

## **Mine versus Wild: a plant conservation checklist of the rich Iron-Ore Ngovayang Massif Area (South Cameroon)**

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### ► **To cite this version:**

Vincent Droissart, Olivier Lachenaud, Gilles Dauby, Steven Dessein, Gyslène Kamdem, et al.. Mine versus Wild: a plant conservation checklist of the rich Iron-Ore Ngovayang Massif Area (South Cameroon). *Plant Ecology and Evolution*, Botanic Garden Meise and Royal Botanical Society of Belgium, 2019, 152 (1), pp.8-29. 10.5091/plecevo.2019.1547 . hal-02079407

**HAL Id: hal-02079407**

**<https://hal.umontpellier.fr/hal-02079407>**

Submitted on 26 Mar 2019

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## Mine versus Wild: a plant conservation checklist of the rich Iron-Ore Ngovayang Massif Area (South Cameroon)

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**Background and aims** – The rapid expansion of human activities in South Cameroon, particularly mining in mountainous areas, threatens this region's exceptional biodiversity. To comprehend the effects of land-use change on plant diversity and identify conservation priorities, we aim at providing a first comprehensive plant checklist of the Ngovayang Massif, focusing on the two richest plant families, Orchidaceae and Rubiaceae.

**Location** – The Ngovayang Massif Area (NMA) is located in the South Region of Cameroon. It is covered by lowland and submontane rainforest (100 to 1110 m elevation).

**Methods** – We compiled a dataset of 6116 georeferenced herbarium specimens, of which 2787 belong to Rubiaceae and Orchidaceae. We used rarefaction methods to explore sampling and diversity patterns, and investigated the altitudinal distribution of rare and/or threatened taxa.

**Key results** – The NMA, which houses about 1500 vascular plant taxa, is the richest documented area for Rubiaceae in Atlantic Central Africa (ACA) and the fifth for Orchidaceae, with respectively 281 and 111 taxa. Among these taxa, 178 (45%) are endemic to ACA and 67 (17%) are considered globally threatened according to IUCN categories and criteria. We show that higher elevation areas (> 750 m), which are also the main areas targeted for mining, are the richest in endangered and/or rare species. Three new records for Cameroon are reported here.

**Conclusion** – The NMA represents an Important Plant Area of Cameroon as confirmed by its exceptional plant diversity (> 20% of the total Flora of Cameroon), by the concentration of many threatened and/or restricted range species (10 taxa are strict endemics of the massif) as well as by the threat on rare habitats (i.e. the submontane vegetation above ~750 m elevation). A management plan involving *in situ* and *ex situ* conservation actions is urgently needed to reduce the potential threats of future mining activities.

**Key words** – Biodiversity, endangered species, Important Plant Area, iron and gold exploitation, new records, orchids, Rubiaceae, submontane forest.

## INTRODUCTION

The flora of Cameroon is one of the richest of the African continent, with about 7000 species recorded to date (Onana 2011, Sosef et al. 2017). Only 10.6% of the Cameroonian land is covered by protected areas (UNEP-WCMC 2018), which is smaller than the global protected area coverage of 14.7% (Saura et al. 2017). The knowledge of the distribution and conservation status of African plants is still patchy, and far below the target 2 of the Global Strategy for Plant Conservation which calls for a comprehensive list of the world's threatened plant species by 2020. Cameroon has been relatively well explored for plants compared to most other tropical African countries but prospecting efforts within the country have been very unequal (Onana 2011, Sosef et al. 2017), and the heterogeneous information on plant distribution limits its effective conservation actions.

The Ngovayang Massif Area (NMA, c. 527 km<sup>2</sup>) is located in Atlantic Central Africa (ACA), which mainly corresponds to the Lower Guinea subregion of White, the floristically richest phytochorion of the Guineo-Congolian region (White 1979, Droissart et al. 2018). The NMA represents a relatively well botanically sampled place in the South Region of Cameroon: more than 6000 herbarium specimens have been collected in this area (compared to the ~90000 specimens collected in Cameroon, Sosef et al. 2017). This sampling effort represents thus more than 5% of the total number of specimens collected in Cameroon, while the surface of the NMA only represents 0.1% of the country. However, information on the distribution of the flora within the NMA is relatively poor because a large part of the herbarium collections are not precisely georeferenced. In fact, about half of them come from the earliest botanical explorer of the area, the German botanist Georg August Zenker (1855–1922), who collected c. 3000 specimens at “Bipindi”. Until now, the only estimation for total number of plant species occurring in the NMA, i.e. 450 vascular plant species, was given by Gonmadje et al. (2011), unfortunately without indication of voucher specimens or sources used to generate this statistic.

The flora of the NMA was addressed in previous studies with more extensive geographic coverage, using a network of permanent sampling plots (1-hectare plot censused). A biogeographical study based on five 1-ha plots and 2673 censused trees with diameter above 10 cm at breast height (Gonmadje et al. 2012) showed that the lowland forests of NMA are dominated by Fabaceae-Caesalpinioideae (also known as Detarioideae), with a high proportion of Guineo-Congolian species (79%), and particularly Lower Guinean species (30%). An extended dataset (fifteen 1-ha plots) obtained by the same team (Gonmadje et al. 2017) has also proven that the decrease of above ground biomass of old-growth forests across an altitudinal gradient in the NMA can at least partially be explained by altitudinal filtering of large-tree species, highlighting the importance of elevational gradient in shaping flora composition.

Currently, the NMA does not have any legal conservation status, but is covered by three exploration permits (EP) with a total coverage of 2972 km<sup>2</sup> (electronic appendix 1): EP 144 covering the main part of the NMA, EP 195 located on N-NE part of NMA and EP 221 on SE part of NMA. The

massif represents one of the largest iron deposits in Central Africa, and prospections have also shown a high percentage of gold in the lowland part, in the south eastern part of the NMA. Magnetite-gneiss ore has been identified as the primary source of iron ore in the NMA. During the prospective phase started near Melombo locality (EP 144) by the Australian exploration company “Legend Mining Limited”, a report indicated the potential for a range of 300–500 Mt of magnetite ore, with a grade of 16–40% Fe (Wendt 2012), which confirms the potential of the NMA to host a large tonnage of magnetite deposits that can be economically exploited. Unpublished reports and one publication (Mimba et al. 2014) underlined that the highest concentrations of gold (Au > 100 ppb) are located in lower elevation areas in the south-eastern part of the NMA, in the heavy mineral fraction of stream sediments. The Legend Mining company announced on 5 August 2014 the completion of the sale of its Ngovayang project to the Indian company “Jindal Steel and Power” for a total of \$17.5M. In these conditions, it is clear that required impact studies have to be conducted by these mining companies, and be based on appropriate, published and widely accessible data. In this context, the use of the Important Plant Areas (IPA) criteria system can offer a rigorous scientific tool to highlight gaps in the current protected areas network, and to render offsetting mechanisms consistent with conservation outcomes (Saenz et al. 2013, Darbyshire et al. 2017).

The amount, quality and accessibility of floristic data concerning the vascular flora of the NMA have significantly increased during the last 15 years, as a result of both recent efforts to combine several big datasets (Dauby et al. 2016, Sosef et al. 2017) and new botanical prospections relying on an accurate geographic positioning system. However, our knowledge about the spatial distribution of the flora and the conservation status of the species within the NMA remains sparse and has never previously been synthesized to date. The main objectives of the present contribution are thus: (1) to compile a database of all herbarium specimens collected in Ngovayang to date; (2) to produce a verified checklist of the two larger plant families present in the NMA, Rubiaceae and Orchidaceae; (3) to analyze sampling and diversity patterns of these two families in the NMA; (4) to identify threatened species within the NMA. Finally, based on our dataset, we also evaluate whether the NMA meets the criteria of Tropical Important Plant Areas according to Darbyshire et al. (2017). Here, we choose to concentrate our analysis on the Rubiaceae and the Orchidaceae first because the two families are important component of tropical forest; together they represent about 15% of the Cameroonian vascular flora (Onana 2011), and second because our team have extensively reviewed their taxonomy (e.g. Azandi et al. 2016, Zemagho et al. 2017) and geographic distribution (e.g. Droissart et al. 2011, Lachenaud et al. 2013) in Central Africa during the last 20 years.

## MATERIAL AND METHODS

### Herbarium records database

Based on recent fieldwork, i.e. the 15 field campaigns organized by our team between 2004 and 2017, and using the RAINBIO database (Dauby et al. 2016), we compiled a dataset with all herbarium collections available collected within

**Table 1 – Checklist of Orchidaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

Distribution categories considered: Wide = widely distributed; NMA = endemic to NMA; Cameroon = endemic to Cameroon; ACA = endemic to Atlantic Central Africa. IUCN Red List Categories considered: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient. New records for Cameroon are indicated by an asterisk (\*). Sources for IUCN Red List Category: <sup>a</sup>IUCN (2018), <sup>b</sup>Onana (2011), <sup>c</sup>personal database, unpublished data, <sup>d</sup>Descourvières et al. (2013). One taxon (*Angraecopsis* sp.) not identified to species level is not included in the checklist.

| Species   | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|---|-------------|--------------------|-----------------------|-----------------|
| <i>Afropectinariella atlantica</i> (Stévant & Droissart) M.Simo & Stévant                   | 1           | ACA                | 910                   | NT <sup>a</sup> |
| <i>Afropectinariella gabonensis</i> (Summerh.) M.Simo & Stévant                             | 16          | Wide               | 440–680               | LC <sup>a</sup> |
| <i>Afropectinariella pungens</i> (Schltr.) M.Simo & Stévant                                 | 1           | Wide               | 910                   | VU <sup>a</sup> |
| <i>Ancistrochilus thomsonianus</i> (Rchb.f.) Rolfe  | 2           | ACA                | 570                   | LC <sup>a</sup> |
| <i>Ancistrorhynchus brunneomaculatus</i> (Rendle) Schltr.                                   | 5           | Wide               | 100                   | DD              |
| <i>Ancistrorhynchus capitatus</i> (Lindl.) Summerh.   | 15          | Wide               | 260–1080              | LC <sup>b</sup> |
| <i>Ancistrorhynchus metteniae</i> (Kraenzl.) Summerh.                                       | 4           | Wide               | 290–900               | LC <sup>b</sup> |
| <i>Ancistrorhynchus schumannii</i> (Kraenzl.) Summerh.                                      | 1           | Wide               | 540                   | LC <sup>b</sup> |
| <i>Ancistrorhynchus straussii</i> (Schltr.) Schltr.   | 6           | Wide               | 140–580               | LC <sup>b</sup> |
| <i>Ancistrorhynchus tenuicaulis</i> Summerh.  | 4           | Wide               | 550–1080              | LC <sup>c</sup> |
| <i>Angraecum angustum</i> (Rolfe) Summerh.  | 2           | ACA                | 570–580               | EN <sup>a</sup> |
| <i>Angraecum eichlerianum</i> var. <i>curvicalcaratum</i> Szlach. & Olszewski               | 5           | ACA                | 100–830               | LC <sup>c</sup> |
| <i>Angraecum ngovayangense</i> sp. ined.  | 1           | NMA                | 850                   | CR <sup>c</sup> |
| <i>Bolusiella zenkeri</i> (Kraenzl.) Schltr.  | 6           | Wide               | 110–550               | LC <sup>b</sup> |
| <i>Brachycorythis kalbreyeri</i> Rchb.f.  | 2           | Wide               | 680–790               | LC <sup>b</sup> |
| <i>Bulbophyllum acutibracteatum</i> De Wild. var. <i>acutibracteatum</i>                    | 1           | Wide               | 100                   | LC <sup>b</sup> |
| <i>Bulbophyllum acutibracteatum</i> var. <i>rubrobrunneopapillosum</i> (De Wild.) J.J.Verm. | 3           | Wide               | 530–640               | LC <sup>b</sup> |
| <i>Bulbophyllum alinae</i> Szlach.  | 3           | Cameroon           | 140–540               | VU <sup>a</sup> |
| <i>Bulbophyllum calypratrum</i> Kraenzl.  | 3           | Wide               | 110–900               | LC <sup>b</sup> |
| <i>Bulbophyllum calypratrum</i> var. <i>graminifolium</i> (Summerh.) J.J.Verm.              | 3           | Wide               | 80–110                | LC <sup>c</sup> |
| <i>Bulbophyllum calypratrum</i> var. <i>lucifugum</i> (Summerh.) J.J.Verm.                  | 1           | Wide               | 470                   | DD              |
| <i>Bulbophyllum carnosisepalum</i> J.J.Verm.  | 1           | Wide               | 140                   | LC <sup>b</sup> |
| <i>Bulbophyllum cochleatum</i> Lindl.   | 16          | Wide               | 140–950               | LC <sup>b</sup> |
| <i>Bulbophyllum colubrinum</i> (Rchb.f.) Rchb.f.  | 1           | Wide               | 620                   | LC <sup>b</sup> |
| <i>Bulbophyllum dolabriforme</i> J.J.Verm.*   | 1           | ACA                | 910                   | EN <sup>a</sup> |
| <i>Bulbophyllum falcatum</i> var. <i>bufo</i> (Lindl.) Govaerts                             | 1           | Wide               | 910                   | LC <sup>b</sup> |
| <i>Bulbophyllum falcatum</i> var. <i>velutinum</i> (Lindl.) J.J.Verm.                       | 8           | Wide               | 100–570               | LC <sup>b</sup> |
| <i>Bulbophyllum fuscum</i> Lindl.   | 1           | Wide               | 800                   | LC <sup>b</sup> |
| <i>Bulbophyllum fuscum</i> var. <i>melinostachyum</i> (Schltr.) J.J.Verm.                   | 16          | Wide               | 100–800               | LC <sup>b</sup> |
| <i>Bulbophyllum imbricatum</i> Lindl.   | 17          | Wide               | 100–830               | LC <sup>b</sup> |
| <i>Bulbophyllum intertextum</i> Lindl.  | 9           | Wide               | 140–950               | LC <sup>b</sup> |
| <i>Bulbophyllum nigritianum</i> Rendle*   | 1           | Wide               | 570                   | DD              |

**Table 1 (continued) – Checklist of Orchidaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species   | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|---|-------------|--------------------|-----------------------|-----------------|
| <i>Bulbophyllum oreonastes</i> Rehb.f.  | 6           | Wide               | 100–900               | LC <sup>b</sup> |
| <i>Bulbophyllum porphyrostachys</i> Summerh.  | 3           | ACA                | 100–140               | NT <sup>a</sup> |
| <i>Bulbophyllum pumilum</i> (Sw.) Lindl.  | 8           | Wide               | 140–570               | LC <sup>c</sup> |
| <i>Bulbophyllum resupinatum</i> var. <i>filiforme</i> (Kraenzl.) J.J.Verm.                      | 2           | Wide               | 80                    | LC <sup>b</sup> |
| <i>Bulbophyllum saltatorium</i> var. <i>albociliatum</i> (Finet) J.J.Verm.                      | 11          | Wide               | 80–650                | LC <sup>b</sup> |
| <i>Bulbophyllum sandersonii</i> (Hook.f.) Rchb.f.   | 7           | Wide               | 100–650               | LC <sup>b</sup> |
| <i>Bulbophyllum sandersonii</i> subsp. <i>stenopetalum</i> (Kraenzl.) J.J.Verm.                 | 15          | Wide               | 100–550               | LC <sup>b</sup> |
| <i>Bulbophyllum schimperianum</i> Kraenzl.  | 1           | Wide               | 1030                  | LC <sup>b</sup> |
| <i>Bulbophyllum schinzianum</i> Kraenzl. ex De Wild. var. <i>phaeopogon</i> (Schltr.) J.J.Verm. | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Bulbophyllum teretifolium</i> Schltr.  | 1           | Cameroon           | 570                   | NT <sup>a</sup> |
| <i>Calyptrochilum christyanum</i> (Rchb.f.) Summerh.  | 7           | Wide               | 100–570               | LC <sup>b</sup> |
| <i>Calyptrochilum emarginatum</i> (Afzel. ex Sw.) Schltr.                                       | 2           | Wide               | 260                   | LC <sup>b</sup> |
| <i>Corymborkis corymbis</i> Thouars   | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Cribbia confusa</i> P.J.Cribb  | 1           | Wide               | 620                   | LC <sup>b</sup> |
| <i>Cynorkis gabonensis</i> Summerh.   | 1           | ACA                | 850                   | NT <sup>a</sup> |
| <i>Cyrtorchis aschersonii</i> (Kraenzl.) Schltr.  | 2           | Wide               | 140                   | LC <sup>b</sup> |
| <i>Cyrtorchis monteiroae</i> (Rchb.f.) Schltr.  | 1           | Wide               | 570                   | LC <sup>b</sup> |
| <i>Cyrtorchis ringens</i> (Rchb.f.) Summerh.  | 16          | Wide               | 290–800               | LC <sup>b</sup> |
| <i>Diaphananthe bidens</i> (Afzel. ex Sw.) Schltr.  | 7           | Wide               | 100–570               | LC <sup>b</sup> |
| <i>Diaphananthe garayana</i> Szlach. & Olszewski  | 8           | Cameroon           | 100                   | EN <sup>c</sup> |
| <i>Diaphananthe ichneumonea</i> (Lindl.) P.J.Cribb & Carlsward                                  | 1           | Wide               | 1030                  | LC <sup>b</sup> |
| <i>Diaphananthe odoratissima</i> (Rchb.f.) P.J.Cribb & Carlsward                                | 5           | Wide               | 80–100                | LC <sup>b</sup> |
| <i>Diaphananthe spiralis</i> (Stévant & Droissart) P.J.Cribb & Carlsward                        | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Diaphananthe pellucida</i> (Lindl.) Schltr.  | 1           | ACA                | 100                   | VU <sup>c</sup> |
| <i>Dolabrifolia aporoides</i> (Summerh.) Szlach. & Romowicz                                     | 25          | Wide               | 100–980               | LC <sup>a</sup> |
| <i>Dolabrifolia bancoensis</i> (Burg) Szlach. & Romowicz  | 2           | Wide               | 570                   | LC <sup>a</sup> |
| <i>Dolabrifolia disticha</i> (Lindl.) Szlach. & Romowicz  | 3           | Wide               | 570–720               | LC <sup>a</sup> |
| <i>Dolabrifolia podochiloides</i> (Schltr.) Szlach. & Romowicz                                  | 1           | Wide               | 540                   | LC <sup>a</sup> |
| <i>Eggelingia gabonensis</i> P.J.Cribb & Laan   | 7           | ACA                | 570–1030              | VU <sup>c</sup> |
| <i>Gastrodia africana</i> Kraenzl.  | 1           | Cameroon           | 690                   | EN <sup>c</sup> |
| <i>Genyorchis apetala</i> (Lindl.) J.J.Verm.  | 1           | Wide               | 570                   | LC <sup>b</sup> |
| <i>Genyorchis platybulbon</i> Schltr.   | 4           | ACA                | 100–140               | LC <sup>c</sup> |
| <i>Graphorkis lurida</i> (Sw.) Kuntze   | 3           | Wide               | 440–680               | LC <sup>b</sup> |
| <i>Kylicanthe cornuata</i> Descourvières, Stévant & Droissart                                   | 2           | ACA                | 730–830               | VU <sup>c</sup> |
| <i>Liparis hallei</i> Szlach.   | 1           | Cameroon           | 230                   | EN <sup>c</sup> |
| <i>Liparis platyglossa</i> Schltr.  | 2           | Wide               | 440–770               | LC <sup>b</sup> |

**Table 1 (continued) – Checklist of Orchidaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species  | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|--|-------------|--------------------|-----------------------|-----------------|
| <i>Listrostachys pertusa</i> (Lindl.) Rchb.f.                          | 24          | Wide               | 100–680               | LC <sup>b</sup> |
| <i>Manniella gustavi</i> Rchb.f.                                       | 2           | Wide               | 600–730               | LC <sup>b</sup> |
| <i>Orestias micrantha</i> Summerh.                                     | 2           | ACA                | unknown               | VU <sup>c</sup> |
| <i>Polystachya adansoniae</i> Rchb.f.                                  | 5           | Wide               | 100–660               | LC <sup>b</sup> |
| <i>Polystachya affinis</i> Lindl.                                      | 1           | Wide               | 830                   | LC <sup>b</sup> |
| <i>Polystachya albescens</i> Ridl.                                     | 1           | Wide               | 650                   | LC <sup>b</sup> |
| <i>Polystachya batkoi</i> Szlach. & Olszewski                          | 1           | ACA                | 550                   | VU <sup>b</sup> |
| <i>Polystachya bipoda</i> Stévant                                      | 1           | ACA                | 830                   | VU <sup>c</sup> |
| <i>Polystachya calluniflora</i> Kraenzl.                               | 3           | Wide               | 620–1080              | LC <sup>b</sup> |
| <i>Polystachya caloglossa</i> Rchb.f.                                  | 2           | Wide               | 470–600               | LC <sup>b</sup> |
| <i>Polystachya camaridioides</i> Summerh.                              | 1           | ACA                | 140                   | VU <sup>c</sup> |
| <i>Polystachya coriscensis</i> Rchb.f.                                 | 33          | Wide               | 100–620               | LC <sup>c</sup> |
| <i>Polystachya dolichophylla</i> Schltr.                               | 19          | Wide               | 110–620               | LC <sup>b</sup> |
| <i>Polystachya elegans</i> Rchb.f.                                     | 12          | ACA                | 140–570               | LC <sup>b</sup> |
| <i>Polystachya fusiformis</i> (Thouars) Lindl.                         | 2           | Wide               | 830–1080              | LC <sup>b</sup> |
| <i>Polystachya golungensis</i> Rchb.f.                                 | 1           | Wide               | 950                   | LC <sup>b</sup> |
| <i>Polystachya lejolyana</i> Stévant                                   | 3           | ACA                | 910–1060              | EN <sup>c</sup> |
| <i>Polystachya letouzeyana</i> Szlach. & Olszewski                     | 1           | ACA                | 580                   | LC <sup>c</sup> |
| <i>Polystachya moniquetiana</i> Stévant & Geerinck                     | 1           | ACA                | 910                   | VU <sup>c</sup> |
| <i>Polystachya obanensis</i> Rendle                                    | 6           | Wide               | 540–660               | LC <sup>b</sup> |
| <i>Polystachya odorata</i> Lindl.                                      | 10          | Wide               | 110                   | LC <sup>b</sup> |
| <i>Polystachya polychaete</i> Kraenzl.                                 | 25          | Wide               | 140–900               | LC <sup>b</sup> |
| <i>Polystachya pyramidalis</i> Lindl.                                  | 4           | ACA                | 600–660               | LC <sup>c</sup> |
| <i>Polystachya ramulosa</i> Lindl.                                     | 7           | Wide               | 600–1080              | LC <sup>b</sup> |
| <i>Polystachya rhodoptera</i> Rchb.f.                                  | 1           | Wide               | 560                   | LC <sup>b</sup> |
| <i>Polystachya riomuniensis</i> Stévant & Nguema                       | 3           | ACA                | 620–760               | VU <sup>c</sup> |
| <i>Polystachya seticaulis</i> Rendle                                   | 3           | Wide               | 180–570               | LC <sup>b</sup> |
| <i>Polystachya supfiana</i> Schltr.                                    | 11          | ACA                | 570–900               | LC <sup>c</sup> |
| <i>Polystachya tessellata</i> Lindl.                                   | 2           | Wide               | 100–620               | LC <sup>c</sup> |
| <i>Polystachya victoriae</i> Kraenzl.                                  | 3           | Wide               | 680                   | NT <sup>b</sup> |
| <i>Rangaeris rhipsalisocia</i> (Rchb.f.) Summerh.                      | 3           | Wide               | 110                   | LC <sup>b</sup> |
| <i>Rhipidoglossum curvatum</i> (Rolfe) Garay                           | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Rhipidoglossum montealenense</i> Descourvières, Stévant & P.J.Cribb | 2           | ACA                | 730–910               | EN <sup>d</sup> |
| <i>Solenangis scandens</i> (Schltr.) Schltr.                           | 2           | Wide               | 80                    | LC <sup>b</sup> |
| <i>Stolzia elaidum</i> (Lindl.) Summerh.                               | 3           | Wide               | 660–910               | LC <sup>c</sup> |
| <i>Tridactyle anthomaniaca</i> (Rchb.f.) Summerh.                      | 1           | Wide               | unknown               | LC <sup>b</sup> |



**Table 1 (continued) – Checklist of Orchidaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species   | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|---|-------------|--------------------|-----------------------|-----------------|
| <i>Tridactyle brevicealcarata</i> Summerh.                | 3           | Wide               | 570–900               | LC <sup>b</sup> |
| <i>Tridactyle eggelingii</i> Summerh.*                    | 3           | Wide               | 900                   | EN <sup>c</sup> |
| <i>Tridactyle lagesensis</i> (Rolfe) Schltr.              | 1           | ACA                | 570                   | NT <sup>b</sup> |
| <i>Tridactyle laurentii</i> Schltr. var. <i>laurentii</i> | 2           | Wide               | 100–540               | LC <sup>b</sup> |
| <i>Vanilla africana</i> Lindl.                            | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Vanilla cucullata</i> Kraenzl. ex J.Braun & K.Schum.   | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Zeuxine gilgiana</i> Kraenzl. & Schltr.                | 1           | Wide               | unknown               | LC <sup>b</sup> |

or nearby the NMA. We took into consideration records that were explicitly mentioned as collected in NMA plus a radius of 3 km around the massif. We extracted 6116 georeferenced records using the shapefile of the Ngovayang area provided by the Interactive Forest Atlas of Cameroon (WRI 2012). For this paper, we focus our effort on the two larger families, Orchidaceae and Rubiaceae (2787 specimens together), for which the authors have particular taxonomic expertise: all specimens with doubtful identification for these two families were physically checked and verified. The species number estimates for other plant families collected in the NMA are mainly derived from Dauby et al. (2016).

Hereafter, for simplicity, we will use the term ‘species’ even if they comprise infraspecific taxa (subspecies or varieties).

### Sampling completeness and diversity analysis

Sampling intensity and species richness were calculated for Rubiaceae and Orchidaceae using a fixed grid cell size of  $0.02^\circ \times 0.02^\circ$  (about 5 km<sup>2</sup>) which was a reasonable balance between precision and detail that can be achieved in the NMA. Rarefaction methods were used to calculate an expected number of species ( $S_k$ ) per grid cell found in subsamples of fixed size (see Droissart et al. 2012 for calculation). For our comparison with raw species richness, we calculate  $S_k$  for  $k = 20$  (i.e. the grid cells where at least 20 herbarium specimens have been collected). Richness estimates and sampling completeness for Rubiaceae and Orchidaceae were compared with sample-based rarefaction curves using the R package *iNEXT* (Hsieh et al. 2016). We used the *iNEXT* package to compute the seamless rarefaction (interpolation) and extrapolation (prediction) sampling curves and the associated 95% confidence intervals of individual-based abundance data.

From the compiled herbarium database, we kept 2484 records with location accurate to 1 km for diversity analysis (grid-cells maps), and 1869 records with location accurate to 100 m for altitudinal range analysis. Maps were prepared with ArcMap 10.5.1 (ESRI 2017).

### IUCN Red List category and conservation analysis

The conservation status of plant species was taken from existing IUCN assessments on the Red List website (IUCN 2018) or in the literature (e.g. Onana 2011, Onana & Cheek 2011, Onana 2013), when available. Eighty-three of these assessments have been provided or corrected based on the authors’ more recent, unpublished data following the IUCN Red List guidelines (IUCN 2017). Most of these preliminary assessments are undergoing publication on the IUCN Red List portal.

To check objectively whether the NMA represents a key site for wild plant and habitat conservation in Central Africa, we applied the Important Plant Area (IPA) criteria using the revised guidelines and methodology recently provided by Darbyshire et al. (2017). A site can qualify as an IPA if it satisfies at least one of three main criteria (threatened species, botanical richness and threatened habitats). For each criterion, all sub-criteria and associated thresholds have been evaluated using the available data.

## RESULTS

### The rich flora of the Ngovayang Massif Area (NMA)

Our complete NMA dataset consists of 6116 specimens (of which 94% are identified to species), 138 families, 636 genera and 1472 species (see electronic appendix 2). These specimens were mainly extracted from the RAINBIO database (4924 specimens) and the additional specimens (1192) came from field expeditions led by the first and last authors between 2004 and 2017.

Most of the specimens from the NMA were collected during two main periods, between 1890 and 1930 (the contribution mostly of one collector: Zenker, see electronic appendix 3) and between 2004 and 2017 (electronic appendix 4). The last period added 318 species to the list of species previously known from the first collecting period which represents an increase of 21.6% (electronic appendix 3).

The two most represented families of the NMA, both in terms of species diversity and number of collections, are Ru-

**Table 2 – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

Distribution categories considered: Wide = widely distributed; NMA = endemic to NMA; Cameroon = endemic to Cameroon; ACA = endemic to ACA. IUCN Red List Categories considered are: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient. Sources for IUCN Red List Category: <sup>a</sup>IUCN (2018), <sup>b</sup>Onana (2011), <sup>c</sup>personal database, unpublished data, <sup>d</sup>Lachenaud et al. (2013), <sup>e</sup>Taedoumg et al. (2011), <sup>f</sup>Verstraete et al. (2013), <sup>g</sup>Sonké et al. (2015), <sup>h</sup>Sonké & Lachenaud (2016), <sup>i</sup>Zemagho et al. (2017), <sup>j</sup>Sonké et al. (2012). <sup>1</sup> Probably specifically distinct from the type variety. <sup>2</sup> *Pausinystalia brachythyrsum*, supposedly an endemic species of the NMA, proves to be identical with *Corynanthe johimbe* (Ntore & Lachenaud, unpublished data). Two taxa (*Canthium* sp. and *Pseudomussaenda* sp.) not identified to species level are not included in the checklist.

| Species   | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|---|-------------|--------------------|-----------------------|-----------------|
| <i>Adenorandia kalbreyeri</i> (Hiern) Robbr. & Bridson                | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Aidia micrantha</i> (K.Schum.) Bullock ex F.White ( <i>s.l.</i> )  | 30          | Wide               | 80–840                | LC <sup>b</sup> |
| <i>Aidia rhacodosepala</i> (K.Schum.) E.M.A.Petit                     | 8           | Cameroon           | 390                   | LC <sup>b</sup> |
| <i>Aidia rubens</i> (Hiern) G.Taylor                                  | 5           | ACA                | 750–840               | LC <sup>b</sup> |
| <i>Aoranche cladantha</i> (K.Schum.) Somers                           | 9           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Argocoffeopsis subcordata</i> (Hiern) Lebrun                       | 8           | Wide               | 450–770               | LC <sup>b</sup> |
| <i>Argostemma pumilum</i> Benn.                                       | 1           | Wide               | 980                   | DD              |
| <i>Atractogyne bracteata</i> (Wernham) Hutch. & Dalziel               | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Aulacocalyx caudata</i> (Hiern) Keay                               | 17          | ACA                | 90–840                | LC <sup>b</sup> |
| <i>Aulacocalyx jasminiflora</i> Hook.f.                               | 12          | Wide               | 110–1010              | LC <sup>b</sup> |
| <i>Aulacocalyx mapiana</i> Sonké & Bridson                            | 4           | Cameroon           | 200–790               | EN <sup>b</sup> |
| <i>Aulacocalyx talbotii</i> (Wernham) Keay                            | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Belonophora coriacea</i> Hoyle                                     | 12          | Wide               | 430–920               | LC <sup>b</sup> |
| <i>Belonophora ongensis</i> S.E.Dawson & Cheek                        | 3           | ACA                | 730–940               | CR <sup>a</sup> |
| <i>Belonophora talbotii</i> (Wernham) Keay                            | 6           | ACA                | 440–760               | VU <sup>a</sup> |
| <i>Belonophora wernhamii</i> Hutch. & Dalziel                         | 7           | ACA                | 490–570               | NT <sup>b</sup> |
| <i>Bertiera aethiopica</i> Hiern                                      | 26          | Wide               | 450–1060              | LC <sup>b</sup> |
| <i>Bertiera batesii</i> Wernham                                       | 6           | ACA                | 430–830               | LC <sup>b</sup> |
| <i>Bertiera bicarpellata</i> (K.Schum.) N.Hallé                       | 20          | Wide               | 80–1010               | LC <sup>b</sup> |
| <i>Bertiera bracteolata</i> Hiern                                     | 3           | Wide               | 430                   | LC <sup>b</sup> |
| <i>Bertiera breviflora</i> Hiern                                      | 21          | Wide               | 80–1010               | LC <sup>b</sup> |
| <i>Bertiera elabensis</i> K.Krause                                    | 18          | ACA                | 80–540                | LC <sup>b</sup> |
| <i>Bertiera globiceps</i> K.Schum.                                    | 7           | Wide               | 570–1060              | LC <sup>b</sup> |
| <i>Bertiera heterophylla</i> Nguembou & Sonké                         | 3           | NMA                | 120–440               | CR <sup>c</sup> |
| <i>Bertiera iturensis</i> K.Krause                                    | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Bertiera laxa</i> Benth.   | 25          | Wide               | 90–910                | LC <sup>b</sup> |
| <i>Bertiera laxissima</i> K.Schum.                                    | 19          | Cameroon           | 450–930               | LC <sup>b</sup> |
| <i>Bertiera lejolyana</i> Nguembou & Sonké                            | 24          | ACA                | 350–1010              | LC <sup>b</sup> |
| <i>Bertiera racemosa</i> var. <i>elephantina</i> N.Hallé <sup>1</sup> | 3           | Wide               | 500–510               | LC <sup>b</sup> |
| <i>Bertiera retrofracta</i> K.Schum.                                  | 39          | ACA                | 80–1010               | LC <sup>b</sup> |
| <i>Calycosiphonia spathicalyx</i> (K.Schum.) Robbr.                   | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Chassalia bipindensis</i> Sonké, Nguembou & A.P.Davis              | 36          | Cameroon           | 130–920               | LC <sup>b</sup> |



**Table 2 (continued) – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species   | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|---|-------------|--------------------|-----------------------|-----------------|
| <i>Chassalia chrysoclada</i> (K.Schum.) O.Lachenaud             | 2           | Wide               | unknown               | LC <sup>c</sup> |
| <i>Chassalia corallifera</i> (A.Chev. ex De Wild.) Hepper       | 1           | Wide               | 900                   | LC <sup>c</sup> |
| <i>Chassalia ischnophylla</i> (K.Schum.) Hepper                 | 4           | ACA                | 110–1030              | LC <sup>b</sup> |
| <i>Chassalia laikomensis</i> Check                              | 1           | ACA                | 1080                  | NT <sup>d</sup> |
| <i>Chassalia macrodiscus</i> K.Schum.                           | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Chassalia pleuroneura</i> (K.Schum.) O.Lachenaud             | 1           | Wide               | 90                    | LC <sup>b</sup> |
| <i>Chassalia subnuda</i> (Hiern) Hepper                         | 3           | ACA                | 80–800                | LC <sup>b</sup> |
| <i>Chassalia tchibangensis</i> Pellegr.                         | 1           | ACA                | 870                   | LC <sup>c</sup> |
| <i>Chassalia zenkeri</i> K.Schum. & K.Krause                    | 25          | ACA                | 110–620               | LC <sup>b</sup> |
| <i>Coffea brevipes</i> Hiern                                    | 6           | Wide               | 770–920               | LC <sup>a</sup> |
| <i>Coffea liberica</i> Hiern                                    | 1           | Wide               | unknown               | LC <sup>a</sup> |
| <i>Coffea mannii</i> (Hook.f.) A.P.Davis                        | 20          | Wide               | 80–1010               | LC <sup>a</sup> |
| <i>Coffea mapiana</i> Sonké, Nguembou & A.P.Davis               | 9           | Cameroon           | 540–940               | VU <sup>a</sup> |
| <i>Coffea mayombensis</i> A.Chev.                               | 7           | Wide               | 510–1010              | LC <sup>a</sup> |
| <i>Collettoecema magna</i> Sonké & Dessein                      | 4           | Cameroon           | 130–730               | EN <sup>c</sup> |
| <i>Corynanthe johimbe</i> K.Schum. <sup>2</sup>                 | 15          | ACA                | 490–760               | LC <sup>c</sup> |
| <i>Corynanthe macroceras</i> K.Schum.                           | 7           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Corynanthe pachyceras</i> K.Schum.                           | 11          | Wide               | unknown               | LC <sup>b</sup> |
| <i>Corynanthe talbotii</i> (Wernham) Å.Krüger & Löfstr.         | 4           | ACA                | unknown               | VU <sup>b</sup> |
| <i>Craterispermum caudatum</i> Hutch.                           | 5           | Wide               | 230–640               | LC <sup>b</sup> |
| <i>Craterispermum ledermannii</i> K.Krause                      | 16          | ACA                | 90–810                | LC <sup>b</sup> |
| <i>Craterispermum parvifolium</i> Taedoumg & Sonké              | 1           | ACA                | 930                   | VU <sup>c</sup> |
| <i>Craterispermum robbrechtianum</i> Taedoumg & Sonké           | 19          | ACA                | 90–1010               | LC <sup>c</sup> |
| <i>CreMASpora thomsonii</i> Hiern                               | 2           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Cuviera acutiflora</i> DC.                                   | 6           | Wide               | 430                   | LC <sup>b</sup> |
| <i>Cuviera physinodes</i> K.Schum.                              | 3           | ACA                | 550–800               | LC <sup>c</sup> |
| <i>Cuviera subuliflora</i> Benth.                               | 5           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Diodella sarmentosa</i> (Sw.) Bacigalupo & Cabral ex Borhidi | 1           | Wide               | 540                   | LC <sup>b</sup> |
| <i>Empogona gossweileri</i> (S.Moore) Tosh & Robbr.             | 8           | Wide               | 470–1080              | LC <sup>b</sup> |
| <i>Empogona macrophylla</i> (K.Schum.) Tosh & Robbr.            | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Euclinia longiflora</i> Salisb.                              | 7           | Wide               | 510–650               | LC <sup>b</sup> |
| <i>Euclinia squamifera</i> (R.D.Good) Keay                      | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Eumachia andeliae</i> sp. ined.                              | 2           | ACA                | 570–800               | LC <sup>c</sup> |
| <i>Eumachia coffeosperma</i> (K.Schum.) Razafim. & C.M.Taylor   | 4           | Wide               | 440–900               | LC <sup>c</sup> |
| <i>Eumachia domaticola</i> (De Wild.) Razafim. & C.M.Taylor     | 3           | Wide               | 850–1030              | LC <sup>c</sup> |
| <i>Eumachia insidens</i> (Hiern) Razafim. & C.M.Taylor          | 4           | Wide               | 380–770               | LC <sup>b</sup> |

**Table 2 (continued) – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species  | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|--|-------------|--------------------|-----------------------|-----------------|
| <i>Eumachia letouzeyi</i> (Robbr.) Razafim. & C.M.Taylor                           | 7           | ACA                | 540–850               | LC <sup>c</sup> |
| <i>Eumachia obovoidea</i> (Verdc.) Razafim. & C.M.Taylor                           | 4           | Wide               | 80–430                | LC <sup>c</sup> |
| <i>Eumachia oddonii</i> var. <i>cameroonensis</i> (Verdc.) C.M.Taylor <sup>1</sup> | 4           | Wide               | 910                   | LC <sup>c</sup> |
| <i>Eumachia sciadephora</i> (Hiern) Razafim. & C.M.Taylor                          | 11          | Wide               | 80–1080               | LC <sup>b</sup> |
| <i>Eumachia viridicalyx</i> (R.D. Good) Razafim. & C.M.Taylor                      | 1           | ACA                | unknown               | DD              |
| <i>Gaertnera bieleri</i> (De Wild.) E.M.A.Petit                                    | 10          | Wide               | 230–910               | LC <sup>b</sup> |
| <i>Gaertnera letouzeyi</i> Malcomber   | 2           | ACA                | 730                   | EN <sup>d</sup> |
| <i>Gaertnera trachystyla</i> (Hiern) E.M.A.Petit                                   | 23          | ACA                | 120–1030              | LC <sup>b</sup> |
| <i>Gardenia imperialis</i> K.Schum.  | 9           | Wide               | 80–420                | LC <sup>b</sup> |
| <i>Geophila afzelii</i> Hiern  | 5           | Wide               | 120–520               | LC <sup>b</sup> |
| <i>Geophila lancistipula</i> Hiern   | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Geophila obvallata</i> Didr.  | 3           | Wide               | 80–570                | LC <sup>b</sup> |
| <i>Globulostylis leniochlamys</i> (K.Schum.) Sonké, O.Lachenaud & Dessein          | 13          | NMA                | 450–910               | CR <sup>c</sup> |
| <i>Globulostylis rammeloana</i> Sonké, O.Lachenaud & Dessein                       | 7           | Cameroon           | 200–730               | VU <sup>f</sup> |
| <i>Globulostylis robbrechtiana</i> Sonké, O.Lachenaud & Dessein                    | 3           | ACA                | 1080                  | NT <sup>f</sup> |
| <i>Heinsia crinita</i> (Afzel.) G.Taylor   | 3           | Wide               | 710                   | LC <sup>b</sup> |
| <i>Heinsia myrmoecia</i> (K.Schum.) N.Hallé  | 4           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Hekistocarpa minutiflora</i> Hook.f.  | 2           | ACA                | 520                   | LC <sup>b</sup> |
| <i>Hymenocoleus globulifer</i> Robbr.  | 2           | ACA                | 910–1030              | LC <sup>c</sup> |
| <i>Hymenocoleus hirsutus</i> (Benth.) Robbr.                                       | 2           | Wide               | 180–830               | LC <sup>b</sup> |
| <i>Hymenocoleus nervopilosus</i> Robbr.  | 2           | Wide               | 440–550               | LC <sup>c</sup> |
| <i>Hymenocoleus neurodictyon</i> (K.Schum.) Robbr.                                 | 2           | Wide               | 760                   | LC <sup>b</sup> |
| <i>Hymenocoleus rotundifolius</i> (A.Chev. ex Hepper) Robbr.                       | 1           | Wide               | 550                   | LC <sup>c</sup> |
| <i>Hymenocoleus scaphus</i> (K.Schum.) Robbr.                                      | 1           | Wide               | 380                   | LC <sup>c</sup> |
| <i>Hymenocoleus subipecacuanha</i> (K.Schum.) Robbr.                               | 6           | Wide               | 110–770               | LC <sup>c</sup> |
| <i>Ixora aneimenodesma</i> K.Schum.  | 18          | ACA                | 170–920               | LC <sup>b</sup> |
| <i>Ixora batesii</i> Wernham   | 2           | Cameroon           | 380–910               | EN <sup>a</sup> |
| <i>Ixora bauchiensis</i> Hutch. & Dalziel  | 1           | ACA                | 750                   | LC <sup>b</sup> |
| <i>Ixora euosmia</i> K.Schum.  | 7           | ACA                | 120                   | LC <sup>b</sup> |
| <i>Ixora guineensis</i> Benth.   | 5           | Wide               | 200–1030              | LC <sup>b</sup> |
| <i>Ixora hippoperifera</i> Bremek.   | 26          | ACA                | 110–730               | LC <sup>b</sup> |
| <i>Ixora macilenta</i> De Block  | 5           | ACA                | 110–800               | LC <sup>b</sup> |
| <i>Ixora minutiflora</i> Hiern subsp. <i>minutiflora</i>                           | 31          | ACA                | 80–1010               | LC <sup>b</sup> |
| <i>Ixora nematopoda</i> K.Schum.   | 3           | ACA                | 310–760               | LC <sup>b</sup> |
| <i>Ixora praetermissa</i> De Block   | 6           | ACA                | 200–910               | LC <sup>b</sup> |
| <i>Ixora synactica</i> De Block  | 10          | Cameroon           | 190–780               | EN <sup>b</sup> |

**Table 2 (continued) – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species  | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|--|-------------|--------------------|-----------------------|-----------------|
| <i>Keetia</i> (?) sp. ined.  | 1           | NMA                | 690                   | CR <sup>c</sup> |
| <i>Keetia leucantha</i> (K.Krause) Bridson                                       | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Keetia mannii</i> (Hiern) Bridson   | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Keetia ripae</i> (De Wild.) Bridson   | 5           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Keetia venosa</i> (Oliv.) Bridson   | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Kupeantha pentamera</i> (Sonké & Robbr.) Cheek                                | 33          | ACA                | 180–920               | LC <sup>b</sup> |
| <i>Kupeantha spathulata</i> (A.P.Davis & Sonké) Cheek                            | 25          | NMA                | 350–920               | CR <sup>c</sup> |
| <i>Lasianthus batangensis</i> K.Schum.   | 19          | Wide               | 200–1030              | LC <sup>b</sup> |
| <i>Leptactina arborescens</i> (Welw. ex Benth. & Hook.f.) De Block               | 11          | Wide               | 510                   | LC <sup>b</sup> |
| <i>Leptactina involucrata</i> Hook.f.  | 5           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Leptactina latifolia</i> K.Schum.   | 1           | ACA                | 770                   | LC <sup>c</sup> |
| <i>Leptactina mannii</i> subsp. <i>arnoldiana</i> (De Wild.) Neuba ex Figueiredo | 7           | ACA                | 350–900               | LC <sup>b</sup> |
| <i>Massularia acuminata</i> (G.Don) Bullock ex Hoyle                             | 21          | Wide               | 80–710                | LC <sup>g</sup> |
| <i>Massularia stewartiana</i> Sonké, E.Bidault & Droissart                       | 1           | ACA                | 710                   | EN <sup>g</sup> |
| <i>Mitragyna ledermannii</i> (K.Krause) Ridsdale                                 | 5           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Morelia senegalensis</i> A.Rich. ex DC.                                       | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Morinda longiflora</i> G.Don  | 4           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Morinda lucida</i> Benth.   | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Morinda morindoides</i> (Baker) Milne-Redh.                                   | 2           | Wide               | 430                   | LC <sup>b</sup> |
| <i>Mussaenda arcuata</i> Poir.   | 5           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Mussaenda elegans</i> Schumach. & Thonn.                                      | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Mussaenda tenuiflora</i> Benth.   | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Nauclea diderrichii</i> (De Wild.) Merr.                                      | 2           | Wide               | unknown               | VU <sup>a</sup> |
| <i>Nichallea soyauxii</i> (Hiern) Bridson  | 34          | Wide               | 110–940               | LC <sup>b</sup> |
| <i>Oldenlandia lancifolia</i> (K.Schum.) DC                                      | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Otomeria micrantha</i> K.Schum.   | 2           | Wide               | 540–830               | LC <sup>b</sup> |
| <i>Otomeria volubilis</i> (K.Schum.) Verdc.                                      | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Oxyanthus brevicaulis</i> K.Krause  | 1           | Wide               | 840                   | VU <sup>b</sup> |
| <i>Oxyanthus doucetii</i> Sonké & O.Lachenaud                                    | 1           | Cameroon           | 430                   | VU <sup>h</sup> |
| <i>Oxyanthus formosus</i> Hook.f.  | 6           | Wide               | 510–840               | LC <sup>b</sup> |
| <i>Oxyanthus gracilis</i> Hiern  | 16          | Wide               | 570–1030              | LC <sup>b</sup> |
| <i>Oxyanthus laxiflorus</i> K.Schum. ex Hutch. & Dalziel                         | 35          | ACA                | 80–930                | LC <sup>b</sup> |
| <i>Oxyanthus oliganthus</i> K.Schum.   | 9           | Wide               | unknown               | VU <sup>b</sup> |
| <i>Oxyanthus setosus</i> Keay  | 13          | ACA                | 630–930               | LC <sup>b</sup> |
| <i>Oxyanthus speciosus</i> DC.   | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Oxyanthus unilocularis</i> Hiern  | 6           | Wide               | 430                   | LC <sup>b</sup> |

**Table 2 (continued) – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species  | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|--|-------------|--------------------|-----------------------|-----------------|
| <i>Parapentas setigera</i> (Hiern) Verdc.  | 1           | Wide               | 450                   | LC <sup>b</sup> |
| <i>Pauridiantha arcuata</i> (S.E.Dawson) Smedmark & B.Bremer                     | 5           | Cameroon           | 470–690               | CR <sup>b</sup> |
| <i>Pauridiantha divaricata</i> (K.Schum.) Bremek.                                | 8           | ACA                | 550–910               | VU <sup>a</sup> |
| <i>Pauridiantha floribunda</i> (K.Schum. & K.Krause) Bremek.                     | 3           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Pauridiantha makakana</i> (N.Hallé) Smedmark & B.Bremer                       | 19          | ACA                | 440–910               | NT <sup>b</sup> |
| <i>Pauridiantha schumannii</i> (Bremek.) Smedmark & B.Bremer                     | 29          | ACA                | 200–1030              | LC <sup>b</sup> |
| <i>Pauridiantha talbotii</i> (Wernham) Ntore & Dessein                           | 1           | ACA                | 920                   | LC <sup>b</sup> |
| <i>Pavetta bidentata</i> Hiern   | 7           | ACA                | 80–1080               | LC <sup>b</sup> |
| <i>Pavetta camerounensis</i> S.D.Manning   | 25          | ACA                | 90–1030               | LC <sup>b</sup> |
| <i>Pavetta gabonica</i> Bremek.  | 9           | ACA                | 570–1040              | LC <sup>b</sup> |
| <i>Pavetta hispida</i> Hiern   | 11          | ACA                | 110–910               | LC <sup>b</sup> |
| <i>Pavetta kribiensis</i> S.D.Manning  | 3           | Cameroon           | 110–310               | EN <sup>b</sup> |
| <i>Pavetta longibrachiata</i> Bremek.  | 1           | ACA                | 700                   | LC <sup>b</sup> |
| <i>Pavetta microthamnus</i> K.Schum.   | 3           | Wide               | 680–800               | LC <sup>b</sup> |
| <i>Pavetta neurocarpa</i> Benth.   | 11          | ACA                | 200–730               | LC <sup>b</sup> |
| <i>Pavetta owariensis</i> var. <i>opaca</i> S.D.Manning <sup>1</sup>             | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Pavetta renidens</i> (K.Krause) Bremek.                                       | 6           | ACA                | 440–650               | LC <sup>b</sup> |
| <i>Pavetta rigida</i> Hiern  | 2           | ACA                | 550                   | LC <sup>b</sup> |
| <i>Pavetta staudtii</i> Hutch. & Dalziel   | 4           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Pavetta suffruticosa</i> K.Schum.   | 11          | ACA                | 500–940               | LC <sup>c</sup> |
| <i>Petitiododon parviflorum</i> (Keay) Robbr.                                    | 5           | ACA                | 110–730               | LC <sup>b</sup> |
| <i>Pleiocoryne fernandensis</i> (Hiern) Rauschert                                | 4           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Pouchetia africana</i> A.Rich. var. <i>aequatorialis</i> N.Hallé <sup>1</sup> | 5           | Wide               | 110–630               | LC <sup>c</sup> |
| <i>Psychotria alatipes</i> Wernham   | 13          | ACA                | 260–1030              | LC <sup>b</sup> |
| <i>Psychotria anetoclada</i> Hiern   | 1           | ACA                | 830                   | LC <sup>c</sup> |
| <i>Psychotria bifaria</i> Hiern  | 3           | Wide               | 130–470               | LC <sup>b</sup> |
| <i>Psychotria brandneriana</i> (L.Linden) Robbr.                                 | 1           | Wide               | 80                    | LC <sup>c</sup> |
| <i>Psychotria breteleri</i> O.Lachenaud  | 6           | ACA                | 450–930               | LC <sup>c</sup> |
| <i>Psychotria brevifissa</i> O.Lachenaud   | 7           | ACA                | 570–1010              | LC <sup>c</sup> |
| <i>Psychotria calceata</i> E.M.A.Petit   | 2           | Cameroon           | 310                   | LC <sup>b</sup> |
| <i>Psychotria conica</i> O.Lachenaud subsp. <i>ngovayangensis</i> O.Lachenaud    | 1           | NMA                | 700                   | CR <sup>c</sup> |
| <i>Psychotria densinervia</i> (K.Krause) Verdc.                                  | 3           | ACA                | 870–1080              | EN <sup>a</sup> |
| <i>Psychotria dewildei</i> O.Lachenaud   | 5           | ACA                | 930–1030              | LC <sup>c</sup> |
| <i>Psychotria droissartii</i> O.Lachenaud  | 2           | ACA                | 90–790                | VU <sup>c</sup> |
| <i>Psychotria ebensis</i> K.Schum.   | 11          | ACA                | 310–910               | LC <sup>b</sup> |
| <i>Psychotria fimbriatifolia</i> R.D.Good  | 3           | Wide               | 760–910               | LC <sup>b</sup> |

**Table 2 (continued) – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species  | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|--|-------------|--------------------|-----------------------|-----------------|
| <i>Psychotria foliosa</i> Hiern  | 16          | ACA                | 90–1030               | LC <sup>b</sup> |
| <i>Psychotria globiceps</i> K.Schum.                                     | 7           | ACA                | 430–1080              | LC <sup>b</sup> |
| <i>Psychotria hexamera</i> (K.Schum.) O.Lachenaud                        | 5           | Cameroon           | 80–900                | LC <sup>c</sup> |
| <i>Psychotria humilis</i> Hiern  | 1           | ACA                | 560                   | LC <sup>c</sup> |
| <i>Psychotria hypsophila</i> K.Schum. & K.Krause                         | 8           | Wide               | 520–930               | LC <sup>b</sup> |
| <i>Psychotria ingentifolia</i> E.M.A.Petit                               | 4           | Cameroon           | 810–910               | LC <sup>b</sup> |
| <i>Psychotria konguensis</i> Hiern                                       | 9           | Wide               | 440–930               | LC <sup>b</sup> |
| <i>Psychotria kupensis</i> Cheek   | 10          | ACA                | 200–1060              | LC <sup>c</sup> |
| <i>Psychotria lagenocarpa</i> K.Schum.                                   | 3           | ACA                | 260–560               | LC <sup>b</sup> |
| <i>Psychotria lanceifolia</i> K.Schum.                                   | 18          | ACA                | 200–850               | VU <sup>a</sup> |
| <i>Psychotria latistipula</i> Benth.                                     | 14          | ACA                | 80–810                | LC <sup>b</sup> |
| <i>Psychotria laxithyrsa</i> O.Lachenaud                                 | 1           | ACA                | 700                   | LC <sup>c</sup> |
| <i>Psychotria ledermannii</i> (K.Krause) Figueiredo                      | 4           | ACA                | 550–830               | LC <sup>c</sup> |
| <i>Psychotria leptophylla</i> Hiern                                      | 20          | Wide               | 90–940                | LC <sup>b</sup> |
| <i>Psychotria letouzeyi</i> E.M.A.Petit                                  | 5           | ACA                | 540–1080              | LC <sup>c</sup> |
| <i>Psychotria longicornis</i> O.Lachenaud                                | 2           | ACA                | 800–1080              | VU <sup>c</sup> |
| <i>Psychotria lucens</i> Hiern   | 4           | Wide               | 550–620               | LC <sup>b</sup> |
| <i>Psychotria maesenii</i> O.Lachenaud                                   | 1           | ACA                | 830                   | VU <sup>c</sup> |
| <i>Psychotria marantifolia</i> O.Lachenaud                               | 4           | Cameroon           | 80–770                | VU <sup>c</sup> |
| <i>Psychotria pendulothyrsa</i> O.Lachenaud                              | 1           | ACA                | 770                   | LC <sup>c</sup> |
| <i>Psychotria potanthera</i> Wernham                                     | 2           | ACA                | 800–900               | LC <sup>c</sup> |
| <i>Psychotria raynaliorum</i> O.Lachenaud                                | 5           | ACA                | 80–940                | LC <sup>b</sup> |
| <i>Psychotria retrorsipilis</i> O.Lachenaud                              | 6           | NMA                | 710–1030              | CR <sup>c</sup> |
| <i>Psychotria rhizomatosa</i> De Wild.                                   | 2           | Wide               | 840–910               | LC <sup>b</sup> |
| <i>Psychotria rhynchodiscus</i> O.Lachenaud                              | 4           | ACA                | 540–810               | LC <sup>c</sup> |
| <i>Psychotria rubescens</i> (Hiern) O.Lachenaud                          | 3           | ACA                | 730–1030              | LC <sup>b</sup> |
| <i>Psychotria rubripilis</i> K.Schum.                                    | 1           | Wide               | 510                   | LC <sup>c</sup> |
| <i>Psychotria satabiei</i> O.Lachenaud                                   | 17          | Cameroon           | 260–910               | LC <sup>b</sup> |
| <i>Psychotria senterrei</i> O.Lachenaud                                  | 2           | Cameroon           | 1010–1030             | VU <sup>c</sup> |
| <i>Psychotria sitae</i> O.Lachenaud subsp. <i>holochlora</i> O.Lachenaud | 2           | ACA                | 640–1080              | VU <sup>c</sup> |
| <i>Psychotria solfiana</i> K.Krause                                      | 16          | ACA                | 230–1010              | LC <sup>c</sup> |
| <i>Psychotria subpunctata</i> Hiern                                      | 1           | Wide               | 560                   | LC <sup>c</sup> |
| <i>Psychotria taedoungii</i> O.Lachenaud                                 | 2           | Cameroon           | 620–650               | NT <sup>c</sup> |
| <i>Psychotria thonneri</i> (De Wild. & T.Dur.) O.Lachenaud               | 4           | Wide               | 830–1080              | LC <sup>c</sup> |
| <i>Psychotria varians</i> O.Lachenaud                                    | 15          | Wide               | 600–1080              | LC <sup>c</sup> |
| <i>Psychotria venosa</i> (Hiern) E.M.A.Petit                             | 5           | ACA                | unknown               | LC <sup>b</sup> |



**Table 2 (continued) – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species   | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|---|-------------|--------------------|-----------------------|-----------------|
| <i>Psychotria villicarpa</i> O.Lachenaud subsp. <i>sessilis</i> O.Lachenaud   | 9           | NMA                | 540–930               | CR <sup>c</sup> |
| <i>Psychotria vogeliana</i> Benth.  | 7           | Wide               | 80                    | LC <sup>b</sup> |
| <i>Psydrax acutiflora</i> (Hiern) Bridson                                     | 4           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Psydrax arnoldiana</i> (De Wild. & T.Durand) Bridson                       | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Psydrax subcordata</i> (DC.) Bridson                                       | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Rothmannia hispida</i> (K.Schum.) Fagerl.                                  | 12          | Wide               | 110–940               | LC <sup>b</sup> |
| <i>Rothmannia lateriflora</i> (K.Schum.) Keay                                 | 16          | Wide               | 110–1010              | LC <sup>b</sup> |
| <i>Rothmannia libisa</i> N.Hallé  | 3           | Wide               | 540–810               | LC <sup>b</sup> |
| <i>Rothmannia longiflora</i> Salisb.  | 11          | Wide               | 430                   | LC <sup>b</sup> |
| <i>Rothmannia macrocarpa</i> (Hiern) Keay                                     | 2           | Wide               | 510–840               | LC <sup>b</sup> |
| <i>Rothmannia octomera</i> (Hook.) Fagerl.                                    | 3           | Wide               | 80–910                | LC <sup>b</sup> |
| <i>Rothmannia talbotii</i> (Wernham) Keay                                     | 6           | Wide               | 110–810               | LC <sup>b</sup> |
| <i>Rothmannia whitfieldii</i> (Lindl.) Dandy                                  | 5           | Wide               | 430                   | LC <sup>b</sup> |
| <i>Rutidea decorticata</i> Hiern  | 7           | Wide               | 650                   | LC <sup>b</sup> |
| <i>Rutidea glabra</i> Hiern   | 10          | ACA                | 200–410               | LC <sup>b</sup> |
| <i>Rutidea hispida</i> Hiern  | 7           | ACA                | 80–930                | LC <sup>b</sup> |
| <i>Rutidea olenotricha</i> Hiern  | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Rutidea rufipilis</i> Hiern  | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Rutidea smithii</i> Hiern  | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Rytigynia membranacea</i> (Hiern) Robyns                                   | 3           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Rytigynia robusta</i> sp. ined.  | 1           | Wide               | 1010                  | LC <sup>c</sup> |
| <i>Sabicea africana</i> (P.Beauv.) Hepper                                     | 4           | Wide               | 80–690                | LC <sup>b</sup> |
| <i>Sabicea apocynacea</i> (K.Schum.) Razafim., B.Bremer, Liede & Saleh A.Khan | 1           | ACA                | 930                   | EN <sup>b</sup> |
| <i>Sabicea calycina</i> Benth.  | 5           | Wide               | 540–1040              | LC <sup>b</sup> |
| <i>Sabicea capitellata</i> Benth.   | 4           | Wide               | 930                   | LC <sup>b</sup> |
| <i>Sabicea dinklagei</i> K.Schum.   | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Sabicea gabonica</i> (Hiern) Hepper  | 3           | ACA                | 90–870                | LC <sup>b</sup> |
| <i>Sabicea gigantostipula</i> K.Schum.  | 2           | ACA                | 810                   | LC <sup>b</sup> |
| <i>Sabicea gracilis</i> Wernham   | 1           | Cameroon           | 90                    | DD              |
| <i>Sabicea laxa</i> Wernham   | 2           | ACA                | unknown               | EN <sup>b</sup> |
| <i>Sabicea medusula</i> K.Schum. ex Wernham                                   | 5           | Wide               | 410–730               | LC <sup>i</sup> |
| <i>Sabicea pilosa</i> Hiern   | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Sabicea trigemina</i> K.Schum.   | 1           | NMA                | unknown               | CR <sup>b</sup> |
| <i>Sabicea venosa</i> Benth.  | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Sabicea xanthotricha</i> Wernham   | 1           | ACA                | 910                   | EN <sup>a</sup> |
| <i>Schumanniphyton magnificum</i> (K.Schum.) Harms                            | 3           | Wide               | 750–840               | LC <sup>b</sup> |

**Table 2 (continued) – Checklist of Rubiaceae from Ngovayang Massif Area (NMA), with their geographical and altitudinal range and their IUCN categories.**

| Species  | # specimens | Geographical range | Altitudinal range (m) | IUCN category   |
|--|-------------|--------------------|-----------------------|-----------------|
| <i>Sericanthe auriculata</i> (Keay) Robbr.                   | 10          | ACA                | 200–920               | VU <sup>b</sup> |
| <i>Sericanthe lowryana</i> Sonké & Robbr.                    | 4           | Cameroon           | 660–760               | EN <sup>j</sup> |
| <i>Sericanthe jacfelicis</i> (N.Hallé) Robbr.                | 1           | ACA                | 710                   | VU <sup>b</sup> |
| <i>Sherbournia buccularia</i> N.Hallé                        | 1           | ACA                | unknown               | LC <sup>b</sup> |
| <i>Sherbournia hapalophylla</i> (Wernham) Hepper             | 3           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Sherbournia streptocaulon</i> (K.Schum.) Hepper           | 8           | ACA                | 730                   | LC <sup>b</sup> |
| <i>Sherbournia zenkeri</i> Hua                               | 2           | Wide               | 450                   | LC <sup>b</sup> |
| <i>Tarenna bipindensis</i> (K.Schum.) Bremek.                | 17          | Wide               | 630–660               | LC <sup>b</sup> |
| <i>Tarenna conferta</i> (Benth.) Hiern                       | 5           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Tarenna eketensis</i> Wernham                             | 4           | Wide               | 650                   | LC <sup>b</sup> |
| <i>Tarenna fusco-flava</i> (K.Schum.) S.Moore                | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Tarenna grandiflora</i> (Benth.) Hiern                    | 19          | Wide               | 80–760                | LC <sup>b</sup> |
| <i>Tarenna lasiorhachis</i> (K.Schum. & K.Krause) Bremek.    | 13          | Wide               | 200–550               | LC <sup>b</sup> |
| <i>Tarenna pallidula</i> Hiern                               | 4           | Wide               | 600–900               | LC <sup>b</sup> |
| <i>Tarenna precdantenna</i> N.Hallé                          | 14          | Wide               | 370–920               | LC <sup>b</sup> |
| <i>Tricalysia amplexicaulis</i> Robbr.                       | 3           | ACA                | 570                   | LC <sup>c</sup> |
| <i>Tricalysia atherura</i> N.Hallé                           | 1           | ACA                | 630                   | VU <sup>a</sup> |
| <i>Tricalysia coriacea</i> (Benth.) Hiern                    | 2           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Tricalysia elliotii</i> (K.Schum.) Hutch. & Dalziel       | 1           | Wide               | 560                   | LC <sup>c</sup> |
| <i>Tricalysia ferorum</i> Robbr.                             | 1           | ACA                | 130                   | VU <sup>c</sup> |
| <i>Tricalysia lasiodelphys</i> (K.Schum. & K.Krause) A.Chev. | 8           | ACA                | 790–910               | LC <sup>b</sup> |
| <i>Tricalysia pangolina</i> N.Hallé                          | 2           | ACA                | 650–710               | LC <sup>b</sup> |
| <i>Tricalysia</i> sp. ined.                                  | 1           | NMA                | 410                   | CR <sup>c</sup> |
| <i>Tricalysia sylvae</i> Robbr.                              | 24          | ACA                | 90–940                | LC <sup>c</sup> |
| <i>Tricalysia vadensis</i> Robbr.                            | 12          | ACA                | 200–770               | VU <sup>c</sup> |
| <i>Trichostachys aurea</i> Hiern                             | 4           | Wide               | 380–950               | LC <sup>b</sup> |
| <i>Vangueriella chlorantha</i> (K.Schum.) Verdc.             | 27          | ACA                | 90–850                | LC <sup>c</sup> |
| <i>Vangueriella laxiflora</i> (K.Schum.) Verdc.              | 22          | Wide               | 260–930               | LC <sup>c</sup> |
| <i>Vangueriella letestui</i> Verdc.                          | 1           | ACA                | unknown               | EN <sup>e</sup> |
| <i>Vangueriella nigerica</i> (Robyns) Verdc.                 | 1           | Wide               | unknown               | LC <sup>b</sup> |
| <i>Vangueriella nigricans</i> (Robyns) Verdc.                | 3           | Wide               | 560                   | LC <sup>b</sup> |
| <i>Vangueriella zenkeri</i> Verdc.                           | 2           | Cameroon           | 930                   | EN <sup>b</sup> |
| <i>Virectaria procumbens</i> (Sm.) Bremek.                   | 3           | Wide               | 430–550               | LC <sup>c</sup> |

**Table 3 – Summary statistics for main areas of Atlantic Central Africa with published inventory data for Orchidaceae and Rubiaceae (SR = species richness).**Areas are classified according to their size (km<sup>2</sup>).

| Place names                        | Area (km <sup>2</sup> ) | Altitudinal range (m) | SR total | SR Orchidaceae | SR Rubiaceae | Sources   |
|------------------------------------|-------------------------|-----------------------|----------|----------------|--------------|---|
| Dom, Bamenda Highland (Cameroon)   | 4.5                     | 1550–1930             | 356      | 12             | 34           | Cheek et al. (2010)                               |
| Bali Ngemba FR (Cameroon)          | 10                      | 1800–2200             | 619      | 66             | 35           | Harvey et al. (2004)                              |
| Mefou “proposed” NP (Cameroon)     | 10                      | 600–900               | 863      | 28             | 103          | Cheek et al. (2011)                               |
| Annobón Island (Equatorial Guinea) | 17                      | 0–598                 | 365      | 28             | 16           | Velayos et al. (2014)                             |
| Ngovayang (Cameroon)               | 527                     | 0–1110                | 1472     | 111            | 281          | This paper  |
| São Tomé and Príncipe              | 990                     | 0–2024                | 1104     | 124            | 74           | Figueiredo et al. (2011)                          |
| Lebialem Highlands (Cameroon)      | 1223                    | 250–2000              | 412      | 33             | 68           | Harvey et al. (2010)                              |
| Mount Oku (Cameroon)               | 1550                    | 1100–3011             | 920      | 85             | 36           | Cheek et al. (2000)                               |
| Bioko Island (Equatorial Guinea)   | 2000                    | 0–3011                | 842      | 136            | 170          | Velayos et al. (2013)                             |
| Mounts Kupe-Manengouba (Cameroon)  | 2390                    | 500–2411              | 2412     | 183            | 213          | Cheek et al. (2004)                               |
| Mount Cameroon (Cameroon)          | 2700                    | 0–4040                | 2435     | 147            | 261          | Cable & Cheek (1998)                              |
| Gabon                              | 257700                  | 0–1070                | 5236     | 400            | 640          | Sosef et al. (2006);<br>Vande weghe et al. (2016) |
| Cameroon                           | 475000                  | 0–4040                | 6883     | 489            | 718          | Onana (2011)                                      |

biaceae (2237 specimens, 65 genera, 281 species) and Orchidaceae (550 specimens, 32 genera, 111 species), followed by Fabaceae s. lat. (306 specimens, 56 genera, 92 species) (electronic appendix 5).

#### A detailed checklist for Rubiaceae and Orchidaceae

We here confirm the presence of 281 Rubiaceae species and 111 Orchidaceae species in the NMA (detailed checklists for these two families are presented in tables 1 & 2). Among areas of comparable size in ACA for which species checklists have previously been published, the NMA ranks first for the diversity of Rubiaceae, and fifth for Orchidaceae (table 3, electronic appendix 6).

*Bulbophyllum* and *Polystachya* (27 species each, 24% of the total for each) are the most diverse genera of Orchidaceae within the NMA. Thirty-nine orchid species have only been collected once in the NMA and one species new to science is reported from there, *Angraecum ngovayangense* sp. ined. which is endemic to the massif (table 1). This taxonomic novelty is currently being published elsewhere. Three orchid species represent new records for Cameroon (table 1): *Bulbophyllum dolabriforme*, *B. nigritianum* and *Tridactyle eg-gelingii*.

Among the Rubiaceae, the most diverse genera are *Psychotria* (51 species, 18% of the total) and *Bertiera* (14 species, 5% of the total), ex-aequo with *Sabicea* (14 species as well). Fifty-seven species have only been collected once in

the NMA, and nine species are endemic to the NMA (*Ku-peantha spathulata*, *Bertiera heterophylla*, *Globulostylis leniochlamys*, *Keetia* (?) sp. ined., *Psychotria conica* subsp. *ngovayangensis*, *P. retrorsipilis*, *P. villicarpa* subsp. *sessilis*, *Sabicea trigemina*, *Tricalysia* sp. ined.). We did not find any new records for Cameroon, but several Rubiaceae species previously thought to have a more northern distribution in Cameroon have been discovered in the NMA thanks to recent prospections: *Aulacocalyx mapiana*, *Chassalia laikomensis*, *Gaertnera letouzeyi* and *Petitiocodon parviflorum*. Four species new to science are also reported from the NMA (see species referred to as “sp. ined.” in table 2) and will be published elsewhere.

#### Sampling and diversity patterns of Rubiaceae and Orchidaceae

The botanical exploration of the NMA and the knowledge of distributional patterns of Rubiaceae and Orchidaceae within the massif is far from complete (fig. 1), but general trends can nevertheless be identified. The 2484 georeferenced specimens collected for the two families are mostly concentrated around eight villages bordering the NMA (fig. 1A), that represent fieldwork starting points. Looking at raw data (fig. 1B & 1C), species richness is correlated with the historical sampling effort (Pearson correlation coefficient  $R = 0.95$ ). For instance, the grid overlapping the Bipindi locality is by far the most sampled (582 herbarium records) and species-rich (183 Rubiaceae and Orchidaceae species).

When using the subsampling procedure (fig. 1D), the correlation between sampling and richness patterns becomes blurred (Pearson correlation coefficient  $R = 0.07$ ), and several grid cells scattered all over the NMA present high expected diversity values.

The assessment of sampling completeness through interpolation and extrapolation curves (fig. 2) shows that, in terms of total species richness, Rubiaceae and Orchidaceae are relatively well known in the NMA; observed sample coverage values being over 90% for both families. From the extrapolation curves, one could expect that total species richness is comprised between 298 and 339 species for Rubiaceae and between 124 and 186 species for Orchidaceae (95% lower and upper confidence limits).

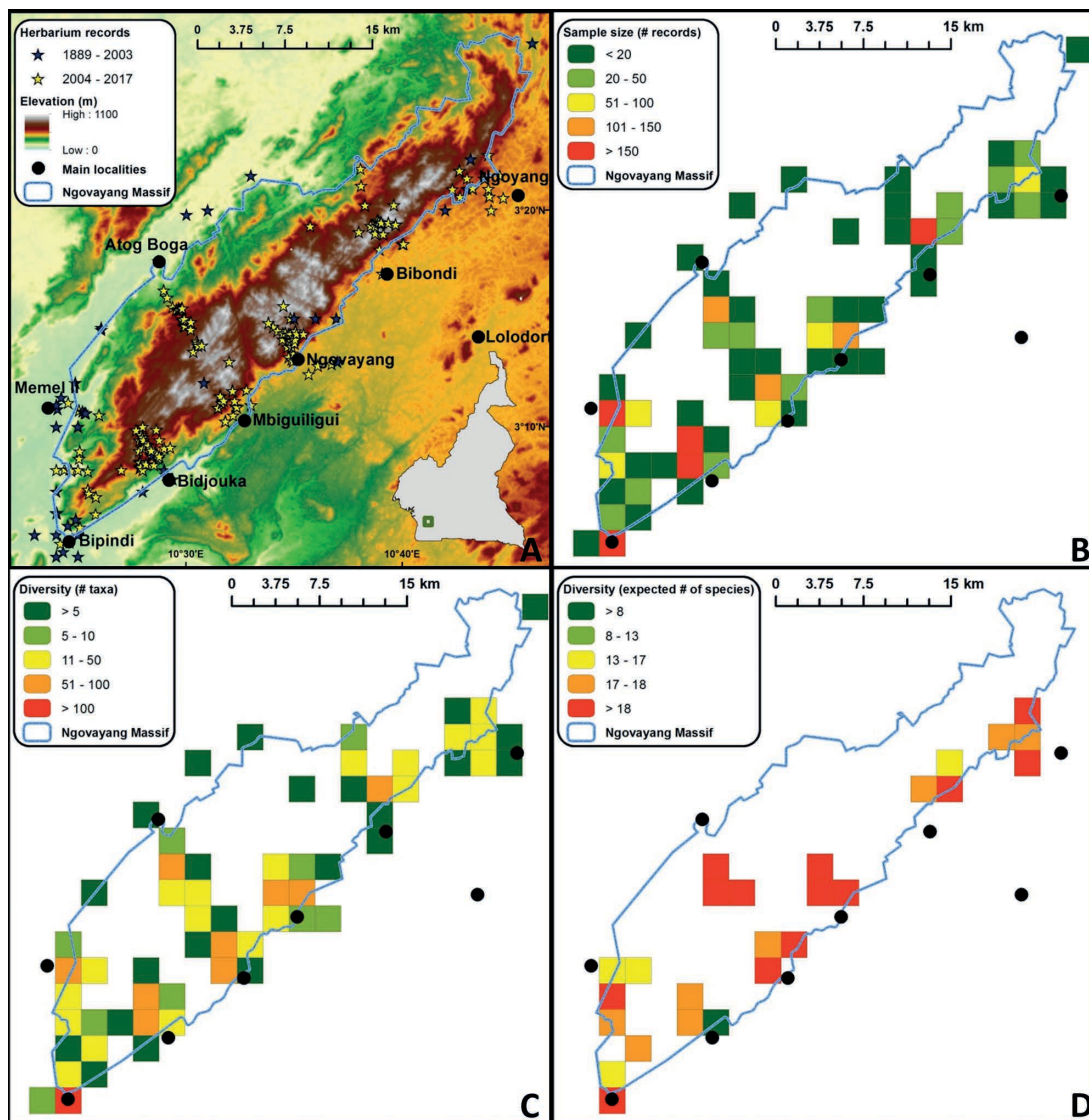
The analysis of altitudinal distribution of Rubiaceae and Orchidaceae in the NMA reveals that the observed (or ex-

pected) number of species for both families tends to increase along the elevation gradient, the areas above 750 m having the highest values (fig. 3). However, extrapolation values between 250 and 500 m and  $> 750$  m for Orchidaceae, and  $< 250$  m for Rubiaceae must be interpreted cautiously because sample coverage is weak (i.e. below 0.75) at these elevation intervals.

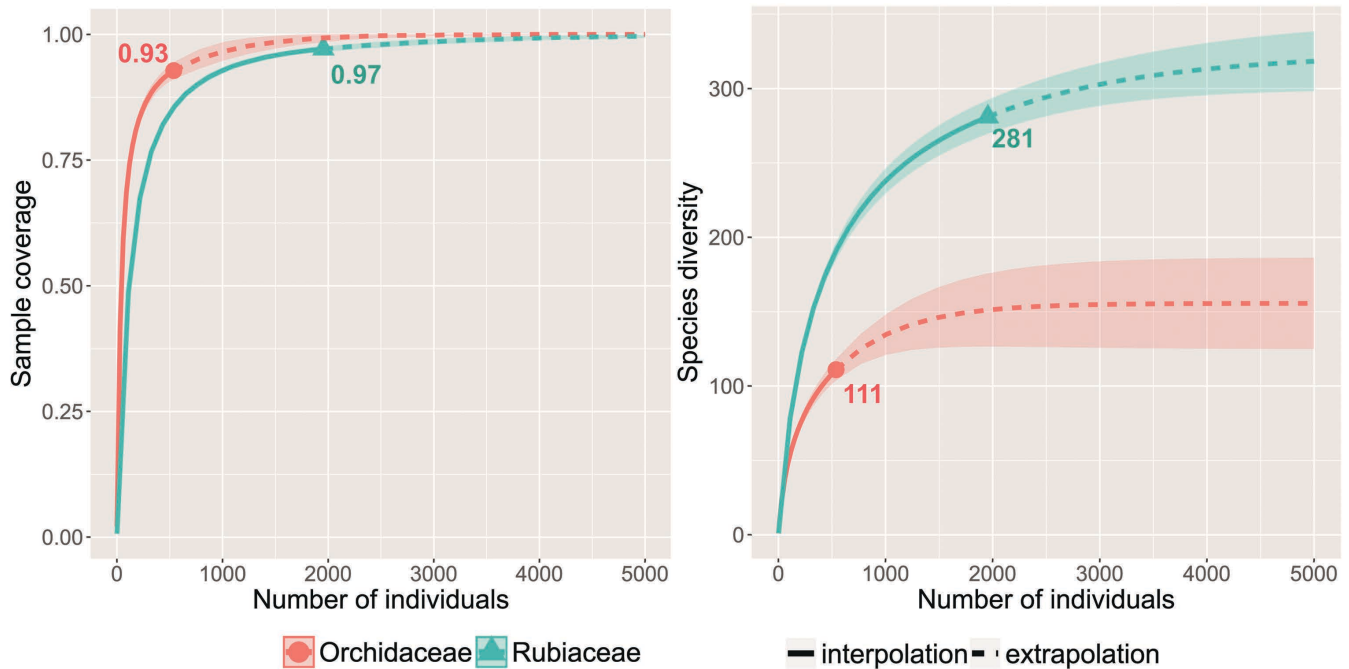
#### Geographical range and conservation status of Rubiaceae and Orchidaceae

About a quarter (27%) of the Orchidaceae and more than half (53%) of the Rubiaceae recorded in the NMA are endemic to ACA (fig. 4). Nine Rubiaceae and one Orchidaceae are endemic to the NMA.

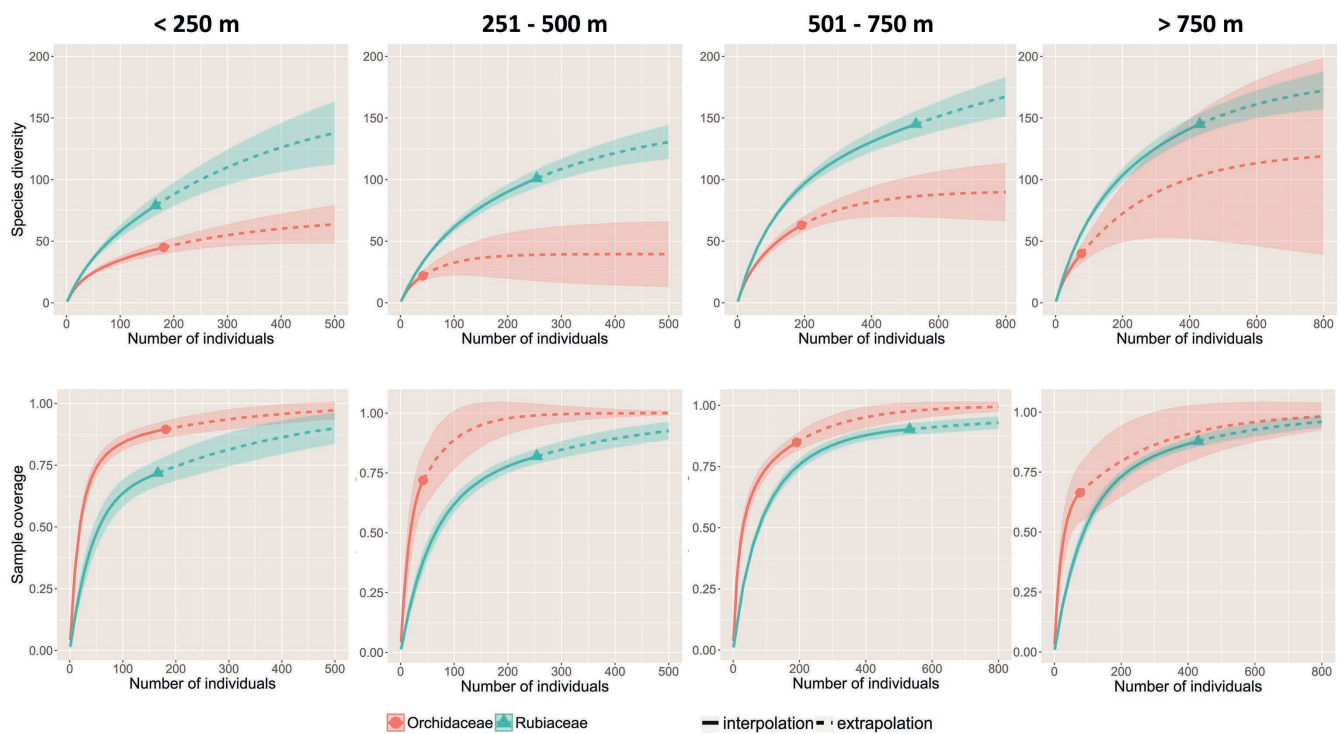
The proportions of threatened (VU, EN, CR) species are 17% and 18% for Rubiaceae and Orchidaceae, respectively (fig. 5).



**Figure 1** – Botanical exploration of Rubiaceae and Orchidaceae in the Ngovayang Massif Area (NMA): A, localization of historical (1889–2003) and recent (2004–2017) herbarium records made in the NMA; B, number of herbarium records (samples) collected per 0.05° grid-cells; C, number of species collected per 0.05° grid-cells; D, expected number of species calculated for 0.05° grid-cells that contain at least 20 herbarium records ( $S_{k=20}$ ).

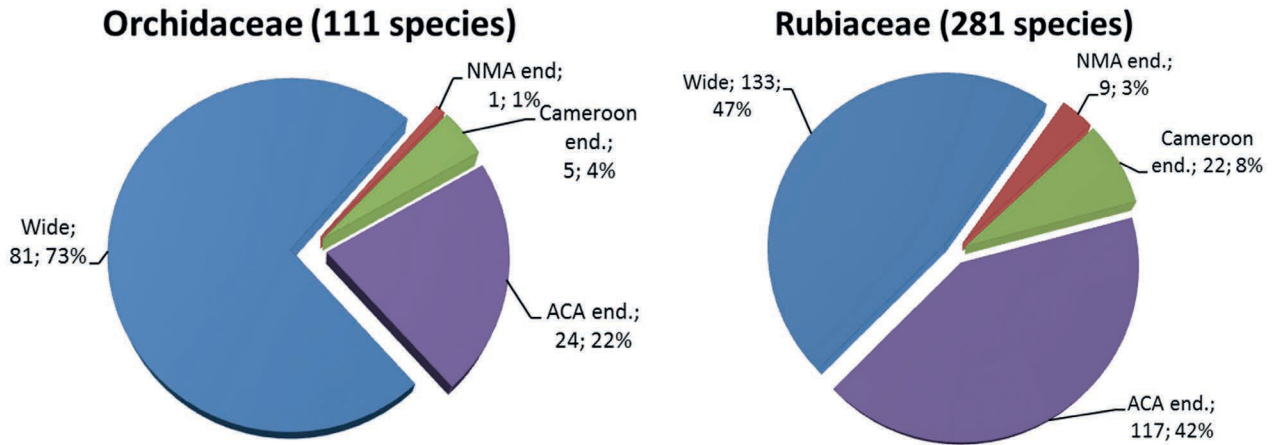


**Figure 2** – Sampling completeness (left) and diversity estimates (right) for Rubiaceae and Orchidaceae in the NMA. Rarefaction/interpolation (solid line segment) and extrapolation (dotted line segments) curves are based on abundance data and represented with 95% confidence intervals (shaded areas). The numbers below rarefaction curves indicate the observed sample completeness (left) and species richness (right).

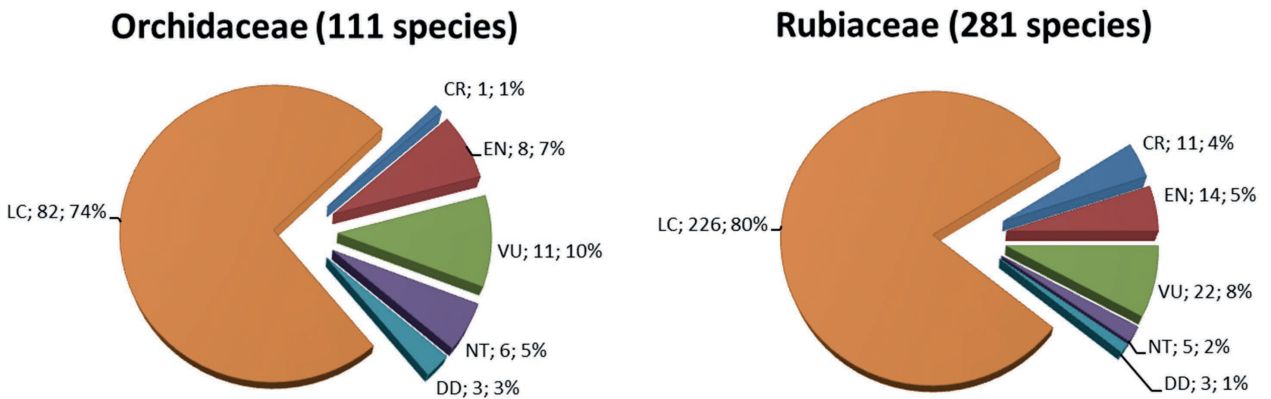


**Figure 3** – Diversity estimates (upper graphs) and sampling completeness (lower graphs) for Orchidaceae and Rubiaceae along the elevation gradient in the NMA. Interpolation (solid line segment) and extrapolation (dotted line segments) curves are based on abundance data and represented with 95% confidence intervals (shaded areas).

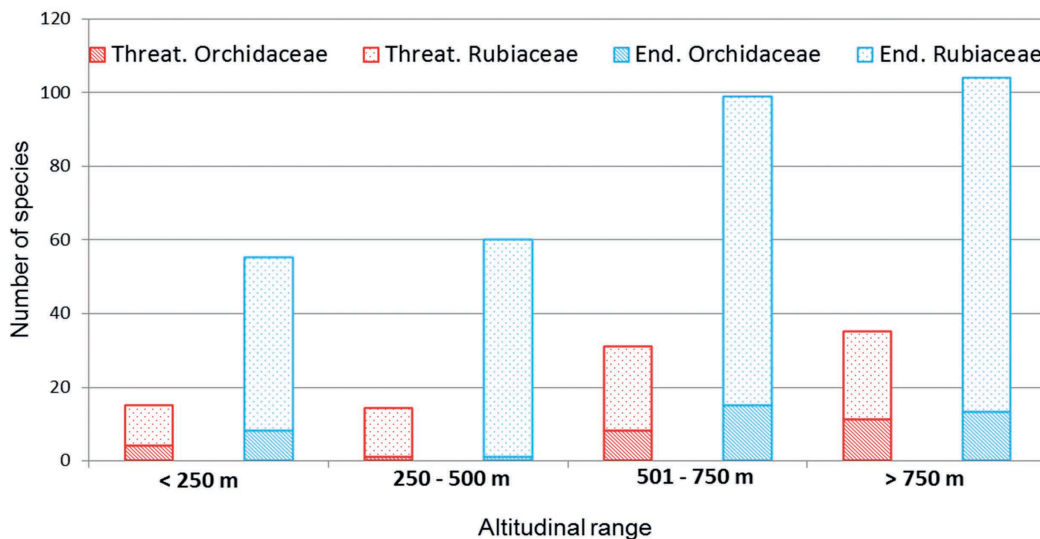




**Figure 4** – Geographical range for Rubiaceae and Orchidaceae recorded from the NMA. Distribution categories considered are: Wide = Widely distributed; NMA end. = endemic to NMA; Cameroon end. = endemic to Cameroon; ACA end. = endemic to Atlantic Central Africa.



**Figure 5** – Proportion of threatened species for Orchidaceae and Rubiaceae recorded from the NMA. IUCN Red List Categories considered are: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient.



**Figure 6** – Number of threatened (= Threat.) species (in red) and species endemic (= End.) to ACA (in blue) along the altitudinal gradient in the NMA.

**Table 4 – Application of Important Plant Area (IPA) criteria to the flora of the Ngovayang Massif Area (NMA).**

IUCN Red List Categories considered are: CR = Critically Endangered; EN = Endangered; VU = Vulnerable. EOO = Extent of Occurrence.

| IPA criteria and sub-criteria  | Ngovayang Massif Area (NMA)  |
|--|--|
| (A) Threatened species   |  |
| A(i) Site contains one or more globally threatened species   | Forty-seven Rubiaceae and 20 Orchidaceae are considered globally threatened (CR, EN or VU) according to IUCN category and criteria (tables 1 & 2, this paper). Fourteen assessments (four Orchidaceae, ten Rubiaceae) are currently published on the IUCN global Red List (IUCN 2018).   |
| A(ii) Site contains one or more regionally threatened species  | Not evaluated, all species considered here have been assessed globally.  |
| A(iii) Site contains one or more highly restricted endemic species that are potentially threatened   | Ten species (1 Orchidaceae, 9 Rubiaceae) are strict endemic to NMA. Twelve species (1 Orchidaceae, 11 Rubiaceae) are assessed as CR (EOO < 100km <sup>2</sup> ).   |
| A(iv) Site contains one or more range restricted endemic species that are potentially threatened   | Twenty-seven species (22 Rubiaceae and 5 Orchidaceae) present in the NMA are endemic to Cameroon. Additionally, 22 species (8 Orchidaceae, 14 Rubiaceae) are assessed as EN (100 km <sup>2</sup> < EOO < 5000 km <sup>2</sup> ).   |
| (B) Botanical richness   |  |
| B(i) Site contains a high number of species within defined habitat or vegetation types   | The NMA houses 21.4% of the total number of plant species recorded to date for Cameroon (1472 species in NMA out of a total of 6883 species), all these species are linked with tropical evergreen forest (lowland forest and submontane forest). Thirty-three Rubiaceae and 16 Orchidaceae are characteristic species for submontane forest and were only collected above 750 m in the NMA. |
| B(ii) Site contains an exceptional number of species of high conservation importance   | Thirty-seven species (31 Rubiaceae and 6 Orchidaceae) present in the NMA are endemic to the massif or to Cameroon, which represent 4.5% of the 815 rare or threatened species documented for Cameroon (Onana & Cheek 2011). The NMA represent one of the 15 richest sites for Cameroon (third richest documented site after Mt Cameroon and Mts Kupe/Manengouba).                            |
| B(iii) Site contains an exceptional number of socially, economically or culturally valuable species  | Not evaluated.   |
| (C) Threatened habitat   |  |
| C(i) Site contains globally threatened or restricted habitat/vegetation type   | Not evaluated.   |
| C(ii) Site contains regionally threatened or restricted habitat/vegetation type  | Not evaluated.   |
| C(iii) Site contains nationally threatened or restricted habitat/vegetation type, AND/OR habitats that have severely declined in extent nationally | Not precisely evaluated, but considering a lower limit of 750 m, Ngovayang might contain more than 5% of submontane vegetation present in Cameroon. Considering the continuous extend of the submontane forest in the NMA, the site represents one of the 5 “best sites” for that habitat nationally.  |

The number of restricted range and threatened species increases with altitude (fig. 6), being double the number above 750 m than below 250 m. Above 750 m, our database reports the presence of 35 species threatened with extinction and 104 species endemic to ACA.

The NMA must be considered as an Important Plant Area (IPA) in ACA, as confirmed by its exceptional plant diversity (> 20% of the total flora of Cameroon), by the concentration of many threatened and/or restricted range species (67 taxa are considered globally threatened according to IUCN and ten taxa are strict endemics of the massif) as well as by the threat to rare habitats (i.e. the submontane forest vegetation above ~750 m elevation). The current knowledge of Rubiaceae and Orchidaceae collected in the NMA as well as their habitat (table 4), allows the NMA to qualify for IPA's criterion A(i, iii, iv) B(i,ii) C(iii).

## DISCUSSION

### The NMA, an Important Plant Area

The NMA houses 21.4% of the total number of plant species recorded to date for Cameroon, while its surface area only represents 0.1% of the country (table 3). It represents the third richest documented site for Cameroon after the Mount Cameroon National Park (2435 plant species, Cable & Cheek 1998) and the Kupe, Mwanenguba and Bakossi Mountains (2412 plant species, Cheek et al. 2004). For the two families here studied in detail (Rubiaceae and Orchidaceae), 17.1% of the species occurring in the NMA are considered threatened according to IUCN red list categories and criteria (IUCN 2012). Additionally, 45% of the Rubiaceae and Orchidaceae

recorded from the NMA are restricted-range species and endemic to ACA. Though no precise vegetation mapping has been made for the NMA to date, we can recognize two main types: the lowland evergreen forest between 0 and 750 m and the submontane vegetation above 750 m (33 Rubiaceae and 16 Orchidaceae were only collected above this elevation in the NMA, table 1 & 2). We also observed particular submontane vegetation associated with rock outcrops during our recent inventories near the locality of Atog Boga, but this habitat remains to date underexplored.

The exceptional plant diversity and endemism level of the NMA should be linked to both environmental/geomorphological gradients and past climatic conditions. The NMA is part of a series of small mountain range stretching along the ocean coast from Southern Cameroon to Congo Brazzaville, and corresponding to several, isolated and putative forest refuges during drier and cooler climatic periods of the Quaternary (Maley 1987, Maley et al. 2018). Based on distribution pattern of endemic orchids to ACA, this series of small mountain ranges has been considered as a unique but discontinuous area of endemism (Droissart 2009). Several species in our checklist such as *Colletocema magna*, *Kupeantha spathulata*, *Afropectinariella atlantica*, *Polystachya bipoda* and *P. lejolyana* are indeed only present in small hills distributed south of the NMA. In addition, several species, which are otherwise largely restricted to southwest Cameroon, are represented by isolated populations in the NMA, e.g. *Aulacocalyx mapiana*, *Chassalia laikomensis*, *Gaertnera letouzeyi*, *Petitiocodon parviflorum*, *Psychotria taedoumgii*, *Dolabrifolia podochiloides* and *Bulbophyllum teretifolium*. As proposed by Gonmadje et al. (2011), the presence of restricted-range species reaching either the most southern or most northern part of their distribution in the NMA tends to confirm that the massif is located at the junction of various phytogeographical influences. In most cases these restricted-range species occur in relatively high elevation areas (e.g. *Chassalia laikomensis* only above 1000 m) and their discovery in the massif is recent, so other similar findings should be expected in the future. Their presence reinforces the importance of the NMA in terms of conservation, and underlines the necessity of developing conservation strategies for these species whose habitat will be strongly impacted by mining activities in the near future.

### Mining threats on the NMA rich biodiversity

Africa is facing an unprecedented mining boom (Edwards et al. 2014) that will potentially have severe impact on the biodiversity of areas with recorded mineral resources. The area affected by mining exploitation depends on the mineral being mined (Edwards 2001), iron exploitation being one of the worse in terms of surface impacted. For biologists, who are usually not involved in the definition of the methods and area to be exploited, it is always extremely difficult to determine what will be the impact of mining on biodiversity and habitats. However, according to aeromagnetic maps produced during the mining exploration stage (electronic appendix 1), the highest concentrations of iron are found in the highest elevation areas of the NMA, i.e. above 750 m, which are also the richest in endangered and/or rare species (fig. 6). Before

starting the effective mining exploitation of the NMA, it is thus essential to set up mitigation and offsetting mechanisms in order to minimize the impact on the environment. The present work highlights several species on which such mitigation programmes should be addressed first, such as the 12 Critically Endangered (CR) species identified for Rubiaceae and Orchidaceae (tables 1 & 2). We have initiated *ex situ* collections and a seedbank in Yaoundé, but this initiative currently covers only a small fraction of the threatened species of the NMA (less than 10%) due to limited resources. In addition, *ex situ* conservation may be very difficult for some species, e.g. due to their peculiar habitat requirements or low germination rates and, for these species, *in situ* conservation and management plans are urgently required.

### CONCLUSION

The NMA represents one of the richest inventoried areas of ACA in terms of plant diversity (table 3). Additional fieldwork in less accessible and/or undersampled areas will certainly reinforce this picture and will allow a better understanding of the distribution and conservation status of plant species within the NMA.

Besides the heterogeneity of sampling highlighted in this work (fig. 1), six species are still classified as Data Deficient (DD) regarding the categories and criteria of the IUCN Red List (tables 1 & 2), showing that fieldwork is required to throw full light on the high plant diversity of the NMA. We suggest that future inventories should involve specialists and be focused on the most diverse plant families identified for the NMA (e.g. Fabaceae s. lat., Apocynaceae s. lat. or Annonaceae; see electronic appendix 5).

### SUPPLEMENTARY DATA

Supplementary data are available at *Plant Ecology and Evolution*, Supplementary Data Site (<https://www.ingentaconnect.com/content/botbel/plecevo/supp-data>) and consist of the following: (1) exploration permits covering the NMA, with Iron ore and gold sampling target areas overlying aeromagnetic image (pdf); (2) Ngovayang Massif Area (NMA) herbarium database (Excel spreadsheet); (3) summary statistic for the ten most active botanists in the NMA (pdf); (4) temporal distribution of collecting efforts in the NMA (pdf); (5) summary statistics for the ten most species-rich families in the NMA (pdf); and (6) species-area curve for total, Rubiaceae and Orchidaceae floras in two countries and 11 sites of Atlantic Central Africa.

### ACKNOWLEDGEMENTS

We are grateful to Dr Jean-Michel Onana, former Head of the National Herbarium of Cameroon (YA), and the staff, for facilitating access to the herbarium collection. The herbarium staff of BR, BRLU, K, P, WAG is thanked for facilities provided to the authors, and for the loan of specimens. We also acknowledge the *Sud Expert Plantes* project under French Ministry of Foreign Affairs, the *Agence Universitaire de la Francophonie* (AUF) and the National Geographic Society (Grant 7711-04 and Grant 8377-07, B. Sonké as PI) for pro-



viding financial supports for the fieldwork. We express our gratitude to the National Geographic Society (Grant C303-15, V. Droissart as PI) who supported *ex situ* conservation activities (orchid living collection and seedbank) in Cameroon. We are also grateful to local authorities and villagers from Atog Boga, Bibondi, Bidjoka, Bipindi, Mbikiliki, Memel II, Ngovayang and Ngoyang for their support and help during fieldwork activities. We express our sincere gratitude to Catherina Guiakam, Sandrine Mayogo and Narcisse Kamdem for maintenance work and collection of specimens in the Yaoundé shadehouse. We also thank reviewers, Jean Michel Onana and Martin Cheek, for their useful comments and suggestions for the final version of this paper.

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Manuscript received 10 Oct. 2018; accepted in revised version 13 Dec. 2018.

Communicating Editor: Elmar Robbrecht.