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Codonoboea (Gesneriaceae) in Terengganu, Peninsular Malaysia, including three new species

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Abstract

Of the 92 *Codonoboea* species that occur in Peninsular Malaysia, 20 are recorded from the state of Terengganu, of which 9 are endemic to Terengganu including three new species, *C. norakhirrudiniana* Kiew, *C. rheophytica* Kiew and *C. sallehuddiniana* C.L.Lim, that are here described and illustrated. A key and checklist to all the Terengganu species are provided. The majority of species grow in lowland rain forest, amongst which *C. densifolia* and *C. rheophytica* are rheophytic. Only four grow in montane forest. The flora of Terengganu is still incompletely known, especially in the northern part of the state and in mountainous areas and so, with botanical exploration, more new species can be expected in this speciose genus.

Keywords

Checklist, key, new species, *Codonoboea norakhirrudiniana*, *Codonoboea rheophytica* and *Codonoboea sallehuddiniana*, endemism

Introduction

The centre of diversity of the genus *Codonoboea* (Gesneriaceae) is Peninsular Malaysia from where at least 92 species of the 140 named species are known (Lim and Kiew 2014). However, while the west coast of Peninsular Malaysia is relatively well-collected and from where 35 species were described (Kiew and Lim 2011), the east coast is comparatively poorly known with, for example, prior to this study, just six described from Terengganu. The total now stands at 20 species.

Terengganu (Figures 1 and 2), one of the eleven states in Peninsular Malaysia, lies on the east coast with a coastline 320 km long, facing the South China Sea. It covers about 150 km^2 and is bounded on the west by the Terengganu Range, a low range of granite hills, the highest of which is Gunung Lawit at 1,519 m elevation. The hills are covered by dipterocarp forest, below 400 m by lowland dipterocarp forest, to 750 m by hill dipterocarp forest merging into lower montane forest at about 1,200 m, above which the mountain peaks are covered by upper montane forest (Ummul-Nazrah et al. 2011). The hills fall steeply with the smaller tributaries, the saraca-streams (*Saraca cauliflora*) of Corner (1988), at first rocky and torrential but, as the ground levels, they become broader though still rocky and are shaded by neram trees, *Dipterocarpus oblongifolius*, that arch over the river. Rheophytes are characteristic of neram rivers where they gain a foothold in cracks in rocky bedrock or on large boulders or on sandy or pebbly spits that are deposited by periodic floods. Neram rivers cease at the tidal reach where the water becomes brackish. Along the coast and about 25–35 km inland, kapur forests, *Dryobalanops aromatica*, predominate and on sandy, frequently waterlogged and podzolic soil, tropical heath forest develops.

The first *Codonoboea* species described from Terengganu, *C. densifolia* (Ridl.) C.L.Lim (originally described as *Paraboea caerulea* Ridl.) was collected in 1904 by E. Rostados from Bukit Bandi [Bundi], Kemaman District, in south Terengganu where there was a tin mine. In 1932 and 1935, E.J.H. Corner collected from Sungai Nipah, Kemaman District and many of the species he collected later proved to be new to science (Kiew 1991a), such as *C. floribunda* (M.R.Hend.) C.L.Lim (Henderson 1933) and *C. corneri* (Kiew) Kiew (Kiew 1990), indicative of the rich biodiversity of the area. In 1986, R. Kiew with S. Anthonysamy explored northern Terengganu discovering two new species, *C. anthonyi* (Kiew) C.L.Lim from Ulu Besut, Besut District and *C. leiophylla* (Kiew) C.L.Lim from Ulu Sungai Setiu, Setiu District (Kiew 1992) and, later, *C. miniata* (Kiew) C.L.Lim was described from Bukit Bauk, Dungun District (Kiew 1995).

One of the objectives of the Flora of Peninsular Malaysia project (Kiew and Rafidah 2007) is to explore and collect from botanically poorly known regions. For this reason, Terengganu has been a focus and the botany team of the Kepong Herbarium, Forest Research Institute Malaysia, has made regular visits to Terengganu, which has led to the discovery of several new species, including *C. personatiflora* (Kiew & Sam, 2012) and the two new species described below as *C. rheophytica* and *C. sallehuddiniana*. The expedition to Gunung Padang, Hulu Terengganu District, revealed *C. padangensis* (Kiew, 2011) and intensive collecting in the Tembat Forest Reserve, Hulu Terengganu District, prior to its being clear-felled for an extension to the Kenyir Dam, revealed a further two new species, *C. tembatensis* (Kiew, 2014) and the new species, *C. norakhirrudiniana*, described below.

Exploration of the Terengganu flora has led, not only to the discovery of the three new species described below, but also to 12 other *Codonoboea* species described from other states being documented from Terengganu (Table 1), bringing the total presently recorded from Terengganu to 20, of which 9 species (Table 2) are endemic to Tereng-

Figure 1. Peninsular Malaysia showing Terengganu State.

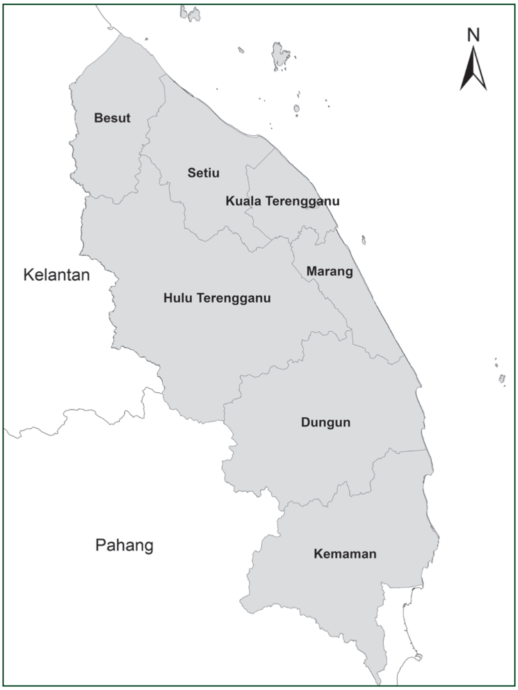

Figure 2. The districts in Terengganu, Peninsular Malaysia.

Table 1. Distribution of Terengganu *Codonoboea* species that occur in other states (Joh – Johor; Ked – Kedah; Kel – Kelantan; Mel – Melaka; Pah – Pahang; Per – Perak; Sel – Selangor; Ter – Terengganu).

Species	States	Districts in Terengganu
C. anthonyi	Kel, Ter	Besut
C. atrosanguinea	Kel, Pah, Ter	Dungun, Hulu Terengganu
C. codonion	Pah, Ter	Dungun, Kemaman, Hulu Terengganu
C. densifolia	Joh, Pah,Ter	Kemaman
C. grandifolia	Pah, Ter	Hulu Terengganu (Gunung Padang)
C. leiophylla	Kel, Ter	Besut, Setiu, Hulu Terengganu
C. platypus	Most states	Dungun, Kemaman, Hulu Terengganu, Setiu
C. puncticulata	Joh, Pah, Ter,	Dungun, Kemaman, Hulu Terengganu
C. quinquevulnera	Joh, Kel, Mel, Pah, Sel, Ter	Besut, Hulu Terengganu
C. rugosa	Ked, Kel, Pah, Per, Ter	Kemaman, Hulu Terengganu
C. salicinoides	Joh, Kel, Pah, Ter	Besut, Dungun, Kemaman

Table 2. Distribution of *Codonoboea* species endemic in Terengganu.

Species	District	Locality
C. corneri	Dungun, Kemaman	Pasir Raja (FRI 65593), Sg. Nipah
C. floribunda	Dungun, Kemaman	Jerangau, Sg Nipah
C. miniata	Dungun	Bkt. Bauk, Bkt. Chabang
C. norakhirrudiniana	Hulu Terengganu	Tembat
C. padangensis	Hulu Terengganu	Gunung Padang
C. personatiflora	Dungun, Kemaman, Hulu Terengganu, Setiu	Jengai, Sg. Nipah, Ulu Telemong, Ulu Setiu
C. rheophytica	Dungun	Rasau Kertih
C. sallehuddiniana	Dungun	Sg Loh, Jerangau, Pasir Raja
C. tembatensis	Hulu Terengganu	Tembat

ganu. *Codonoboea anthonyi* and *C. leiophylla*, first described from Terengganu, have since been found in SE Kelantan.

Three new species are described here. There are undoubtedly more species that await discovery as many areas remain to be explored. Besides a checklist for Terengganu *Codonoboea*, a key is provided to facilitate their identification.

Materials and methods

Specimens, including type specimens of Peninsular Malaysian *Codonoboea* species in the herbaria at BM, K, KEP, KLU, SING and UKMB (acronyms follow Thiers 2019), were examined. All specimens cited were seen by the authors. Literature relevant to the region (West Malesia and Thailand) was consulted. Conventional methods employed in herbarium taxonomy were applied in this study. All measurements were taken from dried herbarium specimens. The spelling of localities follows Hamidah et al. (2011).

Results

Key to *Codonoboea* species in Terengganu

1 Leaves very narrow, to 2 cm wide and at least 6.5 times longer than wide ... **2**

– Leaves more than 2 cm wide and less than 5 times longer than wide ... **3**

2 Lamina 6.6–8.2 times longer than wide (4–15.6 × 0.6–1.9 cm), margin entire. Inflorescences 1–4-flowered. Capsule 1.6–2.9 cm long ... ***C. densifolia***

– Lamina 14–17 times longer than wide (11.5–22 × 0.8–1.3 cm), margin crenate. Flowers single. Capsule 2.8–4.3 cm long. ... ***C. rheophytica***

3 Flowers single ... **4**

– Inflorescences with 2–18 flowers ... **12**

4 Flowers epiphyllous. Leaves spaced on stem ... ***C. corneri***

– Flowers in leaf axils. Leaves crowded towards top of stem ... **5**

5 Rosette herbs to 2–19 cm tall. Leaf lamina to 16 × 5 cm long, lateral veins 7–15 pairs. Flowers campanulate, to 2 cm long ... **6**

– Robust, unbranched herbs 40–100 cm tall. Leaf lamina more than 15 × 4 cm, lateral veins 20 pairs or more. Flowers trumpet-shaped, 3–4 cm long ... **8**

6 Lamina glabrous above, margin more-or-less entire. Capsule conspicuously upturned ... ***C. leiophylla***

– Lamina hairy above, margin minutely serrate. Capsule straight ... **7**

7 Lamina base rounded or cordate, flat above, often with a broad silver-grey band along the midrib, apex rounded. Calyx 1–1.7 mm long; corolla tube shorter (4–5.5 mm) than the lobes (6–7.3 mm). Capsule 2–3 cm long ... ***C. puncticulata***

– Lamina base narrowed, single hairs raised on protruding aeroles, plain-coloured, apex acute. Calyx 3–4.5 mm long; corolla tube longer (12–14 mm) than lobes (4–6.5 mm). Capsule 1.5–2.5 cm long ... ***C. padangensis***

8 Leaves petiolate, petiole to 3 cm long; lateral veins to 20 pairs. Flowers completely bright vermillion. Capsules to 3–4 cm long ... ***C. miniata***

– Lamina sessile; lateral veins 25 pairs or more. Flowers white or purplish or if corolla lobes red, then tube is yellow. Capsules 3.5–12 cm long ... **9**

9 Lamina with tertiary venation forming a pattern of rectangles. Capsules shorter and thicker, 3.5–4.5 cm long, 2–3 mm diameter ... ***C. rugosa***

– Lamina with tertiary venation forming a pattern of polygons. Capsules 5–12 cm long and slender ca. 1.5 mm diameter ... **10**

10 Leaves with upper lamina surface softly and finely velvety; margin minutely serrate, lateral veins ca. 25–27 pairs. Corolla tube pale cream or orange outside, lobes deep crimson, throat golden yellow. Capsules (7.5–)9–12 cm long ... ***C. atrosanguinea***

– Leaves with upper surface coarse and hispid or densely silky, margin coarsely serrate; lateral veins 33–50 pairs. Corolla white or white tinged purple, lobes sometimes deep purple. Capsule 5–9 cm long ... **11**

11 Corolla white, lobes deep purple. Lamina 14–27 × 4.5–7 cm, base often broadly winged and deeply laciniate, upper surface softly and densely silky. Capsule ca. 5 cm long .... ***C. quinquevulnera***

– Corolla white tinged purple, rarely pure white, lobes not a deeper purple than tube. Lamina (15–)26–40(–55) × (5.5–)7–9(–15) cm, base with a narrow wing, upper surface coarsely hispid. Capsule 7–9 cm long .... ***C. platypus***

12 Corolla 15–40 mm long **13**

– Corolla 7–15 mm long **16**

13 Inflorescences short or subsessile, (1–)2–3 flowered. Corolla completely white except for lemon-yellow nectar guides. Usually branching at the base and forming clumps. Petioles slender 3–5.5 cm long, lamina 9–11 cm long, 2–3 times longer than petiole, softly hairy. Capsules 1.5–1.8 cm long, broad at base, 3.5–5 mm thick .... ***C. tembatensis***

– Inflorescences with a long peduncle more than 11 cm long, many-flowered. Flowers purple or rosy purple. Not clump forming. Lamina 4–9 times longer than petiole. Capsules 3–8 cm long, slender, to 1–2 mm thick **14**

14 Petioles 5–6 cm long, lamina broader, ca. 28 × 9 cm. Flowers 35–40 mm long. Capsules 6–8 cm long .... ***C. grandifolia***

– Petioles 1.3–4 cm long, lamina 9–1 × 4–7 cm or 15–34 × 4–8 cm. Flowers 15–20 mm long. Capsules 3–4.5 cm long **15**

15 Leaf lamina shorter 9–17 × 4–7 cm, drying greenish-brown above, margin deeply serrate. Corolla 15–16 mm long, rosy purple, tube slender, 4–6 mm diameter at mouth, lobes reflexed .... ***C. sallehuddiniana***

– Leaf lamina 15–34 × 4–8 cm, drying deep purplish-brown above, margin minutely crenate. Corolla ca. 20 mm long, pale cream with pale pink lobes, tube 6–9 mm diameter at mouth, lobes personate .... ***C. personatiflora***

16 Lamina narrow, 9–15 × 2.3–3 cm, ca. 4.5 times longer than wide; petiole and midrib sometimes drying wrinkled with transverse ribs. Peduncle and pedicels finely slender and thread-like. Capsule short 1.2–1.4 cm long .... ***C. salicinoides***

– Lamina 10–21 × 4–9 cm, ca. 2.5 times longer than wide; petiole and midrib not drying wrinkled with transverse ribs. Capsule 1.5–2.3 cm long **17**

17 Inflorescences with 8–18 flowers. Corolla 2.5–9 mm long. Stem to 20 cm tall **18**

– Inflorescences with (2–)3–4 flowers. Corolla 9–12.5 mm long. Stem robust 40–60 cm tall **19**

18 Corolla 7–9 mm long, calyx 3–5 mm long. Lamina base narrowed then abruptly rounded .... ***C. floribunda***

– Corolla 2.5–4 mm long, calyx 1–1.5 mm long. Lamina base narrowed and cuneate .... ***C. codonion***

19 Stem and petioles glabrescent. Peduncle 6–8.5(–11) cm long. Corolla pale purple with upper lobes deep purple .... ***C. anthonyi***

– Stem and petioles with persistent dense matted pubescence. Peduncle 4.5–6 cm long. Corolla uniformly purple .... ***C. norakhirrudiniana***

New species

Codonoboea norakhirrudiniana Kiew, sp. nov.

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Figure 3

Diagnosis. *Codonoboea norakhirrudiniana* is most similar to *C. anthonyi* (Kiew) C.L.Lim in its 12–19 cm-long oblanceolate leaf lamina that is glabrous above and is narrowed to the base; in its 3–4-flowered inflorescences with peduncles less than 10 cm long, but it is distinct in being a robust herb with a stem to 60 cm tall and 6–7 mm thick (not to 40 cm tall and to 6 mm thick in *C. anthonyi*), the stem and petioles with persistent dense pubescence (not glabrescent), the lower leaves are distant (not with all leaves in a tuft at apex), the peduncle is 4.5–6 cm long (not 6–8.5(–11) cm long) and the flowers are uniformly pale lavender (not pale lavender with deep purple upper lobes).

Type. Peninsular Malaysia. Terengganu, Hulu Terengganu, Tembat Forest Reserve, 5°12.51'N 102°34.22'E, 2 April 2010 Mohd Hairul, M.A. et al. FRI 70907 (holotype KEP; iso. SAN).

Description. Robust, erect, unbranched herb. *Stem* woody, outer layer corky, 16–30(–60) cm tall, 6–7 mm diameter; stem and petiole with persistent, thick matted pubescence. *Leaves* opposite, in a tuft at the top of the stem, lower pairs equal and 0.5–1(–3) cm apart; petioles stout, 0.7–1.3 cm long, deeply grooved above; lamina oblanceolate to narrowly oblanceolate, thinly leathery, glabrous above, 12.5–20 × 3–6 cm, matt, dark green above, whitish-green beneath, drying dark brown above, narrowed into the petiole, margin minutely dentate, teeth to 1.5 mm long, apex acute; midrib and veins in life impressed above, prominent beneath, lateral veins 13–21 pairs; beneath midrib hispid, lateral veins and margin densely and minutely hispid.

Inflorescence a pair-flowered cyme with (2–)3–4 flowers, erect from the upper leaf axils, ca. 3 produced from a single leaf axil and the base of the petiole (epiphyllous), peduncle rosy purple or maroon, 4.5–6 cm long, bract pair pale green, linear, 5–8 × ca. 2 mm, pedicels maroon, purple or brown, 5–9 mm long; peduncle, pedicel and calyx densely hispid, hairs non-glandular. *Flowers:* buds white; calyx brownish-green, 5-lobed divided almost to the base, lobes narrow, 4–4.5 × 0.75 mm, apex acute, keeled, pubescent outside with hairs to 1 mm long, glabrous inside; corolla campanulate, plain pale lavender, 9–13 mm long, throat white inside, minutely pubescent outside, glabrous inside, tube 5–7.5 × 3.5–4 mm, lobes 5, bluntly rounded, upper two, 3.5–5 × 4–5 mm, strongly reflexed, lateral lobes ca. 4 × 4–5 mm, median lobe ca. 4.5–5 × 5–6 mm; stamens 2, joined at corolla base and included in corolla tube, filaments white, stout or expanded at the base, 2–2.5 × 0.5–1.5 mm, anthers white, broadly sagittate, 1.5–1.75 × ca. 1.5 mm, cohering face-to-face, staminodes 2, vestigial, ca. 0.75 mm long; nectary annular, minute, ca. 0.2 mm high; ovary and style densely and minutely pubescent, ovary white, 4–4.5 mm long, style white, ca. 4 mm long projecting beyond the upper corolla lobes, stigma rounded, minute, ca. 0.5 × 1mm. *Fruits* slender, cylindric, 24–40 × 1–2 mm, dehiscing along the upper suture; pedicel 7–15 mm.

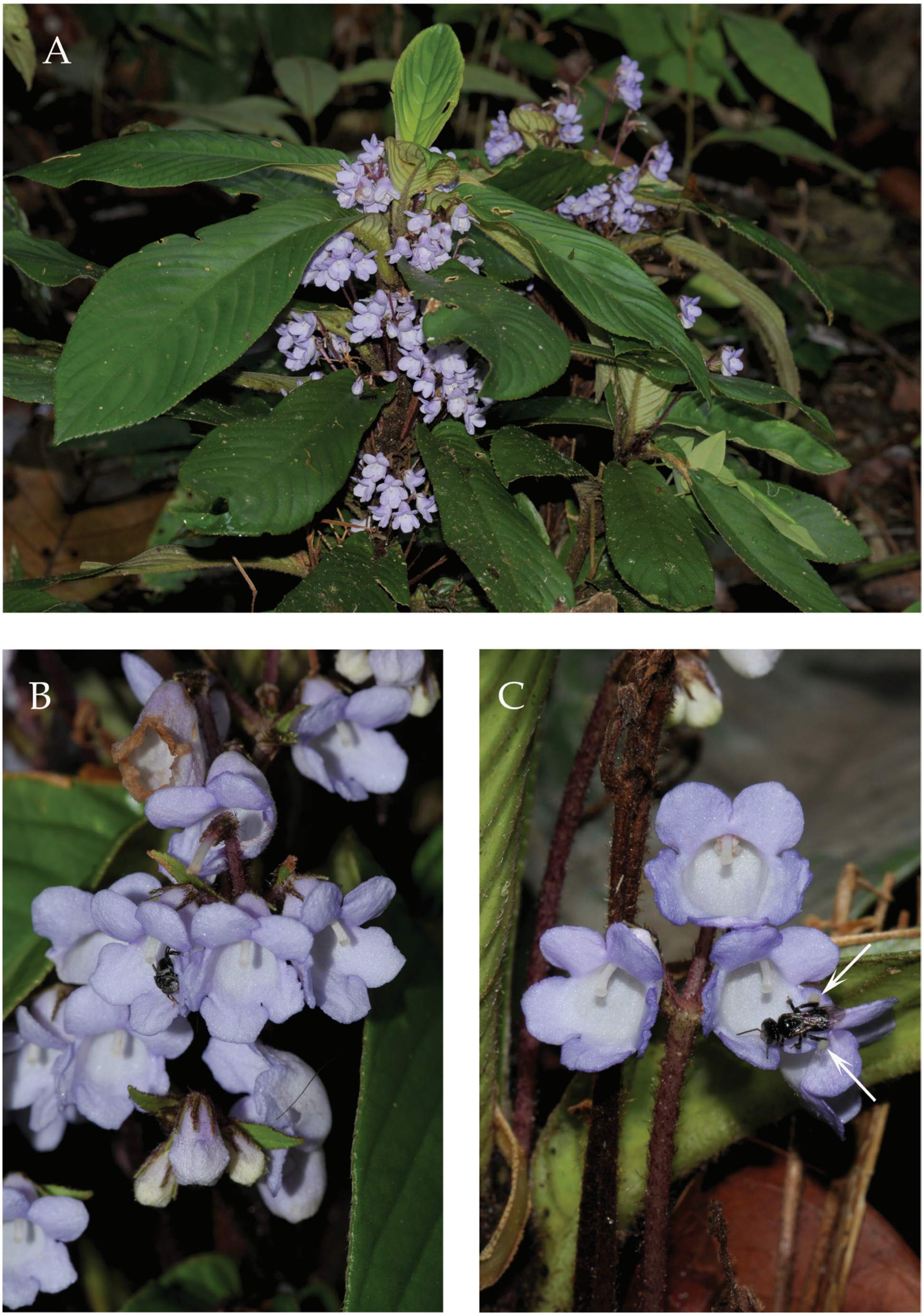

Figure 3. *Codonoboea norakhirrudiniana* Kiew, sp. nov. **A** habit **B** flowers **C** trigona bee leaving flower with full pollen baskets indicated by arrows. (Photographs by Ong Poh Teck).

Distribution. Endemic in Terengganu, Peninsular Malaysia, known only from Tembat Forest Reserve, Hulu Terengganu District.

Ecology. Common in primary or logged-over lowland or hill dipterocarp forest at 390–420 m altitude, on top of ridges or above streams. Flowering gregariously with flowers and fruits on the same plant in March–April and July.

Etymology. Named for Dato' Indera Hj. Nor Akhirrudin bin Mahmud, formerly Director-General of the Forestry Department Peninsular Malaysia, a strong advocate of conservation, who introduced the system of raising the level of protection by the designation of forest reserves as High Conservation Value Forests.

Other specimens examined. Terengganu: Hulu Terengganu, Tembat Forest Reserve – Mohd Hairul, M.A. et al. FRI 60919 (KEP), Mohd Hairul, M.A. et al. FRI 70907 (KEP, SAN), Kamarul, M. et al. FRI 66338 (KEP), Kamarul, M. et al. FRI 67125 (KEP, L, SAN, SING), Kamarul, M. et al. FRI 67147 (KEP, L, SAN, SING), Nor Ezzawanis, A.T. et al. FRI 58126 (KEP, K, SAN, SAR, SING), Ummul Nazrah, A.R. et al. FRI 57005 (KEP, SING), Ummul Nazrah, A.R. et al. FRI 57035 (KEP).

Notes. This species belongs to the Boeopsis group of *Codonoboea* species that have a short campanulate flower with large anthers prominent in the mouth of the corolla and with a minute nectary, all typical characters of a pollen flower (Lim 2014). Molecular analysis demonstrates that this species (labelled *Codonoboea* sp. nov. 5 in phylogenetic tree) clusters with *C. anthonyi* and *C. leiophylla* but is distinct from them (Lim and Kiew 2014).

It grows in the Tembat Forest Reserve. In 2010, the KEP botany team carried out an intensive collecting programme in the area that was designated for clear-felling for the extension to the Kenyir Hydroelectric Dam in an effort to provide a permanent record of this little known forest. As a result, several new species were discovered, such as two species of *Codonoboea*, *C. norakhirrudiniana* and *C. tembatensis* (Kiew, 2014). Although both these species were quite common and widespread within the Tembat Forest Reserve, they have not been found in other forests in Terengganu. The Tembat Forest Reserve has since been clear-felled for the extension to the Kenyir Hydroelectric Dam. The current status of their populations is not known but, because of their restricted distributions, there is the possibility that the widespread clear-felling will ultimately result in their extinction.

Codonoboea rheophytica Kiew, sp. nov.

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Figure 4

Diagnosis. In its extremely narrow leaves, less than 2 cm wide and more than eight times longer than wide, it resembles the other two Peninsular Malaysian rheophytic *Codonoboea* species, *C. densifolia* and *C. salicina*. It shares with *C. salicina* the serrate leaf margin, but it differs in its leaves that have more lateral veins (33–36 pairs vs.13–18 pairs in *C. salicina*) and from *C. densifolia* that has a leaf with an entire margin. *Co-*

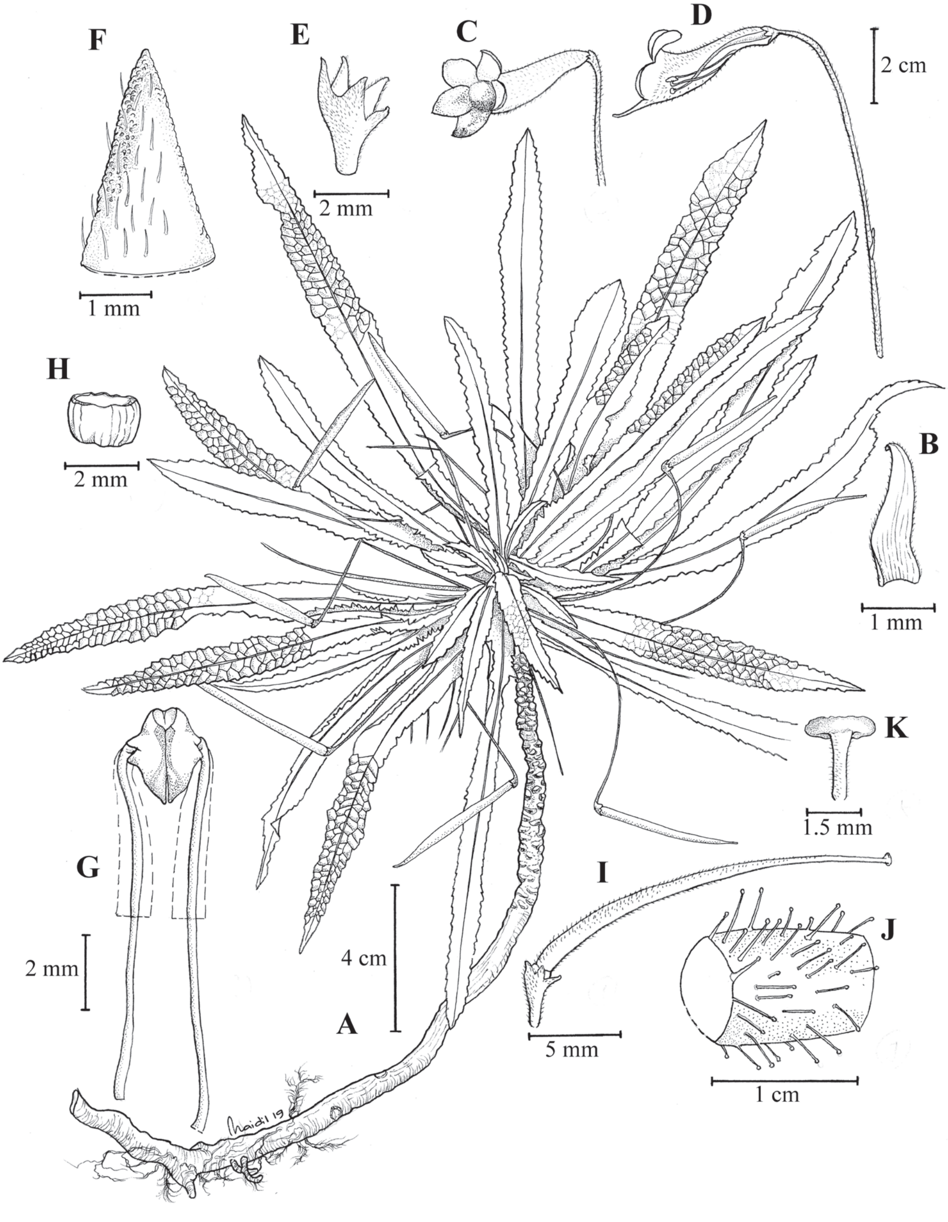

Figure 4. *Codonoboea rheophytica* Kiew, sp. nov. **A** habit **B** bracteole **C** flower **D** flower opened to show position of stamens **E** calyx **F** outer surface of calyx lobe **G** stamens **H** annular nectary **I** young fruit **J** ovary covered in glandular hairs **K** peltate stigma. (All from *FRI 47176*, drawn by Mohamad Aidil Noordin).

donoboea rheophytica differs from both in its sessile leaves (vs. shortly petiolate, petioles 0.5–1.5 cm long), single flowers (not in inflorescences with 2–4 flowers) and longer corolla tube 30–40 × 7–12 mm (vs. 8–9 × 4.5 mm in *C. densifolia* and 3.3 × 3.7 mm in

C. salicina) and longer fruit 3–4.5 cm long (vs. 1.5–3 cm long). Amongst species with similar solitary flowers with a large trumpet-shaped corolla, included stamens, annular nectary ca. 1 mm tall and a large peltate stigma and sessile leaves with a serrate margin, it most resembles *Codonoboea crinita* that has relatively narrow leaves (13.5–)18(–24) × (3–)3.5(–4.5) cm. It differs from *C. crinita* in its much narrower leaves (0.8–1.3 cm wide and 14–17 times longer than wide), in its lamina that is glabrous above, except for the midrib (vs. densely hairy in *C. crinita*), 33–34 pairs of lateral veins, (vs. 22–28(–34) pairs) and shorter fruit 2.8–4.3 cm long (vs. 5.5–8 cm long). In addition, the leaves of *C. crinita* are usually deep purple beneath and have a broad silver-grey band along the midrib on the upper surface. *Codonoboea crinita* grows on soil and is very rarely recorded as a lithophyte and, in spite of being a common and widespread species, it has never been recorded as growing on rocks in rivers or even on river banks.

Type. Peninsular Malaysia. Terengganu, Dungun District, Rasau Kerteh Forest Reserve. 4°35.52'N, 103°17.47'E, 20 Oct 2002, Sam, Y.Y., Angan, A., Mustafa, D. FRI 47176 (holotype KEP; iso: SAN).

Description. Rheophyte, *stem* erect, unbranched, woody, 12–23 cm tall, 5–6 mm diameter; apex and developing leaves densely covered in long, glossy hairs. *Leaves* in a dense tuft at the top of the stem, sessile; lamina narrowly lanceolate, glabrescent above, 11.5–22 × 0.8–1.3 cm, in life bullate, margin serrate, teeth ca. 1–1.5 mm long and 1.5–2 mm broad at base; midrib and veins impressed above, forming conspicuous irregular squares or polygons, midrib shortly hispid, beneath midrib and veins prominent and shortly hispid; lateral veins 33–36 parallel pairs, tertiary veins perpendicular and sending fine veins into sinus between two teeth. *Flowers* single from upper surface of the leaf base. Peduncle and pedicel 6–7.5 cm long, sparsely hairy; bract linear, ca. 2 mm long. Indumentum of peduncle, calyx, corolla and ovary of glandular, long- stalked hairs. Calyx 5-lobed, divided to base, 2–3 mm long, base 1 mm wide, densely pubescent; corolla trumpet-shaped, 3.2–4.5 cm long, white, minutely pubescent outside, glabrous inside, tube 3–3.5 cm long, throat yellow inside, mouth ca. 1.2 cm diameter, lobes 5, broadly rounded, upper two 0.7–1.5 × 0.6–1 cm, edge of lobes purple, upper two erect, lower three spreading, 3–3.5 mm long; stamens 2, white, glabrous, included in corolla tube, filaments ca. 10 mm long, anthers white, broadly sagittate, 2.5–3 × ca. 1.3 mm, cohering face-to-face, staminodes 2, finely linear, 2.5–3 mm long; nectary annular, 1–1.3 mm high; ovary and style densely and minutely pubescent, ovary 11–16 × ca. 1.5 mm, style 9–10 mm long, ovary and style densely hairy; stigma large, peltate 1.3–1.7 mm diameter, with large papillose cells. *Fruits* slender, cylindric, 2.8–4.3 cm long, ca. 1.5 mm diameter, minutely hispid, dehiscing along the upper suture.

Distribution. Endemic in Terengganu, Dungun District, Rasau Kerteh Forest Reserve, known only from the type.

Ecology. Rheophyte clinging onto rock surface along river in regenerated lowland dipterocarp forest at 54 m altitude.

Etymology. Greek – *rheo*, pertaining to flowing water. The rheophytic habit is very unusual in *Codonoboea* species.

Notes. Although *Codonoboea* species are common on rocks close to streams and on river banks, very few, notably *C. densifolia*, *C. salicina* and this new species, grow within the flood zone and are true rheophytes. All three have the typical habit of rheophytes, wiry stem and exceptionally narrow leaves, although *C. densifolia* and *C. salicina* are not obligate rheophytes, since they also grow on steep banks in forest.

Its flower characters place it within the Heteroboea group of species. Other species in this group are large, robust herbs with large, broad leaves quite unlike those of *C. rheophytica*. Molecular analysis confirms that it (labelled as *Codonoboea* sp. nov. 2) falls within this group (Lim and Kiew 2014).

Codonoboea sallehuddiniana C.L.Lim, sp. nov.

urn:lsid:ipni.org:names:77201451-1
Figures 5, 6

Diagnosis. In its habit (stem unbranched, woody, 10–25 cm long, 3–6 mm thick) and its petiolate, narrowly lanceolate or slightly oblanceolate lamina 9–20 cm long with many, deeply impressed veins and a serrate margin with teeth 3–5 × 1.2–2 mm, *Codonoboea sallehuddiniana* resembles *C. breviflora* (Ridl.) Kiew but it is different in its dichasium with two short branches and flowers in pairs (*C. breviflora* has a one-flowered inflorescence), its large foliose bracts 11–12 mm long (not linear and 5–10 mm long), its rosy purple, narrow corolla 15–16 mm long (not shorter, campanulate, pale purple to white corolla and 10–14 mm long) and shorter fruits 3–3.5 cm long (not 3–5.5 cm long).

Type. Peninsular Malaysia. Terengganu, Dungun, Pasir Raja Forest Reserve, Compartment 5, 4°41.62'N, 102°58.35'E, 28 June 2011 Yao, T.L. & Azril, A. FRI 65593 (holotype KEP, barcode KEP210589; iso: E, SING).

Description. Erect, unbranched herb. *Stem* woody, 15–20(–60) cm tall, 3–6 mm diameter. Indumentum of long ferruginous hairs, on stem and petioles dense and glossy, hairs to 1.5 mm long, grooved midrib on upper lamina surface densely hairy, beneath midrib and veins hairy, denser with hairs to 1.5 mm long on the midrib. *Leaves* at the top of the stem, opposite, pairs equal, to 1.5 cm apart; petioles 1.5–3.5 cm long; lamina lanceolate, glabrous above, 9–17.5 × 4–7 cm, in life bullate, glossy green above, yellowish-green near petiole, pale green beneath, drying reddish-brown, margin glabrous, serrate, teeth falcate, 3–5 × 1.5–2 mm long, apex acute; midrib and veins in life impressed above, prominent beneath; lateral veins 15–24 pairs, glabrous above, a fine vein reaching between every third sinus between the teeth. *Inflorescence* erect, from the upper leaf axils, a pair-flowered dichasium with 2 short equal branches, each with 5–10 pairs of flowers; peduncle slender, maroon or dark purple, 11–16.3 cm long, hairy, hairs to ca. 2 mm long, branches 2–5.5 cm long; bract pair at first purple, then semi-transparent pale green, persistent, sparsely hairy outside, glabrous inside, foliose, 3-veined, lanceolate, 11–12 × 3–4 mm decreasing in size towards the apex, margin distantly serrate; pedicels dark purple, ca. 2 mm long, hairy. *Flowers* held more-or-less

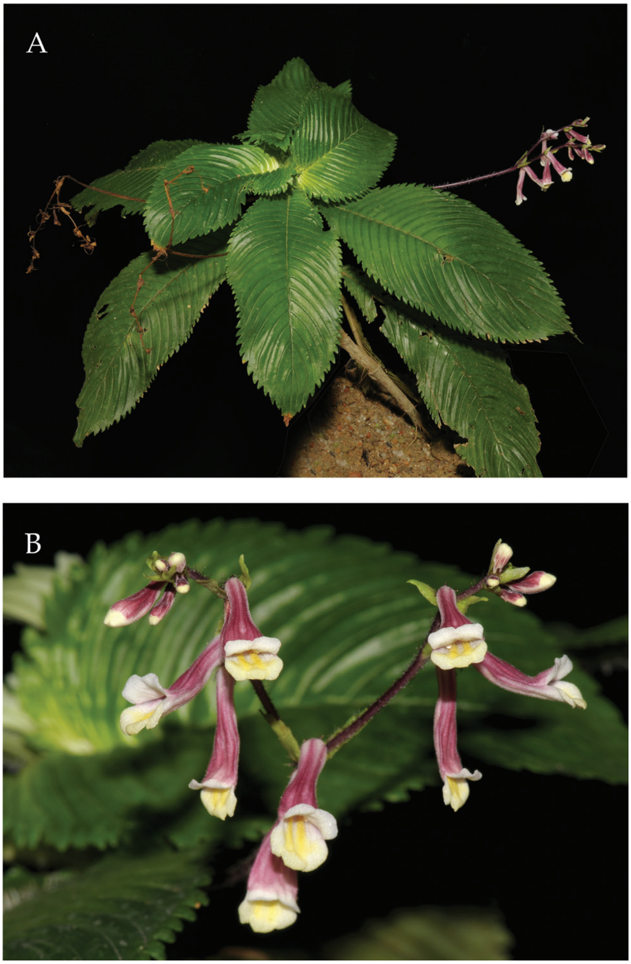

Figure 5. *Codonoboea sallehuddiniana* C.L.Lim, sp. nov. **A** habit **B** Inflorescence. (Photographs by Ong Poh Teck).

horizontally or slightly pendent; calyx dark purple, ca. 3 mm long, densely hairy outside, hairs glandular to 1 mm long, glabrous inside, 5-lobed divided almost to the base; corolla narrowly tubular, 15–17 mm long, 1.5–2 mm diameter at base, slightly dilating and 4–6 mm diameter at the mouth, tube deep rosy purple, whitish towards the mouth with fine deep purple veins that show through in the white throat, minutely hairy outside and on the lower part of floor of throat with two raised yellowish nectar guides running into the mouth and densely covered in glistening hairs, lobes 5, whitish-cream or sometimes green with purple stripe, upper two lobes rounded, 1.5–2.5 × 1–3 mm, reflexed; lower three ca. 2.5–4 × 2–3.5 mm long, spreading, slightly reflexed at tip; stamens 2, filaments slender, ca. 4–5 mm long, glabrous, anthers white, broadly sagittate, 1.5 mm, cohering face-to-face, positioned just inside the corolla tube; nectary annular, ca. 0.7 mm high; ovary and style with densely hairy, ovary violet, ca. 4 mm long, style

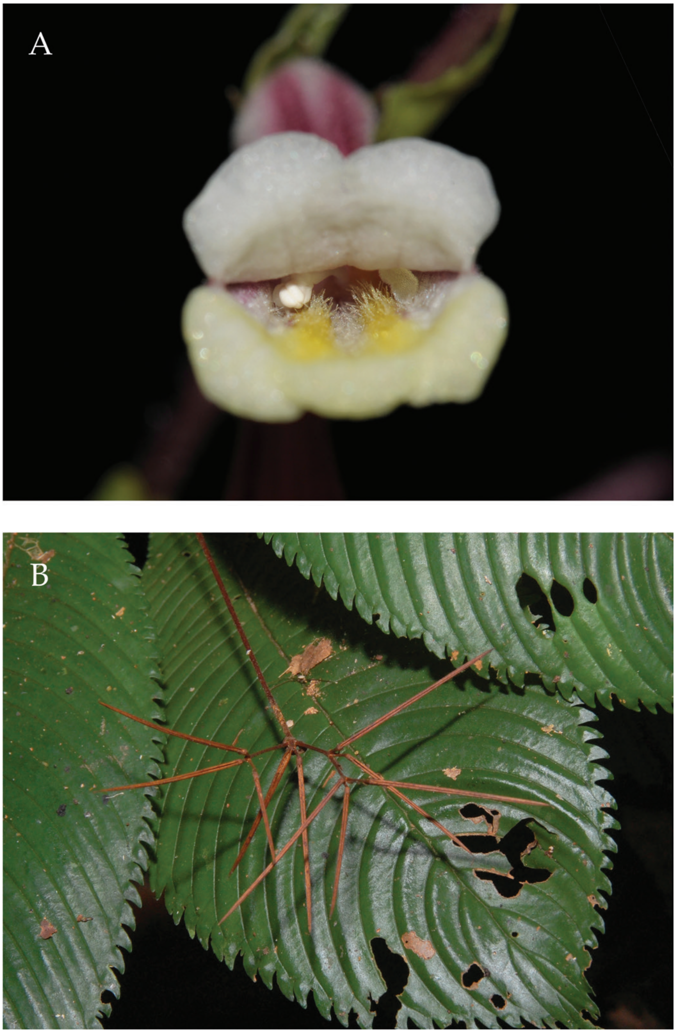

Figure 6. *Codonoboea sallehuddiniana* C.L.Lim, sp. nov. **A** front view of flower **B** Infructescences. (Photographs A by Ong Poh Teck; B by C.L. Lim).

sparsely minutely pubescent, ca. 3.5 mm long and stigma capitate, white, ca. 0.1 mm long. *Fruits* extremely slender, cylindric, 3–3.5 cm long, ca. 0.7–1 mm diameter, glabrescent, dehiscing along the upper suture; pedicel to 7 mm long.

Distribution. Endemic in Dungun District (Jerangau FR, Pasir Raja FR and Sungai Loh), Terengganu, Peninsular Malaysia.

Ecology. Lowland dipterocarp forest, on shaded slopes or top of banks beside old logging road, at 15–50 m altitude.

Etymology. Named for Dato' Sri Dr Sallehuddin bin Ishak, formerly Federal Lands Commissioner of Malaysia, for his strong support of conservation of karst limestone hills in Perak.

Other specimens examined. Terengganu, Dungun, Jerangau Forest Reserve, Kamarul, M. et al. FRI 67177 (KEP); Ong, P.T. & Rafidah, A.R. FRI 71249 (KEP); Dungun, Sungai Loh, Sam, Y.Y. & Markandan, M. FRI 44400 (KEP), from Sungai Loh cultivated in Forest Research Institute Malaysia, Sam, Y.Y. FRI 47049 (KEP).

Notes. The inflorescence of *Codonoboea sallehuddiniana* is unusual for the genus. The basic inflorescence in *Codonoboea* is a pair-flowered cyme that may be reduced to a single flower (as in *C. breviflora*) or be branched once (a dichasial pair-flowered cyme) or many times to form a thyrse. In *C. sallehuddiniana*, the dichasium has two short branches and, on these, are pairs of short-stalked flowers each subtended by a large foliose bract that decreases in size towards the apex. The flowers are all positioned in the same direction. The particularly long, narrow corolla tube that scarcely dilates and has prominent hairs in the mouth is unusual in *Codonoboea.*

Discussion

Habitat

In Terengganu, most *Codonoboea* species have been collected from lowland dipterocarp forest below 250 m elevation in the foothills of the Terengganu Range. Few are found at higher elevations, namely *C. codonion* (to 550 m), *C. puncticulata* (924 m) and, from Gunung (Mount) Padang (at 1,040 m), *C. padangensis* and *C. grandifolia.* However, this is likely an artefact of collecting because very few mountain peaks in Terengganu have been explored botanically. Many species are associated with steep earth slopes, either in forest or on river banks or on rocks but two, *C. densifolia* and *C. rheophytica*, with characteristic narrow leaves, are rheophytes that live on rocks in the flood zone in streams.

No species is recorded from the Marang or Kuala Nerus Districts. This is probably because they are coastal districts and, as yet, no species has been collected from *kapur* forest nor from tropical heath forest, nor from streams and rivers with tidal influence.

Codonoboea species are all obligate shade plants that grow in conditions of high humidity. In Terengganu, they are particularly vulnerable because most grow in forest below 250 m elevation and it is this land that is most vulnerable to land use changes. Populations are eliminated by clear-felling forests for palm oil plantations and infrastructure development such as road building or constructing hydroelectric dams. No *Codonoboea* species is weedy and able to adapt to conditions when the tree canopy is opened up from logging or clear-felling (Kiew 2009).

Distribution

Comparison of species per district illustrates that the northern districts of Besut and Setiu, each with six *Codonoboea* species, are poorer in species compared with 11–12 species recorded for the Dungun, Kemaman and Hulu Terengganu districts. This, however, is likely due to under-collecting; the northern districts are still poorly known. Within the limitation that many areas have still to be explored, particularly in the north and at high elevations, several patterns of distribution can be identified amongst the more widespread species.

Apart from the widespread species (*C. quinquevulnera*, *C. platypus* and *C. rugosa*), the Terengganu flora does not share any species with the Main Range or the west coast states (Table 1). *Codonoboea rugosa* is confined to the northern states and its distribution extends into Thailand. On the east coast, it appears to replace *C. crinita* (Jack) C.L.Lim that is common on the west coast, particularly in the hills. Excluding these widespread species, four species (*C. atrosanguinea*, *C. anthonyi*, *C. leiophylla* and *C. salicinoides*) are shared with Kelantan, four with Pahang (*C. atrosanguinea*, *C. codonion*, *C. grandifolia* and *C. salicinoides*) and two with Johor (*C. densifolia* and *C. puncticulata*). The last two species are much more common in Johor and reach their northern limit in southern Terengganu.

Endemism

Nationally, the level of endemism in *Codonoboea* (as *Didymocarpus*) is high, 94% (Kiew 1991b) and many species are site endemics. Of the 20 species in Terengganu, only three have distributions extending beyond Peninsular Malaysia. *Codonoboea puncticulata* was recorded from Singapore but that population is now extinct; *C. platypus* is known from Sumatra and Borneo; and *C. platypus* and *C. rugosa* from Peninsular Thailand. Of the nine species endemic to Terengganu (Table 2), *C. padangensis* and *C. rheophytica* are each at present known from a single population and *C. miniata*, *C. norakhirrudiniana* and *C. tembatensis* from restricted areas.

Checklist of *Codonoboea* species in Terengganu, Peninsular Malaysia

(Bkt. Bukit (hill); FR Forest Reserve, G. Gunung (mountain), P. Pulau (island), Sg. Sungai (river))

1. *Codonoboea anthonyi* (Kiew) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 256. *Basionym: Didymocarpus anthonyi* Kiew, Gard. Bull. Sing. 44 (1992) 24. *Homotypic synonym: Henckelia anthonyi* (Kiew) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 339. *Type:* Peninsular Malaysia, Terengganu, Ulu Besut, *Kiew RK 2700*, 7 May 1988 (holotype KEP; isotypes K, SING).

Distribution. Endemic in Peninsular Malaysia – Kelantan (Relai FR) and Terengganu.

Ecology. Primary lowland forest to 200 m altitude. Locally common on vertical earth banks or hill slopes by river.

Terengganu specimens examined. BESUT DISTRICT: Pelagat FR – *Kiew, R. RK 2700* (KEP), *Lim, C.L. FRI 64994* (KEP, SAN, SING, L, K, A), *Sam, Y.Y. FRI 46648* (KEP), *Sam, Y.Y. FRI 47022* (KEP); Ulu Besut FR – *Anthonysamy, S. SA 675* (KEP, SING).

2. *Codonoboea atrosanguinea* (Ridl.) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 257. *Basionym: Didymocarpus atrosanguineus* Ridl., Trans. Linn. Soc. Ser. 2, Bot.3 (1893) 328, J. Straits Branch Roy. Asiat. Soc. 44 (1905) 47, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 758, Fl. Malay. Pen. 2 (1923) 518; Kiew, Gard. Bull. Singapore 42 (1989) 49. *Homotypic synonym: Henckelia atrosanguinea* (C.B.Clarke) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 340. *Type:* Peninsular Malaysia, Pahang, Sungai Tahan, *Ridley s.n.* (lectotype SING).

Distribution. Endemic in Peninsular Malaysia – Kelantan (Kuala Aring), Pahang (Tahan and Kenyam Valleys) and Terengganu.

Ecology. In deep shade in primary lowland forest to 200 m altitude, locally common.

Terengganu specimens examined. DUNGUN DISTRICT: Jerangau FR – *Lim, C.L. FRI 73027* (KEP); HULU TERENGGANU DISTRICT: Batu Biwa – *Kiew, R. RK 2320* (KEP); Sekayu FR – *Anthonysamy, S. SA 643* (KEP), *Kiew, R. RK 2693* (KEP), *RK 3787* (KEP), *Yao, T.L. et al. FRI 77368* (KEP); Sg. Cicir FR – *Julius, A. et al. FRI 56113* (KEP); Sg. Perepak FR – *Jutta, M. FRI 59559* (KEP, SING, K), *Lim, C.L. et al. FRI 52898* (KEP. SAN); Sg. Petuang – *Nor-Ezzawanis, A.T. FRI 52288* (KEP), *Phoon, S.N. et al. FRI 51979* (KEP, SAN); Tembat FR – *Mohd Hairul, M.A. et al. FRI 60958* (KEP), *FRI 72228* (KEP), *Siti-Munirah, M.Y. et al. FRI 67864* (KEP, *FRI 67890* (KEP, K); Ulu Telemong FR – *Phoon, S.N. et al. FRI 51587* (KEP, KLU), *FRI 51590* (KEP).

3. *Codonoboea codonion* (Kiew) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 257. *Basionym: Didymocarpus codonion* Kiew, Gard. Bull. Sing. 42 (1989) 49. *Homotypic synonym: Henckelia codonion* (Kiew) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 342. *Type:* Peninsular Malaysia, Pahang, Kuala Kenyam, *Kiew B.H. RK 1204*, 30 September 1982 (holotype KEP; isotype SING).

Distribution. Endemic in Peninsular Malaysia – Pahang (Taman Negara, Gunung Aiis FR) and Terengganu.

Ecology. Lowland to hill forest, 15–550 m altitude, on forest floor, slopes, on ridge tops and stream banks.

Terengganu specimens examined. DUNGUN DISTRICT: Chemerong FR – *Lim, C.L. FRI 64963* (KEP); Jengai FR – *Lim, C.L. et al. FRI 72806* (KEP), *Sam, Y.Y.*

& Mustafa, D. FRI 47151 (KEP); *Anonymous s.n. (0105938)* (SING); Pasir Raja FR – *Sam, Y.Y. & Angan, A. FRI 47164* (KEP). KEMAMAN DISTRICT – Bukit Bandi FR – *Sam, Y.Y. FRI 47181* (KEP); Sg. Nipah *Chan, Y.C. et al. FRI 70608* (KEP, L, SAN, SAR), *Kiew, R. RK 2653* (KEP). HULU TERENGGANU DISTRICT – Batu Biwa: *Kiew, R. RK 2301* (SING); G. Padang: *Moysey, L. 33387* (SING); *FRI 64497* (KEP); Tasik Kenyir: *Lim, C.L. FRI 52983* (KEP), *Julius, A. FRI 56111* (KEP, SAN, SING, L); Ulu Telemong FR: *Kiew, R. RK 5344* (KEP), *Chew, M.Y. FRI 51821* (A, KEP, SING).

4. *Codonoboea corneri* (Kiew) Kiew

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 258. *Basionym: Didymocarpus corneri* Kiew, Blumea 35 (1990) 172, figs. 2 & 4. *Homotypic synonym: Henckelia corneri* (Kiew) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 342. *Type:* Peninsular Malaysia, Terengganu, Sg. Nipah *Kiew RK 2655* (holotype L; isotypes K, KEP, SING).

Distribution. Endemic in Peninsular Malaysia – Terengganu (Dungun and Kemaman Districts).

Ecology. Common on steep earth banks and by streams in lowland forest at ca. 100 m elevation.

Terengganu specimens examined. DUNGUN DISTRICT – Pasir Raja FR *FRI 65593*. KEMAMAN DISTRICT – Sg. Nipah, *Corner s.n.* (SING).

5. *Codonoboea densifolia* (Ridl.) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 259. *Basionym: Didymocarpus densifolius* Ridl., J. Straits Branch Roy. Asiat. Soc. 44 (1905) 51, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 761, Fl. Malay Pen. 2 (1923) 521. *Homotypic synonyms: Paraboea densifolia* (Ridl.) M.R.Hend., Gard. Bull. Straits Settlem. 5 (1930) 79. *Henckelia densifolia* (Ridl.) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 343. *Type:* Peninsular Malaysia, Johor, G. Janing [Janeng], *Lake & Kelsall s.n.*, 20 October 1892 (holotype SING). *Heterotypic synonyms: Paraboea caerulea* Ridl., J. Straits Branch Roy. Asiat. Soc. 44 (1905) 66, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 772, Fl. Malay Pen. 2 (1923) 529; *non Didymocarpus caeruleus* (R.Br.) Koord. – *Didymocarpus azureus* B.L.Burtt, Notes Roy. Bot. Gard. Edinburgh 31 (1971) 44. *Type:* Peninsular Malaysia, Terengganu, 'Bundi' [Bukit Bandi], *Rostados s.n.*, February 1904 (holotype SING).

Distribution. Endemic in Peninsular Malaysia – Johor (Panti FR and Endau-Rompin State Park), Pahang (Pulau Tioman) and Terengganu (Bukit Bandi).

Ecology. Lowland to hill dipterocarp forest 60–750 m altitude, locally common on vertical earth bank and rocky stream bank.

Terengganu specimens examined. KEMAMAN DISTRICT – Bkt. Bandi [Bundi] *Rostados s.n.* (SING).

Note. In Terengganu known only from one old 1904 collection, *Rostados s.n.*, that Ridley (1905) described as *Paraboea caerulea.* It is a very distinct narrow-leaved species not likely to be confused with any other species. It is not known if the ongoing tin-mining in 1904 destroyed its habitat, which would explain why it has not been collected since. Rheophytes are particularly vulnerable to habitat disturbance that would cause increased silt disposition, destruction of river banks or the opening of the canopy. It is likely, therefore, that the Bkt. Bandi population has been eliminated. However, it is common in Johor (Kiew, 1987).

6. *Codonoboea floribunda* (M.R.Hend.) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 261. *Basionym: Paraboea floribunda* M.R.Hend., Gard. Bull. Sing. 7 (1933) 117. *Homotypic synonyms: Didymocarpus floribundus* (M.R.Hend.) B.L.Burtt, Notes Roy. Bot. Gard. Edinburgh 31 (1971) 44. *Henckelia floribunda* (M.R.Hend.) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 345. *Type:* Peninsular Malaysia, Terengganu, Kemaman, Bkt. Kajang, Sg. Nipah, *Corner 26022*, June 1932 (holotype K).

Distribution. Endemic in Peninsular Malaysia, Terengganu (Dungun and Kemaman District).

Ecology. Lowland to upper hill dipterocarp forest, 81–152 m altitude, on forest floor and stream banks.

Terengganu specimens examined. DUNGUN DISTRICT: Jerangau FR: *Lim, C.L. & Nazri, A. FRI 65040* (KEP, SAN, SING), *Julius, A FRI 56176* (KEP, E, SING). KEMAMAN DISTRICT: Bkt. Kajang – *Kiew, R. RK 2686* (SING), *RK 2687* (SING), *RK 2676* (SING), *Corner, E.J.H. SFN 30714* (SING), *Imin, K. et al. FRI 76175* (KEP); Jeram Tanduk *Lim, C.L. et al. FRI 64971* (KEP); Sg. Nipah – *Kiew, R. RK 2653* (KEP), *Sam, Y.Y. FRI 47190* (KEP), *FRI 47199* (KEP), *FRI 47223* (KEP), *Kiew, R. RK 5327* (KEP), *Lim, C.L. FRI 64971* (KEP, SAN, SING, L, K, E), *FRI 65153* (KEP); Ulu Bendong – *Corner, E.J.H. SFN 30110* (L, SING). Sri Bangun: *Sinclair, J. SFN 39863* (SING).

7. *Codonoboea grandifolia* (Ridl.) Kiew

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 261. *Basionym: Paraboea grandifolia* (Ridl.) Ridl., Fl. Malay. Pen. 2 (1923) 531. *Homotypic synonyms: Didymocarpus grandifolius* Ridl., J. Linn. Soc. Bot. 38 (1908) 318 *non Didymocarpus grandifolius* (A.Dietr.) F.G.Dietr. (1834); *Didymocarpus tahanicus* B.L.Burtt, Notes Roy. Bot. Gard. Edinburgh 31 (1971) 46; Kiew, Gard. Bull. Singapore 42 (1989) 61, Malay. Nat. J. 48 (1995) 205; *Henckelia tahanica* (B.L.Burtt) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 357. *Type:* Peninsular Malaysia, Pahang, G. Tahan *Wray & Robinson 5369* (holotype BM; isotype SING).

Distribution. Endemic in Peninsular Malaysia, Pahang (G. Tahan) and Terengganu (G. Padang).

Ecology. Lower montane forest at 1100–1220 m elevation, in shade on very steep earth slopes.

Terengganu specimens examined. HULU TERENGGANU DISTRICT: G. Padang – *Moysey, L. & Kiah SFN 33924* (SING), *FRI 12700* (KEP).

Note. It is a striking species with particularly large leaves and flowers. It only grows on steep earth slopes and appears to be rare and local.

8. *Codonoboea leiophylla* (Kiew) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 264. *Basionym: Didymocarpus leiophyllus* Kiew, Gard. Bull. Sing. 44 (1992) 28. *Homotypic synonym: Henckelia leiophylla* (Kiew) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 348. *Type:* Peninsular Malaysia, Terengganu, Ulu Setiu *Kiew RK 2265*, 28 April 1986 (holotype KEP; isotype SING).

Distribution. Endemic in Peninsular Malaysia, Kelantan (Kuala Aring FR) and Terengganu (Besut, Hulu Terengganu and Setiu districts).

Ecology. Lowland, locally common on vertical earth banks, hill slopes by river, to 100 m altitude.

Terengganu specimens examined. BESUT DISTRICT: G. Tebu FR – *Lim, C.L. FRI 64998* (KEP, SAN, SING). HULU TERENGGANU DISTRICT: G. Lawit – *Kiew, R. RK 2272* (SING). SETIU DISTRICT: Ulu Setiu FR – *Anthonysamy, S. SA 670* (KEP), *SA 662* (KEP, SING), *Kiew, R. RK 2265* (KEP, SING), *Sam, Y.Y. FRI 44386* (KEP, KEP, L, SAN, SAR), *Sam, Y.Y. FRI 46650* (KEP, SAN), *Mohd Shah MS 3509* (SING), *Anthonysamy, S. SA 718* (SING), *Lim, C.L. FRI 64951* (KEP), *FRI 64991* (KEP).

9. *Codonoboea miniata* (Kiew) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 266. *Basionym: Didymocarpus miniatus* Kiew, Novon 5 (1995) 40. *Homotypic synonym: Henckelia miniata* (Kiew) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 350. *Type:* Peninsular Malaysia, Terengganu, Bkt. Bauk (holotype KEP; isotypes L, SING).

Distribution. Endemic in Peninsular Malaysia, Terengganu, Dungun District (Bkt. Bauk area).

Ecology. In coastal forest on the foothills of low sandstone hills, on slopes above small swampy areas or by seasonal streams.

Terengganu specimens examined. DUNGUN DISTRICT: Bkt. Bauk – *Anthonysamy, S. SA 602* (KEP), *Kochummen, K.M. KEP 9491* (KEP); Bkt. Chabang – *Davison, G. GD5* (KEP).

10. *Codonoboea norakhirrudiniana* Kiew (see above)

11. *Codonoboea padangensis* Kiew

Malay. Nat. J. 63 (2011) 661. *Type:* Peninsular Malaysia, Terengganu, Hulu Terengganu District, G. Padang *Ong et al. FRI 66754* (holotype KEP; isotypes E, K, L, SAR, SING).

Distribution. Endemic in Peninsular Malaysia, Terengganu (G. Padang).

Ecology. Locally common on steep slopes in lower montane forest at about 1040 m elevation.

Terengganu specimens examined. Known only from the type population.

12. *Codonoboea personatiflora* Kiew & Y.Y.Sam

Phytokeys 18 (2012) 62. *Type:* Peninsular Malaysia, Terengganu, Kemaman District, Sg. Nipah, Bukit Kajang, *Corner SFN 30540* (holotype SING; isotypes K, L, E, SAR).

Distribution. Endemic in Peninsular Malaysia, Terengganu (Dungun, Kemaman, Hulu Terengganu and Setiu districts).

Ecology. In primary or logged-over lowland mixed dipterocarp forest at low altitudes (below 100 m), on shaded hillsides or slopes, often above streams.

Terengganu specimens examined. DUNGUN DISTRICT: Jengai FR – *Anon. s.n.* 15 Mar 1998 (SING), Compartment 52 *Sam, Y.Y. FRI 47153* (KEP, SAN). HULU TERENGGANU DISTRICT: Ulu Telemong FR – *Kiew, R. RK 5339* (KEP, K, SAR); Ladang Ternakan, Tersat – 31 Oct 2009, *Kamarul, M. FRI 67168* (KEP, SING). KEMAMAN DISTRICT: Sg. Nipah FR, Jeram Tanduk – *Sam, Y.Y. FRI 47197* (KEP, SING). SETIU DISTRICT: Ulu Setiu FR – *Sam, Y.Y. FRI 44395* (KEP).

13. *Codonoboea platypus* (C.B.Clarke) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 267. *Basionym: Didymocarpus platypus* C.B.Clarke, in A.DC. & C.DC., Mongor. Phan. 5, 1 (1883) 94; Ridley, J. Straits Branch Roy. Asiat. Soc. 44 (1905) 46, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 757, Fl. Malay. Pen. 2 (1923) 517. *Homotypic synonym: Henckelia platypus* (C.B.Clarke) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 352. *Type:* Peninsular Malaysia, Melaka, *Griffith 3825* (lectotype K).

Distribution. Sumatra, Peninsular Thailand and throughout Peninsular Malaysia.

Ecology. The commonest *Codonoboea* in Peninsular Malaysia in shaded primary lowland and hill dipterocarp forest to 1000 m altitude. Locally common on vertical earth banks or hill slopes by river.

Terengganu specimens examined. DUNGUN DISTRICT: Jengai FR – *Julius, A. et al. FRI 57761* (KEP), *Lim, C.L. et al. FRI 72830* (KEP); Jerangau FR – *Lim, C.L. et al. FRI 65114* (KEP), *Mohd Hairul, M.A. et al. FRI 69951* (KEP). *FRI 69988* (KEP). KEMAMAN DISTRICT: Bukit Kajang – *Imin, K. et al. FRI 76168* (KEP); Jeram Tanduk – *Lim, C.L. et al. FRI 64977* (KEP), *Sam, Y.Y. FRI 47196* (KEP); Sg. Nipa – *Kiew, R. RK 2666* (KEP). SETIU DISTRICT: Ulu Setiu FR – *Sam, Y.Y. FRI*

44394 (KEP). HULU TERENGGANU DISTRICT: Tembat FR – *Mohd. Hairul, M.A. FRI 60929* (KEP), *Sam, Y.Y. FRI 50341* (KEP), *FRI 50367* (KEP), *Siti-Munirah et al. 67875* (KEP); G. Padang – *Ong, P.T. et al. FRI 67761* (KEP).

14. *Codonoboea puncticulata* (Ridl.) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 268. *Basionym: Didymocarpus puncticulatus* Ridl., J. Linn. Soc. 32 (1896) 510, J. Straits Branch Roy. Asiat. Soc. 44 (1905) 55, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 763, Fl. Malay Pen. 2 (1923) 522; Kiew, Malay Nat. J. 41 (1987) 220. *Homotypic synonym: Henckelia puncticulata* (Ridl.) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 353. *Type:* Peninsular Malaysia, Johor, G. Panti, *Ridley s.n.*, December 1892 (holotype SING; photo K). *Heterotypic synonym: Didymocarpus perditus* Ridl., J. Straits Branch Roy. Asiat. Soc. 44 (1905) 54, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 763, Fl. Malay Pen. 2 (1923) 522. *Type:* Singapore, Selitar, *Ridley s.n.*, 3 Nov 1889 (holotype SING).

Distribution. Singapore (extinct) and Peninsular Malaysia (Johor, Pahang and Terengganu).

Ecology. Lowland to hill forest, 20–924 m altitude, on various habitats, from shaded earth bank, river banks, rock surface in forest floor, river or by waterfall.

Terengganu specimens examined DUNGUN DISTRICT: Bkt. Bauk FR – *Anthonysamy, S. SA 601* (KEP), *Weber, A. UPM 3420* (KEP), *Davison, G.W.H. GD 6* (KEP, SING), *Kochummen, K.M. FRI 2592* (KEP), *Sam, Y.Y. FRI 44397* (KEP, SAN, SAR), *FRI 47170* (KEP), *Saw, L.G. FRI 44888* (KEP, SING), *Sam, Y.Y. FRI 44398* (KEP, SAN); Chemerong FR – *Lim, C.L. FRI 64962* (KEP); Dungun – *Anthonysamy, S. SA 594* (SING); Jengai FR – *Sam, Y.Y. FRI 47154* (KEP, SAN), *Anon. s.n.* (SING), *s.n.* (SING), *s.n. (0105992)* (SING); Pasir Raja FR – *s.n.* (*0105989*) (SING); Rasau Kerteh FR – *Sam, Y.Y. FRI 47172* (KEP), *Saw, L.G. FRI 44992* (SING), *Lim, C.L. FRI 64989* (KEP, SAN), *Chan, Y.C. FRI 16853* (SING), *FRI 16853* (KEP), *Kochummen, K.M. KEP 94938* (KEP); Sg. Paka FR – *FRI 64970* (KEP); Ulu Dungun – *Yong, G.C. RK 3136* (KEP, SING). KEMAMAN DISTRICT: Sg. Nipah – *Corner, E.J.H. s.n.* (SING), *Kiew, R. RK 2675* (KEP, SING), *Sam, Y.Y. FRI 47195* (KEP), *Markandan, M. FRI 42698* (KEP), *Lim, C.L. FRI 64972* (KEP, SAN). HULU TERENGGANU DISTRICT: G. Padang – *FRI 67748* (KEP); Tembat FR – *Mohd. Hairul FRI 60929* (KEP), *Sam, Y.Y FRI 50341* (KEP). *FRI 50367* (KEP); Ulu Berang, Sg. Tersat – *Moysey, L. 33610* (SING).

Notes. This is a variable species. The typical rosette form has a woody rootstock. However, some populations on Bkt. Bauk and in Sg. Paka FR have a creeping main stem that branches and produces long, slender prostrate branches that root at lower nodes. At Sg. Paka FR, both decumbent and rosette forms are sympatric and their flowers are not different. Molecular phylogenetic results confirm that the two forms belong to the same species (Lim, 2014).

15. *Codonoboea quinquevulnera* (Ridl.) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 269. *Basionym: Didymocarpus quinquevulnerus* Ridl., Trans. Linn. Soc. Ser. 2, Bot.3 (1893) 328, J. Straits Branch Roy. Asiat. Soc. 44 (1905) 47, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 758, Fl. Malay. Pen. 2 (1923) 518; Kiew, Gard.Bull. Singapore 42 (1989) 58. *Homotypic synonym: Henckelia quinquevulnera* (Ridl.) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 353. *Type:* Peninsular Malaysia, Pahang, Sg. Tahan, *Ridley 2153* (lectotype K; isolectotype SING).

Distribution. Endemic in Peninsular Malaysia – Johor (Ulu Endau), Kelantan (Kampung La), Melaka, Pahang (Fraser's Hill, Semangkok Pass, Tahan Valleys), Selangor (Klang Gates, Batu Tiga, Kanching FR) and Terengganu (Hulu Terengganu District).

Ecology. Not common, with a scattered distribution in deep shade in primary lowland forest to 200 m altitude.

Terengganu specimens examined. HULU TERENGGANU DISTRICT: G. Lawit – *Anthonysamy, S. SA 677* (KEP); Sekayu FR – *Kiew, B.H. s.n.* (KEP).

16. *Codonoboea rheophytica* Kiew (see above).

17. *Codonoboea rugosa* (Ridl.) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 271. *Basionym: Didymocarpus rugosa* Ridl., J. Straits Branch Roy. Asiat. Soc. 44 (1905) 45, J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 74 (1908) 756, Fl. Malay. Pen. 2 (1923) 517. *Homotypic synonym: Henckelia rugosa* (Ridl.) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 355. *Type:* Peninsular Malaysia, Kelantan, Kuala Lebir, *Gimlett s.n.* (holotype SING). *Heterotypic synonym: Didymocarpus lithophyllus* Kiew, Gard.Bull. Singapore 42 (1989) 54, Gard.Bull. Singapore 44 (1992) 38. *Type:* Peninsular Malaysia, Pahang, Sg. Tahan *Ridley 2152* (holotype K, isotype SING).

Distribution. Peninsular Thailand and Peninsular Malaysia – Kedah (G. Bintang), Kelantan (G. Setong), Pahang (Tahan Valley), Perak (Grik, G. Inas, Temangok) and Terengganu (Besut, Hulu Terengganu and Kemaman Districts).

Ecology. In the lowlands at ca. 70 m to 1000 m in Taman Negara; sometimes on shaded vertical granite rock faces.

Terengganu specimens examined. BESUT: Bkt Tangga, Ulu Besut – *Mohd Shah MS 4999* (KEP, SING). HULU TERENGGANU DISTRICT: G. Padang – *Ummul et al. FRI 64519* (KEP); Sekayu FR – *Lim C.L. et al. FRI 65235* (KEP); Tembat FR *Ong, P.T. et al. FRI 71359* (KEP), *Sam Y.Y. FRI 50342* (KEP), *FRI 50360* (KEP). KEMAMAN DISTRICT: Cukai – *Anthonaysam SA 590* (KEP); Sg. Nipa FR – *Chan, M.Y. et al. FRI 70616* (KEP).

18. *Codonoboea salicinoides* (Kiew) C.L.Lim

In Kiew & Lim, Gard. Bull. Sing. 62 (2011) 271. *Basionym: Didymocarpus salicinoides* Kiew, Gard. Bull. Sing. 44 (1992) 35. *Homotypic synonyms: Henckelia salicinoides* (Kiew) A.Weber, Beitr. Biol. Pflanzen 70 (1998) 355. – *Paraboea salicina* (Ridl.) Ridl. var. *major* Ridl., Fl. Malay Pen. 5 (1925) 325. *Type:* Peninsular Malaysia, Kelantan, Kuala Aring, *Yapp 193* (lectotype K; isolectotype CGE).

Distribution. Endemic in Peninsular Malaysia, Johor, Pahang, Kelantan and Terengganu (Besut, Dungun and Kemaman Districts).

Ecology. Lowlands, 20–213 m altitude, locally common on vertical earth banks, rocky stream banks or forest floor.

Terengganu specimens examined. BESUT DISTRICT: Jertih, Bkt. Yong *Mohd Shah & Samsuri MS 3550* (KEP, SING). DUNGUN DISTRICT: Bkt. Bauk FR – *Anthonysamy, S. SA 596* (KEP), *Davison, G. GD 7* (SING), *GD 8* (KEP), *Jutta, M. FRI 59549* (KEP, SAN, SAR, SING), *Kochummen, K.M. FRI 2587* (KEP), *Lim, C.L. FRI 64954* (KEP), *Saw, L.G. FRI 44890* (KEP, SING); Bkt. Bandi FR – *FRI 44997* (KEP); Dungun – *Anthonysamy, S. SA 595* (KEP). KEMAMAN DISTRICT: Bkt. Kajang: *Anthonysamy, S. SA 584* (KEP), *Corner, E.J.H. SFN 30198* (A, K, L, LAE, SING), Sg. Nipah FR: *Kiew, R. RK 2654* (L, SING), *Rafidah, A.R. FRI 51635* (BKF, KEP, L, SAR, SING), *Sam, Y.Y. FRI 47238* (KEP); Ulu Bendong – *SFN 30027* (L, SING).

19. *Codonoboea sallehuddiniana* C.L.Lim (see above)

20. *Codonoboea tembatensis* Kiew

Gard. Bull. Sing. 66 (2014) 140, Fig. 2. *Type:* Peninsular Malaysia, Terengganu, Hulu Trengganu District, Tembat FR. *Kamarul, M. et al. FRI 67142* (holotype KEP; isotype SAN).

Distribution. Endemic in Peninsular Malaysia, Terengganu (Hulu Terengganu District).

Ecology. In lowland to hill dipterocarp forest, in valleys on shaded slopes above streams or rivers at 200–815 m elevation. It grows as individual plants or forms clumps by branching at the base.

Terengganu specimens examined. HULU TERENGGANU DISTRICT: Tembat FR – G. Tembat *Kiew, R. et al. FRI 57034* (KEP); Ulu Sungai Terengganu Mati – *Siti Munirah, M.Y. et al. FRI 67904* (KEP, K, L, SAN, SING); Sg. Pauh – *Kamarul, M. et al. FRI 75107* (KEP).

Notes. Currently both *C. norakhirrudiniana* and *C. tembatensis* are threatened by possible extinction because, from our current knowledge, they grow only in the Tembat FR area that is being clear-felled for an extension to the Kenyir Hydroelectric Dam.

Conclusions

Botanically, the state of Terengganu is still relatively poorly known compared with the west coast flora of Peninsular Malaysia. Areas that remain largely unknown are the slopes and ridges of the mountains and the north of the state. The river systems that have been explored have proved to be biodiverse and harbour species endemic to Terengganu. The Terengganu Hills have already been identified as an area of high biodiversity importance that requires greater legal protection (Davis et al. 1995).

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RESEARCH ARTICLE

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The valid publication of *Salix suchowensis* (Salicaceae)

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Abstract

The nomenclatural problems of *Salix suchowensis* have been addressed by different authors with varying opinions. However, these efforts were flawed by a lack of observation of relevant specimens. Accordingly, we carefully checked relevant publications and specimens both through internet databases and herbarium visits. Here, we thoroughly review the nomenclatural history of *Salix suchowensis* in light of the new definition of a gathering in the *Shenzhen Code*. We conclude that this name was validly published in the original publication in 1963. Furthermore, a lectotype is designated for the precise application of the name. We hope this article will offer guidance for interpreting similar cases.

Keywords

gathering, lectotypification, nomenclature, Salicaceae, *Salix suchowensis*, type citation, validation

Introduction

Salix L. (Salicaceae) is variably estimated to include 350–520 species, which are widely distributed in temperate and boreal regions of the Northern Hemisphere with a few species in Africa and South America (Fang et al. 1999; Brummitt 2007; Argus et al. 2010). There are 275 species and 82 varieties in China, of which 189 species and 74 varieties are endemic (Fang et al. 1999). Taxa of *Salix* are dioecious and have different times of development for flowers and leaves (Skvortsov 1999) which makes their identification very difficult.

Salix suchowensis W.C. Cheng (in Cheng et al. 1963: 4) is a riparian shrub willow, which is the first species of the genus *Salix* with full genome sequence and a potential bioenergy crop (Dai et al. 2014). Cheng et al. (1963) described *Salix suchowensis* W.C. Cheng and cited two collection numbers, *C.T. Yang 20640* (♂) and "*C.T. Yang 20641* (♀)", as type. Both Zhu (1998) and Yu et al. (2011) therefore considered that the name *S. suchowensis* was not validly published by Cheng et al. (1963). In the most recent complete treatment of Chinese *Salix* species (Fang et al. 1999), the species is recognised as *S. suchowensis* W.C. Cheng ex G. Zhu. However, as emphasised by the new definition of "gathering" in the *Shenzhen Code* (Art. 8.2 footnote, Art. 8 Note 1 and Ex. 4; Turland et al. 2018), *C.T. Yang 20640* and "*C.T. Yang 20641*" are properly identified as a single gathering. Indeed, the collection number "*C.T. Yang 20641* (♀)" appears to represent a later renumbering of some female duplicates of *C.T. Yang 20640*. Therefore, *S. suchowensis* was validly published with the citation of a single gathering (Art. 40.2 of the *Code*; Turland et al. 2018) and is properly attributed to W.C. Cheng alone. Because the citation of that gathering encompassed multiple duplicates, these are treated as syntypes (Art. 40, Note 1). One of them is herein designated as a lectotype, as recommended by Arts. 9.11–9.12 of the *Code*. Additional details are given below. Since observation of herbarium material has increased the range of variation in some morphological characters beyond that reported by Fang et al. (1999), an updated description and notes on habitat and phenology are provided.

Historical background and original material

When the name *Salix suchowensis* W.C. Cheng in Cheng et al. (1963: 4) was published, four collections (*C.T. Yang 20640*, *20641*, *10045* and *R.L. Chao 20515*) were cited. Two collection numbers conserved in NF were designated as types with female ("*C.T. Yang 20641*") and male branches (*C.T. Yang 20640*), respectively.

Zhu (1998) considered that the name was not validly published by Cheng et al. (1963), with two specimens "cited without the indication of a type", contrary to Articles 8.1 and 37.1 of the *Tokyo Code* (Greuter et al. 1994). To validate the name, Zhu referenced the effectively published Latin description and diagnosis of Cheng et al. (1963) and designated *J.L. Guo 89012* (NF) as the holotype. However, the collection *J.L. Guo 89012* (♀) (see discussion below) was not cited in the publication of Cheng et al. (1963). Moreover, the specimen *J.L. Guo 89012* (GAUF) is amongst the original material cited by Feng and Guo (1990) for "*Populus wenxianica* Z.C. Feng & J.L. Guo", which was not validly published but was validated by Zhu (1998) who selected *J.F. Liu 88001* (GAUF) as type. Zhu's citation of locality data for *J.L. Guo 89012* "TYPE: China. Jiangsu: Nanjing, *J.L. Guo 89012*" differs from Feng and Guo's (1990) citation of locality data as "Gansu: Wenxian, Zhongzhai, 30 May 1989." *Salix suchowensis* does not occur in Gansu (Fang et al. 1999). In the Chinese part of their paper, Feng and Guo (1990) cited "郭建林88012" at GAUF, rather than 89012 and Zhu (1998) cited *J.L. Guo 88012* from Gansu as being amongst the original material of *Populus wenxianica* Z.C. Feng & J.L. Guo ex G. Zhu. Therefore, it is probable that a typographical error in the English part of Feng and Guo (1990) led to confusion between two distinct specimens of Salicaceae. However, we have been unable to relocate either Guo's collections at GAUF or NF, so the identity of *J.L. Guo 89012* cannot be confirmed.

Yu et al. (2011) also considered that *Salix suchowensis* was not validly published by Cheng et al. (1963), "with two gatherings indicated as types". They attributed valid publication to "W.C. Cheng in S.Y. Jin & Y.L. Chen" in *A Catalogue of Type Specimens (Cormophyta) in the Herbaria of China* (Jin 1994: 599). That work listed a single collection, *"20641.* T(♂): NFU", as the type of *Salix suchowensis* (Jin 1994). The collector name was omitted (apparently by accident) but the reference to *C.T. Yang* is unquestionable. Neither Jin "Jin & Chen" (1994) nor Yu et al. (2011) cited a specific barcode or accession number. The citation is problematic in that, according to Cheng et al. (1963), the collection numbered *20641* contained fragments with female, not male, inflorescences. Despite this, the restriction to a single gathering and herbarium would suffice for valid publication (Art. 40.2 and Art. 40, Note 1). Therefore, Zhu's (1998) attempt to validate the name using a problematic type created an illegitimate later homonym, the application of which we are not herein attempting to determine.

After checking all specimens of *Salix* deposited in NF (herbarium acronyms follow Thiers 2019), we found eight duplicates of *C. T. Yang 20640* collected from the Arboretum of Nanjing Forestry University. Seven of them are composed of female branches and one (Fig. 1) is composed of male branches (Table 1). All are dated 26 March 1954. The numbering of two of the female duplicates (NF barcodes 04801051 & 04801063 [Fig. 2], ♀) was later changed to "*20641*" with pen on herbarium labels. However, no duplicates with original numbering of "*C.T. Yang 20641*" were located in NF, nor in other Chinese herbaria (via NSII-National Specimen Information Infrastructure http://www.nsii.org.cn/2017/home.php and CVH-Chinese Virtual Herbarium http://www.cvh.ac.cn/search, both accessed 6 June 2019).

The collector C.T. Yang was a colleague of W.C. Cheng who worked a few years for NF then left for the Security Department of Nanjing Forestry University. The location "树木园 [Arboretum]" added by hand to typed herbarium labels is consistent with the handwriting of R.B. Chen, another colleague of W.C. Cheng. This information was obtained from a manager of NF (pers. comm.).

R.B. Chen collected material, later labelled as *Salix suchowensis,* from the Arboretum in 1956 and he participated in the publishing of Cheng's *Dendrology* [I & II] in 1961 and 1964 (Cheng 1964; Huang 2008). Therefore, we infer that Chen was probably familiar with the process of publication of the name. It is possible that Chen discovered that "*C.T. Yang 20641* (♀)" in the protologue of *S. suchowensis* was labelled *C.T. Yang 20640* (♀) in the herbarium and, while annotating specimen labels, also "corrected" the collection number to match the protologue. The ink used for both annotations is similar. It is not possible to determine with certainty who changed the specimen numbers, nor when. However, the typed labels show that *C.T. Yang 20640* was originally intended by the collector to include both male and female duplicates.

Figure 1. *Salix suchowensis*: *C.T. Yang 20640* (NF barcode 04801064!, ♂, isolectotype).

This makes it unlikely that Yang himself was responsible for the later renumbering of some (but not all!) of the female duplicates, which, if done by another worker, was inappropriate. Since Art. 9.2 and Ex. 3 of the *Shenzhen Code* permit obvious errors in type citations to be corrected, Cheng's citation should be corrected to "Kiangsu: *C.T. Yang 20640*, Typus fl. ♂ & ♀!; *C.T. Yang 10045*; *R.L. Chao 20515*". Under Art. 40, Note 1, all eight specimens of *C.T. Yang 20640* are therefore syntypes of the name.

Figure 2. *Salix suchowensis*: *C.T. Yang 20640* (NF barcode 04801063!, ♀, lectotype), renumbered *20641* in herbarium.

The "Shenzhen Code" has clarified the definition of a "gathering" as "a collection presumed to be of a single taxon made by the same collector(s) at the same time from a single locality" (Art. 8.2 footnote). Duplicates given different field numbers or collecting numbers, but collected by the same people at the same time and place, can still

Table 1. Original material of *Salix suchowensis* (*C.T. Yang 20640*).

Herbarium	Barcode number	Collection tag	Herbarium label	Sheet contents
NF	04801045	♀, 20640	C.T. Yang 20640	female branches
NF	04801047	♀, 20640	C.T. Yang 20640	female branch
NF	04801048	♀, 20640	C.T. Yang 20640	female branches
NF	04801051	♀, 20640	C.T. Yang 20641 (20640)	female branches
NF	04801060	♀, 20640	C.T. Yang 20640	female branches
NF	04801063	♀, 20640	C.T. Yang 20641 (20640)	female branches
NF	04801064	–	C.T. Yang 20640	male branches
NF	04801068	♀, 20640	C.T. Yang 20640	female branches

be treated as a single gathering (Art. 8, Note 1, Ex. 4). Even if the original material of *S. suchowensis* had originally been given two collection numbers (*C.T. Yang 20640*, "*20641*"), as cited by Cheng et al. (1963), or had been renumbered by Yang himself before 1963, they would still properly be treated as part of a single gathering because they belong to a single species and were collected by the same person at the same time from a single locality. Therefore, Cheng would have met the requirements of Art. 40.1 and 40.2 for valid publication of *Salix suchowensis* in Cheng et al. (1963) by the citation of a single gathering as type.

Typification

Jin's (1994) faulty listing of "20641. T (♂): NFU" as the type of *Salix suchowensis* does not match any existing duplicate, because neither of the duplicates annotated as "*20641*" are male. Therefore, this listing was insufficient to designate any of the 8 syntype specimens of *C.T. Yang 20640* at NF as lectotype. The same can be said for Yu et al.'s (2011) listing of "*C.T. Yang 20641*" as "holotype". The attempted designation of type by Zhu (1998) is not allowable because the selected specimen was not amongst the syntypes cited by Cheng et al. (1963), as required by Art. 9.12 of the *Code* (Turland et al. 2018). The sheet with barcode 04801063 is designated here as the lectotype because of its handwritten annotation "Typus" by Chen.

Taxonomic treatment

Salix suchowensis W.C. Cheng in Cheng et al., Sci. Silvae Sin. 8(1): 4. 1963

Figures 1–3

Lectotype (designated here). CHINA. Jiangsu: Nanjing, Arboretum of Nanjing Forestry University, 26 March 1954, *C.T. Yang 20640* (NF barcode 04801063!, ♀; isolectotypes: NF barcodes 04801045!, 04801047!, 04801048!, 04801051!, 04801060! & 04801068!, ♀, NF barcode 04801064!, ♂). — For image of lectotype, see Fig. 2.

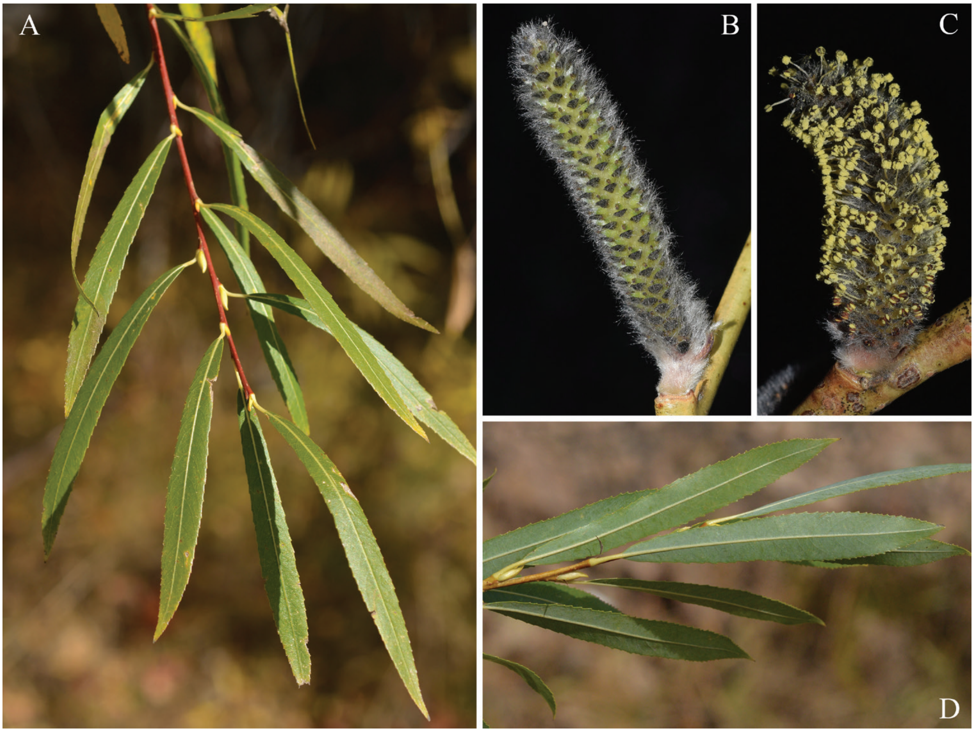

Figure 3. *Salix suchowensis*: **A** branchlet and leaf blades adaxially **B** female catkin **C** male catkin **D** leaf blades abaxially (photo credit: **A, D** by L. He **B, C** by Feiyi Guo).

Shrubs. Branches yellowish-green or purplish-red, glabrous; branchlets sparsely tomentose at first, becoming subglabrous. Buds glabrous. Stipules linear to lanceolate, 0.96–1.42(–2.5) cm; petiole 0.3–1 cm, margin remotely glandular dentate, pubescent to glabrous; leaf blade lanceolate, 5.17–12.25 × 0.63–1.7 cm, abaxially pale, both surfaces glabrous, tomentose when young, adaxially dull green, base cuneate, margin glandular denticulate, apex shortly acuminate; lateral veins diverging from midvein at 45–90°. Catkins before leaves emerge, densely flowered. Male catkin terete, 2.2–4 cm × 0.4–0.67 cm, sessile or subsessile, with scale-like leaflets at base; rachis grey tomentose. Female catkin up to 3.43 cm at maturity, sessile or subsessile, with scale-like leaflets at base. Floral bracts long obovate, abaxially villous, apex obtuse-rounded, purple black distally. Male flower: glands adaxial; stamens 2, connate throughout, anthers yellow or reddish-purple. Female flower: ovary conical, densely grey tomentose, ovules 3–7; stipe short to absent; style conspicuous; stigma 2-cleft. Capsule pilose.

Phenology. Flowering from March to April and fruiting in April and May.

Habitat. Along rivers, stream-sides, or cultivated; near sea level to 900 m a.s.l.

Distribution. Beijing, Hebei, Henan, Jiangsu, Shandong, N Zhejiang.

Additional material examined.—CHINA. **Beijing**: Miyun County, Dajiaoyu, 5 May 1951, *Y. Liu 1507-8* (PE); Yudu Mountain, 900 m a.s.l., 11 June 2019, *F.Y. Guo, Y.M. Wu & D. Liu G2019061105* (BJFC). **Hebei**: Daming County, Dongcao, 100 m a.s.l., 3 June 1972, *Han 165* (PE). **Henan**: Song County, Xiasi, 25 September 1956, *Henanshenglinyeting 1217* (PE). **Jiangsu**: Nanjing, Arboretum of Nanjing Forestry University, 12 April 1954, *C.T. Yang 20645* (NF); ibidem, 26 May 1956, *R.B. Chen s.n.* (NF); Xuanwu Road, 19 May 1956, *C.T. Yang 10045* (NF). **Shandong**: Gudao, Huanghenongchang, 16 July 1959, *T.Y. Zhou 5412* (NAS). **Zhejiang**: Zhuji, Paitou, 24 September 1934, *Y.X. He 2952* (NAS).

Acknowledgements

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RESEARCH ARTICLE

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A new subspecies of *Peucedanum officinale* L. subsp. *album* (Apiaceae) from the eastern part of the Iberian Peninsula

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Abstract

We describe *Peucedanum officinale* L. subsp. *album* Martínez-Fort & Donat-Torres **subsp. nov.**, in which we grouped the thermomediterranean populations scattered along the eastern part of the Iberian Peninsula. The characters that differentiate this new subspecies from other infraspecific taxa in *Peucedanum officinale* are its canaliculated leaflet, the inflorescences much branched and lack of dominant terminal umbels, the umbels are few rayed, sometimes sessile and lateral, the petals are white and the fruit pedicels short, the same or shorter in length than the fruit. We provide here a full description of the new subspecies based on herbarium specimens and field measurements, as well as providing dichotomous keys to the subspecies within *P. officinale*. In addition, we provide a comparison of the ITS sequences of nrDNA with the most closely related taxons.

Keywords

Umbelliferae, Spain, taxonomy, subsp. nov., thermomediterranean, nrITS

Introduction

Peucedanum L. 1753 is one of the most complex genera in the Apiaceae family. Based on the morphological characteristics of the fruit, according to the traditional classification systems, it is characterised by a strong dorsal compression and winged side ribs as in Drude

(1898). It is included within the Peucedaneae tribe, subtribe Ferulinae and has been defined as *Peucedanum* sensu amplissimo. In addition, this genus is broadly represented by 29 species in European flora (Tutin 1968), of which 10 are present in Iberian flora (Guillén and Laínz 2003). In the grouping of Pimenov and Leonov, *Peucedanum* sensu lato includes 100–120 scattered species throughout the Old World and the need for its reduction into natural groups has been proposed (Pimenov and Leonov 1993, Downie et al. 2000).

On the other hand, phylogenetic studies, based on the ITS rDNA sequences, define "*Peucedanum* sensu stricto clade including taxa that are very similar with respect to their ITS sequences and they are very related in habit, sharing not only fruit characters but also vegetative features, like linear-filiform leaf lobes" and it has been regrouped in the Tribe Selineae Spreng (Spalik et al. 2004). Molecular phylogenetic studies confirm the separate taxonomic status of the other taxa which have been accepted as separate genera (Spalik et al. 2004, Winter et al. 2008, Downie et al. 2010). Therefore, the genus is now reduced to a few species and the type of the genus is *Peucedanum officinale* L.

The morphological differences between some populations from the central and eastern coastal parts of the Iberian Peninsula have long since been evidenced with the description and citation of several *P. officinale* subspecies (Boissier 1844, Willkomm and Lange 1880, Cadevall i Diars 1919–1923, Sennen 1913).

The first distinction from the Iberian populations in *P. officinale* was made with the description of *P. stenocarpum* Boiss. & Reut. ex Boiss., 1844 (Boissier 1844), which were grouped under this name, the populations being located in the centre of the Peninsula, characterised by the number of floral scapes (4 to 5), long leaf divisions of 3–4 inches in length (7.6–10.6 cm) and fructiferous raylets that triple the length of fruits, which are elliptic-ovate.

Subsequently, Willkomm and Lange (1880) cited *P. officinale* L. var. *italicum* (Mill.) DC. in Lam. & DC 1805 and *P. paniculatum* Loisel. (1807) in the Peninsula and these were added to encompass the dispersed populations in the central, northern and north-easterly parts of the Peninsula. Finally, these populations were assigned to *P. stenocarpum* (Cadevall i Diars 1919–1923).

Another name proposed was *P. stenocarpum* var. *catalaunicum* Pau in Sennen (1913) (nom. in sched.), but no description or herbarium specimens were provided. Reduron and Muckensturm (2008) gave a short Latin diagnosis but did not designate a lectotype.

Afterwards, *P. stenocarpum* was included as a subspecies of *P. officinale* (viz. *P. officinale* L. subsp. *stenocarpum* Font Quer 1950) and included all the populations in the eastern half of the Peninsula. Its morphological characteristics were summarised as: extended (up to 15 cm) and very narrow (from 0.3 to 2 mm) leaf segments, with between 10 and 64 umbel rays and a ratio of fructiferous pedicel length to fruit length from 0.5 to 1.5 (Font Quer 1954). Font Quer measured some of the populations that we have included in the present study and which have always been assigned the extreme value in the description of his study. Along with the subspecies *officinale,* they are the only two taxa in the group recognised in the Peninsula at this time. *Peucedanum paniculatum* and *P. longifolium* Waldst. & Kit. 1812 were reduced to subspecies of *Peucedanum officinale* due to their ternate leaves, which were divided into linear or linear-lanceolate segments by Frey (1989).

The last subspecies in the group, described in the Iberian Peninsula, *Peucedanum officinale* L. subsp. *brachyradium* García-Martín and Silvestre 1991 specifically in the province of Málaga (Spain), was indicated as an edapho-endemism on peridotites. That description derives from a population with only two individuals and is morphologically distinguished from the subspecies type and from *P. stenocarpum* by the characteristics of its inflorescence and by the dimensions of its fruit and pedicels. García Martín and Silvestre (1992) also suggested similarities with *P. officinale* subsp. *longifolium*.

The latest review undertaken of the genus for the Iberian Peninsula (Guillén and Laínz 2003) recognised only one species with two subspecies, viz. *P. officinale* subsp. *officinale* and *P. officinale* subsp. *brachyradium*. These authors included *P. stenocarpum* as a synonym of *P. officinale* subsp *officinale*, suggesting that there was variability and mixture within and between the populations.

Materials and methods

While conducting fieldwork during the previous years, we located the population of an umbelliferous species in eastern spurs of the Serra Grossa mountain range, which lies in the southern part of the Valencian province (eastern part of the Iberian Peninsula). This species is always found at the bottom and top of rocky areas, on the edges of paths, always in cracks in rocks and on rocky soil. It is characterised by possessing ternatisect leaves, with linear and canaliculated leaf divisions; inflorescences with sessile lateral umbels and with few rays; white-petalled flowers; elliptic fruits with a strong dorsal compression and prominent dorsal ribs and winged marginal ribs, borne on short pedicels. As a result, we assigned it to the genus *Peucedanum* sensu stricto.

To further identify this taxon and compare all of the subspecies of *P. officinale* throughout its area of distribution, we reviewed the herbarium specimens of the genus deposited in the VAL and MA herbaria. We studied all the bibliography about the *P. officinale* subspecies cited and described in the Iberian Peninsula and the monograph on the genus by Frey (1989). For this monograph, 2,500 herbarium sheets from all over Europe were consulted and measurements were taken from 200 of them. For the subspecies *P. officinale* subsp. *brachyradium,* the measurements were provided in the description article (García Martín and Silvestre 1992).

We noted that the population under investigation here had been identified to date as *P. stenocarpum*, widely considered as a synonym of *P. officinale* subsp. *officinale*, despite the fact that it has a series of morphological characters that are not accommodated within any of the subspecies of *P. officinale* (Figures 1B–D). For its characterisation and comparison, measurements of the plants were taken and the morphological ratios calculated for habit, leaves, inflorescences and fruits (Table 2, Suppl. material 1: Figure S1). The specimens belong to the located population in Carcaixent, as well as other closer populations located all along the coastline of the Valencian region (in

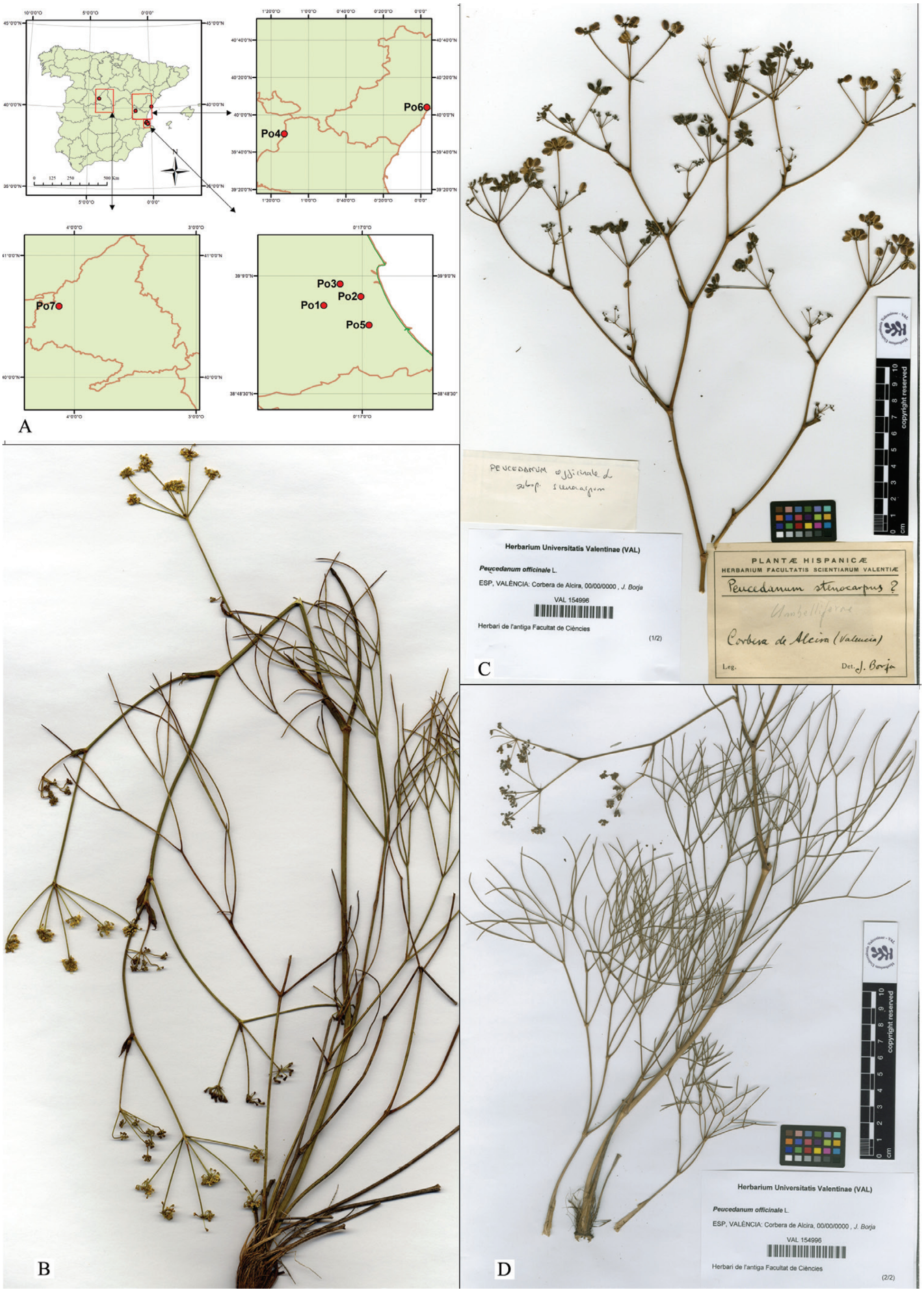

Figure 1. A Maps of studied populations **B** *P. officinale* subsp. *album*. Spain. Valencia: Alzira. Serra de la Murta, 30SYJ2934; on rocky outcrops, 25-IX -2011; J. Martínez-Fort (VAL 223162!) **C–D** *P. officinale* subsp. *album*. Spain. Valencia: Corbera de Alzira, 30SYJ23; J. Borja (VAL 154996!).

Table 1. Field populations (V Valencia, Cu Cuenca, Cs Castellón, M Madrid).

Population	Mountain range	Province/Towns	Local name	YWGS84 coordinates
Po1	Extreme north, Serra Grosa	V: Carcaixent, Alzira	Hort de Soriano-Font de la Parra, Molló de Miramar	39°3.88'N, 0°23.694'W
Po2	Spurs, Sierra de Corbera	V: Llaurí, Favara, Tavernes de la Valldigna	Font de la Granata, Pic Masalari	39°5.43'N, 0°17.238'W
Po3	Spurs, Sierra de Corbera	V: Alzira, Corbera, Llaurí	Serra de la Murta, Creu del Cardenal	39°7.61'N, 0°20.856'W
Po4	Sierra Picarcho	V: Tuejar, Cu:Talayuelas	Umbría del Picarcho	39°49.83'N, 1°13.002'W
Po5	Serra Mondúver	V: Gandia, Xeresa	Cima Mondúver	39°0.45'N, 0°15.834'W
Po6	Desert de les Palmes	Cs: Benicasim	La Comba	40°3.94'N, 0°3.144'E
Po7	South, Sierra de Guadarrama	M: El Escorial	El Escorial	40°35.09'N, 4°7.62'W

Benicasim, Tavernes de la Valldigna, Alzira, Xeresa) (Figure 1A) with the same series of morphological characteristics. Hereafter we referred to this new studied subspecies as *P. officinale* subsp. *album*. To complete the results, we compared these populations with a population assigned to the subspecies type. We selected those populations located further inland, specifically between the provinces of Cuenca and Valencia, which correspond to *P. officinale* subsp. *officinale*. The series of populations, studied in the field, are provided in Table 1.

Measurements were taken in the field and in the laboratory and always carried out with fresh plants. We used a CD-20DCX digital vernier caliper and a metal tape measure and saved measurements on spreadsheets and databases. We created the figure of *P. officinale* subsp. *album* using the holotype VAL 223161 to scan, as well as from the photos taken in the field with a Canon EOS 550D camera of inflorescences and fruits. Other photos were taken with a Leica stereomicroscope MZ 9.5 and a Leica DFC 320 digital camera of the cross-sectional cuts of fruits and leaf details. We obtained the flowering and fructification data while conducting fieldwork and according to the date of the specimens and phenologies from the consulted herbarium sheets. All the other figures are photos of herbarium sheets and pictures of scanned herbarium sheets. We compared and statistically analysed the taken measurements with the Statgraphics Centurion XVI software. For morphological characters, we followed the standardised terminology of Kljuykov et al. (2004). For the taken measurements, we calculated the range obtained from their mean +/- standard deviation. The extreme values beyond this range are in brackets in the tables.

Taking measurements was limited by the small proportion of individuals which were flowering or under fructification in all the populations; indeed, flowering and fructification did not even exceed 4% of the individuals in the largest populations. In the specimens that presented no flowering, measurements were taken from the basal rosette leaves. In all, we took measurements from 31 specimens, of which 19 belonged to populations of the newly proposed taxon and 12 to the type subspecies. In all, 1,316 measurements and ratios were taken and calculated.

Table 2. Measured characters and calculated ratios.

Character				Units	Code
Stem	Size		Plant height	m	T1
	Ramification		First ramification height	m	T2
			T1/T2 ratio		T3
	Diameters		Diameter at the base	cm	T4
			Diameter at the first ramification	cm	T5
			T4/T5 ratio		T6
Leaves	Basal rosette	Blade	Leaf length, including petiole	mm	H1
			Number of leaf divisions (ternate)		H2
			Leaf width at the base of the last division	mm	H3
			Leaf width at the apex of the last division	mm	H4
			Last leaf division length	mm	H5
			H5/H3 ratio		H6
			H4/H5 ratio		H7
			Angle between contiguous leaf divisions of the last ternate	degrees	H8
			Angle between lateral leaf divisions of the last ternate	degrees	H9
		Petiole	Length	mm	H10
			Diameter at its basis	mm	H11
			Diameter before first division (ternate)	mm	H12
	First on stem from the basal rosette	Blade	Number of leaf divisions (ternate)		H13
			Last leaf division length	mm	H14
		Petiole	Length	mm	H15
			Diameter of the petiole at its basis	mm	H16
			Diameter before the first division (ternate)	mm	H17
	Last on stem	Blade	Number of leaf divisions (ternate)		H18
		Petiole	Length	mm	H19
			Diameter before the first division (ternate)	mm	H20
			Diameter at its basis	mm	H21
		Sheath	Sheath length	mm	H22
Inflorescence	Umbel		Bract length	mm	I1
			Bract width	mm	I2
			Number of bracts		I3
			I1/I2 ratio		I4
			Number of rays		I5
			Length of internal rays	mm	I6
			Length of external rays	mm	I7
	Umbellule		Number of raylets		I8
			Length of internal rays	mm	I9
			Length of external rays	mm	I10
			Number of bracteoles		I11
Fruit	Size		Length	mm	F1
			Width	mm	F2
			Wing width of the marginal ribs	mm	F3
	Shape		F3/F2 ratio		F4
			F1/F2 ratio		F5
	Raylet		Fructiferous raylets length	mm	F6
			F1/F6 ratio		F7
			F6/F1 ratio		F8
			F2/F6 ratio		F9

Revised herbarium material

The examined herbarium specimens' material at VAL and MA are listed below.

***Peucedanum longifolium* Waldst. & Kit.**

YUGOSLAVIA. **Dalmatia:** Montes Biokovo, in rupibus calcareis sub cacumine montis Sv. Jure supra opp. Makarska, 1600 m alt. 29-VII-1979, F.Cernoch (MA 357267); ídem (MA 310966)

***Peucedanum officinale* L.**

BULGARIA. **Regio Sophiensis**: distr. urb. Sophia, inter fruticeta supra, 20-IX-1979. N. Andreev, Z. Cerneva & P. Gerginov (MA 309655)

GERMANY. **Maingebaeit:** Würzburg, woodland between Gerbrunn and Kottendorf, 00-VII-1881, G. Evers (MA 713330)

SPAIN. **Aragón**:(MA 88547); Palau (MA 88581). **Alava:** Labastida, Salinillas de Buradón, 12-X-1990, P.M. Uribe-Echebarria & P. Urrutia (MA 523402); Labastida, Salinillas de Buradón, cerro calizo con matorral mediterráneo, 30TWN1320, 5-IX-1998, P.M. Uribe-Echebarría (VAL 144623); Labastida, Salinillas de Buradón, 02-X-1997, M. L. Gil Zúñiga (MA 616760); ídem (VAL 106191) **Albacete:** Molinicos, valle del río Mundo, entre Mesones y la fuente de la Plata, 30SWH587602, 900 m alt., 18-VIII-2002, M.J. Tohá & V.J. Arán (MA 703748); Molinicos, Valle del río Mundo, entre Mesones y la Fte. de la Plata, Laderas calcáreas con Cinar, 30SWH587602, 18-VIII-2002, V.J. Arán & M.J. Tohá (VAL 144146). **Barcelona:** Berga a Labaello, 16-VII-1911, Fre. Sennen (MA 88550); Al lado de la Ermita de S. Jerónimo, IX-1914, Caballero (MA 88584); Montserrat, IX-1905; Marcet (MA 88545). **Castellon:** Benicàssim (La Plana Alta), La Comba, 31TBE43, 07-IV-1990, J. Tirado & C. Villaescusa (VAL 26141); La Pobla Tornesa (La Plana Alta), Bartolo cresta, 31TBE44, 17-IX-1989, J. Tirado & C. Villaescusa (VAL 26140). **Cuenca:** Huete, hacia Garcinarro, valle del arroyo de Valquemado, 13-IX-2003, V. J. Arán & M. J. Tohá (MA 711491); Huete, hacia Garcinarro, valle de arroyo de Valquemado, 10-X-2004, V.J. Arán (MA 751028); Huete, hacia Garcinarro, valle del arroyo de Valquemado, al pie de cerros yesosos, 30TWK2449, 6-VIII-2005, V. J. Arán (VAL 179661); Huete, hacia Garcinarro, valle del arroyo de Valquemado, al pie de cerros yesosos, 30TWK245490, 13-IX-2003, V. J. Arán & M. J. Tohá (VAL 149187); Talayuelas, VII-1979, G. Mateo (VAL 110252); Talayuelas, X-1980, G. Mateo (VAL 110251). **Gerona:** Maçanes, 80 m alt., Font Quer, 12-X-1948 (MA 152333); ídem (MA 382969); Pyrénées à Gombreny, coteaux calcaires, 900 m alt., VIII-1913 (MA 88562), ídem (MA 88561), ídem (MA 88560). **Huesca:** Ayerbe, 600 m alt., 31-VIII-1973, A. Segura Zubizarreta (MA 359384); Arro, 26-IX-1979, P. & G. Montserrat (MA 357236); ídem (MA 311455). **Lérida:** La Granadella (Garrigues), hacia El Solerás, pr. riera de Vall de les Olives, junto a la carretera, 31TCF0486, 365 m alt., 08-IX-2008, V.J. Arán & M.J. Tohá (MA809441); ídem (VAL 196084).

Logroño: Briones, Monte Lara, 1925, Hno. H. Elias (MA 88558). **Madrid:** Chozas, Cutanda, IX, (MA 88552); Entre Villalba y las Zorreras, en la Sierra del Guadarrama, 08-IX-1947, Rivas Goday & C. Pérez (MA 152463); ídem (MA 204879); ídem (MA 382966); Guadarrama, IX-1841, Reuter (MA 88577); Escorial, Graells (MA 720356); Guadarrama, J. Isern. (MA 720260). **Pontevedra:** Santa Maria de Oya, 10 m alt., 20-VIII-1983, S. Silvestre (MA 316210). **Salamanca:** Saucelle, 16-VIII-1978. F. Amich (MA 309660). **Tarragona:** Sant Carles de la Ràpita, Serra de Montsià, 450 m alt., 01-IX-1999, V. J. Arán & J. Masip (MA 631766); Sant Carles de la Ràpita, Serra de Montsià, Font de Burgà, hacia el SE, laderas soleadas sobre la fuente, entre el matorral calcícola. 31TBF9301, 1-VII-1999, Arán & Masip (VAL 41688). **Teruel:** Cantavieja, hacia Mirambel, 30TYK29, 4-IX-1993, Fabregat & López Udias (VAL 81745); Olba, IX-1894 (MA 88548); Castellote, alrededores de las Cuevas de Cañart, 11-IX-1991, C. Fabregat (MA 502852); ídem (VAL 75992); Olba, Caserío de la Berdeja, Ribazos. 30TXK9844, 25-IX-2004. S. López Udias & C. Fabregat (VAL 204090); San Agustín, valle del Mijares, hacia Rubielos de Mora, 30TXK9445, 4-IX-2004, G. Mateo (VAL 151501); Villarluengo, barranco de los Degollados, márgenes de la carretera, 30TYL00, 11-IX-1993, Mercadal (VAL 81675). **Valencia:** Ayora, La Hunde, 30SXJ52, 00-VIII-1981, J. B. Peris (VAL 17838); Bicorp, Cuesta de la Caruma, 25-VIII-1915, C. Vicioso (MA 88549); Corbera de Alcira, 30SYJ23, J. Borja. (VAL 154996); Serra de Corbera, 30SYJ23, 00-X-1944, J. Borja (VAL 117840), Favara: Serra de Corbera, 30SYJ33, 5-IX-1986, G. Mateo & al. (VAL 117826); Sinarcas, 30SXK50, 6-VII-1992, García Navarro (VAL 105040); Sinarcas, Peña del Rayo, 30SXK50, 12-IX-1989, García Navarro, (VAL 102949); Tuéjar (Serrans), Altos del Picarcho, rodenos, 30SXK5311, 12-IX-2004, C. Torres Gómez, G. Mateo & J. Fabado (VAL 217597); Tuéjar a Talayuelas, umbría del Picarcho, 30SXK51, VIII-1980, G. Mateo (VAL 110250); Tuéjar (Serrans) Altos del Picarcho, rodenos, 30SXK5310, 24-IX-2005, C. Torres Gómez (VAL 216649). **Zamora:** Muelas del Pan, 13-VIII-1978, E. Rico (MA 309659); Río Esña, Riberos del pantano de Ricobayo, 00-VII-1972, Rivas Goday & Ladero (VAL 117836). **Zaragoza:** El Frasno, 30TXL26208190, 2-IX-1995, A. Martínez (VAL 216135); Moncayo, 3-VIII-2000, Vicioso (VAL 180380); Torrero, 00-VI-1947, P. Capell S.J. (VAL 180379).

FRANCE. **Pyrénées-Orientales**. Conflent. En allant de Ille-sur-Têt à Montalba a 2 km env. de Montalba, 02-X-1970. J. Vivant (MA 357223); **La Garde Freinet,** an der D. 48 nörlich La Trémoulêde,, 4-X-1963 (MA 626021); **Languedoc-Roussillon**, Aude, sur le versant nord du col d´Extrème entre Villeneuve-des-Corbières et Tuchan, 15-IX-2004. Philippe Rabaute. (MA 802614); **Cher**: IX-1890, A. Le Grand (MA 88575)

HUNGARY. Bács Bodrog, Bezdan, 10-IX-1909, J. Prodan (MA 88576)

Peucedanum paniculatum Loisel.

FRANCE. **Haute Corse**: Castagniccia, Col di Bigorno, 10-IX-1996, J. Lambinon (MA 628116); Ghisoni, 17-VIII-1899, R. Rotges (MA 88546); Ghisoni, Maquis peu touffu, 10-VIII-1929, Dr. C. Gabrel (MA 425140); Massif du Tenda, Col di Bigorno, mun. Bigorno, 07-VIII-1996, L. Serra & A. Bort (MA 623316).

DNA extraction, amplification and sequencing

We made a genetic comparison of the ITS regions of ribosomal DNA between the populations of *P. officinale* subsp. *officinale* and *P. officinale* subsp. *album*, by extending the field sampling to one of the populations close to the classical location where *P. stenocarpum* had been described, El Escorial (Madrid) (Population Po7 in Figure 1 and Table 1). Using fragments of the basal leaves and shoots obtained from the seeds collected in the field, we extracted total DNA with the Plant DNA kit of Omega Bio-Tek, following the manufacturer's instructions. To amplify the ITS regions of ribosomal DNA, we used oligonucleotides ITS5 and ITS4 (White et al. 1990) and the MBL Taq Polymerase kit of Molecular Biology Laboratory SL. Sequencing was done by MACROGEN using these same universal primers. The extraction process of the DNA extracted from the leaves collected in the field was complicated by the presence of metabolites, but was much easier to perform on the shoots of germinated seeds. We extracted DNA and sequenced the ITS region of ribosomal DNA from four populations (Table 3).

The obtained sequences were aligned with CLUSTALW from Bioedit 7.2.5. (Hall 1999). We aligned the consensus sequence obtained with BLASTn (Altschul et al. 1990) to obtain the genus *Peucedanum* sequences, with which a final set of sufficiently long sequences was used to be able to compare them with our sequence (Suppl. material 2: Table S1).

The pairwise genetic distances between sequences were calculated with MEGA, version X (Kumar et al. 2018) with 10,000 bootstraps replicates and gamma distribution (shape parameter = 0.7). The employed model was TN93+G, available in MEGA and amongst the best models obtained previously with JmodelTest and the Bayesian Information Criterion (BIC) (Darriba et al. 2012).

Results and discussion

By taking the morphological differences observed in leaves, inflorescences and fruits, its habitat and distribution in the humid and sub-humid thermomediterranean bioclimatic types as a basis, we distinguished *P. officinale* subsp. *album* as a new subspecies, after its comparison with all the revised herbarium specimens and data provided in the bibliography (Table 4). Compared to the nominated subspecies, with which it has

Table 3. The populations measured and the DNA samples taken. The details of these populations are shown in Table 1 and Figure 1A.

Populations		Number of plants	
Species	**Population (Table 1)**	**Measurements taken**	**DNA sample**
P. officinale subsp. *album*	Po1	4	
	Po2	4	
	Po3	9	
	Po5		1
	Po6		1
	Po8	2	
P. officinale subsp. *officinale*	Po4	12	1
	Po7		1

contact in its distribution, it is easily distinguished by the white colour of the petals (Figure 2A), its inflorescences without dominant umbels and umbels with scarce rays and sometimes sessile and with canaliculated leaflets. There is a difference in the subspecies type that possesses inflorescences with dominant umbels of a greater number of rays and with flat leaflets (Figs 4 A–B). *P. officinale* subsp. *album* can be further distinguished from subspecies *paniculatum*, which is restricted to the islands of Corsica and Sardinia, by its inflorescences, which are much more branched and paniculated, with many rayed umbels and fruit pedicels that are three times the length of the fruit. The subspecies *brachyradium* has very limited distribution being an edapho-endemic species on peridotite of the province of Malaga. It is distinguished by its greater bearing, inflorescence with more rays and fruit pedicels equal in length to the fruit.

Regarding the genetic results obtained, the ITS sequences of the studied specimens that belong to the populations of Xeresa, Benicasim, Tuejar and El Escorial were identical to one another. The length of the obtained consensus sequence was 603 base pairs. It is deposited in GenBank http://www.ncbi.nlm.nih.gov/GenBank). The accession number is KP681852.

This sequence is identical to all the *P. officinale* sequences in GenBank and has a comparable length when using sets of sequences with both 319 bp and 640 bp (with gaps) (Suppl. material 2: Table S1). In comparison, the distance between *P. officinale* and the other species of the *Peucedanum* s.str. varied from 0.003 with *P. gallicum* Latour. and 0.211 with *P. sandwicense* Hillebr. The distance with *P. gallicum* is very small, however it is a species clearly accepted. As the distances are so small between near species, the analysis has not allowed separation genetically at the subspecific level. This supports the intraspecific range in *P. officinale* for the subspecies *album*.

The briefness and the small number of characteristics that have been analysed in the studies have meant that our determination of these populations was complicated. With the exhaustive comparison that we have carried out, we have been able to identify the characteristics (Table 4) that distinguish these coastal populations as another subspecies. In many of the descriptions and determination keys, leaf morphology was stressed: the length, width and angle of the last-order leaf divisions; and some fruit characters or the number of umbel rays were also used to classify the different subspecies. According to the measurements and observations made in the field, we do not consider the length and width of the last leaf division to display good characters for distinction, as it could have already varied in the same population according to the environmental conditions where the plant grows.

Conversely, the leaflets shape characteristics of the last divisions; flat, folded-crested or canaliculated and the shape of inflorescences: with terminal, pedunculate umbels with 17–35 rays that are 30–85 mm long or sometimes with panicled inflorescences or with umbels, some of which are sessile and lateral, with 5–9 rays measuring 8–43 mm, were determining factors for separating the subspecies. Thus, the *album*, *brachyradium* and *paniculatum* subspecies share the combination of canaliculated leaflets and panicled inflorescences or with sessile umbels and fewer rays; as opposed to the *officinale*

Table 4. Comparison between the results obtained from the field measurements that we took with data reported in other studies about *P. officinale* subspecies: subsp. *officinale* (Figure 4C), subsp. *longifolium* (Figure 4E), subsp. *paniculatum* (Figure 4D). Data provided in the monograph of the genus (Frey 1989) and in the description of *P. officinale* subsp. *brachyradium* (García Martín and Silvestre 1992).

Origin of data	**Field data**	**Frey 1989**				**García Martín and Silvestre 1992**
Organ	*album*	*officinale*	*stenocarpum*	*longifolium*	*paniculatum*	*brachyradium*
Habit (cm)	(24)41–98 (130)	60–140(200)	120	(37)70–150(360)	60–100 (120)	250
Leaf	canaliculated	flat	flat	crested	canaliculated	canaliculated
Last division basal leaf length (mm)	(31.3)47.9–83.7(94.4)	(20)30–60(100)	(27)40–85(95)	(13)35–80(165)	(17)24–35(53)	20–55
Last division basal leaf width (mm)	0.3–0.6(0.7)	(0.7)1–2(2.7)	(0.9)1–1.8(2)	(0.5)1–1.8(2.3)	0.5–0.8(1)	0.8–1.3(2.5)
Bracts of umbels	0–1(2)	(0)1–10	0–1(4)	(0)1–10	0–1(2)	(0)1–2(5)
Umbel rays	(3)5–9(12)	(12)17–35(58)	(18)20–37(41)	(14)16–32(49)	9–14(17)	12–18
Umbel ray length (mm)	(2.8)8–43.8(83.7)	(11)30–85(150)	(40)49–90(100)	(18)25–75(108)	(24)30–60(90)	15–40
Umbellule raylets	(7)10–16(18)	(14)18–35(50)	(12)31–30(34)	(7)15–36 (44)	⁇	9–16
Colour of petals	white	yellow	yellow	yellow	yellowish	yellow
Fruit length (mm)	(5.1)5.8–6.9(7.1)	5.5–9	05–7	5.5–7	5.5–6	7.6–9.7
Raylet length/ Fruit length	(0.3)0.5–0.8(1)	2–6	1.5–4	1	1–3	2

and *longifolium* subspecies, which have flat or grooved leaflets and inflorescences with terminal umbels and more rays.

These values obtained in the field have been used for the description of *P. officinale* subsp. *album* (Table 5). Of them all, we obtained statistically significant differences with a 95% confidence level between the two subspecies *album* and *officinale* in the following characters (Table 6). These parameters are the number of rays of the umbels and umbellules (raylets), the length of the fruit and its peduncle and the proportion in the leaves between length and width and angles of separation between the last leaf divisions (leaflets).

Taxonomic treatment

Peucedanum officinale **L. subsp.** ***album*** **Martínez-Fort & Donat-Torres, subsp. nov.**
urn:lsid:ipni.org:names:60479357-2

Diagnosis. *Peucedanum officinale* L. subsp. *album* can be morphologically distinguished by the canaliculated leaflets, inflorescences without dominant terminal umbels, which are often sessile and lateral, with few rays (3) 5–9 (12), umbellules with (7) 10–16 (18) raylets, white-petalled flowers and fruits with a fructiferous raylet as long as or shorter than the length of the fruits.

Type. Spain, Valencia, Tavernes de la Valldigna, eastern spurs of the Serra de les Agulles mountain range, on both ascents to Pic Massalari. 39,09°N, -0,284°W. 300 m alt. Rocky calcareous soil. 23-IX-2012. J. Martínez-Fort (**Holotype**: VAL 223161! Figure 2).

Table 5. Values obtained from the measurements taken in the field.

Code (Table 2)	Character (Table 2)	*P. officinale* subsp. *album*	*P. officinale* subsp. *officinale*
Stem			
T1	Plant height	(0.24)0.41–0.98(1.3) m	(0.27)0.42–1.26(1.74) m
T2	First ramification height	(0.07)0.14–0.39(0.5) m	(0.12)0.15–0.52(0.73) m
T3	T1/T2 ratio	(1.6)2–3.5(3.9)	1.3–3.6(4.6)
T4	Diameter at the base of stem	2.1–4.6(6.3) mm	(2)2.7–6.1(7.3) mm
T5	Diameter at the first ramification	2–4.5(6.2) mm	(1.7)2.3–6.4(8.6) mm
T6	T4/T5 ratio	(0.8)0.9–1.1(1.2)	0.9–1.2(1.3)
Basal rosette leaf			
H1	Leaf length, including petiole	(190)257–538(630) mm	(280)335–505(570) mm
H2	Number of leaf divisions (ternate)	4–5(6)	4–5(6)
H3	Leaf width at the base of the last division	(0.4)0.5–0.8(0.9) mm	(0.5)0.6–1(1.1) mm
H4	Leaf width at the apex of the last division	0.3–0.6(0.7) mm	(0.6)0.7–1.1(1.4) mm
H5	Leaf division length	(31.3)47.9–83.7(94.4) mm	(45.6)47.6–76.7(85.6) mm
H6	H5/H3 ratio	(50.5)70.3–125.8(166.2)	(57.1)62–96.3(108)
H7	H4/H5 ratio	(3.2)4.1–10.7(17.2) $\times 10^{-3}$	(10.2)11.4–18(19.4) $\times 10^{-3}$
H8	Angle between contiguous leaf divisions of the last ternate	(30)32–66(90) degrees	(30)31–45 degrees
H9	Angle between lateral leaf divisions of the last ternate	(45)111–180 degrees	45–138(180) degrees
H10	Length petiole leaf	(42)53–171(250) mm	(55)87–197(240) mm
H11	Diameter at its basis petiole leaf	1.5–2.8(3.4) mm	(2.1)2.2–3.4(3.7) mm
H12	Diameter before first division (ternate) leaf	(1.5)1.9–3.5(4.4) mm	(2.7)2.8–4.4(5.2) mm
Cauline leaves: **First on stem from the basal rosette leaf**			
H13	Number of leaf divisions (ternate)	3–4(5)	(2)3–5
H14	Last leaf division length	(1.8)6.5–36.4(40.8) mm	5–88.8(147.3) mm
H15	Length	(1.2)4.3–61.1(87.3) mm	9.5–73.4(95.2) mm
H16	Diameter of the petiole at its basis	(0.8)0.9–2.2(2.6) mm	(0.7)1.2–2.9(3.1) mm
H17	Diameter before the first division (ternate)	(0.8)1–2.2(2.7) mm	(0.7)0.9–4.2(5.8) mm
Cauline leaves: **Second on stem leaf**			
H18	Number of leaf divisions (ternate)	1–3(4)	2–4
H19	Length	3.2–73.8(120) mm	41–67.5(70) mm
H20	Diameter before the first division (ternate)	(0.5)0.7–1.7(2.1) mm	1–2.4(2.5) mm
H21	Diameter at its basis	0.9–2 mm	1–2.1(2.2) mm
H22	Sheath length	(2)6.5–22.6(28.3) mm	22–29.5(31.4) mm
Umbel			
I1	Bract length	(0.6)0.7 mm	(0.5)0.6 mm
I2	Bract width	1.1(1.3) mm	1.7(1.8) mm
I3	Number of bracts	0–1(2)	0–2(3)
I4	I1/I2 ratio	3.5–7.6(9.1)	(3.2)4.3–10.5(12)
I5	Number of rays	(3)5–9(12)	(13)15–32(35)
I6	Length of internal rays	(2.8)4–24.3(42.6) mm	(5)6.2–24.3(29.7) mm
I7	Length of external rays	(15.7)17.7–52.6(83.7) mm	(21.4)23.5–71.2(82.7) mm
Umbellule			
I8	Number of raylets	(7)10–16(18)	(7)12–24(29)
I9	Length of internal rays	0.2–6.5(13.1) mm	2.1–21.7(35.3) mm
I10	Length of external rays	0.3–17.6(35.1) mm	5.2–43.6(71.2) mm
I11	Number of bracteoles	(4)6–9	(6)7–9(10)
Fruit			
F1	Length	(5.1)5.8–6.9(7.1) mm	(3.7)5.9–8.1(8.5) mm
F2	Width	(2.6)3.3–4.7(5) mm	(2.6)3.3–4.4(4.8) mm
F3	Wing width of the marginal ribs	(0.2)0.4–1(1.1) mm	(0.4)0.6–1.1 mm
F4	F3/F2 ratio	(0)0.1–0.3	0.1–0.2
F5	F1/F2 ratio	(1.2)1.3–1.9(2)	(1.4)1.7–2(2.1)
F6	Fructiferous raylet length	(1.8)2.8–5.3(6.1) mm	(3.8)5.8–10.4(11.7) mm
F7	F1/F6 ratio	(1)1.2–2.3(3.2)	(0.6)0.7–1(1.2)
F8	F6/F1 ratio	(0.3)0.5–0.8(1)	(0.8)1–1.3
F9	F2/F6 ratio	0.6–1.6(2.8)	(0.3)0.4–0.5(0.7)

Table 6. Values with statistically significant differences. Code refers to Table 2.

Code	Organ	subsp. *album*	subsp. *officinale*
I5	Number of rays (u.)*	(3) 5–9 (12)	(13) 15–32 (35)
I8	Number of raylets (u.)*	(7) 10–16 (18)	(7) 12–24 (29)
F1	Fruit length (mm)*	(5.1) 5.8–6.9 (7.1)	(3.7) 5.9–8.1 (8.5)
F6	Fruit raylet length (mm) *	(1.8) 2.8–5.3 (6.1)	(3.8) 5.8–10.4 (11.7)
F7	Fruit length/ Raylet length *	(1) 1.2–2.3 (3.2)	(0.6) 0.7–1 (1.2)
F8	Raylet length/Fruit length **	(0.3) 0.5–0.8 (1)	(0.8) 1–1.3
F9	Fruit width/ Raylet length *	0.6–1.6 (2.8)	(0.3) 0.4–0.5 (0.7)
H7	Last basal leaf division: width/length***	(3.2) 4.1–10.7 (17.2) 10^{-3}	(10.2)11.4–8 (19.4) 10^{-3}
H9	Largest angle for external leaf divisions, last ternate (degrees) ***	(45) 111–180	45–138 (180)

* With more than 30 types of data. Differences obtained between the means with an ANOVA analysis; as normality or homoscedasticity was not met, the result was confirmed by the Kruskal Wallis test.

** With more than 30 data. Differences obtained between the means with an ANOVA analysis.

*** With fewer than 30 data. If normality and homoscedasticity were met, the Mann-Whitney W (Wilcoxon) test was used.

Description. Perennial plant with stem (0.24) 0.41–0.98 (1.3) m high and 2.1–4.6 (6.3) mm in diameter at the base, branching from the lower 1/3–1/2, striate, glabrous. Basal leaves 4- or 5- (6-) ternate, triangular in outline, (190) 257–538 (630) mm in length; petioles cylindrical, (42)53–171(250) mm long, sheathing at the base; linear terminal leaflets, (31.3) 47.9–83.7 (94.4) mm × 0.3 to 0.6 (0.7) mm, canaliculate, length/width ratio of (50) 70–126 (166) range, angle between the closest divisions of the terminals (30) 32–66 (90) degrees and (45) 111–180 degrees between the outermost leaf divisions. Cauline leaves, decreasing in size towards the apex of stems, but with enlarged sheaths. The first leaf on stem from the basal rosette leaf 3–4 (5) times ternate, with terminal divisions of (1.8) 6.5–36.4 (40.8) mm of length and canaliculated. The uppermost ones reduced to the sheath.

Inflorescence without a primary or dominant umbel, umbels arranged along the axis of inflorescence, sometimes sessile and lateral. Umbels compound, rays (3) 5 to 9 (12), inner rays shorter (2.8) 4- 24.3 (42.6) mm, outer rays (15.7) 17.7–52.6 (83.7) mm, bracts 0 or 1 (2), linear-triangular, (0.6) 0.7× 1.1 (1.3) mm. Umbellules with (7) 10 to 16 (18) raylets, bracteoles (4) 6 to 9, linear, gradually widened towards base. Flowers hermaphroditic, sepals 5 triangular, inconspicuous; petals 5, white, inflexed tips; stamens 5, alternate; stylopodium conical, similar in length to the styles; styles parallel at anthesis, becoming divergent in fruiting. Fruits dorsally compressed, elliptical, size (5.1)5.8–6.9 (7.1) × (2.6) 3.3–4.7 (5) mm, apex slightly off emarginated; mericarps homomorphic; median and lateral prominent ribs, apex slightly off emarginated; marginal ribs prominently winged, wings (0.2) 0.4–1 (1.1) mm, wide; commissural vittae 2; vallecular vittae 4; commissure very broad, from wing tip to wing tip. Raylets (1.8) 2.8–5.3 (6.1) mm long. The raylets length/fruit length ratio ranging from (0.3) 0.5–0.8 (1).

Distribution and habitat. It is dispersed in the thermomediterranean sub-humid bioclima (Rivas-Martínez 2004) on rocky soils of limestone and sandstone at the base

Figure 2. Holotype of *Peucedanum officinale* subsp. *album* from Tavernes de la Valldigna, Valencia (VAL 223161!). Photos taken in the field: **A** flowers **B** sessile umbel with three rays **C** fruits. Photos taken with a stereomicroscope **D** Mericarp **E** fruit cross-section **F** leaf underside and bundle.

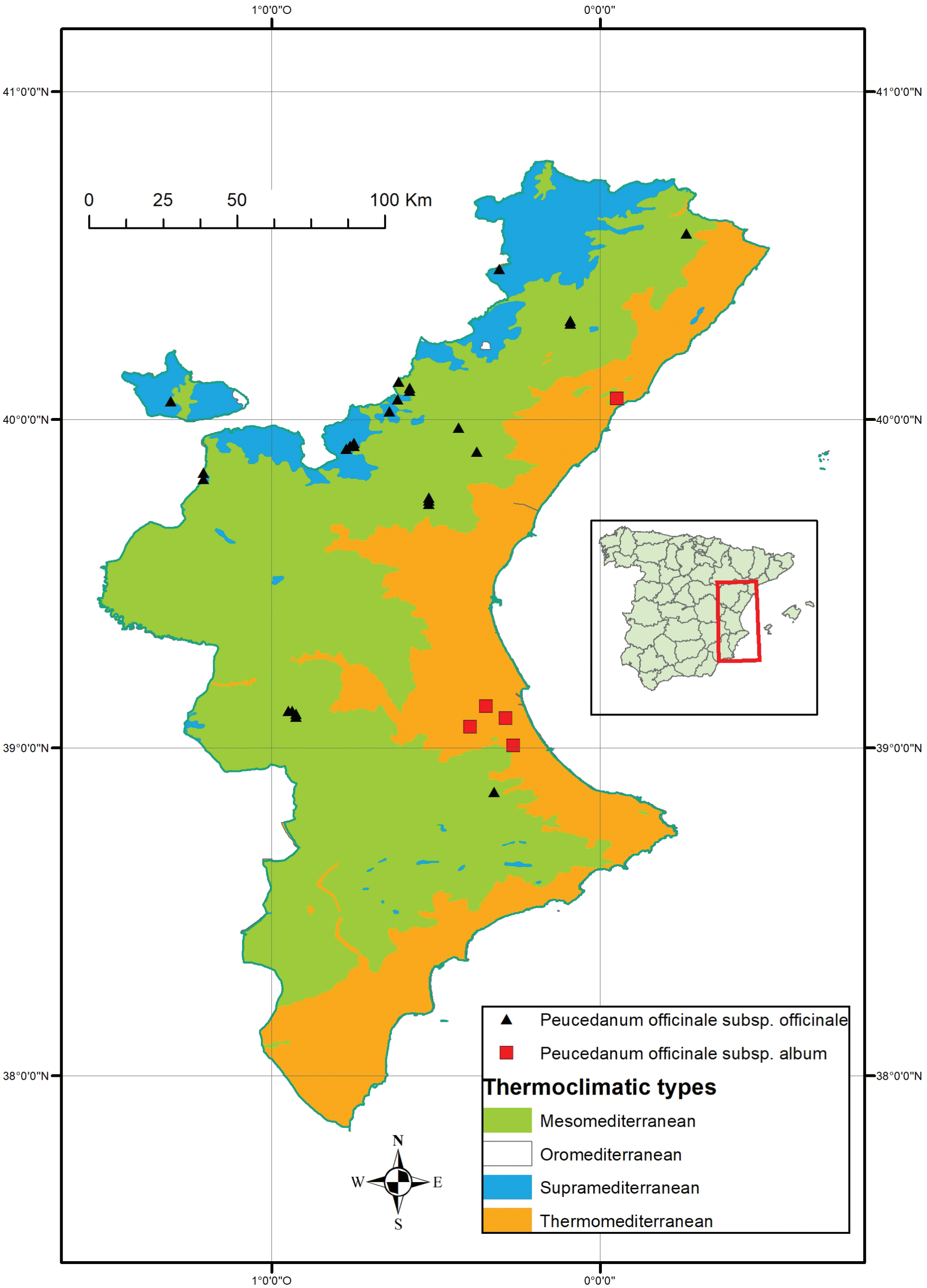

Figure 3. Map of *Peucedanum officinale* subsp. *album* (squares) and *P. officinale* subsp. *officinale* (triangles) on the Valencian Community region (Spain). The thermoclimatic bioclima types of the region are indicated in colour.

Figure 4. Types of bundle leaf **A** Flat-bundle leaflet of *Peucedanum officinale* subsp. *officinale* **B** Canaliculated-bundle leaflet of *Peucedanum officinale* subsp. *album*. A comparison of the other subspecies of *P. officinale* **C** *Peucedanum officinale* subsp. *officinale* **D** *P. officinale* subsp *paniculatum*. **E** *P. officinale* subsp. *longifolium*. **Vouchers**: **C** C. Pérez. (MA 152463) **D** L. Serra & A. Bort, (MA 623316) **E, F** Cernoch, (MA 310966).

and crest of cliffs and rocky slopes. Contacting with wet fringes of *Rubio longifoliae-Quercetum rotundifolie* Costa, Peris and Figuerola (Costa et al. 1983), together with ash and arbutus. With abundant populations on the coastal and southern foothills of the Iberian system (Serra de les Agulles) and on the northern coastal foothills of the external Prebaetic system (Serra Grossa) (Figure 3).

Phenology. Flowering July to October.

Paratypes. SPAIN. Valencia: Alzira. Serra de la Murta, 30SYJ2934; on rocky outcrops, 25-IX-2011; J. Martínez-Fort (VAL 223162!, Figure 1B; Valencia: Corbera de Alzira, 30SYJ23; J. Borja (VAL 154996!; Figure 1C–D); Valencia: Favara, Serra de Corbera, 30SYJ33, 5-IX-1986; G. Mateo & al. (VAL 117826!).

Key to the subspecies of *Peucedanum officinale*

1	Canaliculated leaflets (Figure 4B)	**2**
–	Non-canaliculated leaflets (Figure 4A)	**4**
2	Habit of up to 1 (1.3) m; petals white or pale yellow; fruit length < 7 mm	**3**
–	Habit of up to 1.5 m; petals yellow; fruit length > 7 mm	**subsp.*brachyradium***
3	Umbels with 5 to 9 (12) rays, fructiferous raylets shorter than or equal to fruit length; petals white	**subsp. *album***
–	Umbels with 9 to 14 (17) rays, fructiferous raylets longer than fruit length, up to 3 times the length; petals pale to medium yellow	**subsp. *paniculatum***
4	Fructiferous raylets equal or shorter than fruit length; folded or crested (concave) leaflets	**subsp. *longifolium***
–	Fructiferous raylets longer than fruit length; flat leaflets	**subsp. *officinale***

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Supplementary material 1

Figure S1. Measured characters

Authors: Javier Martínez-Fort, Maela León, Maria P. Donat-Torres

Data type: species data

Explanation note: The figure shows the characters measured on the plants.

Link: https://doi.org/10.3897/phytokeys.131.32173.suppl1

Supplementary material 2

Table S1. Sequences obtained from GenBank to calculate pairwise genetic distances

Authors: Javier Martínez-Fort, Maela León, Maria P. Donat-Torres

Data type: molecular data

Explanation note: Accession numbers of 85 ITS sequences downloaded from GenBank. The sequences from this study are in bold letters.

Link: https://doi.org/10.3897/phytokeys.131.32173.suppl2

PhytoKeys 131: 57–67 (2019)
doi: 10.3897/phytokeys.131.36983
http://phytokeys.pensoft.net

RESEARCH ARTICLE

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Isoetes dubsii and *Isoetes santacruzensis*, two new species from lowland areas in South America

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Abstract

Isoetes dubsii **sp. nov.** and *I. santacruzensis* **sp. nov.**, two new species from lowland areas in South America, are described, illustrated and compared to similar species. *Isoetes dubsii* can be distinguished from other species of the Brazilian Pantanal wetlands by a set of characters including leaves that are long, flexuous and trigonal in transverse section, tri-lobate stems, rudimentary velum, pustulate megaspores of 310−390 μm diameter and laesurae of the megaspore at least four times wider than high. *Isoetes santacruzensis* has flexuous, filiform leaves, 0.4–0.8 mm wide at mid length and reaching up to 15 cm long, black or reddish-black sporangia, sclerified phyllopodia and sparsely verrucate megaspores of 320−390 μm in diameter. We also include a key for species from the Brazilian Pantanal wetlands and Bolivia and spore images for all species that are discussed. *Isoetes dubsii* and *I. santacruzensis* are only known from their type localities and they may deserve special attention concerning their conservation status. However, based on our current knowledge on these species and according to IUCN Red List criteria, they are assessed here as data deficient (DD).

Keywords

Aquatic plants, Bolivia, Brazil, herbarium collections, lycophytes, *Isoetes*, Pantanal wetlands, spores.

Introduction

Herbarium collections are amongst the most important tools for obtaining information about the composition, distribution and content of plant diversity in a given region (Nualart et al. 2017). They represent a cumulative body of knowledge, which has been generated over time. It is also well known that many undescribed species reside in existing herbarium collections (Bebber et al. 2010).

Isoetes L. is the unique extant genus of heterosporous lycophytes in the Isoetales (PPG I 2016). *Isoetes* is morphologically well defined and readily distinguishable from

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any other group of vascular plant by its narrow leaves containing four air-chambers, a single sunken adaxial sporangium covered by a velum and sporangial trabeculae (Taylor et al. 2016). The genus comprises about 250 species (Troia et al. 2016). South America is one of its centres of taxonomic diversity (Troia et al. 2016) with an estimated 64 species (Hickey et al. 2003). Most of the species are narrowly endemic and they occur as aquatic or terrestrial plants in wet soils (Pfeiffer 1922). However, *Isoetes* species are notorious for the difficulties they present in identification, which are partially associated with morphological simplicity (Taylor and Hickey 1992).

Difficulties in the identification have frequently led many *Isoetes* specimens to be deposited in herbaria without determinations or with wrong determinations (Troia and Rouhan 2018). The sculpture of the megaspore is one of the most important characters in the taxonomy of the genus (Pfeiffer 1922) and, in many cases, scanning electron microscopy images (SEM) of megaspores are needed to identify species (Hickey 1986a). The use of SEM adds logistic difficulties in the taxonomy of the genus and, as a result, many *Isoetes* species remain unidentified and/or undescribed in herbarium collections.

Our recent efforts to access the diversity of *Isoetes* in South America has led us to consult herbarium collections where we discovered two species that we recognised as undescribed. One of the new species is from Bolivia and the other is from Pantanal wetlands in Brazil. We provide descriptions to distinguish these species, SEM images of mega- and microspores of species of these regions and a key for the identification of these new species.

Material and methods

Fieldwork was carried out by Balthasar Dubs, a Swiss botanist and ornithologist who intensively collected plants in the Pantanal wetlands in Brazil and found *Isoetes dubsii* on 3 June 1988 in the Pantanal do Rio Negro (currently belonging to the municipalities of Aquidauana and Corumbá), in the state of Mato Grosso do Sul, mid-western Brazil. We also tried to locate this new species in the same area in November 2017. For *I. santacruzensis*, fieldwork was carried out by Timothy J. Killeen on 11 November 1994 in the province of Ñuflo de Chávez, Department of Santa Cruz, Bolivia.

Spore images were generated by transferring the spores to aluminium scanning electron microscope (SEM) stubs coated with a carbon adhesive. The stubs were then coated with gold-palladium-alloy in a sputter-coater for 180 sec, after which the spores were digitally imaged using a Zeiss SIGMA VP. The resulting images were adjusted in Photoshop for contrast and the background was altered to black. To measure the spores, we used a minimum of 20 spores per sporangium, from at least two sporangia. The spore measurements were taken using SEM. The terminology used for the description of the spores follows that of Punt et al. (2007), with some modification using Hickey (1986a).

Taxonomic treatment

***Isoetes dubsii* J.B.S.Pereira, sp. nov.**

urn:lsid:ipni.org:names:77201652-1
Figs 1, 2

Diagnosis. *Isoetes dubsii* is distinguished from other species from the Brazilian Pantanal wetlands by a set of characters that include leaves that are long (90−100 cm), flexuous and trigonal in the transverse section, tri-lobated stems, rudimentary velum, pustulate and small megaspores of 310−390 µm in diameter (average 350 µm) and laesurae of the megaspore at least four times wider than high.

Type. BRAZIL. Mato Grosso do Sul: Fazenda Salina, Pantanal do Rio Negro, 19°30'S, 56°10'W, 3 Jun 1988, *Dubs 829* (holotype: Z!).

Description. Plants aquatic submerged, growing in fresh water ponds. Roots conspicuous, dichotomous. Stems globose, 3–lobate, ca. 2 cm wide. Leaves 90−100 cm long, 0.2–0.3 cm wide at mid length, 50–60 per individual, linear, flexuous, erect, apex attenuate; alae 12–13 cm long, extending from the base ca. 1/10 of total leaf length, red-brown, membranaceous, apex attenuate; subula olive-green, trigonal. Labium present, persistent, 1.5–2.0 × 2.0–2.5 mm, cordate. Ligula not observed in herbarium material. Velum rudimentary. Sclerified phyllopodia absent. Sporangium at the base of the leaf, 8–12 × 3–4 mm, oblong, light brown, concolorous. Megaspores 310–390 µm in diameter (average = 350 µm, n = 20), trilete, white, not lustrous; proximal and distal surfaces pustulate, macrosculpture 3–8 × 22–45 µm, wider than high; laesurae 8–10 × 45–55 µm, at least four times wider than high. Microspores 31–36 µm long (average = 34 µm, n = 20), light brown, monolete, proximal surface smooth, distal surface sparsely echinate.

Distribution and habitat. This species is only known from its type locality (state of Mato Grosso do Sul, Brazil; Fig. 3), where it grows in a fresh water pond at ca. 100 m a.s.l. Although we tried to re-collect *Isoetes dubsii* in the area indicated by Balthasar Dubs, no additional collections have been made.

Etymology. The specific epithet honours the Swiss ornithologist and botanist B. Dubs, for his valuable contributions to the knowledge of the flora and fauna of the Pantanal wetlands of Brazil. He was also the first naturalist to collect *Isoetes dubsii*.

Notes. Amongst the species found in Brazilian Pantanal wetlands, *Isoetes panamensis* Maxon C.V. Morton *sensu lato* is similar to *I. dubsii* due to its long leaves up to 80 cm. However, the megaspores in *I. panamensis* are 380–600 µm (vs. 310–390 µm) in diameter and baculate (vs. pustulate) (Fig. 2).

Conservation status. Since *I. dubsii* is currently known from a single locality, it may deserve special attention concerning its conservation status. However, based on our current knowledge on this species and according to IUCN Red List criteria (IUCN 2012), it is assessed here as data deficient (DD).

Figure 1. Type of *Isoetes dubsii* (image courtesy of the herbarium Z/ZT). Note that the name *Isoetes flexuosa* J.B.S. Pereira on the label sheet is a provisional, never published, name. Photographer: Franziska Schmid

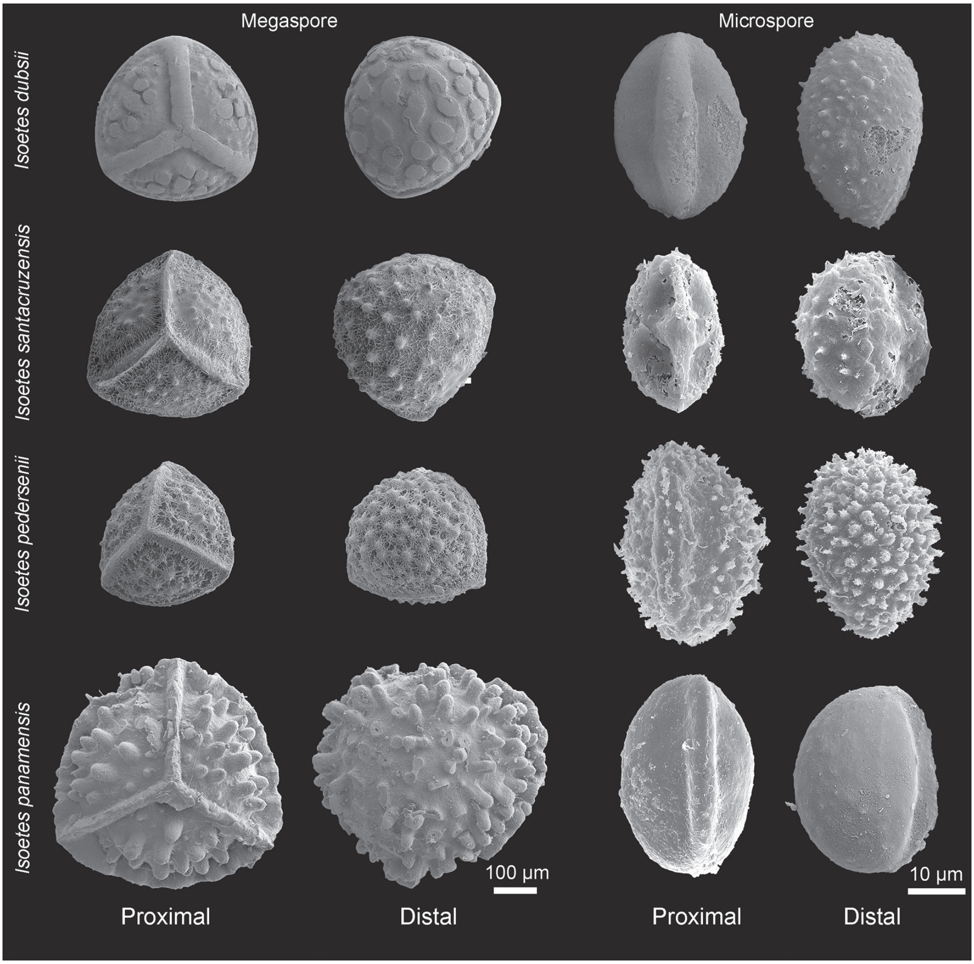


Figure 2. SEM images of the mega- and microspores of *Isoetes dubsii* (*Dubs 829*, Z/ZT), *I. santacruzensis* (*Killeen et al. 7131*, MO), *I. pedersenii* (*Troels 8105*, L) and *I. panamensis* (*Balansa 3294*, P).

Isoetes santacruzensis **J.B.S.Pereira, sp. nov.**

urn:lsid:ipni.org:names:Dear 77201648-1
Figs 2, 4

Diagnosis. *Isoetes santacruzensis* is characterised by having flexuous, filiform leaves ranging from 0.4–0.8 mm wide at mid length and reaching up to 15 cm long, 15−30 leaves per individual, black or reddish-black sporangia, sclerified phyllopodia present, sparsely verrucate megaspores of 320−390 μm (average of 350 μm) in diameter.

Type. BOLIVIA. Santa Cruz: Nuflo de Chaves, 15°32'40"S, 61°59'28"W, 450 m a.s.l., 11 Nov 1994, *Killeen et al. 7131* (holotype: MO!).

Plant aquatic partially submerged or ephemeral terrestrial in rocky granite outcrops. Roots conspicuous, dichotomous. Stems globose, 3–lobate, 0.8–1.2 cm wide.

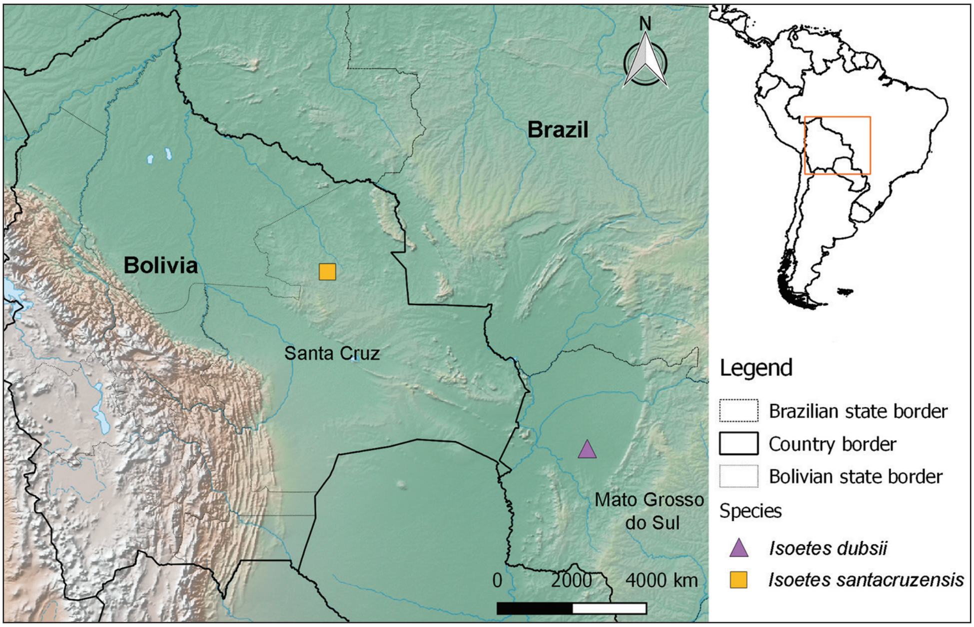


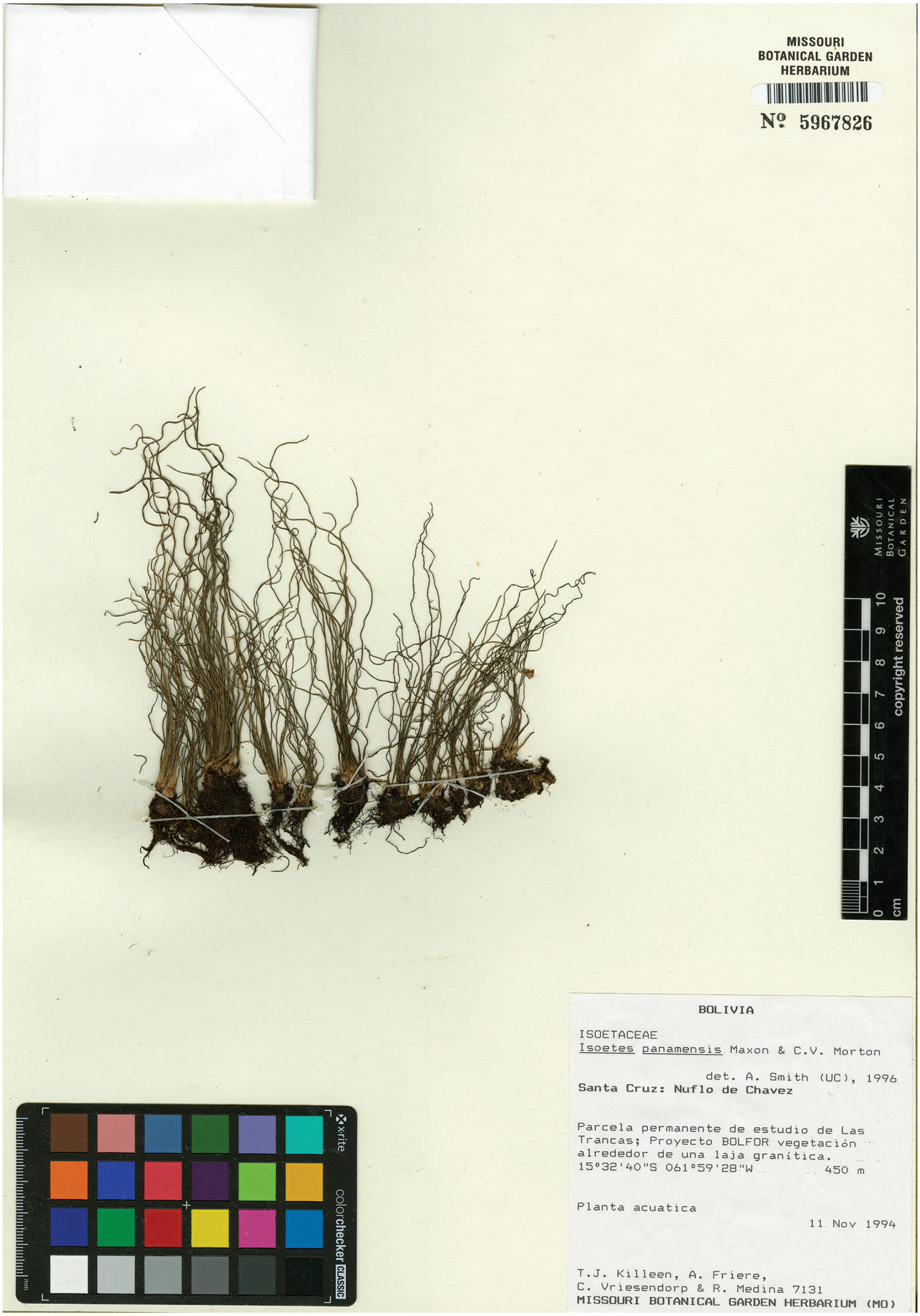
Figure 3. Map showing the type locations of *Isoetes dubsii* and *I. santacruzensis*.

Leaves 6–15 cm long, 0.4–0.8 mm wide at mid length, 15–30 per individual, filiform, flexuous, laxly ascending, apex attenuate; alae 0.3–3.5 cm long, extending from the base ca. 1/5 of total leaf length, hyaline or light brown, membranaceous, apex attenuate; subula olive green, trigonal. Labium present, persistent, cordate, 0.2–0.5 × 0.6–0.9 mm. Ligule not observed in herbarium material. Velum rudimentary to > 0.2 mm wide along the lateral edges of the sporangium. Sclerified phyllopodia present. Sporangium at the base of the leaf 2.5–3.5 × 2.0–2.5 mm, oblong, black or reddish-black, concolorous. Megaspores 320−390 µm in diameter (average = 350 µm, *n* = 20), trilete, white, not lustrous; proximal and distal surfaces sparsely verrucate, macrosculpture 10−25 × 19−31 µm, slightly wider than high; laesurae 26−30 × 16−21 µm, slightly higher than wide. Microspores 23−27 µm long (average = 25 µm, *n* = 20), light brown, monolete, proximal surface smooth, distal surface sparsely echinate.

Distribution and Habitat. *Isoetes santacruzensis* is only known from its type locality, where it grows as aquatic to ephemeral terrestrial in rocky granite outcrops, at elevations of about 450 m.

Etymology. The specific epithet refers to the type region, the Department of Santa Cruz in Bolivia (Fig. 3).

Notes. Until now, six species of *Isoetes* were known from Bolivia, although the presence of unpublished species has already been mentioned (Kessler and Smith 2018). Most of the known Bolivian species are from Andean habitats (Kessler and Smith 2018) and have rugulate, laevigate (Fig. 5) or tuberculate megaspores (see Hickey 1986b, Fig. 2) and laevigate, echinate or tuberculate microspores (Fig. 5).



BOLIVIA

ISOETACEAE
Isoetes panamensis Maxon & C.V. Morton
det. A. Smith (UC), 1996
Santa Cruz: Nuflo de Chavez

Parcela permanente de estudio de Las Trancas; Proyecto BOLFOR vegetación alrededor de una laja granítica.
15°32'40"S 061°59'28"W 450 m

Planta acuatica
11 Nov 1994

T.J. Killeen, A. Friere,
C. Vriesendorp & R. Medina 7131
MISSOURI BOTANICAL GARDEN HERBARIUM (MO)

Figure 4. Type of *Isoetes santacruzensis* (image courtesy of the herbarium MO). Photographer: Mike Blomberg.

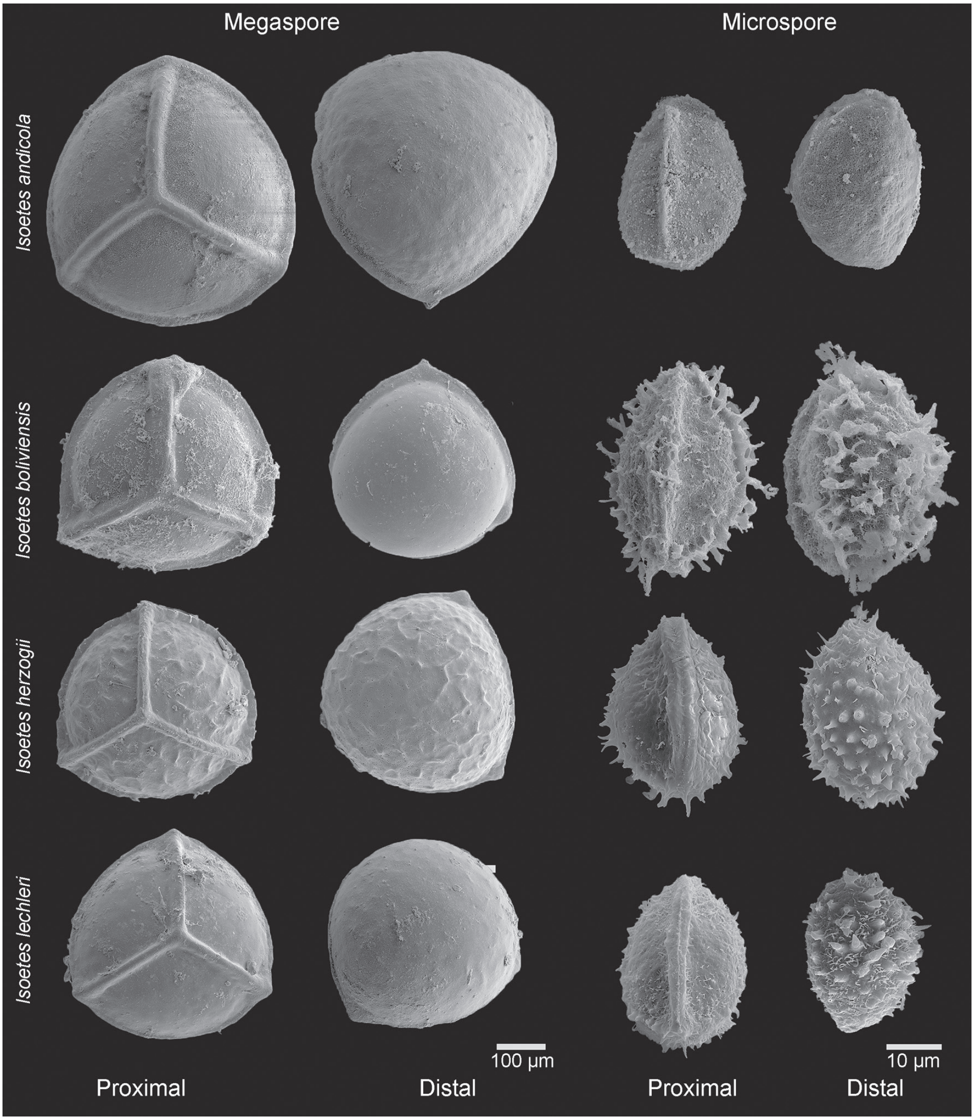


Figure 5. SEM images of the mega- and microspores of *Isoetes andicola* (*Fuentes 13907*, MO), *I. boliviensis* (*Casas 6619*, MO), *I. herzogii* (*Ritter 2209*, MO) and *I. lechleri* (*Solomon 15517*, MO).

Besides habitat, the macrosculpture of at least one of the spore types, megaspore or microspore, helps to differentiate *I. santacruzensis* from the Andean *Isoetes* species (Figs 2, 4). Additionally, *I. santacruzensis* is similar to *I. pedersenii* by its small and verrucate megaspores. However, *I. santacruzensis* can be readily distinguished by its erect and flexuous leaves (vs. ascending, linear and straight; Fig. 6), as well as by the characters present in the taxonomic key.

Conservation status. *Isoetes santacruzensis* is currently known from a single locality. The expansion of agricultural activities and cattle farming in this area show that this species may be prone to the effects of human activities within a very short time.

Figure 6. Type of *Isoetes pedersenii* (image courtesy of the herbarium L). Photographer: Christel Schollaardt.

However, given its potential occurrence in other areas and the lack of current knowledge about its distribution range, *I. santacruzensis* should be assessed as data deficient (DD), according to IUCN criteria (IUCN 2012).

Key to the species from the Brazilian Pantanal wetlands and Bolivia

1	Plants from lowlands < 500 m	**2**
–	Plants from Andean highlands 2500–5200 m	**5**
2	Megaspores baculate (more rarely tuberculate)	***Isoetes panamensis* s.l.**
–	Megaspores pustulate or verrucate	**3**
3	Plant aquatic submerged; megaspores pustulate; laesurae of the megaspore at least four times wider than high	***Isoetes dubsii***
–	Plant amphibious or terrestrial; megaspores verrucate; laesurae of the megaspore slightly wider than high	**4**
4	Leaves ascending, straight; sclerified phyllopodia absent; sporangium hyaline; megaspore densely verrucate on the distal surface; microspore densely echinate	***Isoetes pedersenii***
–	Leaves erect, flexuous; sclerified phyllopodia present; sporangium black or reddish-black; megaspores sparsely verrucate on the distal surface; microspores sparsely echinate	***Isoetes santacruzensis***
5	Plants of cushion bogs; stem vertically elongate; leaves 50–200 per individual	***I. andicola***
–	Plants of lakes, pools, streams and marshes; stem globose; leaves < 50 per individual	**6**
6	Foliar gemmae present; sclerifed phyllopodia present	***I. eshbaughii***
–	Foliar gemmae absent; sclerifed phyllopodia absent	7
7	Leaves flaccid, lax to weakly erect; microspores verrucate or tuberculate on the distal surface	***I. boliviensis***
–	Leaves turgid, stiffly erect; microspores echinate on the distal surface	**8**
8	Leaves without dark pigmentation basally; megaspores rugulate (rarely smooth)	***I. herzogii***
–	Leaves usually with dark brown to nearly sclerotic pigmentation basally; megaspores smooth	***I. lechleri***

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The authors thank the curators and collection managers of the herbaria MO, L and Z/ZT for specimen loans, access to their collections and high-resolution photographs of the types. We are also grateful to Jim Hickey, Michael Kessler and Angelo Troia by their valuable comments on the manuscript. This study was made possible through a fellowship from Capes/ITV (88887.130616/2016) to JBSP and a research fellowship from CNPq (302839/2016-0) to JTFG.

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RESEARCH ARTICLE

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Bolbitis lianhuachihensis (Dryopteridaceae), a new species from Taiwan

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Abstract

A new species of *Bolbitis*, *B. lianhuachihensis* **sp. nov.**, was found in central Taiwan. It most resembles *B. virens* var. *compacta* and *B. hainanensis*. A phylogenetic tree of Taiwanese and other Asian species of *Bolbitis* species supports the recognition of the new species. Morphologically, the combination of anastomosing venation and fewer sterile pinnae are critical characters to discriminate *B. lianhuachihensis* from other Taiwanese *Bolbitis* species. *Bolbitis lianhuachihensis* can be further distinguished from *B. virens* var. *compacta* and *B. hainanensis* by having lanceolate sterile pinnae and absent or fewer free veinlets in small areoles of sterile pinnae. The morphological descriptions, illustration, ecology and distribution of the new species are presented. A key to all Taiwanese *Bolbitis* is also provided.

Keywords

Ferns, Taiwan, taxonomy, venation

Introduction

Bolbitis Schott is a pantropical genus that belongs to Dryopteridaceae and consists of about 80 species (Moran et al. 2010a; PPGI 2016). The plants are terrestrial or lithophytic and usually grow in damp forests, such as valleys or in and along streams. Most *Bolbitis* species have proliferous buds on the terminal pinnae near their apices (Hennipman 1977; Moran et al. 2010b). The genus also exhibits strong sterile-fertile frond dimorphism, and most of its species are pinnate.

In Taiwan, ten taxa have been recorded; namely, *B. angustipinna* (Hayata) H.Ito, *B. appendiculata* (Willd.) K.Iwats., *B. heteroclita* (C.Presl) Ching, *B. laxireticulata* K.Iwats., *B. ×nanjenensis* C.M.Kuo, *B. rhizophylla* (Kaulf.) Hennipman, *B. scalpturata* (Fée) Ching, *B. subcordata* (Copel.) Ching, *B. virens* (Wall. ex Hook. & Grev.) Schott var. *compacta* Hennipman and *B. heteroclita* × *B. subcordata* (Tsai and Shieh 1994; Knapp 2011; 2013). Three of these taxa, *B. laxireticulata*, *B. ×nanjenensis* and *B. heteroclita* × *B. subcordata* are presumed to have a hybrid origin (Iwatsuki 1959; Kuo 1990; Knapp 2011).

In Taiwan, a *Bolbitis* plant appeared unusual due to its few sterile pinnae (Figs 1 and Suppl. material 1: Figure S1). By this character, it was identified as *B. virens* var. *compacta* and resembled *B. hainanensis* Ching & Chu H. Wang (Knapp 2011), but *B.virens* var. *compacta* is found in Indochina (Hennipman 1977), while *B. hainanensis* is endemic to Hainan and Yunnan, China (Dong and Zhang 2005; Zhang et al. 2013). Taiwanese *Bolbitis* also differed from these species by venation. This character has been shown to be helpful in distinguishing many species of *Bolbitis* worldwide (Hennipman 1977). Species of *Bolbitis* may have either free or anastomosing veins. If the latter, a helpful distinguishing character is the number of areoles between the costae and margins, the presence or absence of included free veinlets in the areoles and whether these veinlets are recurrent or excurrent (Hennipman 1977; Moran et al. 2010a). In this study, we compared the morphological characteristics of the undescribed plant, especially with regards to lamina venation, with other species of *Bolbitis* in Taiwan. We also examined the phylogenetic relationship of these plants to existing *Bolbitis* species in Taiwan and to other similar species. Based on the results, we were able to clarify the specific morphological and molecular traits of the *Bolbitis* plant and describe a new species.

Materials and methods

Morphological studies

The undescribed *Bolbitis* was collected in central Taiwan and herbarium specimens at HAST and TAIF were also studied. The keys, descriptions and illustrations in Hennipman's monograph (1977) were investigated to compare the morphological characteristics of our suspected new species with the known *Bolbitis* species. Furthermore, the type specimens of two similar species in nearby regions, *B. hainanensis* (*Wallich 1033*, K) and *B. virens* var. *compacta* (*Tagawa et al. 6802*, L) were analysed. As the type specimen of *B. hainanensis* lacks fertile fronds, we also consulted the protologue (Ching and Wang 1983). The venation of the Lienhuachih plants, two similar taxa and the known *Bolbitis* taxa in Taiwan were depicted. The morphological terminology follows that of Lellinger (2002). Acronyms of herbaria follow Thiers (2019).

Figure 1. *Bolbitis lianhuachihensis* **A** habit; note taller fertile fronds (photographed by Y.-S. Chao) **B** acrostichoid sori (photographed by P.-F. Lu) **C** venation of sterile frond (photographed by Y.-F. Huang).

Phylogenetic analyses

To clarify the phylogenetic position of the undescribed plant, six more *Bolbitis* species from Taiwan and *B. virens* from China were sampled and sequenced in this study. Additional sequences of 19 species were gathered from GenBank, including 17 *Bolbitis* species and two outgroup species. *Elaphoglossum lepervanchii* and *Teratophyllum koordersii* were used as outgroups, based on the phylogenetic trees of *Bolbitis* and related taxa (Moran et al. 2010a; Chen et al. 2017). A total of 30 samples of *Bolbitis* species were included and the voucher information is provided in the Appendix 1.

Total genomic DNA was extracted from young fronds, following a modified cetyltrimethylammonium bromide (CTAB) method (Doyle and Doyle 1990). Two chloroplast markers were used: *rps4-trnS* intergenic spacer was amplified by the primers *rps4-3r.f* (AGT TGT TAG TTG TTG AGT AT) (Skog et al. 2004) and *rps4-trnS* (TAC CGA GGG TTC GAA TC) (Souza-Chies et al. 1997); *trnL-F* intergenic spacer was amplified by the primers from Taberlet et al. (1991) (primer e – GGT TCA AGT CCC TCT ATC CC and primer f – ATT TGA ACT GGT GAC ACG AG). All sequences were aligned using ClustalW (Thompson et al. 1994) and then were manually edited using BioEdit 7.1.3 (Hall 1999). Gaps were treated as missing data.

Phylogeny was inferred by Maximum Likelihood (ML) analyses with GARLI v.2.0.1019 (Zwickl 2006). The best tree was created from the ten independent runs with automatic termination following 10,000 generations without a significant (lnL increase of 0.01) change in topology. A majority-rule consensus tree was calculated in PAUP* v. 4.0b10 (Swofford 2002) to obtain bootstrap support based on 1,000 bootstrap replicates with automatic termination at 10,000 generations under one run in GARLI. Genetic data and the accession numbers of the sequences are listed in the Appendix 1.

Results

Based on the morphological study of the undescribed plant and type specimens of *Bolbitis hainanensis* and *B. virens* var. *compacta* (Suppl. material 1: Figure S2 and S3, respectively), specific characteristics were analysed to separate the three taxa; morphological data in the *Bolbitis* monograph (Hennipman 1977) is also integrated in Table 1. The unknown plant is distinguished from the two morphologically similar species through several characters: smallest fertile pinnae, lanceolate sterile pinna (narrower than others), cuneate bases of sterile pinnae, the smallest angle between veinlets and costae of sterile pinnae and the absence of, or fewer, free veinlets in small areoles of sterile fronds.

The venation in sterile fronds of the unknown plant, *Bolbitis hainanensis*, *B. virens* var. *compacta* and other *Bolbitis* species in Taiwan is illustrated in Fig. 2, showing one

Table 1. Morphological comparisons amongst *Bolbitis lianhuachihensis*, *B. hainanensis* and *B. virens* var. *compacta*.

Characters	*B. lianhuachihensis*	*B. hainanensis*	*B. virens* var. *compacta*
Texture of laminae	Chartaceous	Coriaceous	Chartaceous
Size of fertile pinnae	5–9 × 0.8–1.2 cm	6–10 × 1–1.5 cm	4–11.5 × 0.8–2 cm
Number of lateral pinnae of sterile fronds	1–5 pairs	2–3 pairs	2–7 pairs
Sterile pinna shape	Lanceolate	Oblong-lanceolate	Lanceate
Size of sterile pinnae	14–24 × 3–4.5 cm	17–22 × 5–6 cm	8–23 × 3–4 cm
Bases of sterile pinnae	Cuneate	Narrowly cuneate	Narrowly cuneate or obtuse
Margins of sterile pinnae	Entire	Entire or toothed	Entire
Veinlets with an angle to costae of sterile pinnae	ca. 65°	75°–80°	75°–80°
Row number of areoles between the costae and margins in sterile fronds	2–4 rows	3–4 rows	4–5 rows
Free veinlets in areoles of sterile fronds	Absent or very few	Present	Present

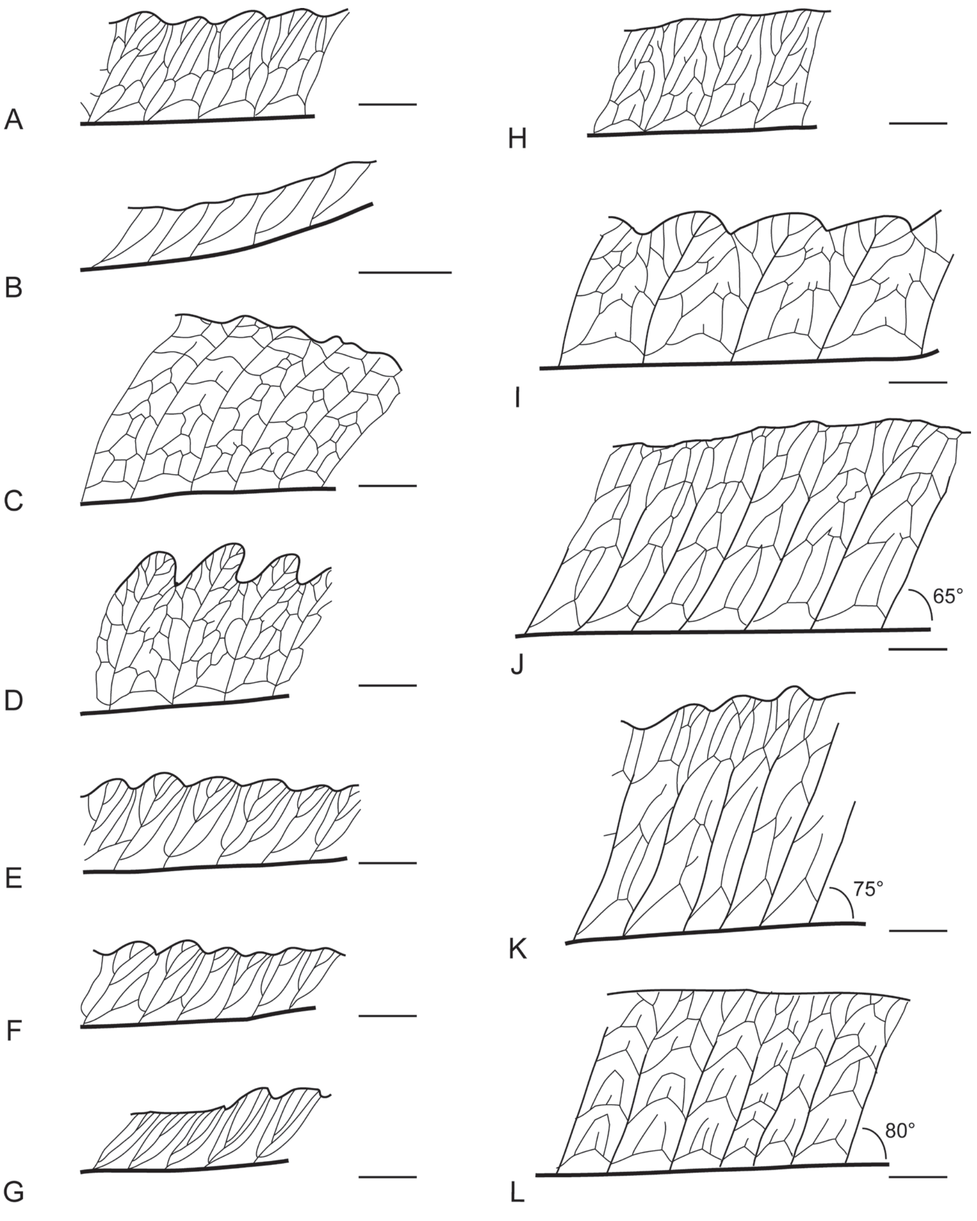

Figure 2. Venation patterns of sterile pinnae from all species of *Bolbitis* in Taiwan **A** *Bolbitis angustipinna* (*Y.-F. Huang 176*, TAIF) **B** *Bolbitis appendiculata* (*Y.-F. Huang* 243, TAIF) **C** *Bolbitis heteroclita* (*Y.-F. Huang* 221, TAIF) **D** *Bolbitis heteroclita* × *subcordata* (*Y.-F. Huang* 366, TAIF) **E** *Bolbitis laxireticulata* (*Y.-F. Huang* 228, TAIF) **F** *Bolbitis* ×*nanjenensis* (*Y.-F. Huang* 213, TAIF) **G** *Bolbitis rhizophylla* (*Y.-F. Huang 124*, TAIF) **H** *Bolbitis scalpturata* (*Y.-F. Huang* 164, TAIF) **I** *Bolbitis subcordata* (*Y.-F. Huang* 254, TAIF) **J** *Bolbitis lianhuachihensis* (holotype specimen, *Y.-S. Chao 3006*, TAIF) **K** *Bolbitis hainanensis* (holotype specimen, *C. Wang 35870*, PE) **L** *Bolbitis virens* var. *compacta* (type specimen, *Tagawa et al. 6802*, L). The angles of veinlets to costae are indicated in *B. lianhuachihensis* (**J**), *B. hainanensis* (**K**), and *B. virens* var. *compacta* (**L**). Scale bars: 5 mm.

side of a pinna of each species. We have found that the venation pattern of some taxa vary between small and larger pinnae, which is also reported by Hennipman (1977). Here we studied the larger pinnae of each taxon. Based on the venation patterns, the examined *Bolbitis* taxa can be divided into three groups: *Bolbitis appendiculata* and *B. rhizophylla* have free veins; *B. laxireticulata* and *B. ×nanjenensis* have mostly free veins and few anastomosing veins; the other species have anastomosing veins. The species with anastomosing veins can be further classified by free veinlets included in areoles or not. *Bolbitis hainanensis*, *B. heteroclita*, *B. scalpturata*, *B. subcordata* and *B. virens* var. *compacta* have free veinlets included in areoles; *B. angustipinna* and the undescribed plant (in pinnae wider than 3.5 cm) have no or very few free veinlets; *B. heteroclita* × *B. subcordata* have few free veinlets. Furthermore, the number of the areole rows between the costae and margins in sterile fronds varies amongst the species. *Bolbitis angustipinna*, *B. scalpturata* and *B. subcordata* have 2–3 rows; *B. hainanensis* and *B. heteroclita* × *B. subcordata* have 3–4 rows; *B. virens* var. *compacta* and the unknown plant have 4–5 rows; *B. heteroclita* has more than 5 rows.

We also find the angles of veinlets to costae to vary. Considering the three similar taxa, the unknown plant has smaller angles than *B. hainanensis* and *B. virens* var. *compacta* (65°< 75° or 80°; Fig. 2 J, K, and L); the latter two taxa have sterile pinnae with veinlets more vertical to the costae than the unknown species (also in the type specimens of the three taxa Suppl. material 1: Figures S1, S2, and S3).

Three presumed hybrid taxa present intermediate venation morphology between their putative parents. *Bolbitis heteroclita* × *B. subcordata* has more free veinlets included in areoles than *B. heteroclita*, but fewer free veinlets included in areoles than *B. subcordata.* Most pinnae of *B. laxireticulata*, like *B. appendiculata*, have free veins, but some pinnae have anastomosing veins, similar to those of *B. subcordata*. Some pinnae of *Bolbitis ×nanjenensis* have free veins like *B. appendiculata*, but some have costal areoles like *B. heteroclita*.

Molecular phylogenetic analyses

The chloroplast DNA (cpDNA) alignment of *rps4-trnS* and *trnL-F* contained 549 bp and 428 bp, respectively, with 239 parsimony-informative sites in total. The log-likelihood score for the most likely ML tree was -4989.8277. Our four specimens of Lienhuachih *Bolbitis* shared the same genotype and occupied a unique place that was well-separated from all other samples species in the phylogenetic tree, different from other Taiwanese *Bolbitis* species and *B. virens* var. *virens* (Fig. 3). In contrast to *B. heteroclita* and *B. subcordata*, the undescribed plant and *B. virens* var. *virens* are in the same clade with unresolved subclades. *Bolbitis virens* var. *virens* and *B. scalpturata* are sister species, then they clustered with *B. crispatula*; the undescribed plant is more phylogenetically distant to *B. virens* var. *virens*.

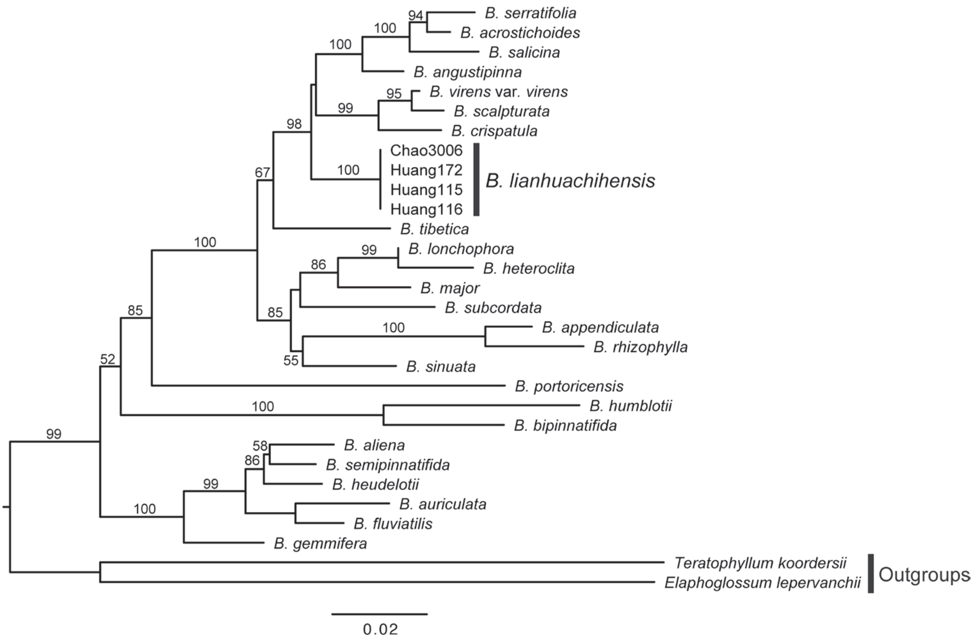

Figure 3. Chloroplast DNA phylogeny of 25 *Bolbitis* species and two outgroups. ML bootstrap support values are indicated on each branch.

Taxonomic treatment

Bolbitis lianhuachihensis Y.S.Chao, Y.F.Huang, & H.Y.Liu, sp. nov.

urn:lsid:ipni.org:names:77201650-1

Fig. 1 and Suppl. material 1: Figures S1

Bolbitis virens var. *compacta* auct. non Hennipman: Knapp, Ferns Fern Allies Taiwan: 440. 2011.

Type. TAIWAN. Nantou County: Lienhuachih, 700 m a.s.l., 11 March 2018, *Yi-Shan Chao 3006* (holotype TAIF!, isotype TAIF!).

Bolbitis lianhuachihensis morphologically resembles *B. virens* var. *compacta* and *B. hainanensis*, from which it is distinguished in having lanceolate sterile pinnae and no free veinlets in areoles of sterile fronds.

Description. Terrestrial or lithophytic. Rhizome short-creeping, thick, densely scaly; scales concolorous, black, lanceolate, 3–5 mm long, 0.5 mm wide, margin entire. Fronds clustered, 40–80 cm long, dimorphic, pinnate. Sterile fronds with stipes 18–50 cm long, near base 2–4 mm diam., scaly, glabrous upwards; lamina broad-ovate, 21–34 × 21–35 cm, chartaceous, conform; lateral pinnae 1–5 pairs, alternate, lanceolate, 14–24 × 3–4.5 cm, bases cuneate, margins entire, undulate, apices caudate or acuminate, basal two pairs of pinnae with winged petiolules < 8 mm; terminal pinna larger or similar to lateral pinnae, sometimes with a bulbil near the apex; veins reticulate, 2–4 rows, no or very few areoles with free veinlets in the largest pinnae (wider than 3.5 cm). Fertile fronds longer than or as long as the sterile ones; stipes 35–50 cm long; lamina oblong-ovate, 7.5–14.5 × 12–18 cm; pinnae 3–4 pairs, alternate, lanceolate, 5–7.5 × 0.8–1.2 cm, base narrow-cuneate, apex acuminate, stalked. Sporangia acrostichoid.

Additional specimens examined. TAIWAN. Chiayi County: Tsenwen Dam, 24 Jan. 1987, *Bi-Jao Wang 10039*, *11009* (HAST, TAIF). **Nantou County:** Lienhuachih, 700 m a.s.l., *Yih-Han Chang 20070317-008* (TAIF), 29 Aug. 2009, *Cheng-Wei Chen Wade 955* (TAIF), 22 Mar. 2015, *Cheng-Wei Chen Wade 4181* (TAIF), 29 Jan. 2016, *Yu-Fang Huang 115*, *116*, *117* (TAIF), 10 Oct. 2005, *Ralf Knapp 697* (P), 22 Oct. 2011, *Ralf Knapp 20111022-4* (HAST), 4 Dec. 2012, *Pi-Fong Lu 24940* (TAIF), 23 Apr. 2006, *Wei-Hsiu Wu s.n.* (TAIF); Tiandi, 830 m a.s.l., 8 Aug. 2006, *Ralf Knapp 20060806-18* (HAST, TAIF), 900 m a.s.l., 26 Sep. 2016, *Yu-Fang Huang 172*, *173*, *174* (TAIF).

Distribution. Taiwan (Fig. 4).

Ecology. Evergreen, broad-leaf forests, often near streams, below 1000 m a.s.l.

Etymology. The specific epithet 'lianhuachihensis' refers to the type locality.

Common name (assigned here). Lian Hua Chih Shih Jyue (蓮華池實蕨; Chinese name).

Preliminary conservation assessment. To date, only three small populations of *Bolbitis lianhuachihensis* Y.S.Chao, Y.F.Huang, & H.Y.Liu have been recorded in Taiwan. However, the estimated number of individuals is smaller than 250. It meets the category Endangered (EN D1) based on the IUCN (2017) criteria.

Note. *Bolbitis lianhuachihensis* can be delimited by the combination of anastomosing venation and fewer sterile pinnae than any other species of *Bolbitis* in Taiwan. It was thought to be related to two similar taxa with "thick laminae" in nearby regions, *B. virens* var. *compacta* and *B. hainanensis* (Knapp 2011). However, based on our study, only *B. hainanensis* has coriaceous laminae, thicker than chartaceous laminar of *B. lianhuachihensis* and *B. virens* var. *compacta*. Moreover, *B. lianhuachihensis* has lanceolate sterile pinnae and very few free veinlets in areoles of sterile pinnae wider than 3.5 cm, differing from the two similar taxa.

In this study, we revealed the venation diversity in the Taiwanese *Bolbitis* species and related taxa. Based on the illustration of venation, it is found that every taxon possesses its own venation morphology, supporting the taxonomic value of venation (Hennipman 1977; Moran et al. 2010a). We have applied several characters, including angles of veinlets to costae, free or anastomosing, row number of areoles between the costae and margins in sterile fronds and free veinlets in areoles or not for sterile fronds. We also found that venation patterns are more complicated, composed of multiple areoles, sub-areoles and free veinlets, which is also reported by Hennipman (1977). A character-state change from free venation to anastomosing venation is reported by Moran et al. (2010a). The venation characteristics in *Bolbitis* species are worthy of further investigation and application to the systematic and evolutionary study. To classify and describe the diverse venation morphology in detail would contribute to further studies of *Bolbitis* systematics.

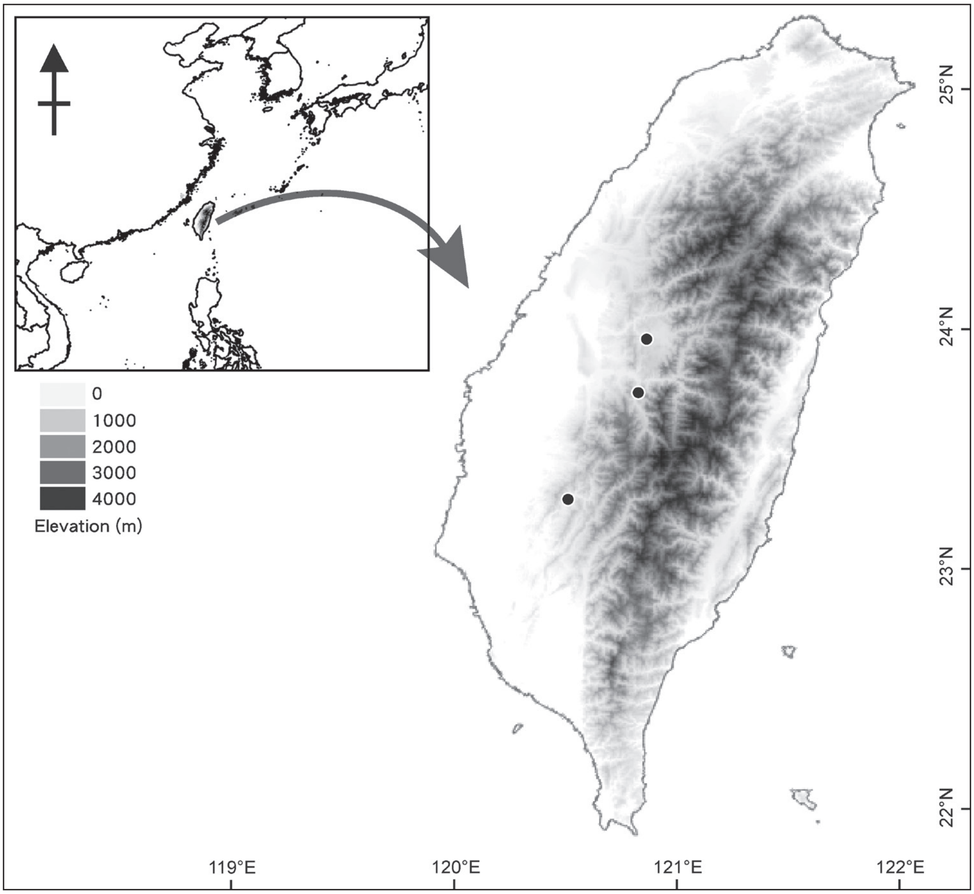

Figure 4. Distribution of *Bolbitis lianhuachihensis* (black circles) in Taiwan.

Key to *Bolbitis* species and hybrids in Taiwan

1 Veins free **2**
– Veins anastomosing **3**
2 Sterile pinnae unequal at base, auriculate; pinna margins with sharp teeth in sinuses .... ***B. appendiculata***
– Sterile pinnae equal at base; pinna margins without sharp teeth .... ***B. rhizophylla***
3 Sterile fronds with few areoles, sometimes only a single series of costal areoles **4**
– Sterile fronds with many areoles, more than one row of areoles between the costae and margins **5**
4 Sterile pinnae linear-lanceolate .... ***B. laxireticulata***
– Sterile pinnae falcate .... ***B. ×nanjenensis***
5 Sterile pinnae linear-lanceolate 6
– Sterile pinnae lanceolate 8

6 Sterile lateral pinnae 15–24 pairs, < 2 cm wide .... ***B. angustipinna***
– Sterile lateral pinnae <10 pairs, > 2 cm wide **7**
7 The space between two secondary veins in sterile pinnae more than 7 mm wide... ***B. subcordata***
– The space between two secondary veins in sterile pinna 3–6 mm wide.......... .... ***B. heteroclita* × *B. subcordata***
8 Sterile terminal pinnae having extremely elongated apex......... ***B. heteroclita***
– Sterile terminal pinnae similar to lateral pinnae **9**
9 Sterile pinnae < 3 cm wide.. ***B. scalpturata***
– Sterile pinnae > 3 cm wide.. ***B. lianhuachihensis***

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Appendix 1

Voucher specimens and GenBank accession numbers for DNA sequences used in this study. Information is presented in the following order: species, voucher, locality, GenBank numbers for *rps4* and *trnL-F*, herbarium. "*"Newly published sequences in this study; "–" no data.

Bolbitis acrostichoides, *Faden s.n.*, Uganda, GU376645, GU376501, US. ***B. aliena,*** *Jimenez 2634*, Bolivia, GU376646, GU376502, NY. ***B. angustipinna,*** *Huang 170*, Taiwan, MK639320*, MK978743*, TAIF. ***B. appendiculata,*** *Huang 0112*, Taiwan, MK639321*, MK978743*, TAIF. ***B. auriculata,*** *Rouhan 183*, Mauritius, GU376650, AY536367, P. ***B. bipinnatifida,*** *Rouhan 155*, Seychelles, GU376676, GU376530, P. ***B. crispatula,*** *Wu et al. 361*, Laos, GU376655, –, MO. ***B. fluviatilis,*** *Carvalho 6457*, Equatorial Guinea, GU376656, GU376510, US. ***B. gemmifera,*** *Fay 1001*, Sierra Leone, GU376657, GU376511, US. ***B. heteroclita,*** *Huang 140*, Taiwan, MK639322*, MK978740*, TAIF. ***B. heudelotii,*** *Fay 1167*, Sierra Leone, GU376662, GU376515, NY. ***B. humblotii,*** *Razafitsalana & Torge 115*, Madagascar, GU376663, GU376516, NY. ***B. lonchophora,*** *Motley 2669*, French Polynesia, GU376664, GU376517, NY. ***B. major,*** *Fraser-Jenkins 1811*, Nepal, GU376665, GU376518, US. ***B. portoricensis,*** *McVaugh 18983*, Mexico, GU376670, GU376523, NY. ***B. rhizophylla,*** *Huang 169*, Taiwan, MK639323*, MK978742*, TAIF. ***B. salicina,*** *Fay 1185*, Sierra Leone, GU376671, GU376525, US. ***B. scalpturata,*** *Huang 164*, Taiwan, MK639324*, MK978741*, TAIF. ***B. semipinnatifida,*** *Steyermark 89173*, Venezuela, GU376672, GU376526, US. ***B. serratifolia,*** *Gutierrez 1014*, Bolivia, GU376673, GU376527, NY. ***B. sinuata,*** *Hoshizaki 1719*, USA, GU376675, GU376529, NY. ***B. subcordata,*** *Huang 106*, Taiwan, MK639325*, MK978736*, TAIF. ***B. tibetica,*** *Fraser-Jenkins 1782*, Nepal, GU376677, GU376531, US. ***B. lianhuachihensis,*** *Chao 3006*, Taiwan, MK978746*, MK978747*, TAIF; *Huang 115*, Taiwan, MK639319*, MK978738*, TAIF; *Y.-F. Huang 116*, Taiwan, MK639318*, MK978737*, TAIF; *Huang 172*, Taiwan, MK639317*, MK978744*, TAIF. ***B. virens* var. *virens,*** *Lu 19796*, China, MK639326*, MK978745*, TAIF. ***Elaphoglossum lepervanchii,*** *Rakotondrainibe 6359*, Madagascar, AY540228, AY536323, P. ***Teratophyllum koordersii,*** *Price 981*, Philippines, GU376715, GU376566, US.

Supplementary material 1

Figures S1–S4.

Authors: Yi-Shan Chao, Yu-Fang Huang, Shi-Yong Dong, Yao-Moan Huang, Ho-Yih Liu

Data type: species data

Explanation note: **Figure S1.** Holotype of *Bolbitis lianhuachihensis* at TAIF (Y.-S Chao 3006). **Figure S2** Holotype of *Bolbitis hainanensis* at PE (C. Wang 35870). **Figure S3.** Holotype specimen of *Bolbitis virens* var. *compacta* at L (*Tagawa et al. 6802*). **Figure S4.** Holotype of *Bolbitis virens* at K (*Wallich 1033*).

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RESEARCH ARTICLE

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Oreocharis tetrapterus (Gesneriaceae), a new species from East Guangxi, China

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Abstract

A new species, *Oreocharis tetrapterus* F.Wen, B.Pan & T.V.Do (Gesneriaceae) from Gupo Mountain area, Hezhou city, Guangxi Zhuangzu Autonomous Region, China, is described and illustrated. The new species has a zygomorphic tetramerous corolla with two adaxial and two abaxial lobes and two fertile stamens in the posterior position, making this a unique combination of floral characteristics in the expanded *Oreocharis*.

Keywords

Didymocarpinae, Didymocarpoideae, Flora of Guangxi, Gupo Mountain Area, New taxon, Trichosporeae

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* These authors contributed equally to this work as first authors.

Introduction

In 2011, *Oreocharis* Bentham was redefined (Möller et al. 2011), and soon afterwards, this genus rapidly grew with the addition of many new species. *Oreocharis sensu lato* now comprises at least 125 species (Möller et al. 2016, Möller 2019). *Oreocharis* is quasi-endemic to China because there are about 14 species distributed in other countries apart from China: namely, *O. primuloides* (Miq.) Benth. & Hook.f. ex Clarke (Japan), *O. hirsuta* Barnett (Thailand), *O. muscicola* (Craib) Mich.Möller & A.Weber (Bhutan, India, Myanmar), *O. longifolia* (Craib) Mich.Möller & A.Weber (Myanmar) and nine species from Vietnam (Wang et al. 1990, 1998, Li and Wang 2004, Wei et al. 2010, Do et al. 2017, Chen et al. 2017, 2018, Möller et al. 2018, Möller 2019).

A joint expedition from the Gesneriad Conservation Center of China (GCCC), Guilin Botanical Garden and Vietnam National Museum of Nature yielded collections of flowering specimens and living plants of an unidentified species of Gesneriaceae in August 2016. Plants raised in cultivation in the GCCC greenhouse from these collected living plants and seeds flowered in 2018. We carefully observed its habit (leaves in basal rosette), flower shape (infundibuliform corolla), number of fertile stamens (two, free, in the posterior position), filament shape (nearly straight) and capsule shape (long and cylindrical bivalved capsules with loculicidal dehiscenc), and identified it as belonging to the expanded *Oreocharis* (Wang et al. 1990, 1998; Möller et al. 2011). The expanded *Oreocharis* includes species of the former *Opithandra* B.L. Burtt (Burtt 1958) that were characterized by two stamens in the posterior position similar to the new species described here (Möller et al. 2011).

Following a careful review of the relevant herbarium specimens and taxonomic publications of *Oreocharis* from Guangxi and adjacent regions, we concluded that this species is new to science. The unusual characteristics of two stamens and zygomorphic flower with 2-lobed upper and lower lips are very rare in the expanded *Oreocharis*. *Oreocharis tetrapterus* F. Wen, B. Pan & T.V. Do is described and illustrated below.

Material and methods

We performed and described the measurements and morphological character assessments of the new species by using collected specimens by BP, GDT, TVD, CLD and FW, living material observed in the field, and cultivated at the nursery of GCCC. All available *Oreocharis* specimens of China, Thailand and Vietnam, stored in the following herbaria were examined: E, GH, HN, IBK, K, KUN, MO, PE, PH, US and VNMN. At the same time, specimen images and name lists of the above-mentioned species (all species belong to former *Opithandra* but now transferred to *Oreocharis*) were obtained and checked from Tropicos (http://www.tropicos.org), JSTOR Global Plants (http://plants.jstor.org), The Plant List (http://www.plantlist.org/) and the International Plant Names Index (http://www. ipni.org). We studied all morphological characters under dissecting microscopes, and described the morphological identification and characters of this new species by using the terminology used by Wang et al. (1998).

Taxonomic treatment

***Oreocharis tetrapterus* F.Wen, B.Pan & T.V.Do, sp. nov.**
urn: lsid: ipni.org: names:60479368-2
Figures 1–3, 4A

Diagnosis. The large bright yellow corolla is 2 lobed with the adaxial and abaxial lips both consistently 2-lobed, with irregular dark reddish-brown spots on the interior surfaces of the corolla lobes and 2 fertile stamens in posterior position distinguishes *Oreocharis tetrapterus* from all other species of *Oreocharis* s. l.

Type. CHINA. Guangxi: Hezhou City, Lisong Town, Gupo Mountain, 24°39'N, 111°36'E, elev. ca. 950 m, on moist surface of granite rocks, in flowering, 25 August 2018, *Wen Fang WF160825-01* (holotype: IBK!, isotype: IBK!).

Description. Perennial herb, rhizome stem inconspicuous, 4–10 mm long, 3–4 mm in diam. Leaves 8–14, in basal rosette; petiole cylindric, 1–5 cm long, 2–3 mm in diam., sparsely to densely curly brown pubescent; leaf blade green to dark green, ovate to broadly elliptic, 3.0–5.5 × 2.2–3.5 cm, adaxially pubescent with nearly erect white hairs, abaxially sparsely pubescent to nearly glabrous but with dense white, slightly curly pubescence along main and lateral veins, lateral veins 5–6 on each side of midrib, adaxially inconspicuously sunk, adaxially conspicuously raised, apex obtuse to rounded, base often slightly asymmetric, margin crenate with 15–20 teeth on each side, more obvious on the lower half. Cymes axillary, inflorescence (1-)2–4-flowered; peduncle greenish brown to brown, 4–8 cm long, ca. 1.5 mm in diam., densely white pubescent; bracts 2, opposite, lanceolate to linear, ca. 5.0 × 1.0–1.5 mm, adaxially appressed white pubescent, abaxially nearly glabrous, margin nearly entire; pedicel green, 7–12 mm long, ca. 1 mm in diam., pubescent with dense, nearly erect hairs . Calyx green, 4-lobed to the base, lobes nearly equal, linear, 6–8 mm long, ca. 1.2 mm wide at base, outside white pubescent, inside glabrous. Corolla 2.2–2.8 cm long, bright yellow, inner side of corolla lobes with irregular dark reddish-brown spots, sometimes entire upper lobes reddish-brown, outside densely white glandular- and eglandular-pubescent, inside glandular puberulent in the throat and on adaxial lobes, tube broadly infundibuliform, 1.8–2.5 cm long, 6.5–8.5 mm in diam.; limb 2-lipped; adaxial lip 2-lobed divided to more than halfway, lobes broadly oblong to semiorbicular, 5–7 × 7–8 mm, abaxial lip 2-lobed to base, oblong, 8–10 × 5.5–7 mm. Stamens 2, in posterior position, 1.5–1.8 cm long, adnate to corolla 6–8 mm from base; filaments linear, yellow, glabrous; anthers narrowly horseshoe-shaped, apex acute, 2-loculed, dehiscing longitudinally; staminode 1, ca. 1.5 mm long, inserted at tube base. Disc tubular, ca. 5 mm high, yellowish green, margin undulate. Pistil 2.5–3 cm long when all corolla lobes outspread and flower completely opened; ovary green, cylindrical, glabrous, 1.8–2 cm long; style pale green, glabrous, 6–10 mm long; stigma bilobed, flabellate, pale green. Capsule linear, dehiscent but commonly one side of the capsule dehiscent first, loculicidal, straight in relation to pedicel, 3.5–4.5 cm long.

Phenology. Flowering in August; fruiting in October.

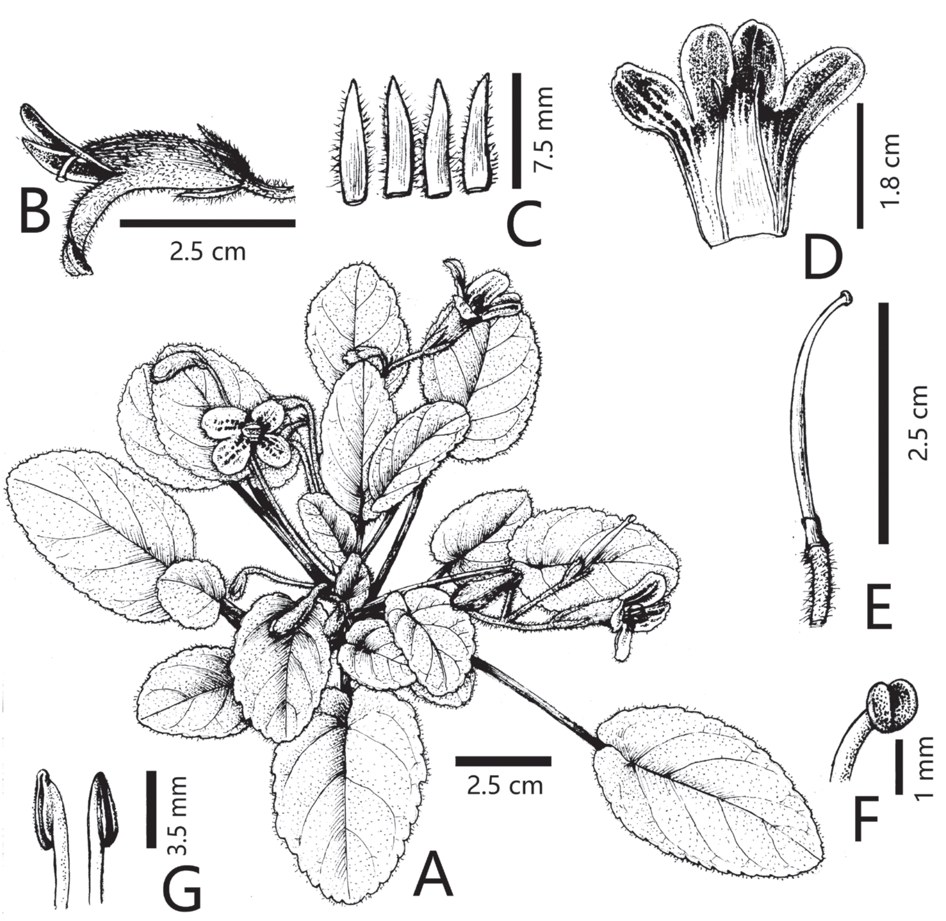

Figure 1. *Oreocharis tetrapterus* F.Wen, B.Pan & T.V.Do sp. nov. **A** habit **B** lateral view of flower **C** adaxial surfaces of calyx lobes **D** opened corolla for showing the two fertile stamens in posterior position **E** pistil with disc, sepals removed **F** stigma **G** anthers in side view. Drawn by Wen-Hong Lin from the holotype.

Etymology. The specific epithet, 'tetrapterus' from the Greek meaning having four wings or wing-like appendages. Here it refers to the four 'wing-like' lobes of the corolla, with adaxial and abaxial lips both having 2 lobes.,

Vernacular name. The Chinese name of this new species is 姑婆山马铃苣苔. The pronunciation of the Chinese of this species is 'Gū Pó Shān Mǎ Líng Jù Tái'.

Distribution and ecology. *Oreocharis tetrapterus* is currently known only from one population of ca. 50 individuals at the type locality. The species may be endangered, but more data is needed to evaluate this reliably. The species grows on moist surfaces, on moss-covered granite rocks with other plants under subtropical bamboo and evergreen broad-leaved forest cover in Hezhou City, Guangxi.

Notes. We understand most other Gesneriaceae with two stamens have them in the anterior position, but this special character, two stamens in the posterior position, has also evolved outside the *Oerocharis* s. l. in the South American *Sarmienta* Ruiz & Pavon

Figure 2. *Oreocharis tetrapterus* F.Wen, B.Pan & T.V.Do sp. nov. in its natural habitat **A** habitat **B** flowering plant **C** plant with flowering cymes **D** frontal view of corolla **E** lateral view of corolla **F** top view of corolla. Photographed by Bo Pan and Fang Wen, charted by Wen-Hua Xu.

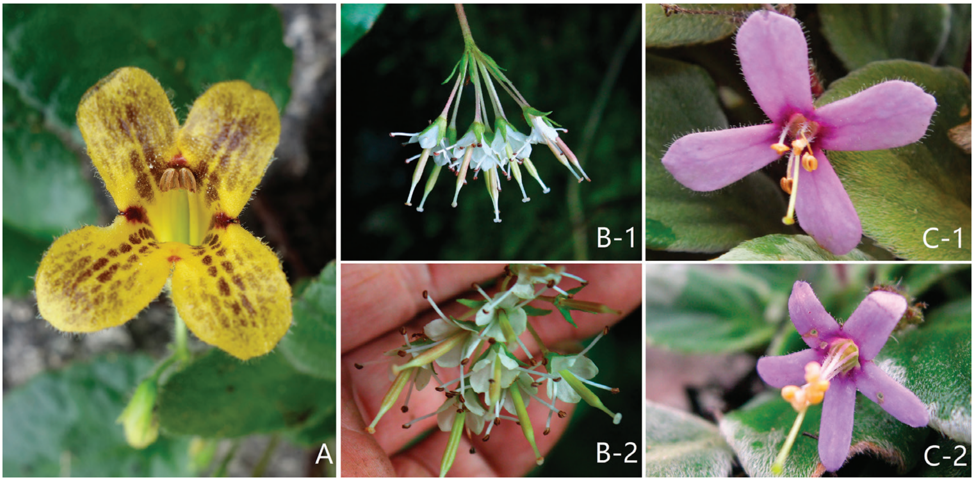

Figure 3. *Oreocharis tetrapterus* F.Wen, B.Pan & T.V.Do sp. nov. **A** lateral view of flower **B** top view of flower **C** lateral view of corolla and pistil and calyx lobes **D** adaxial surface of calyx lobes **E** abaxial surface of calyx lobes **F** pistil, sepals removed **G** opened corolla for showing stamens in posterior position **H** anthers, abaxial view? **I** adaxial leaf surface **J** abaxial leaf surface **K** peduncle indumentum. Photographed by Fang Wen and Bo Pan in the field, charted by Wen-Hua Xu.

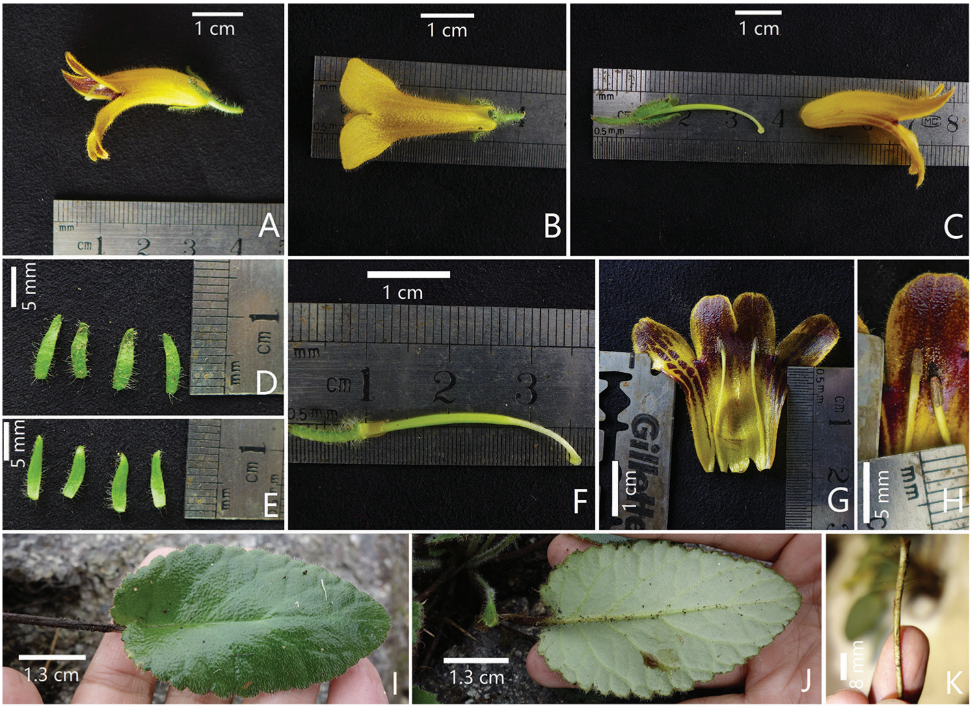

Figure 4. Some species in *Oreocharis* with typically four corolla lobes **A** *Oreocharis tetrapterus* F.Wen, B.Pan & T.V.Do sp. nov. **B** *O. sinensis* (Oliv.) Mich.Möller & A.Weber (**1** Lateral view of flowering cyme **2** Frontal view of flowering cyme) **D** *O. esquirolii* Léveillé (**1** Corolla with four lobes and four stamens **2** Corolla with five lobes and five stamens). Photographed by Fang Wen and Bo Pan, charted by Wen-Hua Xu.

(Ruiz and Pavon 1794) and the Asian/African *Epithema* Blume (Blume 1826, Bransgrove and Middleton 2015). *Oreocharis tetrapterus* is morphologically unique within *Oreocharis* s. l. and can be easily distinguished from the other species with four lobes by its zygomorphic corolla, whereas the others are actinomorphic, for example *O. sinensis* and *O. esquirolii* (*O. esquirolii* also has 5-lobed corolla type, occasionally) (Fig. 4).

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Conservation priorities and distribution patterns of vascular plant species along environmental gradients in Aberdare ranges forest

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Abstract

Distribution patterns of biodiversity and the factors influencing them are important in conservation and management strategies of natural resources. With impending threats from increased human population and global climatic changes, there is an urgent need for a comprehensive understanding of these patterns, more so in species-rich tropical montane ecosystems where little is known about plant diversity and distribution. Vascular species richness along elevation and climatic gradients of Aberdare ranges forest were explored. A total of 1337 species in 137 families, 606 genera, 82 subspecies and 80 varieties were recorded. Correlations, simple linear regression and Partial least square regression analysis were used to assess richness and diversity patterns of total plants, herbs, shrubs, climbers, arboreal and endemic species from 2000–4000 m above sea level. Total plant species richness showed a monotonic declining relationship with elevation with richness maxima at 2000–2100 m a.s.l., while endemic species richness had a positive unimodal increase along elevation with peaks at 3600–3700 m a.s.l. Herbs, shrubs, climbers and arboreal had significant negative relationships with altitude, excluding endemism which showed positive relations. In contrast, both air and soil temperatures had positive relationships with taxa richness groups and negative relations with endemic species. Elevation was found to have higher relative influence on plant richness and distribution in Aberdare ranges forest. For effective conservation and management of biodiversity in Aberdare, localized dynamic conservation interventions are recommended in contrast to broad and static strategies. Establishment of conservation zones and migration corridors are necessary to safeguard biodiversity in line with envisaged global climatic vicissitudes.

Keywords
Aberdare ranges, conservation, elevation, species richness, temperature, vascular plants

Introduction

Tropical afromontane ecosystems are renowned hotspots of biological diversity often with significant numbers of endemic species (Mittermeier et al. 1998; Lovett et al. 2005; Sosef et al. 2017). A combination of non-random climatic and abiotic gradients, and evolutionary processes in montane forests have been reported to influence the myriad distribution patterns and composition of plants' communities found along these mountains (Lomolino 2001). Since montane ecosystems are small and isolated from other similar ecosystems, plant communities in these regions face relatively high extinction rates and low immigration rates (Newmark and McNeally 2018). Therefore, to sustainably manage and conserve these ecosystems an authentic conceptual framework (comprehensive understanding) of species richness and distribution patterns is a prerequisite (Lovett et al. 2005; Sosef et al. 2017; Anderson-Teixeira 2018). According to Dyakov (2010), plant species are distributed in variable habitats but are most abundant in areas which represent their ecological optimum. Also, Lovett (1999) argued that these plants' composition and distribution patterns reflect the underlying anthropogenic disturbances. Therefore, an understanding of these patterns can be used to prioritize regions that either need immediate or different management interventions so as to conserve the targeted species.

Previous studies have reported a significant relationship between elevation and plant communities, indicating that elevation is a strong predictor of vegetation structure and richness (Lomolino 2001, Berhanu et al. 2017). However, the extent of its influences remains unclear since it has both indirect effect on species richness and direct effects on environmental complexes (i.e., temperature, growing season, precipitation, wind velocity, atmospheric pressure and evaporation) which are also crucial in spatial patterns of plants (Whittaker 1967; Blundo et al. 2012; Dyakov 2014). Thus, the trends observed in spatial patterns on a mountainous ecosystem cannot be explained by a single factor but rather by an interaction of multiple factors (Lee et al. 2013; Trigas et al. 2013). The effects of these environmental factors are dynamic and vary among different plant groups and growth forms (Zhou et al. 2019). Bhattarai and Vetaas (2003) found significant trends between woody life forms and elevation gradient, but none among the herbaceous species of the Himalayas in Nepal. Dissimilar distribution of plant communities in relation to environmental gradients has been described in many studies (Hamilton and Perrott 1981; Lovett 1996; Grytnes and Vetaas 2002; Vetaas and Grytnes 2002; Bhattarai and Vetaas 2003; Schmitt et al. 2010; Lee et al. 2013; Trigas et al. 2013; Berhanu et al. 2017).

The Aberdare ranges present an interesting ecosystem in that the northern part of this forest is almost at the equator and the western slopes form part of the easternmost wall of the Gregory Rift valley (Schmitt 1991; Bennun and Njoroge 1999). It is one of the five major water catchment towers in Kenya with three major rivers emanating from this forest, i.e. the Tana, Athi and Ewaso Ng'iro rivers (Muiruri 1978; KFS 2010). Overall, the Aberdare forest provides invaluable social, economic and environmental benefits with estimates indicating that at least one in three people in Kenya depends in some way on the natural resources from this ecosystem (Ark and Group 2011; Rhino 2016). These ranges are renowned for their geographically diverse taxa and high endemism (Hedberg 1964; Hedberg and Hedberg 1979) due to wide elevational gradient and other biotic and abiotic factors (Schmitt 1991; Lambrechts et al. 2003; KFS 2010). The heterogeneous flora along the altitude breath stands out as unique biota above the warmer plains surrounding these volcanoes (Hedberg and Hedberg 1979). Despite its complex vegetation diversity, little has been done to quantify the species richness, composition and altitudinal turnover in this afromontane forest. This study, therefore, aimed at describing the overall floral richness patterns and identify areas with strikingly unique richness so as to provide a baseline framework for immediate or future localized and effective conservation strategies. The specific objectives of the study were to (a) investigate the distribution patterns of the plants, herbs, shrubs, climbers, arboreal and endemic species in Aberdare ranges, (b) explore the degree of influence of elevation, air and soil temperatures on the richness patterns of the same taxon groups, and (c) evaluate conservation priorities based on observed species richness and distribution patterns for the entire Aberdare ecosystem.

Materials and methods

Study site

The study was carried out in the Aberdare mountains, located in central parts of Kenya (Bennun and Njoroge 1999). It stretches for 120 km from north to south from latitude 00°08' to 00°42' south, with an expanse of about 40 km across at its widest point between longitude 36°31' to 35°57' east (Butynski 1999) (Fig. 1). The Aberdare ranges are characterized by undulating hills formed through uplift and warping, then later shaped by volcanism and faulting of the earth surface from early Tertiary to the Pleistocene (Peltorinne 2004), giving rise to geographically isolated islands of complex tropical-alpine vegetation (Hedberg 1964). There are two main peaks; Oldonyo Lesatima (4000 m a.s.l.) to the north and Il Kinangop (3906 m a.s.l.) to the south, separated by a long stretch of land above 3000 m elevation (Muiruri 1978; Bennun and Njoroge 1999). Aberdare exhibits a unique topography sloping gradually to the East while, in contrast, the western slopes drop rapidly along imposing fault escarpments towards the Kinangop plateau and finally the Gregory Rift Valley, giving way to a number of torrential waterfalls that cascade into deep u-shaped ravines (KFS 2010; KWS 2010).

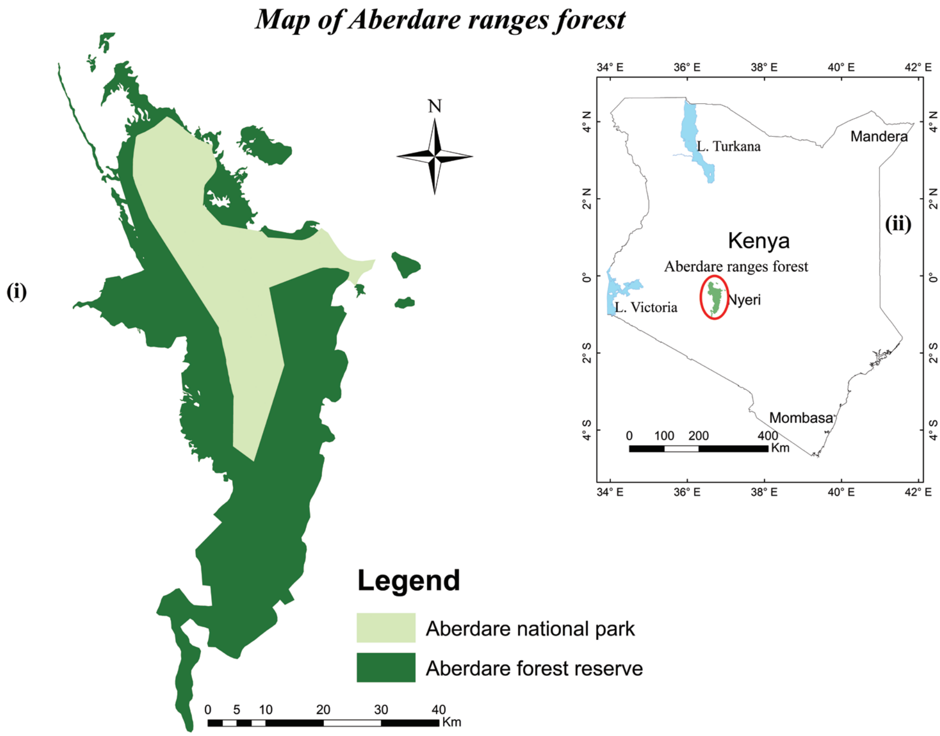

Figure 1. The location of Aberdare ranges forest, (**i**) two sections of forest (**ii**) map of Kenya.

Similar to other East African mountains, vegetation in Aberdare is typical afromontane type characterized by heterogeneous vegetation structure along the elevational gradients (Hedberg 1951; Myers et al. 2000). Three broad vegetation zonations have been described by Schmitt (1991) based on floristic compositions, including the montane forest belt at lower altitudes, the subalpine zone at mid elevation, and the alpine zone at the summit. Administratively, this forest is managed in two sections, i.e., Aberdare national park, size *ca.* 76700 ha., managed by Kenya Wildlife Service (KWS), and Aberdare forest reserve, size *ca.* 139500 ha., governed by Kenya Forest Service (KFS). The national park is situated at higher elevations above *ca.* 2600 m a.s.l. and the regions below this park constitute the forest reserve composed of three forest blocks, Aberdare, Kikuyu escarpment, and Kipipiri forest reserve (KWS 2010; KFS 2010, Lambrechts et al. 2003). Altitude is from 1800 m to 4000 m a.s.l. (Bennun and Njoroge 1999). Climate in Aberdare forest is dominated by the passage of the Inter-Tropical Convergence Zone north and south during its annual cycle, producing a bimodal rainfall distribution (CEPF 2012). Long rains usually come from March to May and short rains from October to November (Lambrechts et al. 2003; KFS 2010). Annual rainfall varies with altitude and exposure to the dominant winds from the Indian Ocean, ranging from 1000 mm on the drier north-western slopes to as much as

3000 mm on the south-eastern slopes (Bennun and Njoroge 1999). The mean maximum temperature is 25.8 °C. while mean minimum temperature is 10.3 °C. (KFS 2010; CEPF 2012).

Data Sources

The floristic surveys were carried out from the year 2016 to 2018, during the optimum flowering and fruiting periods which were mainly after the long and short rains of March-May and November-December respectively. A team of botanists from the National Museums of Kenya and Sino-Africa Joint Research Center undertook the surveys. Fertile voucher plant specimens, with either flower, fruit or both were collected, pressed, and dried. Specimens were identified to species level using varied taxonomic monographs and botanical guide books (FTEA 1952–2012; Blundell 1992; Agnew and Agnew 1994; Beentje et al. 1994; Agnew 2013). Plant species were further categorized into their life forms, including (i) herbs (plants less than 50 cm or less than 100 cm but annual), (ii) shrubs (plants between 50cm to 5 m tall), (iii) climbers (plants with twining herbaceous or woody stems), and (iv) arboreal (plants taller than 5m) (Raunkiaer 1934, Schmitt 1991, Bao et al. 2018). Finally, the dried voucher specimens were deposited in the East African Herbarium (EA), Nairobi, and Wuhan Botanical Garden herbarium (HIB), China.

Endemic species were recorded from published literature and updated by cross-checking with the online occurrence data in Global Biodiversity Information Facility (**GBIF**) (https://www.gbif.org). In addition to field collections, other plant species in Aberdare ranges forest were obtained from the previously collected specimens in the EA herbarium catalogues, series of Flora of Tropical East Africa (FTEA) and other standard references (e.g., Schmitt 1991). Relative altitude range sizes of plant species in Aberdare i.e., the maximum and minimum altitude where a species has been previously recorded or collected, were determined from our collections, as well as from other specimens in the EA herbarium and the standard botanical references. Based on the contemporary description of the Flora of Kenya, information on the floral species and their geographical distributions was considered adequate for this study.

Both air and soil temperature data were obtained from Schmitt (1991), where he calculated the average air temperature from 28 months' recordings from four locations at different altitudes in Aberdare ranges. Extrapolation was done based on a calculation from East African Meteorological Department (1970) of a decrease of 1.7 °C. for every 1000 feet of altitude equivalent to 0.56 °C. per 100 m elevation. Regarding the soil temperature, Schmitt (1991) obtained the mean of 9 months recordings at 70 cm depth of soil in eight different elevations in the Aberdare ranges. He calculated an average of 0.52 °C. decrease per 100m elevation between 1900–3200 m a.s.l. and 1.5 °C. decrease per 100 m between 3200–3600 m a.s.l. (Braun 1986; Schmitt 1991). This criterion was applied to calculate soil temperatures at altitude bands where there were no recordings.

Data analysis

The Aberdare mountain rises from 1800–4000 m a.s.l. However, the onset of continuous forest cover differs in elevation at various sites of forest edges. To control the biases of uneven elevation of forest margins and disjunct forest blocks, we analyzed species from 2000–4000 m a.s.l. as this represents relatively the continuous forest cover in the entire ecosystem (Schmitt 1991, Butynski 1999). Elevation gradient was divided into 20 bands of 100 m interval between the 2000–4000 m altitude in the same manner as Vetaas and Grytnes (2002), Bhattarai et al. (2004) and Grau et al. (2007). Recorded plant species were then interpolated at these 20 100 m bands giving an estimate of gamma diversity defined by Lomolino (2001) as total richness of an entire elevation band. The assumption here was that each species was present in all the elevation bands within its altitude range size, ignoring any disjunctions in its distribution along elevation gradient. Interpolation of species facilitates analysis where there is incomplete sampling as in this study. A comparative analysis conducted on empirical and interpolated species richness data of the Baekdudaegan mountains of South Korea showed similar spatial distribution patterns (Lee et al. 2013). Hence interpolation of taxon richness was best suited for our study as it can give reliable results similar to complete sampling. Each plant species, subspecies or varieties were treated as individual taxa. The relationship between all these plant groups and elevation, air temperature and soil temperature were investigated in IBM SPSS statistic 25 software.

Descriptive statistics were explored to interpret data distributions and normality tests (Table 1). Moderate skewness and negative kurtosis were observed indicating nearly normal distributions as they were below 1 and 2.5 respectively (Zhao and Fang 2006). Arboreals were square-root transformed since it failed Kolmogorov-smirnov normality tests ($P < 0.023$). No transformations were done for other groups as their distributions were normal ($P > 0.05$). Simple scatter plots were used to observe if non-linear relationship existed between plant groups and combined environmental variables studied. All plant groups showed linear relationship, hence Pearson's Correlation analysis was done. Multiple regression model was best suited for data analysis, however,

Table 1. Summary of descriptive statistics of environmental factors and vascular plants groups in Aberdare ranges forest.

Variables	N	Minimum	Maximum	Mean	SD	Skewness	Kurtosis	K-S (P)
Environmental factors								
Elevation	20	2050	3950	3000	132.288	0	-1.200	0.2
Air temperature	20	3.86	16.58	9.73	4.129	0.393	-1.063	0.2
Soil temperature	20	1.3	18.02	11.47	5.098	-0.602	-0.763	0.2
Species richness								
Total plants	1337	171	1032	593.15	62.952	0.087	-1.401	0.2
Endemic species	63	20	37	28.35	6.124	0.027	-1.737	0.124
Plant Life forms								
Herbs	888	144	691	446.25	191.877	-0.224	-1.443	0.2
Climbers	101	2	83	33.15	28.372	0.424	-1.349	0.095
Shrubs	198	24	151	76.05	41.19	0.572	-0.997	0.135
Arboreal	150	1	116	37.7	38.811	0.996	-0.408	0.023

there was significant multicollinearity between the predictors (r > 0.07), which would have given unreliable results. Therefore, Partial Least Squares (PLS) regression model was used (Tobias 1995). PLS regression is robust in multicollinear variables and it focuses on components with maximum covariance with dependent variable (Maestre 2004; Davis et al. 2007; Carrascal et al. 2009), hence, an environmental factor with the highest projection on richness patterns of plants groups could be identified through this model. Relative importance of individual predictor was evaluated using Variable Importance in Projection (VIP) values i.e., the higher the VIP the higher the importance in projection. PLS regression with a Python 2.7 extension module was used in IBM SPSS statistic 25 software. In addition to PLS regression, simple linear regression of each environmental factor on each studied plant group was also calculated.

Results

The Aberdare ranges forest has high plant diversity. The majority of the plants recorded were seed plants totaling 1255 taxa including forbes while 86 were ferns. The top-ranking families as per the number of taxa were Asteraceae 11%, Poaceae 8%, Fabaceae 7%, Lamiaceae 4%, Cyperaceae 4%, Rubiaceae 4%, Euphorbiaceae 3% and Orchidaceae 3%. Other families had fewer species with some having a single species. According to plant life forms, most taxa were herbs 64.2%, then shrubs 11.9%, arboreal 11.5% and climbers were 7.5% of the total taxa recorded (Fig. 2). Endemic species composed of varied life forms were 4.7% of the total taxa recorded. Average altitude range for total taxa excluding endemic species was 1585 m. Among the life forms, herbs had the highest average altitude range at 1614 m, climbers 1578 m, shrubs 1490 m, and the lowest was arboreal at 1350 m. Endemic species had the lowest average altitude range of 1139 m.

Pearson's correlation analysis showed significant relationship between total plants, endemic species, life forms groups and environmental variables (see Table 2). Elevation

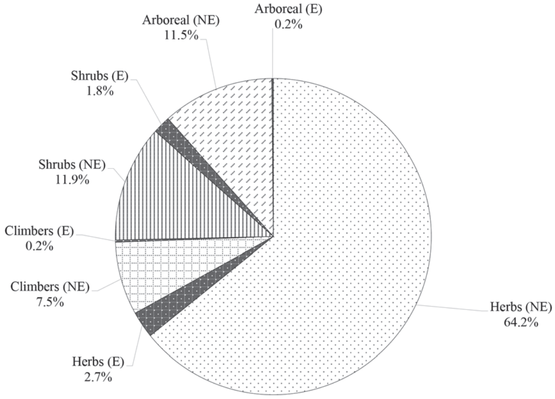

Figure 2. Proportions of endemic and non-endemic plants species life forms. (E – endemics, NE – non endemics).

Table 2. Correlation analysis between environmental factors and plant species groups.

		Correlations								
		Altitude	**Air temp.**	**Soil temp.**	**Total plants**	**Herbs**	**Shrubs**	**Climbers**	**(Sqrt) Arboreal**	**Ende-mics**
Altitude	Pearson Correlation	1	-.985**	-.977**	-.997**	-.991**	-.975**	-.977**	-.984**	.832**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N		20	20	20	20	20	20	20	20
Air temp.	Pearson Correlation		1	.938**	.987**	.963**	.992**	.982**	.994**	-.806**
	Sig. (2-tailed)			0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N			20	20	20	20	20	20	20
Soil temp.	Pearson Correlation			1	.965**	.984**	.912**	.913**	.932**	-.767**
	Sig. (2-tailed)				0.000	0.000	0.000	0.000	0.000	0.000
	N				20	20	20	20	20	20
Total plants	Pearson Correlation				1	.991**	.981**	.985**	.988**	-.853**
	Sig. (2-tailed)					0.000	0.000	0.000	0.000	0.000
	N					20	20	20	20	20
Herbs	Pearson Correlation					1	.948**	.959**	.961**	-.844**
	Sig. (2-tailed)						0.000	0.000	0.000	0.000
	N						20	20	20	20
Shrubs	Pearson Correlation						1	.989**	.995**	-.825**
	Sig. (2-tailed)							0.000	0.000	0.000
	N							20	20	20
Climbers	Pearson Correlation							1	.988**	-.877**
	Sig. (2-tailed)								0.000	0.000
	N								20	20
(Sqrt) Arboreal	Pearson Correlation								1	-.828**
	Sig. (2-tailed)									0.000
	N									20
Endemics	Pearson Correlation									1

**. Correlation is significant at the 0.01 level (2-tailed). (Sprt) refers to transformed variable by square rooting

had negative correlation with herbs, shrubs, climbers and arboreal. Total plants also had negative correlation with elevation but endemic species showed a weak positive relationship. Both air and soil temperatures showed significant positive relations with all life form groups. Endemic species had negative correlations with air and soil temperature while total plants had positive relationship with both temperatures. Simple linear regression indicated variations in richness patterns of the studied taxa groups. Elevation explained 99.3% of total plant richness and 69.2% for endemic species. Air and soil temperatures also had higher influence on total plant richness explaining 97.4% and 93.2% respectively. Strikingly, temperature variables showed lower prediction on endemic species with just 64.9% explained by air temperature and 58.9% by soil temperatures. In general, all the environmental factors had significant prediction on all life form groups' richness and distribution patterns (*P* < 0.000) (Table 2). Soil temperature was found to have the least influence on richness patterns prediction compared to other environmental factors.

Total plants showed significant monotonic declining trend with increasing elevation ($\beta = -0.997$, $R^2 = 0.95$). Total plants species richness peaked at 2000–2100 m a.s.l. with 1032 taxa then gradually declined to just 171 taxa at the summit of the mountain. On the contrary, endemic species increased with increasing elevation ($\beta = 0.832$, $R^2 = 0.692$) with richness maximum at 3300–3700 m a.s.l., suggesting that endemism was favored in high altitudes with associated harsh climatic conditions. Similar significant monotonic declining trends along the altitude were also observed among the life forms groups; herbs ($\beta = -0.991$, $R^2 = 0.982$), shrubs ($\beta = -0.975$, $R^2 = 0.950$), climbers ($\beta = -0.977$, $R^2 = 0.954$), and aboreals ($\beta = -984$, $R^2 = 0.983$). Trends of life form groups along air and soil temperature gradients are listed in Table 3.

PLS regression model indicated the importance of each studied environmental factor in projecting richness patterns among the studied groups. Elevation, air and soil temperatures projected significant richness trends for total plants ($R^2 = 0.988$) and low projection in endemic richness trends ($R^2 = 0.639$). Other proportions of variance explained by our PLS model in herbs, shrubs, climbers and arboreal were also high and significant (Table 4). Elevation was indicated to have the highest relative importance in richness patterns of all the plant groups (V.I.P. > 1) (Maestre 2004). Air temperature showed high relative importance in projection of all studied groups except for the herbs which was slightly below 1 (Table 4). Soil temperature was the least influencing variable overall in all the studied groups. Elevation had negative and positive relationship with total plants and endemic species respectively. In contrast, air and soil temperatures showed positive relationships with total plants and life form groups but negative relations with endemic species It was interesting to note that similar results shown in correlation and simple linear regression analysis were also observed in PLS model.

Plants of special concern

Aberdare ranges forest harbors a number of globally important plant species. A total of 73 species have been assessed globally to be threatened and 30 species are possibly threatened according to Botanic Gardens Conservation International threat search

Table 3. Simple linear regression of altitude, air temperature, soil temperature and each plant group.

Environmental variables	Total plants	Endemics	Herbs	Shrubs	Climbers	Arboreal
Altitude						
Pearson Correlation (r)	-0.997	0.832	-0.991	-0.975	-0.977	-0.984
Sig (1-tailed) ($p < 0.05$)	0.000	0.000	0.000	0.000	0.000	0.000
Model Summary (R^2)	0.993	0.692	0.982	0.950	0.954	0.969
Air Temperature						
Pearson Correlation (r)	0.987	-0.806	0.963	0.992	0.982	0.994
Sig (1-tailed) ($p < 0.05$)	0.000	0.000	0.000	0.000	0.000	0.000
Model Summary (R^2)	0.974	0.649	0.928	0.984	0.964	0.988
Soil Temperature						
Pearson Correlation (r)	0.965	-0.767	0.984	0.912	0.913	0.932
Sig (1-tailed) ($p < 0.05$)	0.000	0.000	0.000	0.000	0.000	0.000
Model Sum (R^2)	0.932	0.589	0.968	0.832	0.833	0.869

Table 4. Partial least square regression of combined environmental factors and species richness groups.

Species Groups	Parameters	V.I. P	W	L	Proportion of Variances explained (adjusted R^2)
Total Plants					0.988
Elevation	-0.553	1.014	-0.585	-0.583	
Air Temperature	3.423	1.004	0.580	0.575	
Soil Temperature	-9.427	0.982	0.567	0.574	
Endemic species					0.639
Elevation	0.053	1.037	0.599	0.583	
Air Temperature	3.241	1.005	-0.580	-0.576	
Soil Temperature	2.615	0.957	-0.552	-0.574	
Herbs					0.980
Elevation	-0.316	1.012	-0.584	-0.583	
Air Temperature	-10.046	0.984	0.568	0.575	
Soil Temperature	8.803	1.005	0.580	0.574	
Shrubs					0.941
Elevation	-0.066	1.015	-0.586	-0.583	
Air Temperature	5.936	1.033	0.596	0.576	
Soil Temperature	-4.647	0.95	0.548	0.574	
Climbers					0.935
Elevation	-0.098	1.020	-0.589	-0.583	
Air Temperature	-0.743	1.025	0.592	0.576	
Soil Temperature	-5.419	0.953	0.550	0.574	
Arboreals					0.962
Elevation	-0.005	1.014	-0.586	-0.583	
Air Temperature	0.392	1.024	0.591	0.576	
Soil Temperature	-0.241	0.960	0.555	0.574	

2019 (https://tools.bgci.org/threat_search.php). This is a clear indication of the global importance of Aberdare ranges forest as a biodiversity hotspot and the urgent need for effective conservation measures to protect the threatened species and the rich plant diversity in general. The majority of the threatened species were herbs with 70 species, shrubs 12, climbers 11 and the arboreal numbered 10 (see Appendix 1).

Discussion

Plant species richness and distribution patterns

Plants diversity in Aberdare ranges is high, based on the total taxa recorded in our study. This was higher than the previous survey done by Schmitt (1991) which documented 778 species in 128 families and 421 genera. Altitude was found to have relatively higher influence on distribution and richness patterns of plant species in this forest. This suggests that the heterogeneous vegetation structure exhibited in the Aberdare ranges is a manifestation of altitude increase. This phenomenon has attracted a lot of debate with several factors mentioned as explanatories for habitat heterogeneity, e.g., energy, water, soils, and area. However, these factors are known to have direct influence on plant physiological processes which in turn control plant growth and spatial richness; at the same time these factors are directly influenced by altitude (Whittaker 1967; Rahbek

1997; Schmitt et al. 2013; Berhanu et al. 2017). Therefore, altitudinal gradient can be regarded as an overall fundamental factor with indirect effects on species richness patterns. Dyakov (2014) argued that altitude can be used to provide insightful information on plants richness and distribution patterns, especially in ecosystems where other abiotic parameters are missing and this notion has been supported by this study. Total plant species in Aberdare showed a monotonic declining relationship with optimum altitude ranging between 2000–2100 m a.s.l., which was simply the foot of the Aberdare ranges. The aggregation of species at lower elevation indicated mass effect which coincided with Rahbek's (1997) observation that lowlands represent sink habitats with higher species richness than other higher elevation zones. This higher richness is likely due to the infusion of species from surrounding lowland vegetation which could not survive at higher elevations (Rahbek 1997). It is also probable that human transferred species might have been perfectly integrated and naturalized during early historic community settlements in and around Aberdare mountains (Trigas et al. 2013). The known harsh environmental constraints at higher elevations such as cooler temperatures, low energy, shorter growing seasons, solifluction, isolation, etc., could have deterred to an extent any immigration, dispersal and invasiveness of new plant species at these elevated areas (Hedberg 1964; Vetaas and Grytnes 2002; Dyakov 2014). Furthermore, monotonic decline of species richness could be due to the absence of true montane flora in Aberdare, where the current richness patterns are a result of the spread of lowland species that could withstand and adapt to the mentioned harsh conditions associated with higher elevations (Hedberg and Hedberg 1979; Trigas et al. 2013). Numerous studies in similar montane ecosystems have reported monotonic decline of floristic richness. In Ethiopian afromontane vegetation, species richness peaked between 1600–1700 m a.s.l. which was lower than Aberdare despite both mountains flanking the Great Rift Valley (Berhanu et al. 2017). Vetaas and Grytnes (2002), using interpolated data of Nepal Himalayas, found a hump-shaped unimodal relationship with maxima species richness between 1500–2500 m a.s.l., which was similar to this study.

There was a slight increase in richness of herbs between 2000–2100 m a.s.l. then a monotonic decline as altitude increases. Herbs showed higher gamma diversity i.e., total species in each altitude band, compared to other studied plant groups in entire altitude gradient of Aberdare ranges. Regarding this observation, this study contrasted with Schmitt et al. (2010) generalization that herbs are more sensitive to small-scale changes in environmental conditions while woody plants are affected by environmental changes at larger scale. If this was the case then woody species richness i.e., shrubs and arboreal would be more abundant at higher altitudes which was not observed in this study. As floral richness is known to be maximum at altitudes associated with their optimal climatic gradients (Lomolino 2001; Dyakov 2014), based on this study 2000–2200 m a.s.l. seems to be the focal altitude for total plants in Aberdare ranges forest. The effects of heavy deforestation at lower altitudes in close proximity to local communities around the forest (Butynski 1999; Lambrechts et al. 2003; KWS 2010; KFS 2010) were not shown in our study. It was expected that richness in shrubs and arboreal would be low at the foot of the range as a result of overexploitation then a slow or even absent succession by arboreal species afterwards.

Endemism

A total of 63 species were endemic in Aberdare ranges forest. Most of these endemics were herbs - with 35 species, then shrubs 23, climbers 3 and the lowest were arboreal with 2 species (see Appendix 2). The altitudinal range sizes, i.e., between the minimum and maximum altitude, of these endemic species varied from as low as 100 m for *Cissampelos friesiorum* Diels, 150 m for *Senecio margaritae* C.Jeffrey to 2500 m for *Adenocarpus mannii* (Hook.f.) Hook.f. and *Erica sylvatica* (Welw. ex Engl.) Beentje. Endemic species had positive relations with elevation and negative relations with both air and soil temperatures. There was a continuous spread of endemic species in the entire forest; however, higher richness was observed at higher altitude. Endemism richness maxima ranged between 3200–3900 m a.s.l., which overlapped with the endemic species of the Himalayas mountain which peaked between 3500–4500 m a.s.l. (Vetaas and Grytnes 2002). This study supported the generalization that endemic species as restricted range taxa were manifested by the survival of species in refugia during Pleistocene climatic fluctuations and/or their resilience and adaptation to unique long-term abiotic conditions that promoted morphological differentiation of relict taxa (Lovett and Friis 1994; Lovett et al. 2000). Higher endemism towards the top of Aberdare ranges might be a result of temporal individual responses of plant species to climatic vicissitudes leading to novel assemblages at high altitudes as different species move individually up the slope (Lovett et al. 2005). There was a notably rapid increase in endemic richness at 2700–3000 m a.s.l. which coincided also with the rapid decrease in total plant species richness. This striking feature was also observed among the endemics of the Himalayas in Nepal although at higher altitudes above 4000 m a.s.l. (Vetaas and Grytnes 2002). The authors at Himalayas Nepal argued that timberline and glaciation limits are responsible for the inverse relationship between endemism and total plant richness. However, this view was only partially supported in our study due to the current absence of glaciers in the Aberdare ranges which are thought to have disappeared during early Holocene glaciation (Young 1980; Rosqvist 1990; Mark and Osmaston 2008). This study therefore suggests that perhaps localized competition among plant species has an effect on endemic richness and diversity although this largely remains a speculative concept. Increasing isolation and decreasing surface area at higher elevation which are responsible for fragmentation of species population, have been argued to facilitate endemism because of the small population's vulnerability to speciation (Trigas et al. 2013 and references there in). The formation of the Aberdare mountains during the break-up of Gondwanaland millions of years ago led to isolation of plant species that existed then. Over time these species have undergone speciation, resulting in numerous endemic species (Butynski 1999).

Conservation priorities

In the wake of elevated anthropogenic threats and global climatic vicissitudes, conservation and management of Afromontane ecosystems should be prioritized, particularly for future biodiversity and sustainable provision of ecological services (Muiruri 1978; Myers et al. 2000; Hannah et al. 2002; Kiringe et al. 2007; KFS 2010; Schmitt et al. 2010; Di Minin et al. 2013; Anderson-Teixeira 2018). Afromontane forests are thought to provide survival options for plants in a changing climate through the close physical proximity of a wide range of habitats with varied biotic and abiotic factors (Lovett et al. 2005). Thus, the Aberdare ranges with its proven diverse flora and unique physical properties calls for more effective management interventions. Floristic composition and spatial patterns studied in this forest can steer conservation strategies by pinpointing exceptional rich species and ecologically unique zones (Platts et al. 2010). Thence, the type of management regime to be implemented should target the causal factors of observed richness patterns since species richness is an indicator of environment history (Lovett et al. 2000; Platts et al. 2010). This implies that any conservation intervention to be undertaken should focus on maintaining the forms and magnitudes of disturbances the existent vegetation has adapted to. For the case in Aberdare, higher endemic richness at higher elevations indicates the existence of undisturbed long-term environmental stability as argued by Lovett and Friis (1994), Sosef (1994) and Lovett et al. (2000). Therefore, disturbances should be minimized at this zone because the vegetation might not be resilient to perturbation. Networks of roads and camp sites should be reduced, if not totally eliminated, in upper parts of the forest (KFS 2010; KWS 2010). According to Connell (1978), Phillips et al. (1994) and Lovett et al. (2000) high species diversity is a result of intermediate levels of disturbance that enhances recruitment and regeneration of new species. If this concept of disturbance-driven species richness is applied at lower elevations of Aberdare, where there is a history of exploitation by local community (Butynski 1999), then it means that the great species richness observed at this region could be due to disturbance. Therefore, a suitable management intervention should complement the previous disturbances at appropriate levels and magnitude so as to maintain plant species complementation. This will necessitate some controlled small-scale extraction and utilization of forest resources around the foot of Aberdare ranges. Regulated extraction and utilization of forest products could be the best conservation strategy at species level as this can be an intermediate disturbance if well managed. The carrying capacity of the vegetation area to be grazed should be established prior to grazing.

In view of envisaged climatic changes, it has been suggested that ecosystems migrate to new regions as a result of climatic fluctuations (Hannah et al. 2002; Lovett et al. 2005). In fragmented ecosystems characterized by isolated habitats that are surrounded by agricultural or other human activities, such ecosystems will have no room for migration resulting in total collapse (Hannah et al. 2002). This scenario resonates with the present situation in the Aberdare ranges with agricultural activities surrounding the forest almost entirely. To overcome the impending predicament of ecosystem collapse, creation of corridors seems to be the best strategy, perhaps the only way, to facilitate ecosystem migration and enhance survival of species (Lovett et al. 2005).

Completion of a perimeter electric fence around the Aberdare ranges almost a decade ago has impacted significantly on both ecological and economic aspects of this region (Ark and Group 2011). However, the long-term effects of this fence regarding migration and population increase of wildlife, particularly the large herbivores, have not been adequately addressed (Butynski 1999; Ark and Group 2011). A complete barrier to the migration of elephants has increased damage to vegetation mostly around their traditional migratory routes to the lower Laikipia savanna and Mount Kenya (Ark and Group 2011). Prolonged damage to vegetation in such areas will result in larger open grounds with reduced plant diversity which will lead to minimal utilization of nutrients by plants since the full range of plant niches is not covered (Lovett et al. 2005). This unbalanced destruction of vegetation in the Aberdare ranges will disrupt its ecological equilibrium and threaten the ecosystem functioning and sustainability in the long run (Tilman et al. 1996, 2006). In addition, the expanding populations of range-restricted elephants and other herbivores will increase vegetation damage in the near future. A management intervention in this respect should be at vegetation level and must aim at balancing utilization and regeneration of resources to maintain adequate vegetation cover and rich species diversity, thus maintaining ecological balance and ecosystem productivity of the Aberdare range forest. Migratory corridors should be established, perhaps along the traditional migratory routes, to facilitate seasonal migration of large herbivores in an out of Aberdare ranges.

Wildfires in the Aberdare ecosystem have been common incidences for past decades, occurring mostly during dry seasons in the months of January, February or March and a few cases in September (KFS 2010; KWS 2010). Causes of these fires vary from arsonist ferrying poles, charcoal burning, nearby litter burning during farmland preparations, camp fires and improper cigarette butt disposal by tourists (KFS 2010; KWS 2010; Njeri et al. 2018). Vegetation damages caused by fire are higher at the upper parts of Aberdare including the established plantations due to higher fuel biomass (Njeri et al. 2018). As a result, fragile habitats like the moorland which harbors high endemic and threatened species are negatively impacted. However, fires have also been found to facilitate regeneration of *Juniperus procera* Hochst. ex Endl., *Bambusa vulgaris* Schrad, *Hagenia abyssinica* (Bruce ex Steud.) J.F.Gmel. including some Pines, Cypress and Eucalyptus trees (KFS 2010; KWS 2010; Nyongesa and Vacik 2018). Therefore, the current management approach of prevention and suppression of fire implemented by the KWS and KFS in Aberdare is feasible in the moorland but misplaced in areas with fire-dependent plant species. This study recommends the implementation of an Integrated Fire Management (IFM) framework proposed by Nyongesa and Vacik (2018) in Mount Kenya forest as they are similar ecosystems. In IFM framework, fire-sensitive sites are protected while prescribed-burning is undertaken in fire-dependent ecosystems.

Conclusion

Aberdare ranges forest is exceptionally rich with diverse flora and high endemic species. Floral richness in the entire mountain monotically declined along elevation and temperature gradients. Similar declines of richness were also depicted by the plant life form groups suggesting that growth forms can serve as surrogates for spatial physiognomy of plants that can guide in prioritizing specific areas for conservation (Acharya et al. 2011). Endemic species, by contrast, increased along the studied environmental gradients with richness maxima at higher elevations. The sharp increase of endemism at mid elevations coinciding with rapid reduction in total plant richness raises doubt on the role of competition in the evolution of endemic novelties.

In summary, the Aberdare ranges forest is composed of strikingly diverse flora uniquely distributed along elevational and temperature gradients. Observed richness and distribution patterns in the entire Aberdare range can provide tentative estimates for conservation importance (Acharya et al. 2011). For effective conservation and management of this ecosystem, both natural and human-induced changes should be put into consideration, and a dynamic site-specific management intervention be implemented rather than broad static interventions. This study proposes subdivision of the Aberdare ranges forest into conservation zones where different management programs can be implemented at specific zones based on the characteristics and composition of vegetation in those zones. Further, the study recommends enrichment planting with native species along with exotic species in attempts to rehabilitate heavily deforested patches in the Aberdare ranges forest. Exotic species including *Cupressus lusitanica* Mill, *Pinus patula* Schiede ex Schltdl. & Cham. and *Juniperus procera* Hochst. ex Endl. have been planted to about 35, 444 ha without enrichment planting (Butynski 1999). It has been found that the establishment of exclusively exotic species does not accelerate natural succession in degraded lands due to absence of native species (Mosandl and Günter 2008). Therefore, subsequent enrichment planting with native species after plantations of exotic species will likely accelerate restoration of biodiversity especially if animal-dispersed species are planted in Aberdare ranges forest (Mosandl and Günter 2008).

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Appendix 1

Plants of special concern in Aberdare ranges forest

Family	Plant species	Conservation status	Life form	Altitude range (m a.s.l.)
Acanthaceae	*Asystasia lorata* Ensermu Kelbessa	threatened	herb	1400–2000
Amaranthaceae	*Chenopodium murale* L.	threatened	herb	1070–2750
	Chenopodium opulifolium Schrad.U	threatened	herb	760–2100
Anacardiaceae	*Rhus longipes* Engl.	threatened	shrub or tree	1000–2400
Apiaceae	*Torilis arvensis* Link	possibly threatened	herb	1560–2850
Apocynaceae	*Carissa spinarum* L	possibly threatened	shrub	0–2250
	Cynanchum viminale (L.) Bassi	threatened	herbaceous climber	100–2200
	Pentarrhinum abyssinicum subsp. *angolense* (N.E.Br.) S.Liede & A.Nicholas	threatened	herbaceous climber	1400–2200
Araliaceae	*Polyscias kikuyuensis* Summerh.	possibly threatened	tree	1750–2620
Asparagaceae	*Asparagus racemosus* Willd.	near threatened	woody climber	1160–2900
Aspleniaceae	*Asplenium adamsii* Alston	possibly threatened	herb	2400–3400
	Asplenium aethiopicum (Burm.f.) Becherer	threatened	epiphyte	1150–3700
	Asplenium monanthes L.	threatened	herb	1950–3400
	Asplenium rutifolium (P. J. Berg.) Kunze	threatened	epiphyte	750–2300
Basellaceae	*Basella alba* L.	threatened	herbaceous climber	0–2450
Bignoniaceae	*Jacaranda mimosifolia* D. Don	threatened	tree	1970–1970

Family	Plant species	Conservation status	Life form	Altitude range (m a.s.l.)
Boraginaceae	*Cynoglossum lanceolatum* Forskál	threatened	herb	1100–3220
	Heliotropium zeylanicum (Burm. fil.) Lam.	threatened	herb	0–1740
Brassicaceae	*Barbarea intermedia* Boreau	threatened	herb	3050–3950
	Cardamine africana L.	threatened	herb	1000–3400
	Farsetia stenoptera Hochst.	threatened	herb	500–1700
	Thlaspi alliaceum L.	threatened	herb	3050–3600
Campanulaceae	*Lobelia bambuseti* R.E.Fr. & T.C.E.Fr.	possibly threatened	shrub	2350–4000
Canellaceae	*Warburgia ugandensis* Sprague	threatened	tree	1100–2230
Cannabaceae	*Celtis africana* Burm. fil.	threatened	tree	30–2400
Caprifoliaceae	*Valerianella microcarpa* Loisel.	possibly threatened	herb	2800–3500
Caryophyllaceae	*Corrigiola litoralis* L.	threatened	herb	1200–2190
	Drymaria cordata (L.) Roem. & Schult.	possibly threatened	herb	870–2700
	Uebelinia crassifolia T. C. E. Fries	possibly threatened	herb	2500–4000
Celastraceae	*Hippocratea goetzei* Loes.	threatened	climber	0–3000
Asteraceae	*Ethulia scheffleri* S.Moore	threatened	herb or subshrub	1500–2500
	Gynura campanulata C.Jeffrey	threatened	herb	1600–1615
Asteraceae	*Helichrysum ellipticifolium* Moeser	threatened	herb or subshrub	2500–4800
	Hypochaeris glabra L.	threatened	herb	1850–3000
	Lactuca inermis Forssk.	possibly threatened	herb	500–3300
	Laphangium luteoalbum (L.) N.N.Tzvel.	threatened	herb	300–3850
	Microglossa pyrifolia (Lam.) O. Kuntze	possibly threatened	shrub	50–2650
	Senecio amplificatus C.Jeffrey	threatened	herb	2900–3500
	Solanecio angulatus (Vahl) C. Jeffrey	threatened	herbaceous climber	1800–2500
Convolvulaceae	*Cuscuta australis* Hook.fil.	threatened	herbaceous climber	1750–2170
	Ipomoea wightii (Wall.) Choisy	threatened	herb	1040–2400
Cucurbitaceae	*Peponium vogelii* (Hook. fil.) Engl.	threatened	herbaceous climber	10–2600
Cupressaceae	*Cupressus lusitanica* Mill.	possibly threatened	tree	2600–2640
Cyperaceae	Carex monostachya A.Rich.	threatened	herb	2700–4500
	Carex phragmitoides Kük.	threatened	herb	2500–3100
	Carex vallis-rosetto K.Schum.	threatened	herb	1000–3300
	Cyperus afroalpinus Lye	possibly threatened	herb	1000–3000
	Fimbristylis complanata subsp. *keniaeensis* (Kük.) Lye	possibly threatened	herb	1500–2700
	Fimbristylis ovata (Burm.f.) J.Kern	possibly threatened	herb	0–2200
Dennstaedtiaceae	*Hypolepis goetzei* Hieron. ex Reimers	threatened	herb	2100–3050
Dichapetalaceae	*Dichapetalum madagascariense* (Dup.-Thou.) Poir.	near threatened	climber	1500–2400
Dryopteridaceae	*Arachniodes webbiana* (A.Braun) Schelpe	threatened	herb	1380–2600
	Dryopteris antarctica (Baker) C.Chr.	threatened	herb	2500–3320
Ebenaceae	*Diospyros abyssinica* (Hiern) F.White	possibly threatened	tree	0–2400
Euphorbiaceae	*Croton alienus* Pax	threatened	shrub or small tree	1525–1825
	Euphorbia brevitorta P.R.O.Bally	threatened	herb	1500–2000
Lamiaceae	*Plectranthus caespitosus* Lukhoba & A.J.Paton	possibly threatened	herb	1500–2850
	Plectranthus punctatus subsp. *edulis* (Vatke) A.J.Paton	threatened	herb	1800–3200
Fabaceae	*Crotalaria agatiflora* subsp. *engleri* (Baker f.) Polhill	possibly threatened	herb	1500–3500
	Crotalaria jacksonii Baker f.	threatened	shrubs	2200–3000
	Lotus corniculatus L.	possibly threatened	herb	1400–2700
	Rhynchosia hirta (Andrews) Meikle & Verdc.	Possibly threatened	herb	0–1850
Lentibulariaceae	*Utricularia gibba* L	threatened	herb	10–2550
Malvaceae	*Hibiscus surattensis* L.	threatened	herb	0–1700
	Malva verticillata L.	threatened	herb	1200–4050
	Sparrmannia ricinocarpa (Eckl. & Zeyh.) O.Kuntze	threatened	shrub	1550–3380
Myrtaceae	*Eucalyptus globulus* subsp. *maidenii* (F.Müll.) Kirkpatrick	threatened	tree	cultivated

Family	Plant species	Conservation status	Life form	Altitude range (m a.s.l.)
Ophioglossaceae	*Ophioglossum vulgatum* L.	possibly threatened	herb	1000–3250
Orchidaceae	*Calanthe sylvatica* (Thouars) Lindl.	threatened	herb	900–3000
	Cyrtorchis arcuata (Lindl.) Schltr.	possibly threatened	epiphyte	0–3300
	Habenaria keniensis Summerh.	threatened	herb	1950–2950
	Polystachya caespitifica subsp. *latilabris* (Summerh.) P.J.Cribb & Podz.	threatened	herb	1800–2200
Orobanchaceae	*Phelipanche ramosa* (L.) Pomel	threatened	herb	1735–2250
Passifloraceae	*Adenia globosa* subsp. *pseudoglobosa* (Verdc.) de Wilde	threatened	woody climber	0–1850
Pinaceae	*Pinus radiata* D.Don	threatened	tree	2800–2800
Poaceae	*Aira caryophyllea* L.	threatened	herb	2000–4500
	Andropogon distachyos L.	threatened	herb	1700–3000
	Bromus catharticus Vahl	threatened	herb	2300–2700
	Calamagrostis epigejos (L.) Roth	threatened	herb	2000–3000
	Chloris virgata Sw.	threatened	herb	10–2120
	Lolium temulentum L.	threatened	herb	1900–2300
	Streblochaete longiarista (A.Rich.) Pilg.	threatened	herb	1500–3280
Polygonaceae	*Persicaria decipiens* (R. Br.) K. L. Wilson	threatened	herb	1100–1100
	Grammitis cryptophlebia (Baker) Copel.	threatened	epiphyte	1900–2150
	Pleopeltis macrocarpa (Bory ex Willd.) Kaulf.	possibly threatened	herb	1000–3600
Potamogetonaceae	*Potamogeton pusillus* L.	threatened	herb	600–2000
Pteridaceae	*Pellaea viridis* (Forsk.) Prantl	possibly threatened	herb	650–2250
Rosaceae	*Alchemilla fischeri* Engl.	threatened	herb	2320–3440
	Prunus africana (Hook.fil.) Kalkm.	threatened	tree	1350–2750
	Rubus keniensis Standl.	possibly threatened	shrubs	1950–2800
Rubiaceae	*Galium spurium* L.	threatened	herb	1250–2700
	Mussaenda microdonta Wernham	threatened	shrub or tree	1830–2100
	Rubia cordifolia L.	threatened	climber herb	1140–3120
Rutaceae	*Toddalia asiatica* (L.) Lam.	possibly threatened	shrub	0–3000
Scrophulariaceae	*Cycnium tubulosum* Engl.	threatened	herb	130–2400
Smilacaceae	*Smilax aspera* L.	threatened	shrub	1450–2745
Thelypteridaceae	*Christella dentata* (Forssk.) Brownsey & Jermy	possibly threatened	herb	45–2200
	Stegnogramma pozoi (Lagasca) K.Iwats.	threatened	herb	2050–3350
	Stegnogramma pozoi var. *petiolata* (Ching) W.A.Sledge	threatened	herb	2050–3350
Urticaceae	*Obetia radula* (Baker) B.D.Jacks.	threatened	tree	700–2000
	Parietaria debilis G.Forst.	possibly threatened	herb	1700–4200
Verbenaceae	*Lantana viburnoides* Vahl	possibly threatened	Woody herb or shrub	0–1950
Xanthorrhoeaceae	*Aloe nyeriensis* Christian	threatened	shrub	1760–2100

Appendix 2

Endemic species in Aberdare ranges forest

Family	Plant species	Habit
Acanthaceae	*Asystasia lorata* Ensermu Kelbessa	perennial herb
Apiaceae	*Pimpinella keniensis* C. Norman	perennial herb
	Afrosciadium friesiorum var. *bipinnatum* (C.C. Towns.) P.J.D. Winter	perennial herb
	Heracleum taylori C. Norman	perennial herb
Apocynaceae	*Brachystelma keniense* Schweinf.	perennial herb
Asteraceae	*Helichrysum formosissimum* var. *guilelmii* (Engl.) Mesfin Tadesse	perennial woody herb or shrub
	Helichrysum formosissimum Sch.Bip.	perennial woody herb or shrub
	Senecio aequinoctialis R.E.Fr.	perennial woody herb

Family	Plant species	Habit
Asteraceae	*Helichrysum brownei* S. Moore	perennial herb or shrublet
	Senecio roseiflorus R.E. Fr.	perennial woody herb or shrub
	Dendrosenecio battiscombei (R.E.Fr. & T.C.E.Fr.) E.B. Knox	perennial shrub
	Helichrysum chionoides Philipson	perennial shrub
	Dendrosenecio brassiciformis (R.E.Fr. & T.C.E.Fr.) Mabb.	perennial shrub
	Dendrosenecio keniensis (Baker f.) Mabb.	perennial shrub
	Senecio jacksonii S. Moore	perennial herb
	Dendrosenecio keniodendron (R.E.Fr. & T.C.E.Fr.) B. Nord.	perennial shrub
	Carduus silvarum R.E.Fr.	perennial herb
	Senecio amplificatus C. Jeffrey	perennial herb
	Carduus millefolius R.E. Fr.	annual or perennial herb
	Helichrysum gloria-dei Chiov.	perennial shrub
	Senecio margaritae C. Jeffrey	perennial shrub
	Gynura campanulata C. Jeffrey	perennial herb
Brassicaceae	*Oreophyton falcatum* O.E. Schulz	perennial herb
Campanulaceae	*Wahlenbergia pusilla* Hochst. ex A. Rich.	perennial herb
	Lobelia bambuseti R.E.Fr. & T.C.E.Fr.	perennial shrub
	Wahlenbergia virgata Engl.	perennial herb
	Lobelia telekii Schweinf.	perennial shrub
	Lobelia deckenii (Asch.) Hemsl.	perennial shrub
	Lobelia gregoriana subsp. *sattimae* (R.E.Fr. & T.C.E.Fr.) E.B. Knox	perennial shrub
Caryophyllaceae	*Uebelinia crassifolia* T. C. E. Fries	annual herb
Cucurbitaceae	*Zehneria subcoriaceae* Y.D. Zhou & Q.F. Wang	perennial herbaceous climber
Cyperaceae	*Carex runssoroensis* var. *aberdarensis* Kük.	perennial herb
Ericaceae	*Erica silvatica* (Engl.) Beentje	perennial shrub
	Erica filago (Alm & T.C.E.Fr.) Beentje	pluriannual shrub
Fabaceae	*Adenocarpus mannii* Hook.f.	perennial shrub
	Trifolium cryptopodium Steud. ex A. Rich.	perennial herb
	Crotalaria jacksonii Baker f.	annual shrub
Loranthaceae	*Agelanthus sansibarensis* subsp. *montanus* R. M. Polhill & D.	perennial shrub
Lythraceae	*Nesaea kilimandscharica* var. *ngongensis* B. Verdcourt	perennial woody herb or shrub
Malvaceae	*Abutilon longicuspe* var. *pilosicalyx* Verdc.	perennial shrub
Menispermaceae	*Cissampelos friesiorum* Diels	perennial herbaceous climber
Moraceae	*Dorstenia afromontana* R. E. Fries	annual herb
Passifloraceae	*Adenia globosa* subsp. *pseudoglobosa* (Verdc.) de Wilde	perennial shrubby climber
Poaceae	*Eragrostis amanda* Clayton	perennial herb
Primulaceae	*Embelia keniensis* R.E.Fr.	pluriannual arboreal
Ranunculaceae	*Delphinium macrocentrun* Oliv.	perennial herb
	Anemone thomsonii Oliv.	perennial herb
	Ranunculus aberdaricus Ulbr.	perennial herb
Rosaceae	*Alchemilla johnstonii* Oliver	perennial shrub
	Alchemilla ellenbeckii Engl.	perennial herb
	Alchemilla cyclophylla T.C.E.Fr.	perennial herb
	Rubus friesiorum Gust	perennial shrub
	Alchemilla argyrophylla T.C.E.Fr.	perennial shrub
Rubiaceae	*Galium ruwenzoriense* (Cortesi) Ehrend.	perennial herb
	Pavetta abyssinica var. *lamurensis* Verdc.	pluriannual arboreal
	Oldenlandia friesiorum Bremek.	perennial herb
	Canthium oligocarpum subsp. *friesiorum* (Robyns) Bridson	pluriannual shrub or tree
	Galium glaciale var. *satimmae* Verdc.	perennial herb
Scrophulariaceae	*Bartsia longiflora* Hochst. ex Benth.	perennial herb
Solanaceae	*Solanum agnewiorum* Voronts.	perennial shrub
Xanthorrhoeaceae	*Aloe nyeriensis* Christian	perennial shrub
Apiaceae	*Afrosciadium friesiorum* (H. Wolff) Winter	perennial herb
	Afrosciadium englerianum H. Wolff) P.J.D. Winter	perennial herb

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RESEARCH ARTICLE

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Taxonomic novelties in Amaryllidaceae from the Department of Ancash, Peru, and a new combination in *Clinanthus*

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Abstract

Clinanthus inflatus (Amaryllidaceae) and *Ismene parviflora* are described from Ancash Department in Peru. The flower of *C. inflatus* is urceolate, and resembles that of *Urceolina* (Amaryllidaceae tr. Eucharideae), a unique morphology for the genus. *Ismene parviflora*, with its small, loosely formed, narrowly funnelform-tubular perigone with a ventricose limb, appears to have some affinity to subgen. *Pseudostenomesson* and may represent an intermediate form between the former and species of subgen. *Ismene*. *Stenomesson rubrum* is transferred to *Clinanthus* as *C. ruber* on the basis of its narrowly lorate leaf morphology.

Resumen

Clinanthus inflatus (Amaryllidaceae) e *Ismene parviflora* se describen del departamento de Ancash en el Perú. La flor de *C. inflatus* es urceolada, y se asemeja a la de *Urceolina* (Amaryllidaceae tr. Eucharideae), una morfología única para el género. *Ismene parviflora*, con su forma suelta, perigonio angostamente funeliforme-tubular con una limbo ventricoso, parece tener alguna afinidad al subgen. *Pseudostenomesson* y puede representar una forma intermedia entre el primero y las especie de subgen. *Ismene*. *Stenomesson rubrum* se transfiere a *Clinanthus* como *C. ruber*, sobre la base de su morfología de hoja acintada estrecha.

Keywords

Amaryllidaceae, Andean biodiversity, Clinantheae, Hymenocallideae, *Ismene*, monocots, Neotropical flora, taxonomy

Introduction

Amaryllidaceae is a cosmopolitan family of geophytic herbs (Meerow and Snijman 1998), comprised of three subfamilies: Agapanthoideae Endl., Allioideae Herb., and Amaryllidoideae (Chase et al., 2009), with the largest number of genera placed in Amaryllidoideae (Meerow and Snijman 1998). The subfamily has three main areas of diversity: southern Africa, Eurasia, and the Americas (Meerow and Snijman 1998; Meerow et al. 1999; Meerow et al. 2000; Meerow and Snijman 2001; Meerow and Clayton 2004; Meerow et al. 2006). Phylogenetic analyses of DNA sequences have resolved close cladistic relationships along biogeographic lines (Meerow et al. 1999; Meerow et al. 2000).

Meerow et al. (1999) demonstrated with multiple plastid sequences that the endemic American genera were sister to the Eurasian clade, and further that the American clade was comprised of two sub-clades, the so-called Hippeastroid and Andean tetraploid clades (Meerow 2010; Meerow et al. 2000). The Hippeastroids consist of two tribes, Hippeastreae and Griffineae Rav. (García et al. 2017; Garcia et al. 2014; Meerow et al. 2000). The Andean tetraploid clade contains four monophyletic tribes: Eucharideae Hutch., Eustephieae Hutch., Clinantheae Meerow, and Hymenocallideae Meerow (Meerow 2010; Meerow et al. 2000). The new species described in this paper are members of Clinantheae and Hymenocallideae, respectively.

Clinanthus Herb. was segregated from *Stenomesson* Herb. by Meerow et al. (2000), who demonstrated with nrDNA ITS sequences that the latter was polyphyletic. There are 15–20 species in the genus, which has never been monographed (León et al. 2006; unpubl. herbarium data). Peru is its center of diversity, and the genus occurs from southern Ecuador to northern Chile (Leiva and Meerow 2016). There are still novelties in the genus that await description (A. Meerow, pers. observ.). The genus is particularly diverse in northern Peru, and the complex orogeny of the Andes in Peru seems to have functioned as a species pump for the genus (Meerow 2010). The species are primarily found above 2000 m (León et al. 2006; unpubl. herbarium data), but several have colonized the Peru Current-cooled hills (*lomas*) of the Peruvian Pacific coast at much lower elevation (León et al. 2006; unpubl. herbarium data), in some cases occurring both there and in the Andes [e.g., *C. coccineus* (Ruiz & Pav.) Meerow]. One species, *C. humilis* (Herb.) Meerow, which retains the ovary inside the bulb until shortly before seed ripening (Herbert 1839; Baker 1871), reaches elevations above 4000 m (León et al. 2006; unpubl. herbarium data). Many are local endemics known only from the type localities (León et al. 2006). Photos and a specimen at USM sent to the first author for identification have been determined to represent an undescribed species in the genus, with unique floral morphology. We describe it here as *Clinanthus inflatus*. We also make a new combination in the genus *Clinanthus* for the species hitherto known as *Stenomesson rubrum* Herb. This species is transferred to *Clinanthus* based on its narrowly lorate leaf morphology.

Ismene Salisb., along with *Leptochiton* Sealy, are the central Andean components of tribe Hymenocallideae, with probably no more than 10 species (A. Meerow, unpubl. data). Many are also local endemics, primarily in Peru, but extending to Ecuador and

Bolivia (Meerow unpubl. data). A number of years ago the first author received photos and a specimen on loan from the second author for identification. The plant was determined to be an undescribed *Ismene* species, unique for both the small size of the flowers and their morphology, strikingly divergent from the rest of the species in the genus. We describe it herein as *Ismene parviflora*.

Material and methods

No specimens matching the new species other than the holotypes have been observed in herbarium collections in Peru, nor encountered by the first author in collections examined over the past 40 years at F, GB, K, MO, and NY. Herbarium acronyms follow Thiers (2019). Descriptions are based on holotypic material. Terminology used for the morphological descriptions follow Stearn (2004), Meerow and Snijman (1998), and Radford et al. (1974), with minor modifications. Photographic plates were composed with Corel Paint Shop Pro 2018 (Corel Corp., Ottawa, Ontario, Canada) from photos taken or received by both authors. The distribution map was also created with Corel Paint Shop Pro 2018 using license free maps of Peru (https://i.pinimg.com/736x/0c/9e/40/0c9e4008594c2228041624520f483f89--volunteers-the-south.jpg) and South America (https://i.pinimg.com/originals/67/83/ee/6783eeaff49338e5e4ae05c21d4b8312.jpg), both downloaded from Pinterest.

Results

Taxonomic treatment

Clinanthus inflatus **Meerow & A.Cano, sp. nov.**
urn:lsid:ipni.org:names:60479369-2
Figs 1A–C, 2

Diagnosis. This species differs from all known species of *Clinanthus* by the uniquely inflated perigone, the shape and coloration of which is reminiscent of the genus *Urceolina* Rchb. (Euchárideae) or superficially certain species of Andean vaccinioid Ericaceae.

Type. PERU. Ancash: Prov. Recuay, Dist. Cotaparaco, Sector Santa Cruz, 2450 m, 6 Mar 2007. *M. Morales & E. Jara 767* (holotype: USM!).

Description. Small terrestrial geophytic herb (Fig. 1A); bulb small, globose-ellipsoidal, ca. 2 cm diam., prolonged into neck 7.5–8 × 60–70 mm. Leaves 2–3, sessile, narrowly lorate, 4–6 × 90–110 mm, slightly canaliculate, obtuse at apex, with conspicuous midrib, glabrous, green, synanthous. Inflorescence pseudo-umbellate, borne at apex of naked scape; scape cylindrical, solid, 150–200 mm long (as observed), terminated by 2 spathe bracts, bracts green, ovate lanceolate. Flowers 2–3, pendulous, 35–40 mm long; pedicels slender, 15–20 mm long at anthesis; perigone

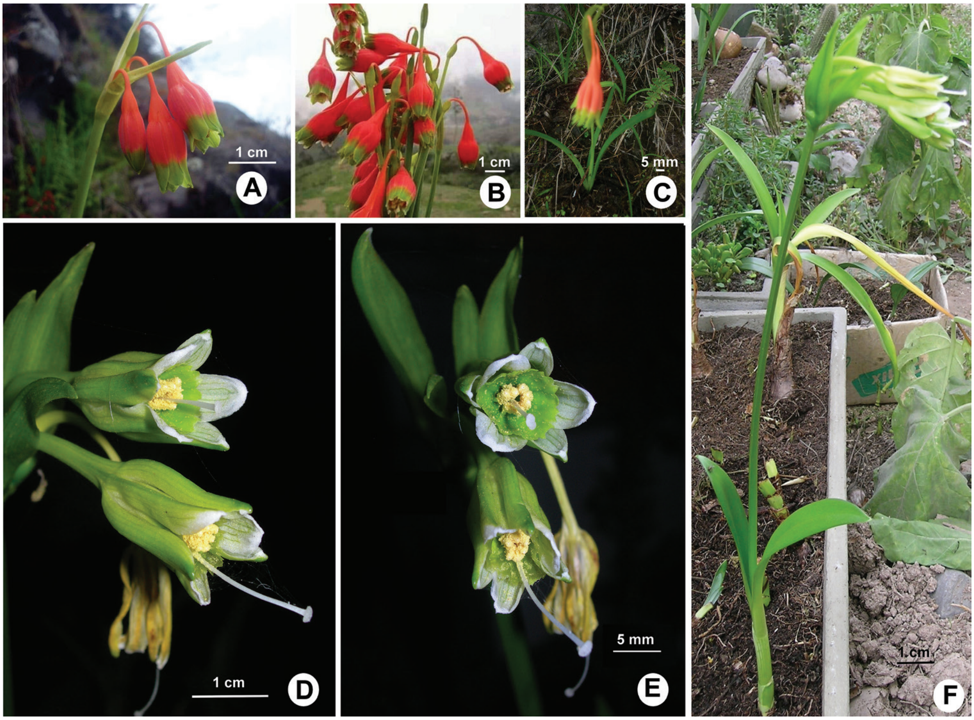

Figure 1. A–C *Clinanthus inflatus*. Photos by anonymous source, used with permission. **A** Inflorescence in habitat **B** bouquet of cut inflorescences **C** habit in nature **D–F** *Ismene parviflora*, photos by Asunción Cano **D–E** flowers **F** habit in cultivation.

consisting of 6 tepals in 2 whorls, fused into a tube that is narrowly cylindrical in proximal 15–17 mm and arcuate proximally, abruptly dilated distally to ca. 8 mm at throat; limb urceolate, abruptly inflated to ca. 33 mm in diam., then slightly constricted in distal 10 mm; tepals 6, bright orange-red proximally, concrescent, green in distal 10 mm with yellowish green margins, glabrous; outer tepals elliptical, 5–6 × 13–14 mm, apiculate; inner tepals elliptical, 5.5–6.5 × 12–13 mm, minutely apiculate. Stamens 6, basally connate into cylindrical staminal cup or corona, 7.4–7.6 × 11.0–11.5 mm, reaching to ca. 2 mm from the apex of the limb, salmon proximally, prominently 6-lobed, the lobes white distally and coarsely dentate along their edge, ca. 2 × 3 mm; free filaments short, inserted at sinus between the lobes; anthers grouped in the center of the flower (but not connivent), ca. 3 mm long, linear, dorsifixed, versatile, longitudinally dehiscent; pollen yellow. Style ca. 45 mm long, exerted ca. 5 mm past apex of the limb, white; stigma capitate, papillate, white, 2–2.3 mm wide. Ovary inferior, green, oblong, ca. 5 × 10 mm, 3-loculed, placentation axile, ovules oblong, flattened, ca. 20 per locule, superposed. Capsule and seed not seen.

Distribution and ecology. *Clinanthus inflatus* is known only from the type locality (Fig. 3), in seasonally dry vegetation.

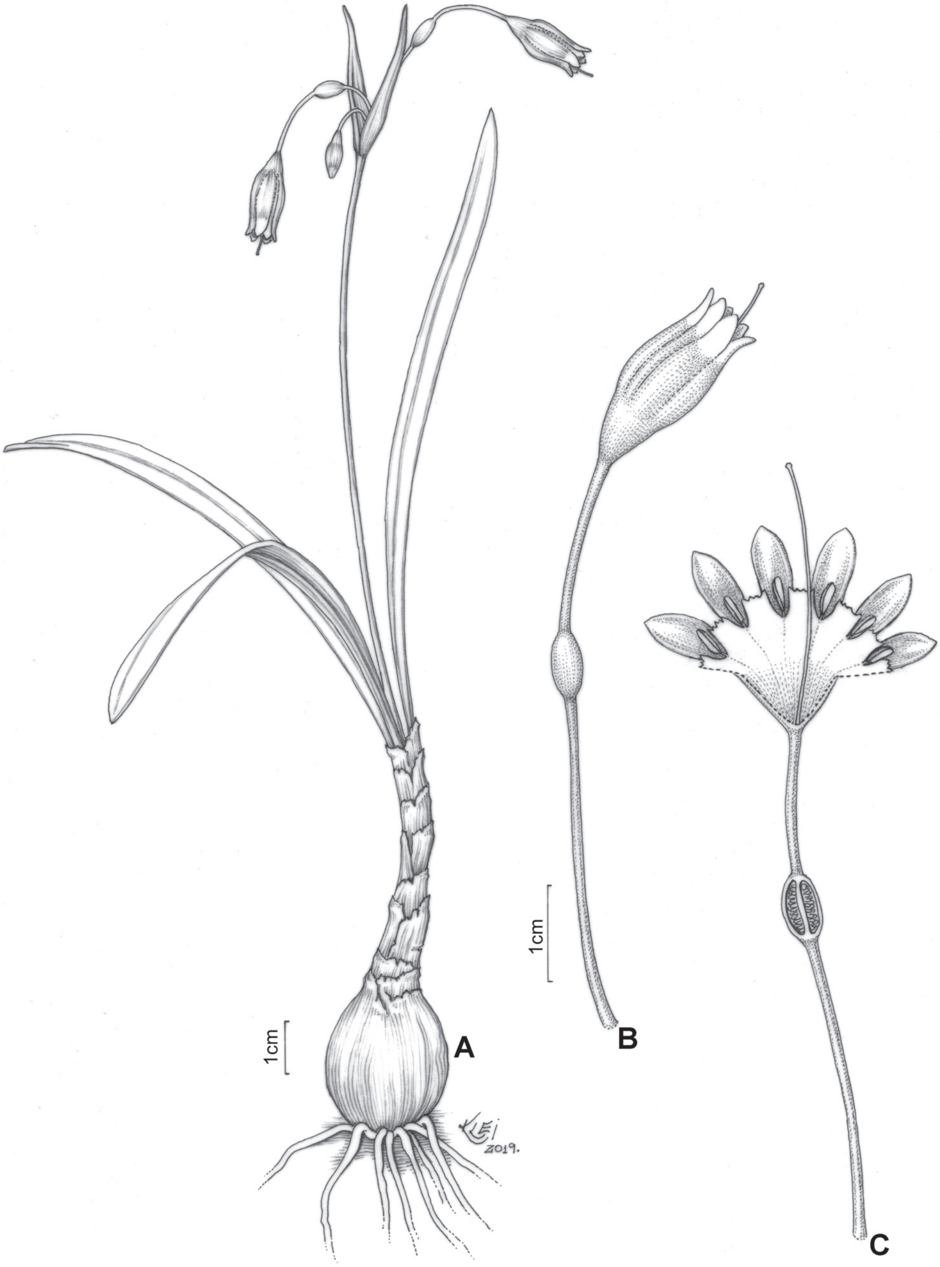

Figure 2. *Clinanthus inflatus*. **A** Habit **B** whole flower **C** whole flower cut open to show staminal corona and ovule number. Drawing by Klei Sousa.

Phenology. Plants were collected in flower in March.

Etymology. The specific epithet is from Latin and refers to the abruptly inflated perigone.

Figure 3. Map of northern Peru showing type localities of *Clinanthus inflatus* (white circle) and *Ismene parviflora* (black square). Inset: map of South America with Peru filled in black.

Preliminary conservation status. Since nothing is known of the distribution of this species beyond the type locality, it is best to place it in the category Data Deficient (IUCN 2012, 2017). The type specimen label indicates that it was abundant at the collection site.

Notes. The urceolate perigone of *C. inflatus* is yet another example of the convergent evolution that characterizes the tetraploid Andean lineages (Meerow 2010). It seems to have affinity with the subclade of *Clinanthus* (Meerow et al. 2000) that includes *C. campodensis* (Ravenna) Meerow, *C. humilis*, *C. recurvatus* (Ruiz & Pav.) Meerow, and *C. ruber* (Herb.) Meerow & A. Cano, all with leaves < 1 cm wide, and relatively small flowers.

Clinanthus ruber (Herb.) Meerow & A.Cano, comb. nov.

urn:lsid:ipni.org:names:60479371-2

Stenomesson rubrum Herb. Amaryllidaceae: 199; Pl. 28. 1837. *Pancratium rubrum* Pav. ex Steud. Nomencl. Bot. [Steudel], ed. 2. 2: 251. 1841. TYPE: Pavon s.n. (Holotype: FI!, isotype: BM!).

Coburgia coccinea Herb., Curtis's Bot. Mag. 67: t. 3865. 1841, syn. nov., non *Coburgia coccinea* (Ruiz & Pav.) Herb., Edwards' Bot. Reg. 28 (Misc.): 54 (1842). (Fig. 4B, D).

Notes. *Pancratium rubrum* (Herb.) Pav. ex Steud. was not included in Ruiz and Pavon (1802), even though a specimen from their expedition (FI!, FI011974) is labelled as the type of *S. rubrum* Herb. The name was validated by von Steudel (1841). Ravenna

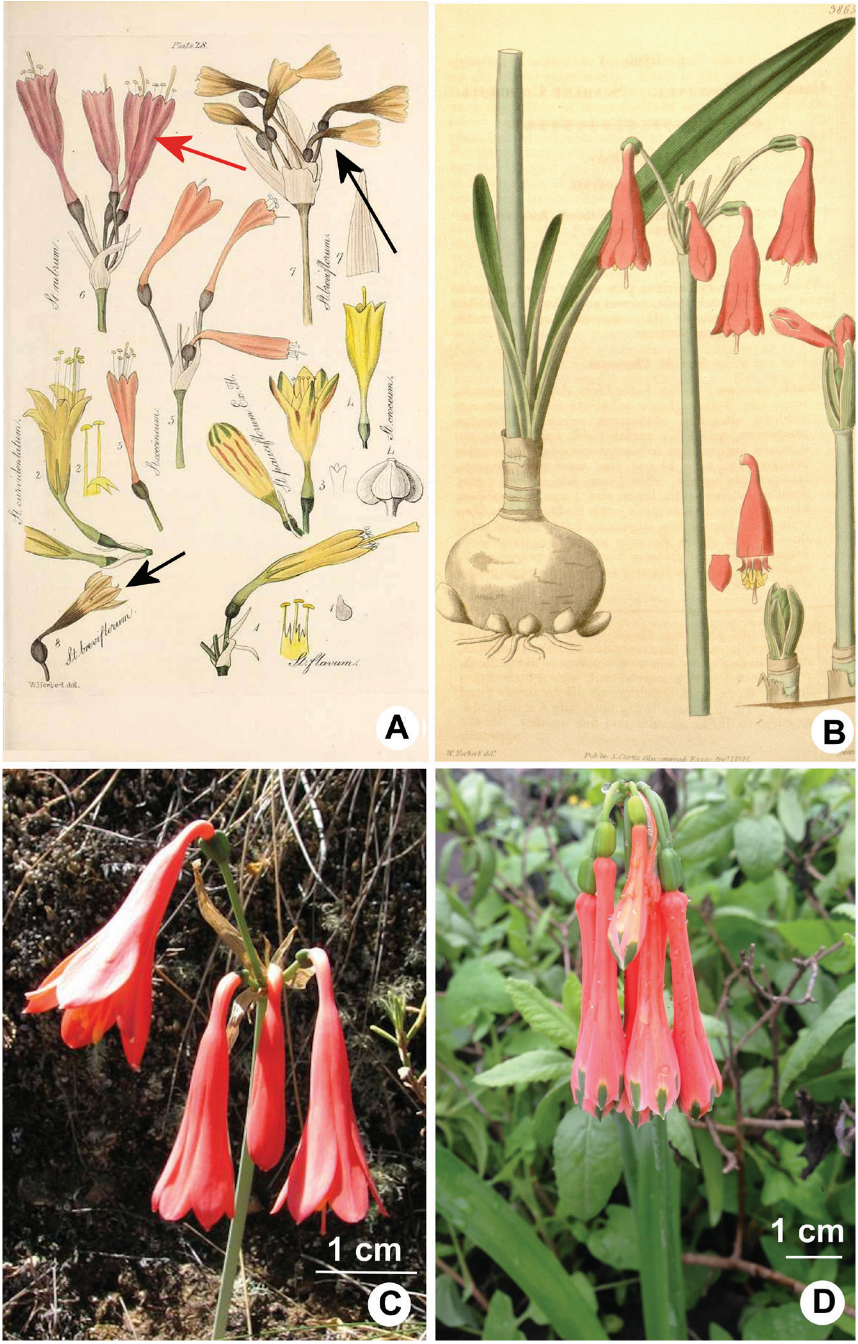

Figure 4. A Plate 28 from Herbert (1837) with *Stenomesson rubrum* Herb. illustrated (number 6, red arrow). *Stenomesson breviflorum* Herb. is illustrated in the same plate (numbers 7 & 8, black arrows), evidence that Herbert considered these two different species **B** Painting of *Coburgia coccinea* Herb. [= *Clinanthus ruber* (Herb.) Meerow & A. Cano] that accompanied the description by Herbert (1841) **C** *Clinanthus ruber*, photographed in Peru. Photo by Oscar de Viveroscar **D** *Clinanthus coccineus* (Ruiz & Pav.) Meerow, loma form, photographed in Lima Dept., Peru. Photo by Norton Cuba Melly.

(1978) believed that the type specimen represented *Stenomesson flavum* (Ruiz & Pav.) Herb., a species that was originally illustrated and described in Ruiz and Pavon (1802) as *Pancratium flavum* Ruiz & Pav. We believe that Ravenna (1978) was mistaken in this regard. The specimen has a single scape that bears only three flowers, and the stamens are barely if at all exerted from the perigone. *Stenomesson flavum* always has > 3 flowers and the stamens are exerted at least 1 cm from the limb.

Herbert (1837) illustrated *S. rubrum* (Fig. 4A), which he seemed to consider distinct from *Stenomesson coccineum* (Ruiz. & Pav.) Herb. [≡ *Clinanthus coccineus* (Ruiz. & Pav.) Meerow], a decision with which we agree. Herbert (1837) also surmised that errors were made regarding Ruiz and Pavon types and plates in regard to both species. Four years later, Herbert (1841) published *Coburgia coccinea* Herb. (Fig. 4B). He made no reference to either *S. rubrum* or *S. coccineum*, though the flower in the plate (Fig. 4B) looks very similar to the flower illustrated for *S. rubrum* (Fig. 4A). The well-illustrated leaf morphology in the plate undoubtedly places the plant in *Clinanthus*. One year later, Herbert (1842) assigned both *Pancratium coccineum* Ruiz [sic] and *Stenomesson coccineum* to synonomy with *Coburgia coccinea*. We thus regard *Coburgia coccinea* Herb. (1841) as distinct from *Coburgia coccinea* (Ruiz & Pav.) Herb. (1842), nom. illeg., but conspecific to *Clinanthus ruber*, and include it in the synonymy of the latter taxon here.

Ravenna (1978) diagnosed *Clinanthus coccineus* (Ruiz & Pav.) Meerow as belonging to his *Stenomesson* subgen. *Fulgituba* Ravenna (1974), along with *Clinanthus incarnatus* (Kunth) Meerow, *C. microstephius* (Ravenna) Meerow, *C. variegatus* (Ruiz & Pav.) Meerow and other species, all of which have varying apical zones of green on the tepals. Recent collections in Peru (N. C. Melly, S. Leiva, pers. comm.) confirm this, with *Clinanthus coccineus* (Fig. 4D) found both in coastal *lomas* and in the northwestern Andean slopes. Ravenna (1978) seems to have considered *S. rubrum* a synonym for *S. breviflorum* Herb. We disagree with this assessment. Herbert (1837) illustrated both in the same plate (Fig. 4A). The type specimen of *S. breviflorum* (Maclean s.n. K!, K000322395 & 396) clearly bears pseudo-petiolate leaves, which confirms its place in *Stenomesson* rather than *Clinanthus*. *Clinanthus ruber* is fairly widespread in northern Peru, and can have red or pink flowers, but never more than five in all the material we have seen. It is variable in the degree to which the limb spreads from the throat of the perigone. The flowers are without any green apical zone, and bear relatively narrow leaves < 1 cm wide.

Ismene parviflora **Meerow & A.Cano, sp. nov.**

urn:lsid:ipni.org:names:60479370-2
Figs 1D–F, 5

Diagnosis. *Ismene parviflora* differs from all other species of the genus by the small flowers (< 4 cm long), that are loosely funnelform, terminating with a ventricose limb, but not infundibular to the degree of *I. vargasii* and *I. morrisonii* (subgen. *Pseudostenomesson* Meerow), the latter species to which it approaches in size. All other species of *Ismene* have large, crateriform flowers (subgen. *Ismene*) or large, zygomorphic flowers (subgen. *Elisena*).

Figure 5. *Ismene parviflora*. Drawing by Klei Sousa. **A** Habit **B** whole flower **C** whole flower cut open to show staminal corona and ovule number.

Type. Perú, Ancash: Prov. Recuay, Dist. Cotaparaco, Sector Santa Cruz, 2332 m, rocky slope with shrubs and silty soil, 6 Mar 2007. *M. Morales & E. Jara 767* (holotype: USM!).

Description. Terrestrial geophytic plant from subterranean bulb. Bulb not seen. Leaves 2, oblanceolate-lorate, ca. 15 × 150–170 mm, bright green, glabrous, slightly canaliculate, obtuse, tightly sheathing proximally and forming a green aerial pseudostem 40–60 mm long, synanthous. Inflorescence pseudo-umbellate, borne on a naked scape; scape ancipitous, solid, 200–250 × ca. 18 mm, terminated by 2 ovate-lanceolate green bracts that persist at anthesis, over-topping flowers by several cm, bracts 50–55 × 7.5–9.6 mm, acute. Flowers 3–5, mostly perpendicular to scape, loosely funnelform-tubular, shortly pedicellate, pedicels 2–3 mm long; perigone 35–37 mm long, consisting of 6 tepals in two whorls, fused proximally into a tube that is cylindrical for proximal 20 mm, ca. 1.5 mm wide, then dilating to 3.5 mm at throat; tube curved proximally; limb slightly ventricose, apically ca. 10 mm wide, tepals loosely concrescent, not spreading significantly; outer tepals elliptical, concave, mostly green abaxially, white towards apex, adaxially white with green veins in distal ½–2/3, green below, 13.5–14.0 × 4.5–5.0 mm, apiculate; inner tepals ovate-elliptical, less concave than outer, 13.0–13.5 × 5.0–5.2 mm, minutely apiculate, colored like outer. Stamens 6, fused into green staminal cup 6.5–7.5 × 3.5–3.7 mm, cylindrical in proximal 6 mm, abruptly ampliate in its distal 1 mm to ca. 4 mm, coarsely and unevenly dentate at rim; free filaments inserted ca 2 mm below rim of cup, filiform, white, incurved, ca. 1 mm long; anthers oblong, closely appressed to each other but not connivant, 3.5–4.5 mm long, pollen yellow. Style exerted 10–15 mm past the limb apex, 40–45 mm long, white, filiform; stigma capitate, papillose, white, 2–3 mm wide. Ovary globose, ovules 1 or 2 per locule, basal. Capsule and seed not seen.

Distribution and ecology. *Ismene parviflora* is known only from the type locality (Fig. 3), in seasonally dry vegetation.

Phenology. Plants were collected in flower in March.

Etymology. The specific epithet is from Latin and refers to the small size of the flowers.

Preliminary conservation status. Since nothing is known of the distribution of this species beyond the type locality, it is best to place it in the category Data Deficient (IUCN 2012, 2017). The type specimen label says it was abundant at the collection site.

Notes. *Ismene parviflora* has greatest affinity morphologically to the two members of *Ismene* subgen. *Pseudostenomesson* (Velarde) Meerow, *I. vargasii* (Velarde) Gereau & Meerow and *I. morrisonii* (Vargas) Velarde, but the unique morphology of the new species make it difficult to assign *I. parviflora* to *I.* subgen. *Pseudostenomesson* with confidence at this time. Ravenna (1988) disagreed with the transfer by Velarde (1949) of *Stenomesson morrisonii* Vargas to *Pseudostenomesson* Velarde, but based on the same information (Vargas 1943), we believe it belongs with *I. vargasii* in *I.* subgen. *Pseudostenomesson*. In particular, the photo in Vargas (1943) shows the typical foliar morphology of *Ismene*, i.e. the aerial pseudostem formed by the tightly sheathing leaf bases. The two species of subgen. *Pseudostenomesson* are found in the Departments of Junin (*I. vargasii*) and Apurimac (*I. morrisonii*), and, unlike *I. parviflora*, have larger, fully infundibular, and completely green perigones.

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