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An enigmatic genus on an enigmatic island: the re-discovery of *Kalappia* on Sulawesi

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The Indonesian island of Sulawesi possesses a biota defined by anomaly (Wallace 1869). It has high levels of endemism (Michaux 2010) but, despite attracting research interest since the time of biogeographic pioneers such as Alfred Russell Wallace, the island remains relatively undocumented (van Welzen et al. 2011) with collection rates below much of the wider region (Kessler et al. 2002). As currently known, the flora suggests a placement within the Austral-Asian amalgamative region of Wallacea, which encompasses the chain of islands between Borneo and New Guinea (van Welzen et al. 2011).

The region has been designated a biodiversity hotspot. Sulawesi, the largest landmass within Wallacea, is absolutely critical to successful conservation of its diverse fauna and flora (Cannon et al. 2007). Extraction of both natural gas and valuable metal ore deposits is a major contributor to deforestation in Sulawesi, particularly the mining of nickel, across the 15,400-km^2 ultramafic outcrop that constitutes approximately 8.8% of the total land area (van der Ent et al. 2013). Extraction is most prominent in the Soroako area close to the town of Malili (Fig. 1). A number of botanists including Meijer, Reppie, and van Balgooy visited Malili from the 1930s to the 1970s. Among the collections made were fewer than 10 specimens of a legume tree species from a very small area of wet tropical forest. This was described as *Kalappia celebica,* the single species in the genus (Kostermans 1952). The taxon exhibits anthers that dehisce via a pair of apical pores. This type of anther dehiscence is rare in legumes but observed in other closely related taxa and is indicative of buzz pollination by bees (Tucker 1998). The anthers of *Kalappia* also feature a prominent spur that extends from the base of one of the two apical pores (Fig. 2). This combination of characters is apparently unique to *Kalappia*. The function of these spurs may be homologous with the porate anther appendages found in the Melastomataceae that are thought to enhance visual attractiveness and facilitate gripping for visiting bees (Renner 1989).

Timber of *Kalappia* trees has been exploited for use in house construction, ship-building, and in furniture manufacture. Even prior to scientific description of the species, timber export to Makassar, the largest city in Sulawesi, had been observed by Kostermans (1952). This evident threat to the species coupled with its restricted distribution led to an IUCN red list conservation assessment of "Vulnerable" (IUCN 1998). A lack of collections since the 1970s gave rise to the suspicion that the taxon was likely endangered (Lewis 2005) or potentially even extinct.

In 2010, two sterile herbarium specimens of a tree from the Kolaka area of Sulawesi (Fig. 1), with the local name "kelapi" were tentatively identified as *K. celebica* by Elizabeth Widjaja and accessioned in Herbarium Bogoriense (BO). The Kolaka region is approximately 140 km south of the original collection area of the species near Malili. In 2016, we visited a deforested area further inland near the village of Abuki (Fig. 1) where at least 20 trees are retained for the honey-producing bees that frequent them. Additionally, forest near Abuki was visited, where *K. celebica* was observed to be a notable component of the tree community with 20 mature trees observed within ~2.5 ha. A number of individuals were in flower (Fig. 2) allowing floral dissection, related taxon comparison, and verification that these trees were indeed a new spatially distinct population of *K. celebica*.

Following these new observations (collections: Trethowan 707–721 lodged in the herbaria at Kew (K) and Bogor (BO)), we update *K. celebica*'s previous IUCN

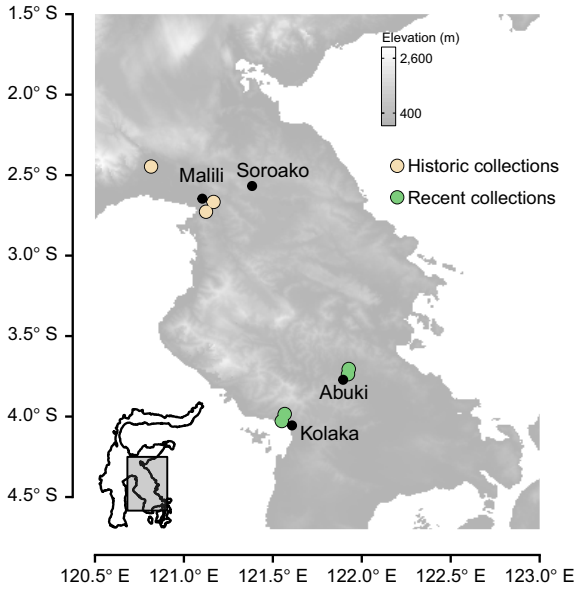


FIG. 1. Map of collection localities for *Kalappia celebica* in Sulawesi, Indonesia. The collections around Malili are highly threatened due to nickel mining. The Kolaka collections are the only two trees left in the vicinity. The Abuki collections are from a copse of trees retained for the honey bees they support and another population that is threatened due to logging.

assessment (IUCN 1998) with a new preliminary conservation assessment. We calculated the extent of occurrence (EOO) and area of occupancy (AOO) using herbarium specimen point data mapped in GeoCat (Bachman et al. 2011). EOO is a measure of the geographic range of a species; using a convex hull measure. AOO is a measure of the area within which a species is found, not including areas between occurrence localities. We calculate AOO by summing the number of 2-km^2 grids that *K. celebica* occupies. Based on 19 herbarium specimens (Trethowan 707–721, Widjaja 9618, and 9901, Meijer 11256, Neth. Ind. For. Service bb.32456, Boschproefst. bb.13572) from K, BO, and the digitized collections of Leiden, an EOO of 6,460 km^2 (IUCN category Vulnerable) was calculated, this being indicative of *K. celebica* inhabiting a wide area (digitized collections *available online*).[6] According to Landsat data, there are large tracts of relatively inaccessible wet, tropical forest in good condition between the currently sampled localities (Cannon et al. 2007), inhabiting similar soil types and elevational range to known *K. celebica* populations. These areas have not been surveyed by the authors, nor to our knowledge during other collecting trips, but represent potential suitable habitat for the species, possibly harboring additional populations. The calculated AOO of 28 km^2 (IUCN category Endangered) does not take this potential presence into account and is thought not to represent the total area occupied by the species. Therefore, the assessment here is based upon EOO results.

Threats to remnant individuals and stands of trees are apparent at each collection locality (Abuki, Malili, and Kolaka). The population near Abuki is highly threatened due to its presence in "Hutan Produksi" or production forest where individuals can be legally harvested for timber. Based upon our observations, no regeneration program is facilitated locally. The copse of *K. celebica* retained for honey production in Abuki is privately owned, where threat arises from potential redirection in the business model induced by productivity decline or fluctuation in demand for honey. The population around Malili has not been recently visited by botanists and whether a viable population remains is unknown. The expanding human population and ongoing nickel mining and extraction in the Malili region decrease the likelihood that these trees have survived. Based on personal observation (L. A. Trethowan) and conversations with local villagers, it became clear that the collections near Kolaka derive from the only two trees left in the vicinity, one of which is in a private garden where the owner is yet to allow the tree to be felled for timber, despite lucrative offers, and the other in a nearby tourist park. If we remove these two individuals near Kolaka from the conservation assessment on the assumption that they do not represent a viable population, this results in a much smaller EOO (1,495 km^2) and AOO (20 km^2), which correspond to an Endangered categorization. However, here we follow the categorization based upon EOO of all individuals, the area of which covers a greater proportion of the expanse of forest where *K. celebica* is likely to occur, and we therefore designate *K. celebica* as Vulnerable: VU B1 a,b(i,ii,iii,iv) according to IUCN (2014) guidelines. The multiple threats listed above, and our alternative EOO and AOO, indicate that a future conservation status of Endangered for *K. celebica* may be appropriate when further data become available. *Kalappia celebica* is typical of many tropical trees for which IUCN threat category assessments are fraught with difficulties posed by lack of data about the extant status of historical collections and lack of data for surrounding, as yet unexplored, and under-collected habitat areas (Nic Lughadha et al. 2018). Identification of extant populations of *K. celebica* was only possible through funding for travel to remote areas where the risk of failure to collect data is high due to the innate difficulties with accessibility. However, to gather the baseline knowledge about rare and threatened species, exploration of the more remote areas of any given region is crucial and should be encouraged.

The rediscovery of little-known legume genera continues to shed light on previously unresolved relationships within the legume family (Cardoso et al. 2017). Combined morphological and phylogenetic data placed

[6] http://bioportal.naturalis.nl

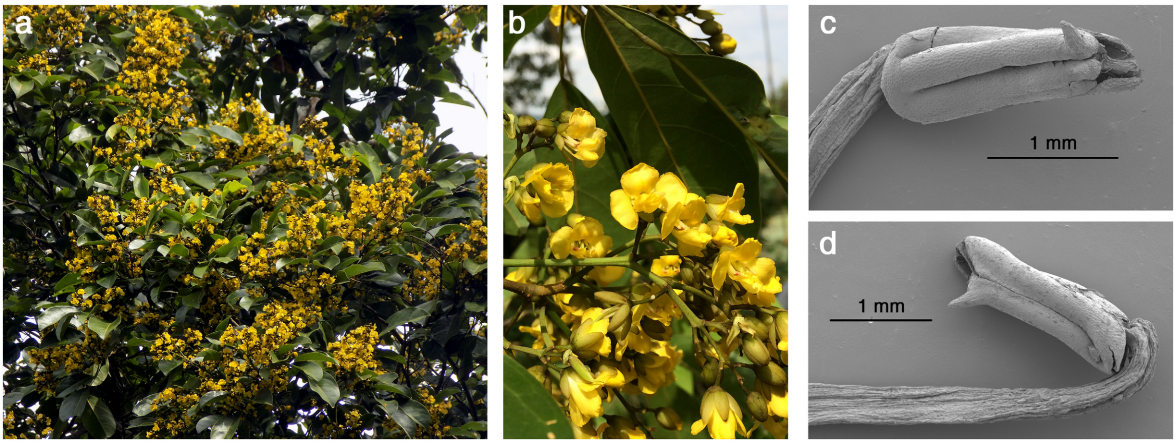


Fig. 2. Foliage, (a) inflorescence, (b) flowers, and (c, d) spurred porate anthers of *Kalappia celebica* collected near Abuki village, Sulawesi. Photo a courtesy of Alvin, undergraduate at Universitas Halu Oleo; b was taken by L. A. Trethowan. Images c and d were recorded with a Hitachi S4700 field emission scanning electron microscope.

Kalappia in a Southeast Asian/Pacific/Australian clade alongside the genera *Storckiella, Petalostylis*, and *Labichea* (Zimmerman et al. 2017). *Storckiella* inhabits wet tropical areas of New Caledonia, Australia, and Fiji, while *Petalostylis* and *Labichea* grow in arid regions of Australia (Lewis 2005). Coupled with this biogeographic distinction is an association of all the four genera to phytonutrient-poor, heavy metal rich, ophiolitic soils (ultramafic soils being a high nickel concentration example, formed over mantle-derived geology).

Kalappia and its relatives offer an opportunity to understand what dictates the distribution of species across Sulawesi and the equally enigmatic southeast Asian archipelago. Study of phylogenetic niche conservatism explores the extent to which species retain ancestral ecological traits and environmental distributions (Wiens et al. 2010). Closely related taxa generally share similar traits and environment (Wiens et al. 2010). There are, however, clades and landscapes that offer contrasting patterns (Cardillo et al. 2017). This is the case for the *Kalappia*, *Storckiella*, *Petalostylis*, and *Labichea* clade that exhibits edaphic conservatism (found on ophiolitic soils) but heterogeneity in climate (tropical and arid). Added to this, these genera have a pan-Austral-Asian distribution, occupying mainland Australia and islands from Sulawesi to Fiji. This clade, therefore, has the potential to provide empirical evidence for the dual impact of environmental variability and an archipelagic setting upon dispersal. This may help us understand the environmental variables that underpin the segregate floras of Sunda, Wallacea, and Sahul (van Welzen et al. 2011).

Generic gaps still remain in the legume phylogeny (LPWG 2017). Within subfamily Dialioideae, in which *Kalappia* is placed, the genera *Uittienia* and *Androcalymma* are yet to be sampled (Zimmerman et al. 2017) and, as for *Kalappia* previously, recent collections are lacking. Their modern collection and conservation status assessment remain a priority.

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Literature Cited

Bachman, S., J. Moat, A. W. Hill, J. de Torre, and B. Scott. 2011. Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. ZooKeys 150:117–126.

Cannon, C. H., M. Summers, J. R. Harting, and P. J. Kessler. 2007. Developing conservation priorities based on forest type, condition, and threats in a poorly known ecoregion: Sulawesi, Indonesia. Biotropica 39:747–759.

Cardillo, M., P. H. Weston, Z. K. Reynolds, P. M. Olde, A. R. Mast, E. Lemmon, A. R. Lemmon, and L. Bromham. 2017. The phylogeny and biogeography of *Hakea* (Proteaceae) reveals the role of biome shifts in a continental plant radiation. Evolution 76:1928–1943.

Cardoso, D., D. J. Harris, J. J. Wieringa, W. M. São-Mateus, H. Batalha-Filho, B. M. Torke, G. Prenner, and L. P. de Queiroz. 2017. A molecular-dated phylogeny and biogeography of the monotypic legume genus *Haplormosia*, a missing African branch of the otherwise American-Australian Brongniartieae clade. Molecular Phylogenetics and Evolution 107:431–442.

IUCN. 1998. *Kalappia celebica*: World Conservation Monitoring Centre: The IUCN Red List of Threatened Species 1998: e.T33287A9767998. International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.UK.1998.RLTS.T33287A9767998.en

IUCN. 2014. Guidelines for using the IUCN Red List categories and criteria. International Union for Conservation of Nature. https://www.iucnredlist.org/documents/RedListGuidelines.pdf

Kessler, P. J., M. M. Bos, S. S. Daza, A. Kop, L. P. M. Willemse, R. Pitopang, and S. R. Gradstein. 2002. Checklist of woody plants of Sulawesi, Indonesia. Blumea Supplement 14:1–160.

Kostermans, A. J. G. H. 1952. Notes on two leguminous genera from eastern Indonesia. Reinwardtia 4:451–457.

Lewis, G. P. 2005. Tribe Cassieae. Pages 111–125 *in* G. P. Lewis, B. Schrire, B. A. Mackinder, and M. Lock, editors. Legumes of the world. Royal Botanic Gardens, Kew, UK.

LPWG, (Legume Phylogeny Working Group). 2017. A new subfamily classification of the Leguminosae based on a taxonomically comprehensive phylogeny. Taxon 66:44–77.

Michaux, B. 2010. Biogeology of Wallacea: geotectonic models, areas of endemism, and natural biogeographical units. Biological Journal of the Linnean Society 101:193–212.

Nic Lughadha, E., B. E. Walker, C. Canteiro, H. Chadburn, A. P. Davis, S. Hargreaves, E. J. Lucas, A. Schuiteman, E. Williams, and S. P. Bachman. 2018. The use and misuse of herbarium specimens in evaluating plant extinction risks. Philosophical Transactions of the Royal Society B 374:20170402.

Renner, S. S.. 1989. A survey of reproductive biology in Neotropical Melastomataceae and Memecylaceae. Annals of the Missouri Botanical Garden 76:496–518.

Tucker, S. 1998. Floral ontogeny in legume genera *Petalostylis*, *Labichea*, and *Dialium* (Caesalpinioideae: Cassieae), a series in floral reduction. American Journal of Botany 85:184–208.

van der Ent, A., A. J. M. Baker, M. M. J. van Balgooy, and A. Tjoa. 2013. Ultramafic nickel laterites in Indonesia (Sulawesi, Halmahera): mining, nickel hyperaccumulators and opportunities for phytomining. Journal of Geochemical Exploration 128:72–79.

van Welzen, P. C., J. A. N. Parnell, and J. W. F. Slik. 2011. Wallace's Line and plant distributions: Two or three phytogeographical areas and where to group Java? Biological Journal of the Linnean Society 103:531–545.

Wallace, A. R. 1869. The Malay Archipelago. Macmillan, London, UK.

Wiens, J. J., D. D. Ackerly, A. P. Allen, B. L. Anacker, L. B. Buckley, H. V. Cornell, E. I. Damschen, T. J. Davies, J.-A. Grytnes, and S. P. Harrison. 2010. Niche conservatism as an emerging principle in ecology and conservation biology. Ecology Letters 13:1310–1324.

Zimmerman, E., P. S. Herendeen, G. P. Lewis, and A. Bruneau. 2017. Floral evolution and phylogeny of the Dialioideae, a diverse subfamily of tropical legumes. American Journal of Botany 104:1019–1041.