

# The endemic and non-endemic vascular flora of Madagascar updated

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**Background and aims** – The *Catalogue of the Vascular Plants of Madagascar* project aims to evaluate and enumerate the native and naturalized vascular plant flora of Madagascar. In light of the past two decades of intensive collecting and taxonomic work, all relevant published literature and available specimens are being reassessed in order to evaluate the taxonomic status and distribution of the native and naturalized taxa of vascular plants. Here we provide current figures for the total numbers of vascular plants and levels of endemism at the order, family, genus and species levels, comparing them to previous historical counts and analyzing the distribution of the non-endemic element of the flora.

**Key Results** – At the time of writing (April 2010), more than a century after Baron first counted 4,100 species of vascular plants in Madagascar, the *Madagascar Catalogue* database had registered a total of 14,883 accepted names at all taxonomic levels (64 orders, 243 families, 1,730 genera, 11,220 species and 1,626 infraspecific taxa). Of the 11,220 species of vascular plants in Madagascar, 10,650 (95%) are angiosperms, of which 331 are naturalized introduced species. The remaining accepted indigenous angiosperm species total 10,319, of which 8,621 (84%) are endemic to Madagascar (82% endemism for all indigenous vascular plants). Among the 1,698 non-endemic species of indigenous angiosperms, a total of 1,372 (81%) also occur in Africa, of these 654 (39%) are present only in Africa and Madagascar.

**Key words** – Endemism, flora, Madagascar, non-endemism.

*“It may now be said with perfect truth that the vegetable productions of Madagascar have been, though not thoroughly, very extensively explored, and that the majority of the plants inhabiting the island are known to science.”*

Rev. Richard Baron, 1 November 1888.

## INTRODUCTION

The island of Madagascar is renowned for its exceptional biodiversity, with extraordinary levels of species diversity and endemism, a consequence of over 100 million years of evolution in relative isolation (Goodman & Benstead 2005). At the center of that biodiversity is a flora unparalleled in its diversity and distinctiveness. However, despite more than two centuries of botanical exploration, the inventory, description, and documentation of the Malagasy flora are still far from complete.

In 2003, the Missouri Botanical Garden commenced development of a dedicated on-line resource for the dissemination of detailed information on the vascular plant flora of Madagascar. The *Catalogue of the Vascular Plants of Madagascar* represents an analysis and evaluation of the current status of the taxonomy of every vascular plant genus based both on the published literature and the examination of all available specimens. The resulting database enumerates all accepted indigenous and naturalized species present in Madagascar and their synonyms, and provides estimates of the number of undescribed species in each genus. The information is presented as a freely available, on-line, browsable and searchable database (<http://www.efloras.org/madagascar>) that includes nomenclatural data, verified representative specimen data, type and specimen-vouchered living plant images, maps, vernacular names and conservation status. The data derive in part from the *Flore de Madagascar et des Comores* series, published by the Paris Museum, which has

so far treated 165 of the 222 (74%) traditionally recognized plant families in Madagascar, which amount to approximately 6,500 species (Phillipson et al. 2006). The first volume, treating Aponogetonaceae, appeared in 1936, and most of the subsequent volumes were published during the following thirty years. Full or partial taxonomic treatments for genera in some of the remaining families have been published elsewhere (notably in the journal *Adansonia*), and some excellent detailed monographs, such as for the legumes (Du Puy et al. 2002) and palms (Dransfield & Beentje 1995) are available. Our knowledge of the flora of Madagascar is thus advancing steadily. However, many of the treatments in earlier volumes are now badly outdated and are of little use today, and some families/genera have never been treated. For many groups there thus remains an urgent need for taxonomic revision.

Moreover, to reconcile nomenclatural inconsistencies among the taxa shared between Africa and Madagascar, and thereby to render more comprehensive their synonymy, during the past year we have brought core *Madagascar Catalogue* data into the *African Plants Database* developed by the Conservatoire et Jardin botaniques de la Ville de Genève and the South African National Biodiversity Institute in Pretoria (<http://www.ville-ge.ch/cjb/bd/africa/>). The combined databases now extend the scope of the APD nomenclatural index to include all taxa present in continental Africa and Madagascar.

Although Madagascar has been widely recognized for many years as a unique centre of diversity and endemism, until now precise figures for the flora have not been available (Morat & Lowry 1997). Based on the *Madagascar Catalogue*, we present here: (1) a current estimate of the total numbers of indigenous and naturalized vascular plant taxa in Madagascar; (2) updated figures for the levels of endemism at the family, genus and species level, as well as an analysis of the distribution of the non-endemic element of the flora; and (3) a discussion of the updated figures for diversity and endemism in the context of the historical progression of our knowledge on the flora of Madagascar during the course of the 20<sup>th</sup> and start of the 21<sup>st</sup> century.

## RESULTS

### Diversity, endemism and non-endemism

As of April 2010 the *Madagascar Catalogue* database had registered a total of 14,883 accepted names at all taxonomic levels, the ranks of family and above following the most recent Angiosperm Phylogeny Group classification (APG III 2009), comprising: 64 orders, 243 families, 1,730 genera, 11,220 species and 1,626 infraspecific taxa (392 subspecies, 1,137 varieties and 97 forms) (table 1). Pteridophyte data are not yet complete, but a recent account by Rakotonrainibe (2003) enumerated a total of 586 species (265 endemic species, 45%) in Madagascar, of which 563 species are currently incorporated into the *Madagascar Catalogue* (257 endemic species, 46%). The gymnosperms are represented in Madagascar by only seven species: six in the genus *Podocarpus* L'Hér. ex Pers. (all endemic) and a native non-endemic species of *Cycas* L. (*C. thouarsii* Gaudich).

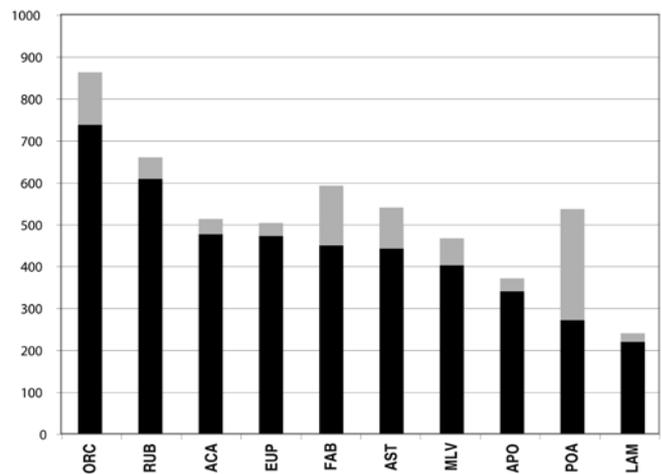
**Table 1 – Actual figure of the Malagasy flora.**

Pterido. = Pteridophytes; Gymno. = Gymnosperms; Angio. = Angiosperms.

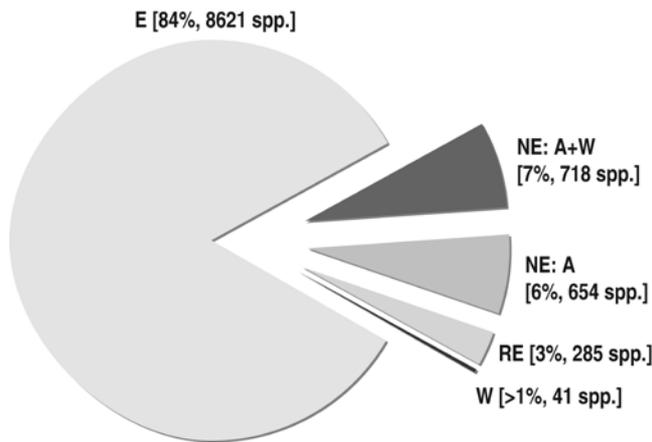
	Pterido.	Gymno.	Angio.	total
orders	15	2	47	64
families	29	2	212	243
genera	107	2	1,621	1,730
species	563	7	10,650	11,220
subspecies	0	0	392	392
varieties	39	5	1,093	1,137
forms	0	0	97	97

Five families are endemic to Madagascar: Asteropeiaceae, Barbeuiaceae, Physenaceae, Sarcolaenaceae and Sphaerosepalaceae. Currently, Orchidaceae are the family with the largest number of species (862 species), followed by Rubiaceae (660 species) and Fabaceae (592 species). Among the families that contain only endemic species, the more diverse are the Balsaminaceae (one genus, *Impatiens* L. with 173 species), Pandanaceae (two genera, *Martellidendron* Callm. & Chassot [five species] and *Pandanus* Parkinson [84 species]) and Bignoniaceae (eleven genera and 75 species). The latter family is currently being revised by MWC and PBP, and is expected to exceed 100 endemic species.

A total of 1,730 vascular plant genera containing indigenous species are known from Madagascar, of which 321 (19%) are endemic. Among the endemic genera, the most species rich are *Aspidostemon* Rohwer & H.G.Richt. (Lau-



**Figure 1** – The ten families with the largest number of endemic species in the Malagasy native angiosperm flora. Black, endemic species; grey, non-endemic species. ORC: Orchidaceae (862 species: 737 E [85%], 125 NE); RUB: Rubiaceae (660 species: 608 E [92%], 52 NE); ACA: Acanthaceae (512 species: 476 E [93%], 36 NE); EUP: Euphorbiaceae (504 species: 473 E [94%], 31 NE); FAB: Fabaceae (592 species: 449 E [76%], 125 NE); AST: Asteraceae (540 species: 441 E [88%], 99 NE); MLV: Malvaceae (466 species: 402 E [86%], 64 NE); APO: Apocynaceae (371 species: 339 E [91%], 32 NE); POA: Poaceae (536 species: 271 E [51%], 265 NE); LAM: Lamiaceae (240 species: 219 E [91%], 21 NE). Families' acronyms following Weber (1982).



**Figure 2** – Endemism and non-endemism in the Malagasy native angiosperm flora; E, Endemic; NE, Non-Endemic; RE, Regional Endemic; A, Africa; W, World (extra-Africa).

raceae) and *Microsteira* Baker (Malpighiaceae) (each with 28 species), followed by *Capurodendron* Aubrév. (Sapotaceae) (23 species), *Schizolaena* Thouars (Sarcolaenaceae) (twenty species) and *Rhopalocarpus* Bojer (Sphaerosepalaceae) (seventeen species). Among the endemic genera, 139 (43%) are monotypic and 87 (27%) have only two or three species. Several of the monotypic genera are illustrative of the biogeographically unique Malagasy flora, such as *Humbertia* Lam. (Convolvulaceae), the basal genus sister to the rest of the family (Stefanović et al. 2002) and formerly placed in a family on its own; *Barbeuia* Thouars, the sole genus of Barbeuiaceae, an isolated family within the order Caryophyllales (Cuénoud et al. 2002); *Diegodendron* Capuron (Bixaceae), sister to the Neotropical genus *Bixa* L. (Bayer et al. 1999), formerly recognized as an endemic family Diegodendraceae; *Malagasiasia* L.A.S. Johnson & B.G. Briggs (Proteaceae), sister to the monotypic Australian genus *Catalepidia* P.H. Weston (Weston & Barker 2006), and *Takhtajania* Baranova & J.-F. Leroy (Winteraceae), an emblematic basal genus that likely dates to the upper Cretaceous (84 mya) (Marquinez et al. 2009).

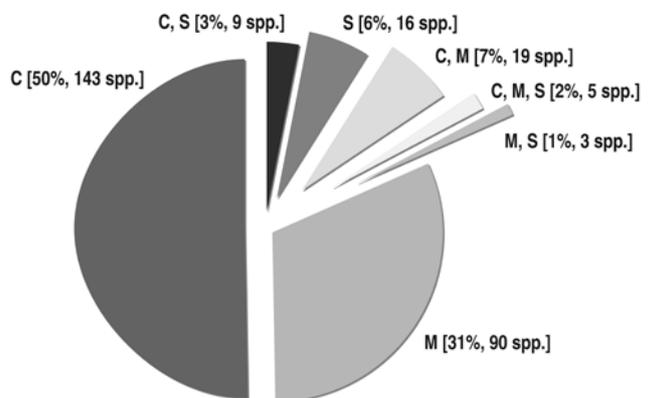
Currently, the *Madagascar Catalogue* lists 10,889 accepted vascular plant species indigenous to Madagascar (i.e. excluding naturalized species), of which 8,884 (82%) are endemic to Madagascar, and thus 2,005 (18%) species (1,698 angiosperms) are native but non-endemic. More than 50% of the endemic flora is concentrated in ten families (fig. 1). Among the non-endemic species, their global distribution range most frequently includes part of continental Africa. A total of 1,372 angiosperm species (81% of the angiosperm non-endemic species) are shared with Africa, of which 654 species are present only in Africa and Madagascar (fig. 2). The remaining non-endemic species are shared among the nearby western Indian Ocean islands (Comoros, Mascarenes, and Seychelles) (285 species) and Asia and/or the New World (41 species). The distribution of the 285 species shared with the regional islands is shown in figure 3. The 143 species shared only with the Comores belong to 46 families, of which 31 are represented by only one or two species; the three families with the most species are Orchidaceae (34 species), Fabaceae (eight species) and Poaceae (seven species). The ninety spe-

cies shared only with the Mascarenes belong to 31 families, of which fifteen are represented by only one or two species; the three families with the most species are Orchidaceae (thirty species), Rubiaceae (seven species) and Myrtaceae (four species). It is interesting to note that Orchidaceae with their minute seeds have the highest number of angiosperm species shared with the western Indian Ocean islands. Recent molecular phylogenetic studies have revealed the relationships and patterns of speciation among Orchidaceae of the Mascarenes with respect to Madagascar (Micheneau et al. 2008).

Below the species level, the *Madagascar Catalogue* lists many infraspecific taxa on a provisional basis only, since further systematic studies are generally required to evaluate whether they merit recognition, and if so, at what taxonomic level.

### Current figures in comparison to historical counts

With great confidence, the Rev. Richard Baron announced the first count for the vascular flora of Madagascar before the Linnaean Society on 1 Nov. 1888, citing 4,100 indigenous species, of which about 3,000 (73%) were endemic (Baron 1889). He then compiled the first comprehensive list of taxa in the *Compendium des Plantes Malgaches* (1900–1906), enumerating over 4,700 species and varieties amongst 970 genera (Dorr 1987). Perrier de la Bâthie intended to continue Baron's *Compendium* through the serial publication of a *Catalogue des plantes de Madagascar* (1930–1940); in his 1936 *Biogéographie des Plantes de Madagascar*, Perrier de la Bâthie counted 6,765 native species (out of a total flora of 7,370) of which 5,820 (86%) were considered to be endemic. More than twenty years later, Humbert (1959) enumerated 7,900 species, 81% of which he considered to be endemic, and estimated that the eventual total would reach 10,000 species. Koechlin et al. (1974) then increased the enumeration to 8,500 species without reconsidering the level of endemism and estimated a total number of vascular plants at 10,000–12,000 species, the latter figure following the estimate of DeJardin et al. (1973). Phillipson (1994) incorporated the c. 1,170 endemic species described between 1959 and 1992, as well as a proportional estimate of new records of non-endemic species, to arrive at a total of 9,345 species



**Figure 3** – Distribution of the non-endemic Malagasy species shared only with the regional western Indian Ocean islands; C, Comores islands; S, Seychelles islands; M, Mascarenes islands.

**Table 2 – Historical progression of knowledge on the Malagasy flora.**

1889, Baron; 1900–1906, Baron's *Compendium* (Dorr 1987); 1936, Perrier de la Bâthie; 1959, Humbert; 1974, Koechlin et al.; 1994, Phillipson; 2010, *Madagascar Catalogue* (square brackets refer to angiosperms only). Nat., naturalized; NE, Non Endemic; E, Endemic; \*not including Pteridophytes; \*\* not known for naturalized species.

Years	1889	1900–1906	1936	1959	1974	1994	2010
Families	-	-	191	183	207	-	243
Genera	-	970	1289	1280*	1382	-	1730
Species	4100	4700	7370	7900	8500	9345	11220
Pterido.	-	-	505	550	550	-	563
Gymno.	-	-	3	5	5	-	7
Angio.	-	-	6862	7345	7945	-	10650
Genera							
Nat.	-	-	150	1040** (81%)	-	-	113
Native NE	-	-	901 (79%)	240 (19%)	-	-	1296 (80%)
E	-	-	238 (21%)	-	-	-	321 (20%)
Species							
Nat.	-	-	605	1500** (19%)	-	-	331
Native NE	-	-	945 (14%)	-	-	-	2005 [1698] (18%)
E	3000 (73%)	-	5820 (86%)	6400 (81%)	-	7570 (81%)	8884 [8621] (82%)

(with 7,570 endemic) (table 2). The present *Madagascar Catalogue Project* represents the first effort since Perrier de la Bâthie (1930–1940) to list all of the vascular plant species indigenous or naturalized in Madagascar, and with the current figure of 11,220 vascular plant species, we are now approaching the highest earlier estimate of 12,000 species (table 2). With regard to the level of native species endemism, the current figure of 82% (84% for angiosperms only) is close to the 83% reported by Goodman & Benstead (2005) for a subset of c. 3,000 species that included the ferns (only 45% endemism). When the current *Madagascar Catalogue* database is partitioned by habit, species endemism for trees and shrubs combined reaches 92%, which compares to the 96% endemism figure reported by Schatz (2001) for a subset of 4,220 trees and large shrubs. The level of endemism for herbs is only 72%, reflecting again the much lower levels of endemism in the predominantly herbaceous large families Poaceae (536 species, 51% endemic) and Cyperaceae (304 species, 39% endemic). Since the *Madagascar Catalogue Project* reviews each genus and provides an estimate of the number of undescribed species (nearly all of which will be endemic), we can extrapolate based on those genera for which full evaluations have been completed. This allows us to provide new estimates for both the total number of indigenous and naturalized plant species in Madagascar as well as the true level of species endemism among the indigenous flora (Phillipson et al. in prep.). Both figures appear to be converging on the estimates of Phillipson et al. (2006) of 14,000 species of indigenous and naturalized plants and 85% indigenous species endemism, confirming Madagascar's critical role in harbouring a unique and globally important assemblage of plants.

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#### REFERENCES

- African Plants Database (version 3.3.2) [online] Conservatoire et Jardin botaniques de la Ville de Genève and South African National Biodiversity Institute, Pretoria. Available at <http://www.ville-ge.ch/musinfo/bd/cjb/africa/> [accessed 28 Mar. 2011].
- Angiosperm Phylogeny Group (APG III) (2009) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Botanical Journal of the Linnean Society* 161: 105–121. doi:10.1111/j.1095-8339.2009.00996.x
- Baron R. (1889) The flora of Madagascar. *Botanical Journal of the Linnean Society* 25: 246–294. [Biodiversity Heritage Library: <http://www.biodiversitylibrary.org/item/8381#page/302/mode/lup>]
- Bayer C., Fay M.F., De Bruijn A.Y., Savolainen V., Morton C.M., Kubitzki K., Alverson W.S., Chase M.W. (1999) Support for an expanded family concept of Malvaceae with a recircumscribed order Malvales: a combined analysis of plastid atpB and rbcL

- DNA sequences. *Botanical Journal of the Linnean Society* 129: 267–303. doi:10.1111/j.1095-8339.1999.tb00505.x
- Catalogue of the vascular Plants of Madagascar [online] Missouri Botanical Garden, Saint-Louis. Available at <http://www.efloras.org/madagascar> [accessed 28 Mar. 2011].
- Cuénoud P., Savolainen V., Chatrou L.W., Powell M., Grayer R.J., Chase M.W. (2002) Molecular phylogenetics of Caryophyllales based on nuclear 18S rDNA and plastid *rbcL*, *atpB*, and *matK* DNA sequences. *American Journal of Botany* 89: 132–144. doi:10.3732/ajb.89.1.132
- Dejardin, J., Guillaumet, J.-L., Mangenot, G. (1973) Contribution à la connaissance de l'élément non endémique de la flore malgache (végétaux vasculaires). *Candollea* 28: 325–391. [available at [http://horizon.documentation.ird.fr/exl-doc/pleins\\_textes/pleins\\_textes\\_5/b\\_fdi\\_06-07/06537.pdf](http://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_5/b_fdi_06-07/06537.pdf)]
- Dorr L.J. (1987) Rev. Richard Baron's Compendium des Plantes Malgaches. *Taxon* 36: 39–46. doi:10.2307/1221349
- Dransfield J., Beentje H. (1995) *The Palms of Madagascar*. Kew, Royal Botanic Gardens.
- Du Roy D.J., Labat J.-N., Rabevohitra R., Villiers J.-F., Bosser J., Moat J. (2002) *The Leguminosae of Madagascar*. Kew, Royal Botanic Gardens.
- Goodman S.M., Benstead J.P. (2005) Updated estimates of biotic diversity and endemism for Madagascar. *Oryx* 39: 73–77. doi:10.1017/S0030605305000128
- Humbert H. (1959) Origines présumées et affinités de la flore de Madagascar. *Mémoires de l'Institut Scientifique de Madagascar, Sér. B: Biologie Végétale* 9: 149–187.
- Koechlin J., Guillaumet J.-L., Morat Ph. (1974) *Flore et végétation de Madagascar*. Vaduz, Cramer.
- Micheneau C., Carlswald B.S., Fay M.F., Bytebier B., Pailler T., Chase M.W. (2008) Phylogenetics and biogeography of the Mascarene angraecoid orchids (Vandaeae, Orchidaceae). *Molecular Phylogenetics and Evolution* 46: 908–922. doi:10.1016/j.ympev.2007.12.001
- Marquinez X., Lohmann L.G., Faria Salatino M.L., Salatino A., González F. (2009) Generic relationships and dating of lineages in Winteraceae based on nuclear (ITS) and plastid (*rpS16* and *psbA-trnH*) sequence data. *Molecular Phylogenetics and Evolution* 53: 435–449. doi:10.1016/j.ympev.2009.07.001
- Morat Ph., Lowry II P.P. (1997) Floristic richness in the Africa-Madagascar region: a brief history and perspective. *Adansonia* 19: 101–115.
- Perrier de la Bâthie H. (1930–1940) (ed.) *Catalogue des plantes de Madagascar*. Académie Malgache. Antananarivo, G. Pitot et Cie.
- Perrier de la Bâthie H. (1936) *Biogéographie des Plantes de Madagascar*. Paris, Société d'Éditions géographiques, maritimes et coloniales.
- Phillipson P.B. (1994) Madagascar. In: Davis S.D. et al. (eds) *Centres of plant diversity*: 271–281. Cambridge, UK, WWF & IUCN.
- Phillipson P.B., Schatz G.E., Lowry II P.P., Labat J.N. (2006) A catalogue of vascular plant of Madagascar. In: Ghazanfar S.A., Beentje H.J. (eds) *Taxonomy and ecology of African plants, their conservation and sustainable use*: 613–627. Kew, Royal Botanic Gardens.
- Rakotondrainibe F. (2003) Checklist of the pteridophytes of Madagascar. In: Goodman S.M., Benstead J.P. (eds) *Natural history of Madagascar*: 295–313. Chicago, The University of Chicago Press.
- Schatz G.E. (2001) *Generic Tree Flora of Madagascar*. Royal Botanic Gardens, Kew.
- Stefanović S., Krueger L., Olmstead R.G. (2002) Monophyly of the Convolvulaceae and circumscription of their major lineages based on DNA sequences of multiple chloroplast loci. *American Journal of Botany* 89: 1510–1522. [JSTOR: <http://www.jstor.org/stable/4124069>]
- Weber W.A. (1982) Mnemonic three-letter acronyms for the families of vascular plants: a device for more effective herbarium curation. *Taxon* 31: 74–88. doi:10.2307/1220592
- Weston P.H., Barker N.P. (2006) A new suprageneric classification of the Proteaceae, with annotated checklist of genera. *Telopea* 11: 314–344. [available at [http://www.rbgsyd.nsw.gov.au/data/assets/pdf\\_file/0009/80856/Tel11Wes314.pdf](http://www.rbgsyd.nsw.gov.au/data/assets/pdf_file/0009/80856/Tel11Wes314.pdf)]
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