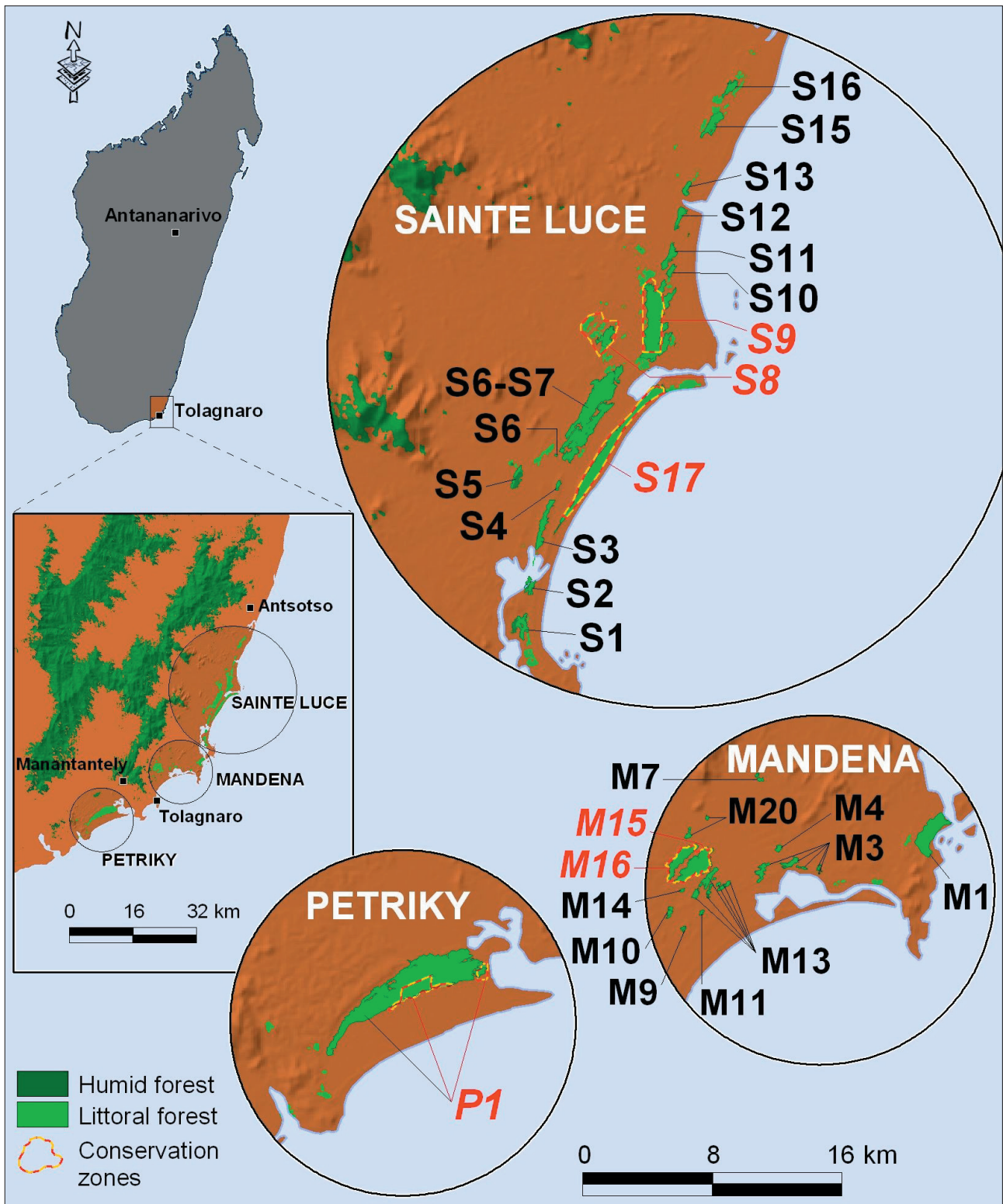


FIGURE 1. Map of the Sainte Luce, Mandena and Petriky areas in southeast Madagascar, indicating the location of major littoral forest parcels (light green), including those that comprise the newly-established conservation zones at the three sites (dashed red and yellow lines).

began collecting specimens as part of an effort to document the island's woody plants in a new herbarium that had recently been established in Antananarivo by forest botanist René Capuron. Over the following three decades, approximately 500 plant collections were made at Mandena, several of which represented species new to science, and Capuron himself visited the site on at least four occasions.

Starting in 1986, QIT Madagascar Minerals (QMM) began an extensive exploration program along the eastern coast of Madagascar to locate deposits of heavy mineral sands containing titanium dioxide. Major mineral sediments were found at Mandena, Sainte Luce, and Petriky (for example Figure 1, 2) underneath southeastern Madagascar's largest remaining stands of littoral forest, a distinctive type of humid evergreen

forest restricted to unconsolidated sand within a few kilometers of the Indian Ocean (Vincelette et al. 2003 and 2007a, Consiglio et al. 2006, Rabenantoandro et al. 2007). As the mining project was developed, a series of studies commissioned by QMM clearly demonstrated the importance of the region's biodiversity and identified many issues with ramifications for environmental conservation (Ganzhorn et al. 2007). In late 2003, Rio Tinto, which had previously acquired QMM, provided further support to addressing biodiversity issues in the Tolagnaro region with the promulgation of its Biodiversity Strategy and Guidelines (Rio Tinto 2004), officially launched in November 2004 during the IUCN World Conservation Congress in Bangkok, Thailand.

As part of QMM's initial environmental impact assessment conducted in the late 1980s and early 1990s, a preliminary study was undertaken to document the flora of the littoral forests of the Tolagnaro region and to identify plant species (and infraspecific taxa) that might be endemic to these forests and whose continued survival might thus be placed at risk by the mining operation. Using data gathered in the field by a team of experienced botanists as part of an extensive botanical inventory of the Sainte Luce, Mandena and Petriky sites (an ongoing endeavor that to date has generated more than 1,500 additional collections) supplemented with information from the available literature and specimens deposited in the major herbaria containing collections of Malagasy plants (within Madagascar as well as in France and the USA), a list was compiled of plant taxa that had been documented from one or more of the three sites but were not known from recent specimens made elsewhere. This list was presented in an unpublished technical report (Lowry 1991) that comprised part of QMM's initial environmental impact assessment. Each taxon on this list of potential 'priority plant species for conservation' was classified into one of two categories:

- Priority 1: taxa known only from the planned mining path at Sainte Luce, Mandena and Petriky
- Priority 2: taxa restricted to the QMM mine exploration zone

The original list comprised a total of 29 priority taxa, 16 classified as Priority 1 taxa and 13 as Priority 2 taxa (Lowry 1991). These became one of the primary foci of QMM's *in-situ* and *ex-situ* propagation and conservation activities (Vincelette et al. 2007b) and were the target of intensive field studies to learn more about the distribution, ecology and biology of these species in an effort to ensure that the mining company would be able to implement appropriate measures to ensure their long term survival (see for example Randriatafika et al. 2007). Protection of the priority taxa also provided a major impetus for the establishment in 2000 of a 230 ha community-managed conservation zone at Mandena comprising parcels M15 and M16 (for example Figure 1) and formally incorporated into Madagascar's growing network of protected areas in 2008. A conservation zone was also established at Sainte Luce in 2005 encompassing 747 ha of forest and wetland, and 125 ha were included in a conservation zone at Petriky in 2008 (Vincelette et al. 2007a and 2007c).

When QMM's revised environmental and social impact assessment was conducted in 2001, the original list of priority plants provided a decade earlier by Lowry (1991) was re-evaluated and updated in a second unpublished report (Lowry 2001). The process of updating the list involved the following aspects:

- Taxa on the initial 1991 list were re-examined with regard to their presence within each of the three planned mining zones (Sainte Luce, Mandena and Petriky) rather than collectively for the three sites as in the initial study.
- Taxa were evaluated with respect to the IUCN Red List criteria (IUCN 2001) in an effort to ensure that consideration was given to all taxa that were potentially threatened or otherwise of conservation concern.
- Taxa that had been added to the overall floristic list in the decade between 1991 and 2001 were examined using the same criteria as those applied by Lowry (1991) and were included on the revised list of priority plant taxa as appropriate.
- New collections made between 1991 and 2001 of taxa on the original priority list were recorded and the list was updated accordingly.

Analysis of the updated information resulted in a revised list that included a total of 27 priority taxa, five of which were classified as Priority 1 taxa and 22 as Priority 2 taxa (as reported by Lowry 2001). Since then, all of these priority taxa have remained a focus of QMM's environment, conservation and restoration activities. However, as exploitation will first begin in the Mandena zone in late 2008, the status of the priority taxa known from this site is of the most immediate concern. In this paper we re-examine and update the status of the priority taxa for conservation occurring at Mandena.

## METHODS

In order to identify Priority 1 and Priority 2 taxa at Mandena we first generated a list of all plants recorded from the area by consulting two key sources. The TROPICOS database (Missouri Botanical Garden-a) is the world's largest and most comprehensive source of botanical data, containing extensive information on the Malagasy flora, including all data gathered as part of the flora and vegetation component of the QMM environmental impact assessment study, supplemented with information on more recent collections made in the region and in other littoral forest sites along Madagascar's east coast (see Consiglio et al. 2006) as well as on Malagasy species recently described as new to science. The SONNERAT database (Muséum National d'Histoire Naturelle) contains extensive records of collections from Madagascar along with digitized images of thousands of type specimens, many of which are not represented in other herbaria. Data from these two sources were combined, checked and corrected as necessary to generate a comprehensive list of all taxa recorded from Mandena.

Using this updated floristic list, data were then examined to determine which taxa are widely distributed within Madagascar and / or have been documented from outside the Tolagnaro region during the last 20 years. These taxa, whose continued survival is not directly threatened by the mining operation, were excluded from further consideration as potential local endemics. The remaining taxa were regarded as possibly endemic to the Mandena area and therefore potentially at risk and candidates for Priority 1 or Priority 2 status. Recently published taxonomic works were consulted to extract relevant information that had not yet been captured into the TROPICOS or SONNERAT databases. We also examined the field books of botanists who had recently collected in the Tolagnaro region for additional informa-





FIGURE 2: Littoral forest at Petriky, southeast of Tolagnaro (Fort Dauphin), where many QMM priority plant species occur, including eight that are shared with Mandena. The road on the right of the image was opened in the mid-1980s to provide access for QMM's exploration work (Photo: J. Rabenantoandro/QMM).

tion. The data obtained through these steps were compiled in an 'endemic species data file', which has been kept up-to-date as new information has become available.

The list of taxa in the data file was then compared with the 1991 list of priority taxa in order to identify those whose status had changed as a result of information that had become available in the intervening years. Taxa that had originally met the criteria for Priority 1 or Priority 2 status in 1991 but no longer did were noted, and the reasons for their change in status were recorded. Examples of such changes in status include broadened species circumscriptions that encompassed populations from other parts of Madagascar and the discovery of populations at sites within the Tolagnaro region but outside the mine exploration zone. Information on taxa belonging to groups currently being studied was solicited from specialists and was included in the re-evaluation of species whenever possible.

We then reviewed data on all Malagasy plant species on the IUCN Red List (IUCN 2008) and noted those recorded from the Mandena area. Because Red Listed taxa are widely regarded as of potential conservation concern, all those present at Mandena were included in the data file, regardless of whether they were considered to be endemic there or whether they met the criteria for Priority 1 or Priority 2 status. Botanists conducting taxonomic research on various Malagasy plant groups were also consulted to determine whether they knew of any species that they regarded as potentially endemic to the Mandena area but had not previously been classified as priority taxa or included in the endemic species data file. These taxa were likewise added to the data file.

In order to facilitate fieldwork by QMM staff conducted as part of a program to locate and identify populations of taxa in the endemic species data file, a field guide was compiled containing detailed information on each taxon, including collection records with geographic coordinates, scanned images and drawings, species descriptions, and notes provided by specialists (when available). An intensive campaign of fieldwork was conducted between July 2000 and February 2001 in areas outside the Mandena zone and beyond the limits of the proposed mining path to locate populations of the species listed in the data file from new localities where their presence had not previously been recorded. Each new population was documented using the same standard techniques (Missouri Botanical Garden-b) that had previously been used for the flora and vegetation environmental impact assessment study and subsequent fieldwork. The information obtained was used to update the list of priority species, as reported by Lowry (2001). Fieldwork has continued since then and relevant data have systematically been entered into the endemic species data file.

Finally, the information contained in the endemic species data file was incorporated into a GIS and was used to map each taxon in order to conduct a visual evaluation of its geographic distribution, and to confirm whether any populations had been recorded within the previous 20 years outside the mine exploration area or whether the taxon must be regarded as endemic to Mandena. The results of these analyses were used to generate a revised list of Priority 1 and Priority 2 taxa using the criteria indicated above.

## RESULTS

The current revised and updated floristic list for the Mandena area contains a total of 414 species of vascular plants (see Rabenantoandro et al. 2007 for a complete listing). This list is not definitive and will in all likelihood change with new identifications and additional fieldwork. It does, however, accurately reflect the current state of knowledge of the area's flora as of late 2007.

Table 1 lists the 40 taxa recorded within the QMM mining area (Sainte Luce, Mandena and Petriky) that have at one time or another been regarded as Priority 1 or Priority 2 taxa (see Figures 3, 4, 5, 6 for example). These include the 29 taxa on the original 1991 priority species list (Lowry 1991) along with 11 taxa from Mandena that were added to the list in the 2001 update (Lowry 2001).

TABLE 1. List of the 29 priority plant taxa identified for the 1991 QMM environmental impact assessment and the 11 priority taxa from Mandena added in 2001, with their current (2008) status along with the reasons for changes in status, additions and removals from the list.

Taxon (as indicated in the 1991 flora study and / or the 2001 update)	Family	Priority category in 1991 list	Priority category in 2001 list	Current priority category in 2008	Known from Mandena	Reason of change in priority category (if any) or addition to removal from priority taxon list
<i>Asteropeia micraster</i> Hallier f.	Asteropeiaceae	Not listed	2	Not listed	+	Species limits recently revised by specialists; found at Mahabo outside the Tolagnaro region
<i>Astrotrichilia elliotii</i> (Harms) Cheek	Meliaceae	1	2	2	+	Found in the Mandena conservation zone (M15), in parcel M7 (off mine path), and in Petriky; probably occurs elsewhere in Madagascar but not recently documented
<i>Apodytes</i> sp. nov.	Icacinaceae	2	Not listed	Not listed	+	Found at Antsotso outside the Tolagnaro region; recently described as <i>A. bebile</i> Labat et al.
<i>Canthium</i> sp. nov.	Rubiaceae	Not listed	1	1	+	Species recently recognized by specialist (not yet published)
<i>Capurodendron delphinense</i> Aubrév.	Sapotaceae	2	2	2	-	Status unchanged, occurs at Petriky
<i>Cissus leucophlea</i> (Scott-Elliot) Suss.	Vitaceae	1	1	1	-	Status unchanged, occurs at Petriky
<i>Croton louvelii</i> Leandri	Euphorbiaceae	2	Not listed	Not listed	+	Specimens now placed in <i>C. daphniophyllum</i> ined.
<i>Croton trichotomus</i> Geiseler var. <i>pulchellus</i> (Baill.) Leandri	Euphorbiaceae	Not listed	1	2	+	Specimens previously unidentified, found in the Petriky conservation zone
<i>Cryptocarya elliotii</i> Kosterm.	Lauraceae	1	1	1	-	Now included in <i>Aspidostemon parvifolium</i> (Scott-Elliot) van der Werff, which remains a Priority 1 taxon
<i>Cynorkis elata</i> Rolfe	Orchidaceae	1	2	2	+	Found in the Mandena conservation zone (M15), in parcel M7 (off mine path), and in the Sainte Luce conservation zone (S9)
<i>Diphasia madagascariensis</i> H. Perrier	Rutaceae	2	Not listed	Not listed	-	Taxon now placed in <i>Vepris madagascariensis</i> (H. Perrier) Mziray; recent collections made outside the Tolagnaro region
<i>Dombeya australis</i> Scott-Elliot ssp. <i>australis</i>	Malvaceae s. lat.	1	Not listed	Not listed	+	Recent collections made outside the Tolagnaro region
<i>Dombeya mandenensis</i> Arènes	Malvaceae s. lat.	1	2	2	+	Found in the Mandena conservation zone (M15 & M16) and at Sainte Luce
<i>Dracaena bakeri</i> Scott-Elliot	Ruscaceae	1	2	2	+	Found in the Mandena conservation zone (M16)
<i>Eligmocarpus cynometroides</i> Capuron	Fabaceae	2	1	1	-	Populations from outside Petriky now extinct
<i>Eugenia cloiselii</i> H. Perrier	Myrtaceae	2	Not listed	Not listed	+	Recent collections made outside the Tolagnaro region
<i>Eulophia palmicola</i> H. Perrier	Orchidaceae	Not listed	2	Not listed	-	Not present at Mandena (collected in 1995 outside mine area at Nahampoina private reserve)
<i>Euphorbia francoisii</i> Leandri var. <i>francoisii</i>	Euphorbiaceae	Not listed	2	2	+	Specimens previously unidentified; found in the Mandena conservation zone (M15 & M16) and in the Petriky conservation zone
<i>Euphorbia lophogona</i> Lam.	Euphorbiaceae	Not listed	2	2	+	Specimens previously unidentified; found in the Mandena conservation zone (M15 & M16) and in the Sainte Luce conservation zone (S9)

TABLE 1. Continued

Taxon (as indicated in the 1991 flora study and / or the 2001 update)	Family	Priority category in 1991 list	Priority category in 2001 list	Current priority category in 2008	Known from Mandena	Reason of change in priority category (if any) or addition to removal from priority taxon list
<i>Kalanchoe rosei</i> Raym.-Hamet & H. Perrier ssp. <i>serratifolia</i> Humbert	Crassulaceae	2	Not listed	Not listed	-	Now regarded as a hybrid and no longer considered a valid taxon
<i>Leptolaena delphinensis</i> G. E. Schatz & Lowry	Sarcolaenaceae	Not listed	2	2	+	Species recently described by specialists; found in the Mandena conservation zone (M15 & M16) and in the Sainte Luce conservation zone (S9)
<i>Malleastrum mandenense</i> J.-F. Leroy	Meliaceae	2	2	2	+	Found in the Mandena conservation zone (M15 & M16), in the Sainte Luce conservation zone (S9 and S17) and at Petriky
<i>Meineckia websteri</i> Brunel & J. Roux	Euphorbiaceae	1	1	1	-	Status unchanged; found in the Petriky conservation zone
<i>Memecylon delphinense</i> H. Perrier	Myrtaceae	1	Not listed	Not listed	+	Found at Antsotso outside the Tolagnaro region
<i>Mollugo decandra</i> Scott-Elliott	Mollugonaceae	2	Not listed	Not listed	-	Recent collections made outside the Tolagnaro region
<i>Oncostemum dauphinense</i> H. Perrier	Myrsinaceae	1	Not listed	Not listed	+	Found at Antsotso outside the Tolagnaro region
<i>Ophiocolea delphinensis</i> H. Perrier	Bignoniaceae	2	Not listed	Not listed	+	Found at Antsotso outside the Tolagnaro region
<i>Pentarhopalopilia</i> sp. nov.	Santalaceae	2	2	Not listed	+	Recently described as <i>Pilgerina madagascariensis</i> Z.S. Rogers et al., a new monotypic genus, and now known from outside the Tolagnaro region
<i>Pentopetia boivinii</i> Costantin & Gallaud	Apocynaceae	Not listed	1	Not listed	+	Specimens previously unidentified; found at Mahabo outside the Tolagnaro region
<i>Phyllanthus cryptophilus</i> (A. Juss.) Müll. Arg.	Phyllanthaceae	1	Not listed	Not listed	+	Recent collections made outside the Tolagnaro region
<i>Polyalthia pendula</i> Capuron ex G. E. Schatz & Le Thomas	Annonaceae	2	2	2	-	Status unchanged
<i>Pseudocatha</i> sp. nov.	Celastraceae	1	2	2	+	Found in the Mandena conservation zone (M16)
<i>Pyrostria</i> sp. nov.	Rubiaceae	Not listed	1	2	+	Species recently recognized by specialist (not yet published); found in Sainte Luce conservation zone (S8)
<i>Secamone</i> sp. nov.	Asclepiadaceae	1	1	2	+	Material from Mandena now identified as <i>S. humbertii</i> Choux, a Priority 2 taxon found in the Mandena conservation zone (M16) and the Petriky conservation zone
<i>Stephanodaphne cremostachya</i> Baill.	Thymelaeaceae	2	Not listed	Not listed	+	Found at Manantantely and on Pic Saint Jacques outside the Tolagnaro region
<i>Tachiadenus longifolius</i> Scott-Elliott	Gentianaceae	1	Not listed	Not listed	+	Found at Antsotso outside the Tolagnaro region
<i>Talinella dauphinensis</i> Scott-Elliott	Portulacaceae	1	Not listed	Not listed	-	Recent collections made elsewhere in Madagascar
<i>Vitex bracteata</i> Scott-Elliott	Lamiaceae	1	2	2	-	Occurs at Petriky only, incl. in conservation zone (incorrectly listed previously as present at Mandena)
<i>Vitex grandidiana</i> W. Piep.	Lamiaceae	Not listed	2	2	+	Specimens previously unidentified; found in the Mandena conservation zone (M15 & M16) and in the Sainte Luce conservation zone (S9)
<i>Vitex tristis</i> Scott-Elliott	Lamiaceae	Not listed	1	2	+	Specimens previously unidentified; found in swamp forest in the Mandena conservation zone (M15 & M16) and in the Sainte Luce conservation zone (S8 & S9)



Of the 29 priority taxa on the original 1991 list, a total of 14 were removed in 2001 (for example Table 1). Most of these (12 taxa) were taken off the list because populations were discovered at sites outside the mine area where they will not be directly threatened by the mining operation. In one instance, however, a species was removed because the collections of this taxon had been re-identified as a different, more widespread species that did not meet the criteria for Priority 1 or Priority 2 status. In the remaining case the taxon was found to be a hybrid and was therefore removed from the list.

Of the 15 priority taxa listed in 1991 that remained on the 2001 list (for example Table 1), eight were unchanged in status whereas six were transferred from Priority 1 to Priority 2 status, in each case because one or more populations were located within the parcels designated as the Mandena conservation zone (parcels M15 and M16) and / or in parcel M7 located outside the mine area (for example Figure 1). A single species, *Eligmocarpus cynometroides*, restricted to Petriky, was elevated from Priority 2 to Priority 1 status because the only known population from outside the Petriky area was extirpated.

The addition of 11 taxa from Mandena to the priority species list in 2001 (for example Table 1) was based on several considerations. Six priority taxa (three Priority 1 and three Priority 2) were represented among the herbarium material that was not fully identified until after completion of the 1991 report. Four more priority taxa (two Priority 1 and two Priority 2) were recognized as new by specialists in the course of preparing recently published taxonomic revisions (Schatz et al. 1999 and 2001) and ongoing research, and one additional Priority 2 taxon was documented for the first time in the decade prior to 2001.

The re-evaluation of the priority species conducted for the present analysis based on information gathered since 2001, resulted in changes in status for eight taxa (for example Table 1). Three of these taxa (*Asteropeia micraster*, a new species of *Pentarthopalopilia*, and *Pentopetia boivinii*) were removed from the list because populations were located outside the Tolagnaro region, and one taxon that had been added in 2001



FIGURE 3. Flowers of *Dombeya mandenensis* (Malvaceae sensu lato), a Priority 2 species known only from Mandena (where it occurs within the newly-established conservation zone, comprising parcels M15 & M16) and from Sainte Luce (Photo: D. Rabehevitra).

(*Eulophia palmicola*) was removed because it had been listed as occurring at Mandena by error. The four remaining taxa (*Croton trichotomus* var. *pulchellus*, *Vitex tristis*, and one new species in each of the genera *Pyrostria* and *Secamone*) were transferred from Priority 1 to Priority 2 status because continued fieldwork had led to the discovery of populations in the conservation zones at Sainte Luce, Mandena and/or Petriky.

Of the 29 priority taxa on the original 1991 list, 18 are known from Mandena (for example Table 1) but only one (a new species of *Pseudocatha*) appears to be endemic there, where it occurs within the Mandena conservation zone. Among the 11 priority taxa from Mandena added in 2001, none are endemic to the site.

Table 2 lists the 15 taxa present at Mandena that are classified as threatened on the most recent IUCN Red List (IUCN 2008). Three of these taxa have been assigned to the Critically Endangered (CR) category, seven are treated as Endangered (EN), and the remaining five are regarded as Vulnerable (VU). Only three of the 15 taxa classified as threatened based on the Red List criteria (two CR and one VU) qualify as Priority 2 species.



FIGURE 4

FIGURE 4. Fruit of *Malleastrum mandenense* (Meliaceae), another Priority 2 species, recorded from the conservation zones at both Sainte Luce and Mandena, as well as from Petriky (Photo: D. Rabehevitra).



FIGURE 5

FIGURE 5. Fruits of an undescribed species of *Pyrostria* (Priority 2) in the coffee family (Rubiaceae), restricted to Mandena and the conservation zone at Sainte Luce (parcel S8) (Photo: D. Rabehevitra).



FIGURE 6

FIGURE 6. Flowers of *Vitex grandidiana* (Lamiaceae), a Priority 2 species found in the conservation zone at Mandena (M15 & M16) and Sainte Luce (S9) (Photo: P. P. Lowry II).



TABLE 2. List of plant species recorded from the Mandena site listed as threatened on the 2008 IUCN Red List, along with their current (2008) status on the list of Priority 1 and Priority 2 taxa (CR = Critically Endangered; EN = Endangered; VU = Vulnerable).

Taxon	Family	IUCN threat status (criteria)	Priority category
<i>Leptolaena delphinensis</i> G. E. Schatz & Lowry	Sarcolaenaceae	CR (A3cd)	2
<i>Beccariophoenix madagascariensis</i> Jum. & H. Perrier	Arecaceae	CR (B1+2cd)	Not listed
<i>Euphorbia francoisii</i> Leandri var. <i>francoisii</i>	Euphorbiaceae	CR (B1ab(iii,v))	2
<i>Intsia bijuga</i> (Colebr.) Kuntze	Fabaceae	EN (A1cd)	Not listed
<i>Dalbergia maritima</i> R. Vig.	Fabaceae	EN (A1cd+2cd)	Not listed
<i>Dalbergia delphinensis</i> Bosser & R. Rabev.	Fabaceae	EN (A2cd, B1+2bcde)	Not listed
<i>Asteropeia micraster</i> Hallier f.	Asteropeiaceae	EN (A3cd)	Not listed
<i>Leptolaena pauciflora</i> Baker	Sarcolaenaceae	EN (A3cd)	Not listed
<i>Milletia taolanaroensis</i> Du Puy & Labat	Fabaceae	EN (B1+2abc)	Not listed
<i>Sarcolaena delphinensis</i> Cavaco	Sarcolaenaceae	EN (B1ab(ii,iii)+2ab(ii,iii))	Not listed
<i>Ravenea sambiranensis</i> Jum. & H. Perrier	Arecaceae	VU (A1c)	Not listed
<i>Phylloxylon xylophyloides</i> (Baker) Du Puy et al.	Fabaceae	VU (A2cd)	Not listed
<i>Euphorbia lophogona</i> Lam.	Euphorbiaceae	VU (B1ab(iii,v))	2
<i>Dypsis scottiana</i> (Becc.) Beentje & J. Dransf.	Arecaceae	VU (D1)	Not listed
<i>Nepenthes madagascariensis</i> Poir.	Nepenthaceae	VU (D2)	Not listed

## DISCUSSION

Re-evaluation of the original 1991 list of priority species presumed to be restricted to the QMM mine site, produced as part of the initial environmental impact assessment, has led to significant modifications, including changes from Priority 1 to Priority 2 status for seven taxa, the removal of 14 taxa from the list, and the addition of 10 taxa newly found to occur at Mandena, all but one of which are classified as Priority 2 taxa (for example Table 1). These changes are the result of two decades of intensive fieldwork, specimen identification and taxonomic analysis, all of which have continued since completion of the revised environmental and social impact assessment in 2001, reflecting a sustained interest on the part of QMM staff and the international botanical community in both the flora of the littoral forests in the Tolagnaro area and the long-term protection of local, range-restricted species.

Expanded inventory work, both within the Tolagnaro area and elsewhere in Madagascar – especially in association with community-based conservation projects in other littoral forest areas such as Mahabo (the nearest sizeable stand to the north of Tolagnaro) and at nearby sites with extensive intact low elevation forest such as Tsitongambarika in the Vohimena range – will no doubt generate valuable information necessitating improvements to the list. Further changes will also result from future taxonomic research as new species are described and the circumscriptions of previously recognized taxa are clarified.

The original flora study conducted for the 1991 QMM environmental impact assessment focused only on identifying species endemic to the mine exploration zone as a whole, without distinguishing between the Sainte Luce, Mandena and Petriky sites. Subsequent analyses in which each site was considered separately have resulted in important refinements to the initial list, indicating that a total of 15 currently recognized priority species are known to occur at Mandena, 12 of which have been found within one or more of the Mandena forest parcels that will

be less directly impacted by the mining project [i.e. the Mandena conservation zone (M15/M16) and M7], where their populations are now being monitored closely. Of the three remaining taxa, one occurs at the Sainte Luce conservation zone (a new species of *Pyrostria*) and another at the Petriky conservation zone (*Croton trichotomus* var. *pulchellus*), where monitoring activities are also being conducted, expanding the scope for implementing effective conservation measures, including both *in-situ* and *ex-situ* approaches and the incorporation of these taxa in restoration activities. Just a single apparent Mandena endemic, a new species of *Canthium*, has not yet been located within the Mandena conservation zone or parcel M7, although it has been cultivated at the QMM nursery at Mandena since 2004 and is currently being monitored carefully to gather detailed information on its reproductive biology, including pollination, fruit and seed development, germination, and other key aspects for developing effective *in-situ* and *ex-situ* conservation measures.

Comparison of the priority taxa from Mandena listed in Table 1 with the 15 species from the site that are classified as threatened in the 2008 IUCN Red List shows limited overlap (for example Table 2). While most of the taxa on the Red List must be regarded as of conservation importance, they include only three Priority 2 taxa from Mandena (two that are currently recognized as Critically Endangered and one as Vulnerable). None of the 12 remaining taxa have been assessed using the Red List criteria, a fact that underscores the urgent need to expand efforts to evaluate the entire Malagasy flora, and in particular the island's thousands of locally endemic taxa. The discrepancy between the two lists also helps to illustrate the fact that the current Red List status of some widespread species, such as *Intsia bijuga* and *Leptolaena pauciflora*, both of which occur at Mandena, may not adequately reflect the available information on their distribution and the threats they face. This situation is now being rectified by the IUCN Madagascar Plant Specialist Group, which, in addition assessing

an initial set of ca. 3,000 Malagasy species, is also carefully reviewing and updating earlier assessments.

It will continue to be important to update the list of priority species at Sainte Luce, Mandena and Petriky on a regular basis as new information becomes available, and to adjust and improve activities aimed at ensuring the survival of these taxa. At the same time, it will also be necessary to continue monitoring populations of these plants and to compile information for conservation and restoration efforts, including data on population structure and density, regeneration, and ecological requirements. Further botanical inventory work must concurrently be pursued in other parts of the Tolagnaro region and beyond – especially in areas that have not yet been explored – in an effort to discover new populations of species on the priority list. Finally, intensive studies recently initiated on the priority taxa occurring at Sainte Luce and Petriky, similar to those conducted on plants recorded from Mandena, must be expanded to ensure the long-term survival of the locally endemic taxa restricted to these sites.

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