

## RESEARCH ARTICLE

## Rare orchid species in Malaysia: New records, recollections and amended descriptions

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## Abstract

*Paphiopedilum exul*, *Calanthe chrysoglossoides*, and *Luisia brachystachys* are reported here as new records for Malaysia, whereas *Bryobium cordiferum* subsp. *borneense*, *Habenaria rostelifera*, and *Taeniophyllum rugulosum* are three rare orchid species recollected from Sarawak, Perlis, and Perak, respectively. This paper highlights brief descriptions and photographic illustrations of each species for easy identification. Besides, notes on morphological comparisons with the closely related species and artificial taxonomic keys are included as well.

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## Introduction

Southeast Asia including Peninsular Malaysia and Borneo spans about 3% (4.5 million km<sup>2</sup>) of earth's total land area that harbours approximately 20–25% of earth's higher plant species [1, 2]. Substantial anthropogenic habitat alterations, forest fires, and the overexploitation of wild-life in the said vast region are detrimental to its biodiversity [3]. Malaysian vegetation comprises evergreen, montane, mixed deciduous, heath and alpine, limestone, and ultramafic forests supporting a wealth of plant diversity [4]. Worth mentioning is the northernmost corner of Peninsular Malaysia, including Perlis and Kedah, bordered by Thailand in the north constitutes a significant component of the Thai and Burmese flora [5–7]. The forests lie mainly on hilly terrain of limestone, which is part of the Setul and Chuping limestone formation with unique geological formation and high level of flora endemism [8, 9]. However, these forests are declining rapidly because of forest clearance for quarries, timber extraction and other forms of agricultural and infrastructure developments [7, 10–12]. Thus, uncountable number of the plant species may have gone extinct.

Orchidaceae is the most abundant flowering plant family in Malaysia. Approximately, 978 species recorded in Peninsular Malaysia [13–19] and 3,000 species have been recorded in Sabah and Sarawak [13]. Major collective records of Malaysian orchid species were monographed by many botanists, including R. E. Holttum [20], H. N. Ridley [21], J. J. Smith [22], J.

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J. Vermeulen [23], I. M. Turner [24], G. Seidenfaden, and J. J. Wood [25]. In the past two decades, several studies on the orchid diversity covering various elevation gradients and vegetation types in Malaysia involved local conservationist. Of these, the most significant studies on Malaysian orchids include [12, 14, 26–28]—limestone forest; [13]—peat swamp forest; [29, 30]—hill forest; [31]—lowland forest; [32–36]—montane forest; [37]—coastal heath forest; [38, 39]—logged forest.

Judging by these past and recent works on orchid flora in Malaysia, it is apparent that Malaysia possesses one of the world's richest orchid floras in one of the largest remaining areas of tropical rainforest in the Old World. Undoubtedly, there are more species still awaiting discovery in the remaining extensive forests of Peninsular Malaysia and Borneo. We are reporting new orchid species to the flora of Malaysia and recollection of additional two rare species aimed at elucidating the diversity of orchids in Malaysia. The rare taxa were found and identified whilst working on the diversity and conservation of wild orchids in the undisturbed and disturbed forests of Malaysia. This paper provides brief description, taxonomic notes, relevant notes on ecology and distribution, morphological comparisons with the closely related species, artificial taxonomic keys, and photographs to facilitate easy identification of these species in the field.

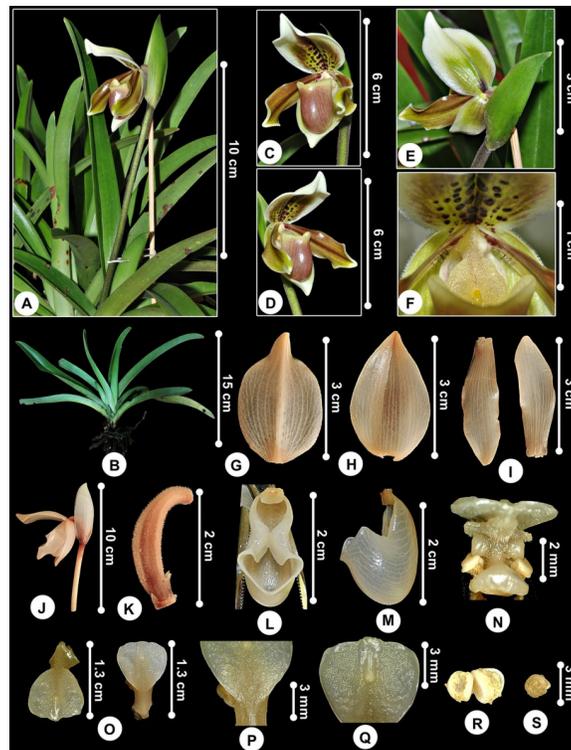
## Materials and methods

Specimen collections were carried with permission from the Forest Department Peninsular Malaysia and Forest Department Sarawak [Access License Ref.—JH/100 Jld. 23 (246); Invitation Letter Ref.—(20)JHS/IAD/600-7/101/Jld.1]. Living specimens were transplanted into an *ex-situ* conservatory, and then further nurtured into identifiable samples. The complete specimens were processed using standard herbarium preparation technique of [40]. Our locality data are withheld to protect the populations from illegal collections. Prior to the morphological examination, methylated spirit-preserved and fresh flower specimens were dissected, described and photographed under AM4113ZT Dino-Lite Digital Microscope. Alpha taxonomy with reference to the type specimens, monographs and protologues was employed in the identification process, evaluation of the species' distribution status, and a comparative morphology study with the closely similar species. Digitised images of herbarium collections, botanical drawing and records deposited in National Herbarium of the Netherlands (NHN) accessed through Browse Dutch Natural History Collections: BioPortal (Naturalis) (<http://bioportal.naturalis.nl/>), Herbarium of Singapore Botanic Gardens (SING) accessed through BRAHMS Online managed by University of Oxford (<http://herbaria.plants.ox.ac.uk/bol/sing>), Swiss Orchid Foundation (<https://orchid.unibas.ch/index.php/en/>), Kew Herbarium Catalogue (<http://apps.kew.org/herbcat/gotoSearchPage.do>), Natural History Museum Specimen Collection (<https://data.nhm.ac.uk/>), Herbarium of Aarhus University (AAU) ([https://www.aubot.dk/search\\_form.php](https://www.aubot.dk/search_form.php)), Museum National D'Histoire Naturelle (MNHN) (<https://science.mnhn.fr/all/search>), and Plants of the World Online (POWO) (<http://www.plantsoftheworldonline.org/>) were examined prior to the taxonomic treatment and assessment on range of distribution for each species. The range of distribution from historical and current localities was plotted in Google Earth maps. The accepted names were validated via KEW World Checklist of Selected Plant Families (WCSP) [41].

## Results and discussions

### New records for Malaysia

*Paphiopedilum exul* (Ridl.) Rolfe, Orchid Rev. 4: 364 (1896); Fig 1.



**Fig 1. *Paphiopedilum exul*.** A. Single flower. B. Plant. C, D, E. Flower from front, lateral and back view. F. Flower front view showing spotted dorsal sepal and hairy staminode. G. Dorsal sepal. H. Dorsal sepal from dorsal and back view. I. Petals. J. Inflorescence. K. Pedicel-with-ovary. L. Labellum from top view. M. Labellum from lateral view. N. Gynostemium from lateral view showing anthers. O. Staminode. P. Staminode showing base connate to the gynostemium. Q. Staminode showing mucronulate apex. R. Anthers. S. Pollinarium. Note: G-S are preserved specimens.

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Homotypic synonyms:—*Cypripedium insigne* var. *exul* Ridl., Gard. Chron., ser. 3, 10: 94 (1891); *Cypripedium exul* (Ridl.) Rolfe, J. Hort. Cottage Gard., ser. 3, 22: 301 (1892); *Cordula exul* (Ridl.) Rolfe, Orchid Rev. 20: 2 (1912). Type: THAILAND. Central Thailand, Bangkok, 1891, Ridley SING0056352 (SING-photo!).

Heterotypic synonyms:—*Cypripedium exul* var. *aureum* Rolfe, Orchid Rev. 4: 162 (1896); *Paphiopedilum exul* var. *aureum* (Rolfe) Pfitzer in H.G.A.Engler (ed.), Pflanzenr., IV, 50(12): 75 (1903); *Paphiopedilum exul* f. *aureum* (Rolfe) O.Gruss & Roellke, Orchidee (Hamburg) 51: 420 (2002).

Specimen examined:—MALAYSIA. Perlis, ca. 100 m elev., 31 October 2019, Besi *et al.* EDW113 (UPM!).

**Description.** *Plants* mostly terrestrial, less often lithophytic, caespitose, ca. 20 cm tall including inflorescence. *Stem* ca. 1 cm, short. *Leaves* 7–10 per shoot, 6–21 × 1.7–2 cm, plain green, green to yellowish green, pale green below, venations faint, strap-shaped to oblong elliptic, apex acute with minute cleft, suberect, rigid, fleshy, canaliculated, conduplicate basally, grooved, glabrous, veins prominent below, margin entire. *Inflorescence* single flowered, ca. 15 cm long, slender, erect, pubescent, green covered with dense dark purple indumentum, pedicel-with-ovary completely covered by a large greenish white bract. *Floral bract* folded, lanceolate, apex acuminate, hairy basally, grooved, veins sunken, greenish white, more than half the pedicel-with-ovary length, 4.9 × 1.4 cm. *Pedicel-with-ovary* ca. 2.4 cm long, curved, pubescent, indumentum white, clavate, ridged, reddish green. *Flower* 4.5 × 3.5 cm, dorsal surface of sepals

and petals pubescent with short white and dense indumentum, greenish white in general, sepals suffused green, petals greenish brown with clear dark brown veins arching towards apex, pouch showy and glossy reddish-purple pouch hooded by dorsal sepal. *Dorsal sepal* 3.4 × 2.7 cm, cucullate, broadly ovate; apex cuspidate, folded, recurved, ca. 5.5 mm long; base rounded; ventral side white suffused yellowish brown, glossy dark brown spots; spots suffused over lower half from basal to the central area, arranged in lines, contrast with the yellow background; dorsal side suffused green, blotched dark brown at base, sparsely hairy; prominent, raised median outer keel covered by dark brown hairs; margin white, entire, covered by dense white indumentum. *Synsepalum* 3.5 × 2.1 cm, cucullate, ovate, apex obtuse, base cordate, yellowish green, venation green, bordered white, margin covered by dense white indumentum, back side outwardly keeled, suffused green, blotched dark brown at base as in dorsal sepal. *Petals* 3.4 × 1 cm, more than twice as long as wide, outspread, almost horizontally, oblanceolate, apex obtuse, margins undulate and minutely hairy, proximally black hairs occur on surface at the base, greenish brown at both sides, suffused green towards apex and margins, prominent reddish brown at inner side, minutely spotted at base, recurved forward around the pouch. *Pouch or labellum* 2.8 × 1.4 cm, slipper-shaped, side lobes rectangular, incurved, glossy, reddish green, pale green at mouth, venation brown, hairy interior at the nectary and dorsal opening. *Staminode* 8 × 8 mm, obovate, yellowish green, verruculose, hairy, indumentum dark brown, indumentum much longer near the base of the gymnostemium, apex mucronulate, central teeth rounded, base connate to the gymnostemium, anthers and stigma hidden behind staminode, margin slightly recurved; fovea 2 × 0.9 mm, narrowly ovate, yellow, bears a shiny bright yellow knob-like wart at base (umbo); anthers 2, positioned on either one side, 2.5 × 1.4 mm; stigma ca. 4.7 mm, widely ovate. *Pollinia* 2, 2 × 1.3 mm; gymnostemium ca. 5 mm.

**Distribution.** It was an endemic species to limestone cliffs on the east side of the Phuket-Krabi Gulf of Peninsular Thailand [41, 42]. In Peninsular Malaysia, the specimen of the first record reported in this paper was collected from Perlis (Fig 2). The exact locality is withheld in this paper to protect the population from illegal collections. *P. exul* were also reported seen in Kedah, however, we have no authentic specimens to substantiate this claim.

**Etymology.** In Greek, *Paphos* means birthplace of the mythological goddess Aphrodite; and *pedilon* means slipper, referring to the slipper-shaped labellum [43]. The species epithet, *exul* was derived from an English word 'exile' by Ridley means 'banished one' because of the geographical isolation from the closely allied one, *P. insigne* (Wall. ex Lindl.) Pfitzer [43]. Hence, the common name, Excluded Paphiopedilum.

**Habitat and ecology.** It grows on the cliff in a limestone hill forest, dried but shaded (Fig 3).

**Taxonomic notes.** The newly recorded *P. exul* belongs to subg. *Paphiopedilum* sect. *Paphiopedilum*. Subg. *Paphiopedilum* sect. *Paphiopedilum* characterised by having single flowered (or at most 2-flowered), linear or spatulate petals that are more than twice as long as broad, pouch side lobes incurved, and strap-shaped and plain green leaves [44]. *Paphiopedilum exul* has been described by several authors under different names due to the wide variation in pouch, staminode and dorsal sepal morphologies. This species closely resembles *P. insigne*, but has smaller flowers and belongs in its alliance [45]. The former species differs by having sepals shorter (3.2–3.8 cm vs 5–6.4 cm) [46], staminode apex apiculate instead of emarginated and roundly bilobed, and anthers hidden behind the staminode [47]. In [47], *P. exul* differs by having the leaves surface yellowish rather than glaucous as in *P. insigne*. However, this character is rather unreliable as leaf colouration changes depending on the habitat and ecological conditions. Plants found in Perlis has slight variations in dorsal sepal and petals and staminode morphologies if compared to the one found in Peninsular Thailand (see Table 1). The base connate to the gymnostemium rather than bilobed and free as illustrated in [47], and the sepals

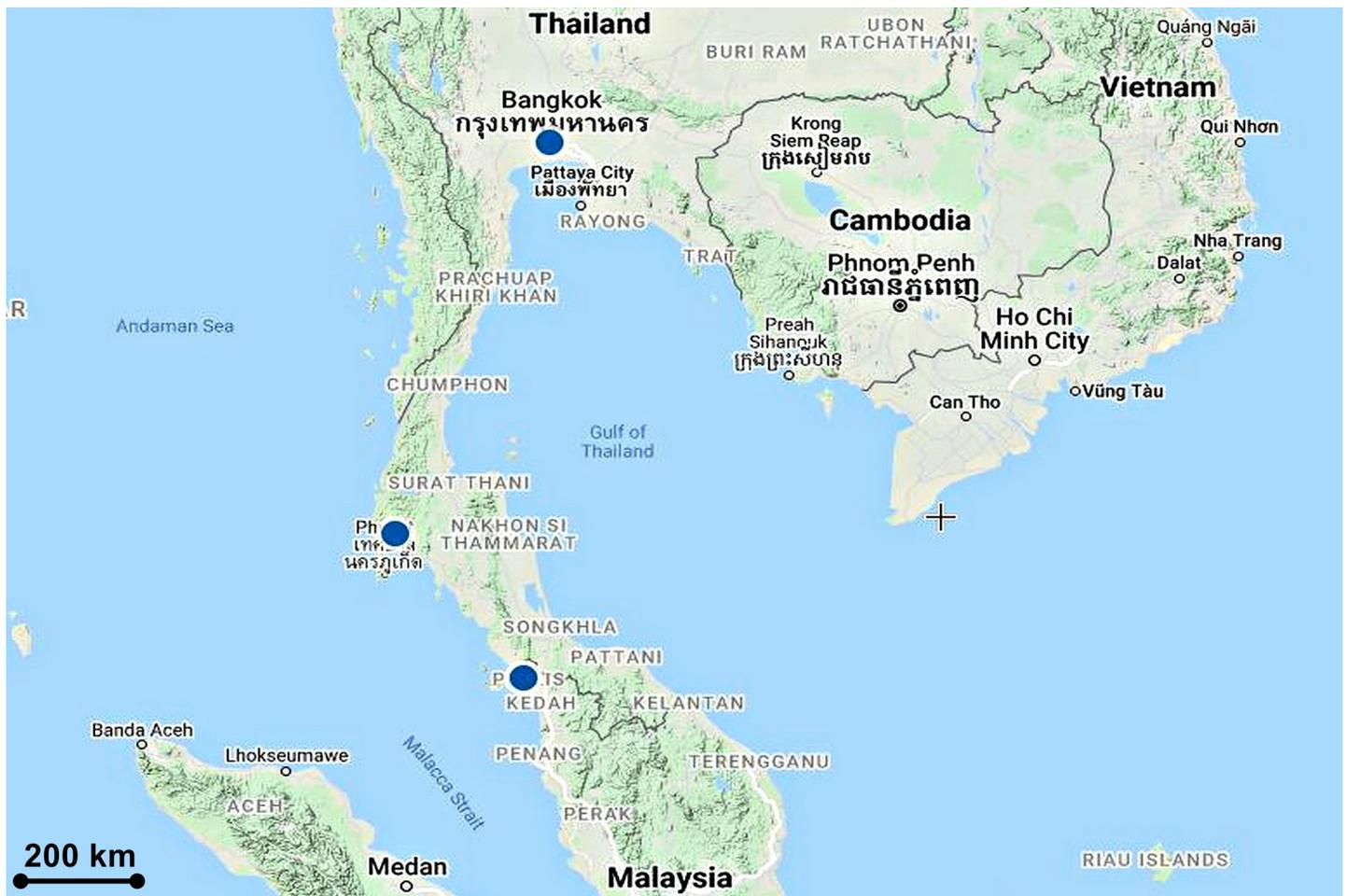


Fig 2. Distribution of *Paphiopedilum exul*.

<https://doi.org/10.1371/journal.pone.0267485.g002>



Fig 3. *P. exul* growing on the cliff of a limestone forest. Photos by Muhamad Faizal Md Azmi.

<https://doi.org/10.1371/journal.pone.0267485.g003>

**Table 1. Comparison of morphological characters of *P. exul* from Perlis and *P. exul* from Thailand.**

Characters	<i>P. exul</i> from Perlis (Besi et al. EDW113)	<i>P. exul</i> from Thailand (Besi et al. EDW114)	<i>P. exul</i> from Thailand [46]
Flowers sizes	ca. 3.5 cm across	ca. 5 cm across	ca. 6.5 cm across
Pedice-with-ovary	pubescent, reddish green, ca. 2.4 cm long	pubescent, reddish green, ca. 4 cm long	pubescent, yellow-green, 2.2–4 cm long
Dorsal sepal shape	broadly ovate, apex cuspidate	broadly ovate, apex cuspidate	ovate-elliptic, apex obtuse
Dorsal sepal size	3.4 × 2.7 cm	3.8 × 2.7 cm	3–4.8 × 2.5–3 cm
Petals shapes	oblanceolate, apex obtuse, margins undulate	oblanceolate, apex obtuse, margins undulate	oblanceolate to narrowly oblong, apex obtuse, margins undulate
Petals sizes	3.4 × 1 cm	4.1 × 1.5 cm	4.3–5 × 1.4–1.7 cm
Synsepalum shape	ovate, apex obtuse	ovate, apex obtuse	oblong-elliptic, apex obtuse
Synsepalum size	3.5 × 2.1 cm	3.8 × 2.3 cm	3.4–4.7 × 1.6–2.5 cm
Pouch colour	glossy, reddish green with brown veins	glossy, reddish green with brown veins	glossy, yellowish-beige with darker veins
Pouch size	2.8 × 1.4 cm	3.5 × 1.5 cm	3–3.5 × 1.9 cm
Staminode shape	obovate, apex mucronulate with the central teeth rounded, base connate to the gynostemium	obovate, apex mucronulate with the central teeth rounded, base connate to the gynostemium	obovate, apex obtuse to rarely retuse, base bilobulate rounded and free
Staminode size	8 × 8 mm	8 × 7 mm	6–8 × 7–9 mm

<https://doi.org/10.1371/journal.pone.0267485.t001>

are shorter [46]. Also, the peculiarity seen at the flower size (Table 1). Minor variation in staminode shape, flower size, and leaf pattern across localities are common in *Paphiopedilum* [44, 48, 49]. *Paphiopedilum exul* is having no near allies among the Peninsular Malaysian species. It is easily distinguishable if compared to the other single-flowered with long and spotted petals *Paphiopedilum*, such as *P. barbatum* (Lindl.) Pfitzer, *P. bullenianum* (Rchb.f.) Pfitzer, and *P. callosum* var. *sublaeve* (Rchb.f.) P.J.Cribb.

### Artificial key to *Paphiopedilum* subg. *Paphiopedilum* from Peninsular Malaysia, with usually single flowers (or at most 2 flowers) per plant

Leaves elliptic to oblong-elliptic, yellowish or bluish green, usually mottled; flowers bluish green. . . . .  
*P. bullenianum*, *P. barbatum*, *P. callosum* var. *sublaeve* (sect. *Barbata*)

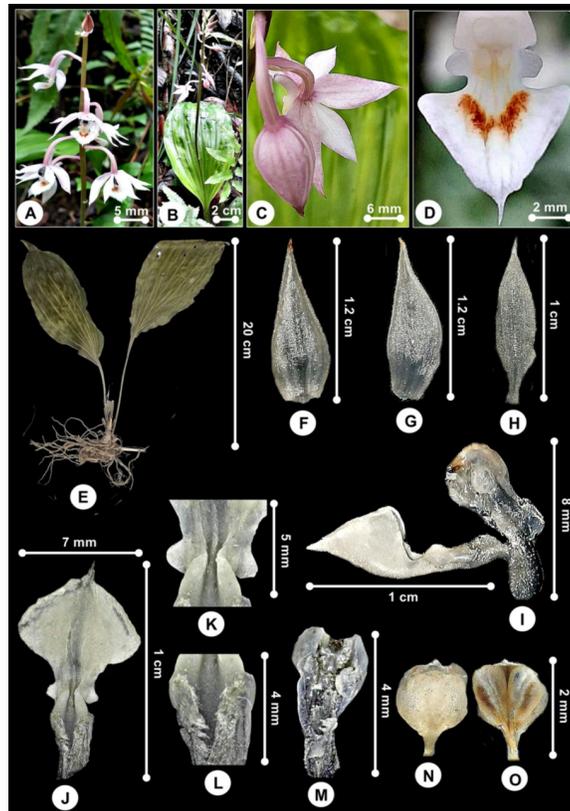
Leaves strap-shaped to oblong-elliptic, plain green; flowers yellowish green. . . . .*P. exul* (sect. *Paphiopedilum*)

**Species reference.** *Cypripedium insigne* var. *exul* Ridl. [50]; *Cypripedium exul* var. *aureum* Rolfe [46], *Paphiopedilum exul* var. *aureum* (Rolfe) Pfitzer [47].

**Additional specimens examined.** THAILAND. Peninsular Thailand, Kasoom, Phangnga, Nov 1897, Curtis SING0141768 (SING-photo!); 1892, Ridley SING0141766 (SING-photo!); 19 November 1901, Communic. ex. Herb. Hort. Bot. Bog., L.1527086 (NHN-photo!); 19 November 1901, Communic. ex. Herb. Hort. Bot. Bog., L.1527085 (NHN-photo!); 12 December 1918, Mhd Haniff SING0141767 (SING-photo!); Central Thailand, Bangkok, 2 April 1925, Kerr K000595625 (K-photo!); 2 August 2020, cultivated Besi et al. EDW114 (UPM!).

*Calanthe chrysoglossoides* J.J.Sm., Bull. Dép. Agric. Indes Néerl. 43: 24 (1910); Fig 4.

Type: INDONESIA. Java, Gunung Salabintana (Selabintana), Jackson 1506, 1165 (syntype BO-photos!).



**Fig 4.** *Calanthe chrysoglossoides*. A. Inflorescence. B. Plant in the natural habitat. C. Dorsal view of the flower. D. Labellum with a central orange mark. E. Plant (dried specimen). F. Dorsal sepal. G. Lateral sepal. H. Petal. I. Lateral view of the labellum and Gymnostemium showing canaliculated claw. J. Labellum (flattened). K. Close-up of the labellum side lobes. L. Pubescent claw. M. Gymnostemium including foot. N. Anther-cap. O. Pollinia. Note: F-O are preserved specimens.

<https://doi.org/10.1371/journal.pone.0267485.g004>

Specimen examined:—MALAYSIA. Selangor, Batang Kali, ca. 1000 m elev., 12 October 2020, Besi et al. EDW122 (UPM!).

**Description.** *Plants* terrestrial, ca. 20 tall without inflorescence. *Pseudobulbs* clustered, single-leaved. *Leaves* ovate to wide elliptic, apex acuminate, ca. 20 × 8 cm, abruptly narrowed to a ca. 10–15 cm long and sulcate petiole, plicate, very shortly pubescent beneath. *Inflorescence* ca. 30–40 cm long, arised from pseudobulbs which just forming, emerging together with the leaf; rachis ca. 13 cm long, 10- to 15- flowered placed laxly; floral bracts narrowly triangular, very acute, 5 mm long, greenish yellow, persistent. *Flowers* 2.2 × 1.5 cm, opening widely, white, the sepals flushed purple or pink on the outside, prominent median nerve, labellum pale pink with a central orange mark, glabrous inside, finely pubescent outside, spur short at ca. 3 mm long. *Dorsal sepal* 1.2 × 0.5 cm, oblong-ovate, apex acuminate. *Lateral sepals* 1.2 × 0.4 cm, obliquely elliptic, apex acuminate. *Petals* 1 × 0.3 cm, oblong-ovate, apex acuminate, base cuneate, finely pubescent outside. *Labellum* 1.1 × 0.7 cm, flabellate from a short claw, 3-lobed, side lobes very small and rounded, 1 mm long; midlobe 6 × 7 mm, spade-shaped, almost circular, disk slightly concave, minutely apiculate, base cuneate, a deep median ridge running from the base to apex, a 5 mm long linear and verrucose callus at base; claw short, 6 mm long, canaliculated, wall raised and rounded, sparsely pubescent. *Gymnostemium* 4 mm long including foot, stout, clavate, pubescent below the stigma and on the margins; apex 2.5 × 2 mm; anther-cap 2 × 2 mm, rounded, cucullate; pollinia 2 × 1 mm, triangular, outer surface slightly sulcate.

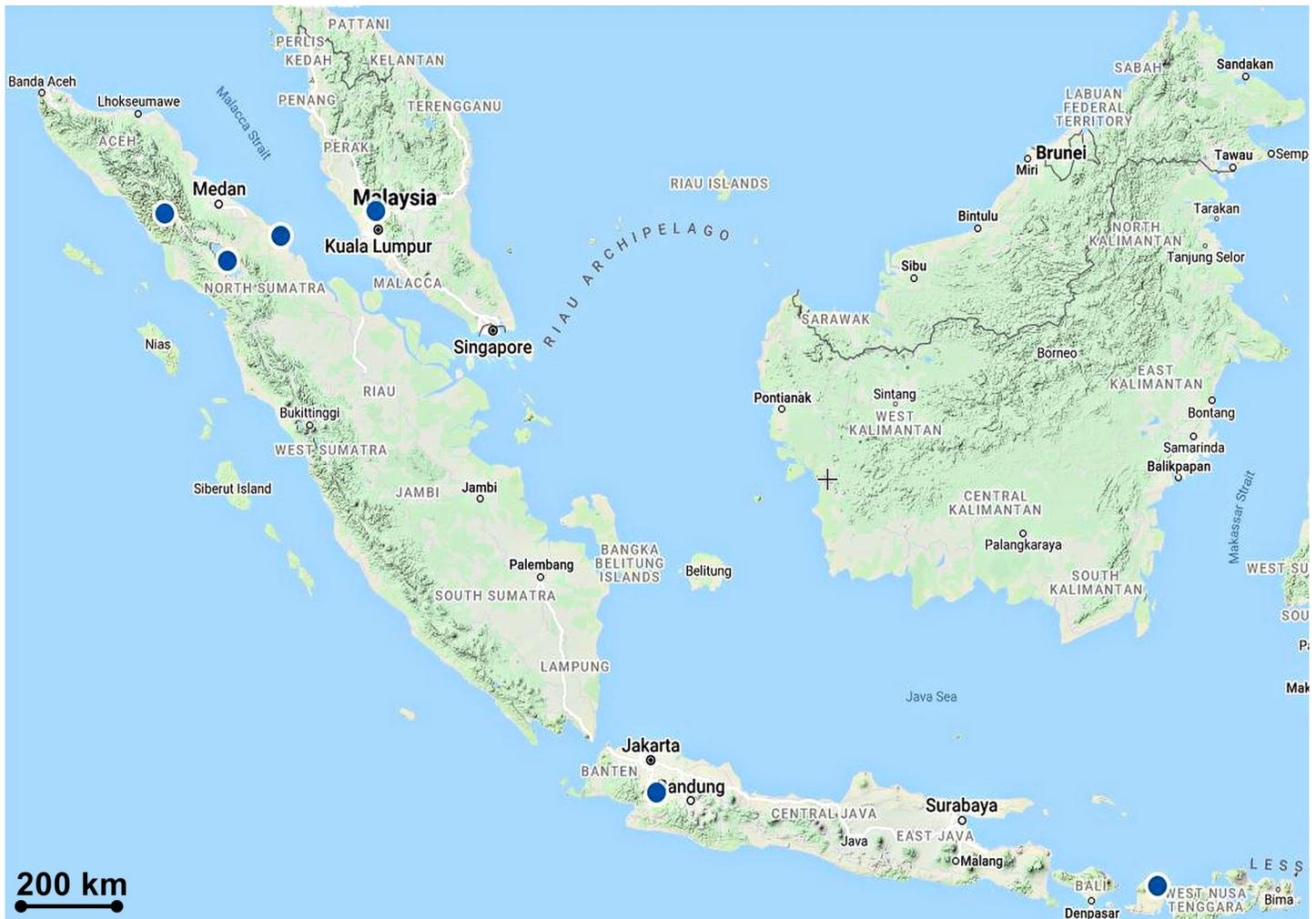


Fig 5. Distribution of *Calanthe chrysoglossoides*.

<https://doi.org/10.1371/journal.pone.0267485.g005>

**Distribution.** It was an endemic species to Indonesia, reported from Java, Sumatra, Lesser Sunda Islands, until our recent discovery of a population from Selangor, Malaysia (Fig 5).

**Etymology.** The genus name, *Calanthe* is from the Greek *kalos*, means beautiful, and *anthos*, means flower, in reference to the showy flowers of the type species, whereas the species epithet *chrysoglossoides* is derived from Greek *chrysous*, golden, and *glossa*, tongue, alluding to the colour of the labellum in the type species [43].

**Habitat and ecology.** Growing in a shaded lower montane forest at elevation ca. 1,000 m. An undisturbed forest area but connected to a highly developed area for hotel and shopping complexes.

**Taxonomic notes.** *Calanthe chrysoglossoides* is similar to *C. monophylla* Ridl. and *C. taenioides* J.J. Sm. that occur in montane forests and belongs to sect. *Monophylla*. The two species were the only representative of the single-leaved *Calanthe* found in Peninsular Malaysia. In comparison, the species are having a creeping rhizome and only one full-sized leaf to a pseudo-bulb, except *C. chrysoglossoides* has larger flowers with broader sepals and petals, and ovate or almost circular labellum midlobe instead of narrow or bilobed at apex.

Artificial key to *Calanthe* sect. *Monophylla* from Peninsular Malaysia

1	Flowers glabrous, yellowish white . . . . . <i>C. taenioides</i>
	Flowers finely pubescent outside, pinkish white. . . . . 2
2	Labellum apically bilobed, lobules diverging and rounded. . . . . <i>C. monophylla</i>
	Labellum apically unlobed, apiculate. . . . . <i>C. chrysoglossoides</i>

**Species reference.** *Calanthe monophylla* Ridl. [51] and *Calanthe taenioides* J.J.Sm. [51, 52].

**Additional specimens examined.** INDONESIA. Sumatra, Toba, Residency of Tapianoeleli, Vicinity of Loemban Lobo, 27 July 1936, *Rahmat Si Boeea L.1495195* (NHN-photo!); Sumatra, Toba, Residency of Tapianoeleli, Headwaters of Aek Mandosi, 29 September 1936, *Rahmat Si Boeea L.1495233* (NHN-photo!); Sumatra, Asahan, 3–15 October 1936, *Rahmat Si Boeea L.1495231, L.1495232, L.1495234* (NHN-photo!); Sumatra, east coast, Aek Boeloe Bolon, 7 November 1936, *Rahmat Si Boeea L.1495238* (NHN-photo!); Sumatra, North Sumatra, Gunung Leuser Nature Reserves, Aceh, 22 June 1979, *Wilde et al. L.1495198* (NHN-photo!); Lesser Sunda Islands, Lombok, 19 June 1909, *Elbert L.1495201* (NHN-photo!).

***Luisia brachystachys*** (Lindl.) Blume, Rumphia 4: 50 (1849); Fig 6.

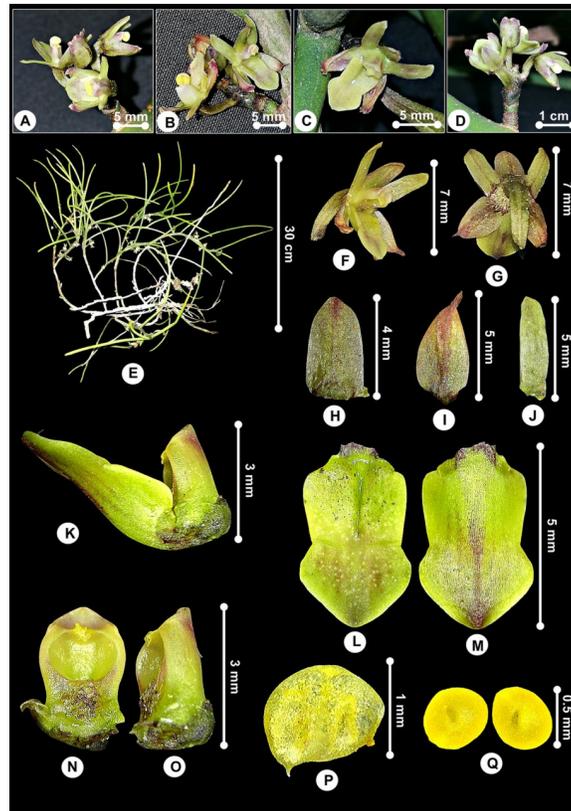
Homotypic Names:—*Mesoclastes brachystachys* Lindl., Gen. Sp. Orchid. Pl.: 44 (1830). Type: BANGLADESH. *Wallich K000891542* (syntype K-photo!).

Heterotypic Synonyms:—*Luisia indivisa* King & Pantl., Ann. Roy. Bot. Gard. (Calcutta) 8: 201 (1898); *Luisia siamensis* Rolfe ex Downie, Bull. Misc. Inform. Kew 1925: 384 (1925). Type: THAILAND. Me Sue, near Chiengmai (Chiangmai), 7 April 1912, *Kerr K000891534* (unknown type K-photo!).

Specimen examined:—MALAYSIA. Kedah, Bukit Pedu, ca. 500 m elev., 12 August 2020, *Besi et al. HS113* (UPM!).

**Description.** Plants epiphytic. Stems suberect or curved, branching, lower part brownish grey or glaucous, upper part, greenish, terete, 10–30 cm, stout, ca. 4 mm in diam., internodes 1–2 cm. Leaves 5–13 cm × 2–3 mm, green, sometimes glaucous, terete, apex obtuse, straight to slightly recurved at apex. Inflorescences 3 to 5 per stem, 2 cm long, 2- to 4-flowered; rachis 1 cm; peduncle 8 mm long, wrinkled, swollen; floral bracts ovate-triangular, ca. 1 mm, fleshy. Pedicel-with-ovary 6 mm long, sulcate, greenish brown. Flowers opening widely, 7 × 5 mm, sepals and petals yellowish green, abaxial midvein purplish brown, labellum pale yellow with purplish tint at epichilium, Gymnostemium green, purple margined, anther cap yellow spotted with purple; pedicel and ovary pale yellow, tinged with purplish brown, ca. 6 mm. Dorsal sepal 4 × 2 mm, ovate, apex obtuse. Lateral sepals 5 × 2.5 mm, ovate-oblong, slightly hooded, dorsally slightly carinate, keeled abaxially, keel becoming winged at apex, apex obtuse. Petals 5 × 1 mm, linear-oblong, apex obtuse. Labellum 5 × 3 mm, glabrous, fleshy, hypochilium concave, deep indentation between epichilium and hypochilium, more or less rectangular, ca. 2.8 × 2.8 mm, indistinct lateral lobes at base; epichilium ca. 2 × 3 mm, suborbicular or heart-shaped, 2 × 3 mm, apex obtuse; hypochilium thick, grooved at the middle. Gymnostemium 3 mm long, 2 mm wide at apex, stout; stigma large, orbicular; anther-cap 1 × 2 mm; pollinia 0.5 × 0.5 mm, orbicular.

**Distribution.** Distributed in Bangladesh, India, Thailand, Myanmar, Vietnam, Laos, Indonesia, and Malaysia. In Malaysia, the plant was collected from Kedah in the northern part of Peninsular Malaysia (Fig 7).



**Fig 6. *Luisia brachystachys*.** A, B. Flowers from top and lateral views. C. Flower's front view. D. Inflorescence. E. Plant. F. Flower's lateral view. G. Flower's dorsal view. H. Dorsal sepal. I. Lateral sepal. J. Petal. K. Labellum and Gynostemium. L. Labellum's abaxial view. M. Labellum's adaxial view. N. Gynostemium's front view. O. Gynostemium's lateral view. P. Anther-cap, Q. Pollinia.

<https://doi.org/10.1371/journal.pone.0267485.g006>

**Etymology.** The genus name commemorates the Spanish explorer Don Luis de Torres (–1493) who was an interpreter for Christopher Columbus on his first voyage to the Caribbean [53]. The species epithet, *brachystachys* is from the Greek, *brachys* means short, whereas *stachys* means an ear of corn [43]; alluding to the short flower spike of this species.

**Habitat and ecology.** Grow on tree trunks at tops of a conglomerate hill forest with elevation of 600 m.

**Taxonomy notes.** *Luisia brachystachys* resembles *L. zollingeri* Rchb.f. in W.G. Walpers in plant size and having semi-orbicular to heart-shaped epichilium, but differ in having hypochilium separated from the epichilium by a rather indistinct shallow ridge, indistinct and not incurved lateral lobes at base, epichilium lacking of two lateral cushions and upcurved, and narrower oblong (not ovate) petals. On the basis of these morphological variations, the two species can be easily recognized as distinct species if compared to the other *Luisia* species found in Peninsular Malaysia, for examples, *L. antennifera* Blume, *L. curtisii* Seidenf., *L. jonesii* J.J.Sm. Moreover, hypochilium with 5 to 15 nerves and thickly cushioned epichilium are diagnostic characters for *L. zollingeri* [54]. Also, the plant that we discovered is very similar to specimens of *De Silva* K000873795 (K-photo!) and *Lobb* K000873796 (K-photo!), especially on the morphology of the flowers based on the illustrations on the herbarium sheets.



Fig 7. Distribution of *Luisia brachystachys*.

<https://doi.org/10.1371/journal.pone.0267485.g007>

### Artificial key to *Luisia* from Peninsular Malaysia with small flowers ca. 5 mm wide and petals shorter or same length as sepals

1	Plants and flowers usually large; plants pendant more than 30 cm long; flowers more than 1 cm wide; petals filiform, longer than sepals. . . . .	<i>L. antennifera</i> , <i>L. curtisii</i> , <i>L. jonesii</i>
	Plants and flowers small; plants less than 30 cm long; flowers ca. 5 mm wide; petals shorter or same length as sepals. . . . .	2
2	Petals ovate, as long as dorsal sepal, together forming a hood; labellum bilobed. . . . .	<i>L. zollingeri</i>
	Petals linear, narrower than dorsal sepal, 1 mm wide; labellum simple. . . . .	<i>L. brachystachys</i>

**Species reference.** *Luisia zollingeri* Rchb.f. in W.G.Walpers [53].

**Additional specimens examined.** THAILAND. Me Sue, near Chiengmai (Chiang Mai), 07 April 1912, 457 m elev., *Kerr K000891534* (K-photo!); INDIA. Sikkim, Dooars, Mount Anduson, March 1897, 457 m elev., *s. coll. K000891541* (K-photo!); Assam, 01 April 1899–30 April 1899, *Prain’s Collector L.1521919* (NHN-photo!); Unknown locality, 1994, *De Silva*

K000873795 (K-photo!); *Lobb* K000873796 (K-photo!); BANGLADESH. *Wallich* K000891542 (K-photo!); MYANMAR. Tanintharyi, Dawei, May 1897, *Batten* BM000538804 (NHM-photo!); VIETNAM. Anam, Nha Trang, 22 March 1960, *Sigaldi* P00324094 (MNHN-photo!); LAOS. Brikhane, Wiengchan (Vientiane), 27 March 1932, *Kerr* P00324095 (MNHN-photo!).

## Recollections and amended descriptions

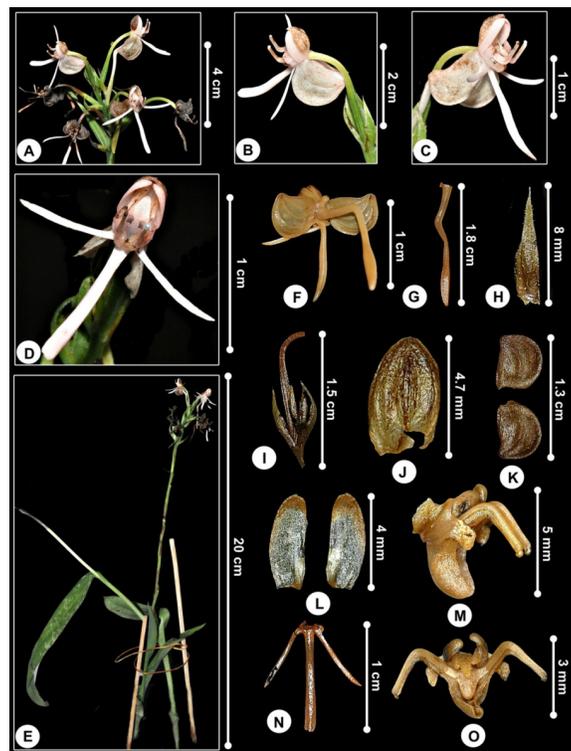
*Habenaria rostelifera* Rchb.f., *Otia* Bot. Hamburg.: 34 (1878); **Fig 8.**

Homotypic synonym:--*Pecteilis rostelifera* (Rchb.f.) M.A.Clem. & D.L.Jones, *Austral. Orchid Rev.* 83(6): 53 (2018). Type: THAILAND. Peninsular Thailand, Trang, 30 May 1919, *Mhd Haniff* SING0047370 (holotype SING-photo!).

Heterotypic synonyms:--*Habenaria hancockii* Rolfe, *Bull. Misc. Inform. Kew* 1896: 202 (1896); *Habenaria roseata* Ridl., *J. Straits Branch Roy. Asiat. Soc.* 49: 42 (1908). Type: THAILAND. Peninsular Thailand, Trang, Cultivated in the Penang Gardens, 29 June 1906, *s.coll.* SING0180012 (SING-photo!).

Specimen examined:--MALAYSIA. Perlis, ca. 100 m elev., 2 August 2020, *Besi et al.* EDW108 (UPM!).

**Description.** Terrestrial. *Plants* up to 20 cm tall. *Stems* ca. 20 cm tall, erect, terete, glabrous, with 2–3 leaves and 1–2 bract-like leaflets. *Cataphylls* up to 2 cm long, tubular, erect, clasping on the stem, with a protruding ovate apex up to 5 mm long, pale greenish with a distinct pale white margins. *Leaves* 12–15 × 1–1.4 cm, spreading, widely spaced, narrowly oblanceolate-oblong, apex acute, often apiculate, adaxial green, abaxial glaucous, pale greenish margins, 3-veined. *Bract-like leaves* 7, up to 2.5 cm long, erect, lanceolate, apex acuminate, basal



**Fig 8. *Habenaria rostelifera*.** A. Inflorescence. B, C, D. Flower from lateral and front view. E. Plant. F. Flowers from back view showing spur. G. Spur. H. Floral bract. I. Pedicel-with-ovary and floral bracts. J. Dorsal sepal. K. Lateral sepals. L. Petals. M. Gynostemium from lateral view showing protruding anther canals. N. Trilobed labellum. O. Gynostemium from top view showing protruding rostellum. Note: F-O are preserved specimens.

<https://doi.org/10.1371/journal.pone.0267485.g008>

sheathing, margins minutely denticulate to coarsely, shortly glandular-hairy, green to pale green at apex. *Inflorescences* lax, 7-flowered, often flowered terminally; rachis 3 cm long. *Floral bracts* 4–5, lanceolate, acuminate, 8 × 1.5 mm, shorter than the pedicel-with-ovary, margins shortly hairy. *Pedicel-with-ovary* 1.4 cm long, cylindrical-fusiform with a long beak ca. 1.5 mm long. *Flowers* 1.4 × 0.6 cm, pale salmon-pink, lateral sepals with large brown blotch in the middle, fragrant. *Dorsal sepal* 4.7 × 2.6 mm, suborbicular, apex cuspidate, margin entire, shortly hairy. *Lateral sepals* 6 × 5 mm, obliquely ovate to rounded, apex obtuse, reflexed, 3 prominent sunken veins, margins minutely denticulate. *Petals* 4 × 1.5 mm, oblong, apex cuspidate, margin denticulate, shortly hairy, forming a hood with the dorsal sepal. *Labellum* ca. 11 mm long, deeply 3-lobed above a short united part; midlobe linear to oblong, apex rounded, canaliculated, 11 × 1 mm; side-lobes divaricate, linear to oblong, apex attenuate, 7 × 0.5 mm; spur cylindrical, nearly as long as the ovary to slightly longer, geniculate, thickened and slightly folded apically, ca. 1.7 cm long. *Gynostemium* 5.1 mm long; foot ca. 3 mm long; anther hooded by dorsal sepal, canals ca. 5 mm long, geniculate at the middle, narrower towards lobed apex; stigmas ca. 2 mm long, freely projecting, rather short; rostellum 3-lobed with arms ca. 1.7 mm long and a middle 3-lobed tongue protruding, postulate, ca. 1.5 mm long; stielidia oblong, apex rounded, geniculate, ca. 1.7 mm long; wings oblong, grooved, ca. 2 mm long. *Pollinia* not seen.

**Distribution.** Cambodia, China South-Central, Laos, Malaya, Thailand, Vietnam [41]. In Peninsular Malaysia, it was found in Perlis (Fig 9).

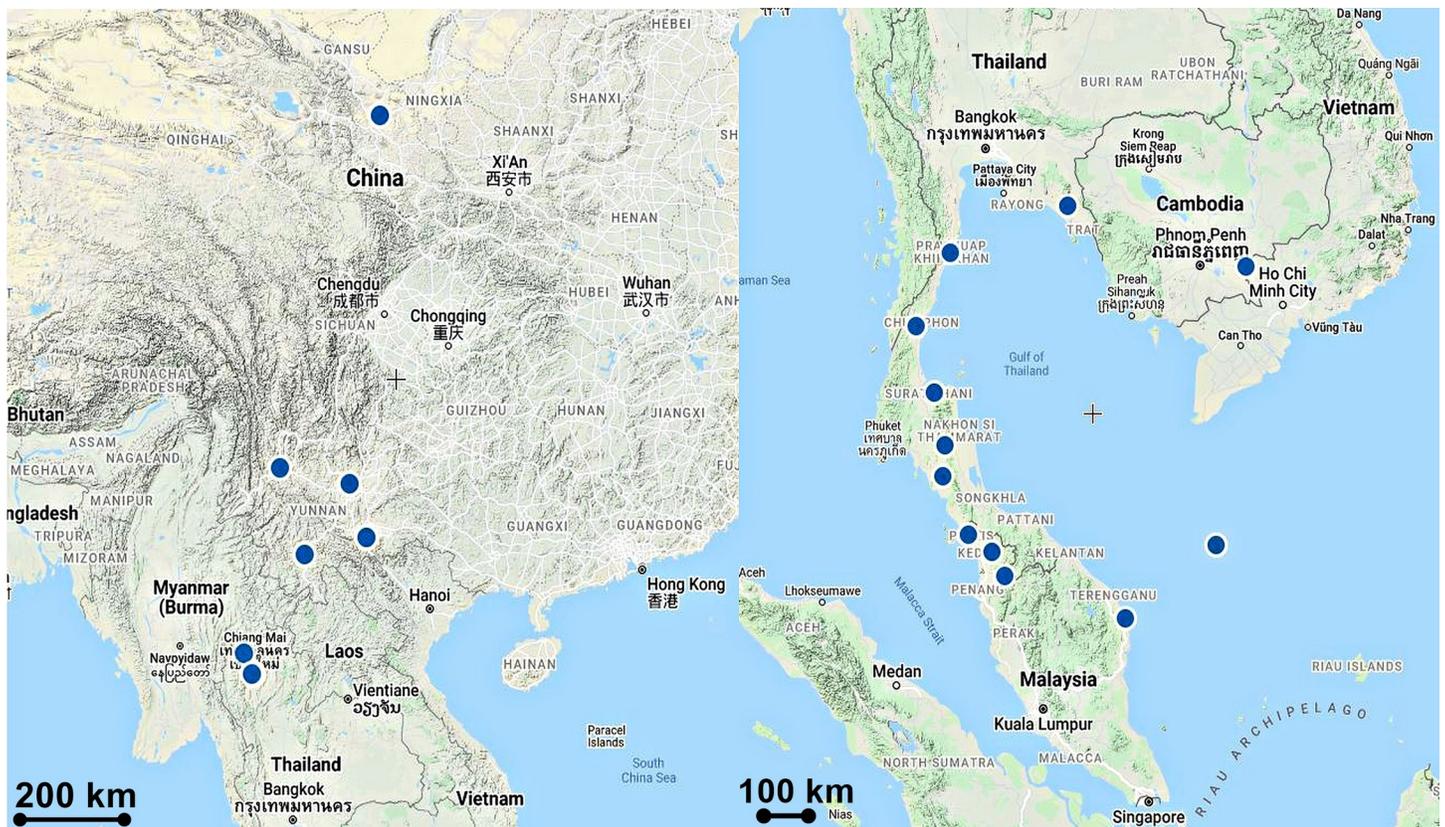
**Etymology.** In Latin, *Habena* means reins referring to the long, strap-like divisions of the petals and labellum [43]; *rostellifera* derived from rostellum, a beak, referring to the beak-like and protruding rostellum [55].

**Habitat and ecology.** Found in open places in deciduous forest.

**Taxonomy notes.** The *H. rostellifera* complexes including *H. rostrata* Wall. ex Lindl. and *H. erostrata* Tang & F.T. Wang has a labellum with three equal and spreading linear lobes and a transversal structure in front of the spur entrance [55]. Another easily visible diagnostic character is the labellum with its three spreading linear and about equally long lobes and the fairly long anther canals which are geniculate bent upwards. The long and filiform 3-lobed labellum differentiate *H. rostellifera* from any other *Habenaria* species found in Peninsular Malaysia, *H. acuifera* Wall. ex Lindl., *H. carnea* Weathers, *H. dentata* (Sw.) Schltr., *H. kingii* Hook.f., *H. medioflexa* Turrill, *H. paradiseoides* J.J.Sm, *H. reflexa* Blume, *H. rhodocheila* Hance, *H. rumphii* (Brongn.) Lindl., and *H. singaporensis* Ridl.. Both *H. rostellifera* and the following species, *H. rostrata*, have ovaries with a prominent beak which can also be clearly seen in the fruiting stage [55]. The tongue in front of the rostellum was regarded as an outgrowth of the labellum as shown by [56]. Reichenbach regarded this protruding structure as part of the rostellum, which the epithet name *rostellifera* was coined after this prominent character [55, 57].

### Artificial key to *Habenaria* from Peninsular Malaysia, has leaves linear and acute, and a labellum with three linear lobes

1	Leaves wide, more than 2 cm wide, ovate to oblanceolate. . . . .	<i>H. acuifera</i> , <i>H. carnea</i> , <i>H. dentata</i> ., <i>H. kingii</i> , <i>H. medioflexa</i> , <i>H. reflexa</i> , <i>H. rhodocheila</i> , <i>H. rumphii</i> , <i>H. singaporensis</i>
	Leaves linear to narrowly lanceolate, 0.5 to 1.5 cm wide. . . . .	2
2	Flowers white, lateral sepals oblong with acute tips; labellum lobes linear, more than 1 mm wide. . . . .	<i>H. paradiseoides</i>
	Flowers pale salmon pink, lateral sepals ovate to rounded; labellum lobes filiform, 0.5–1 mm wide. . . . .	<i>H. rostellifera</i>



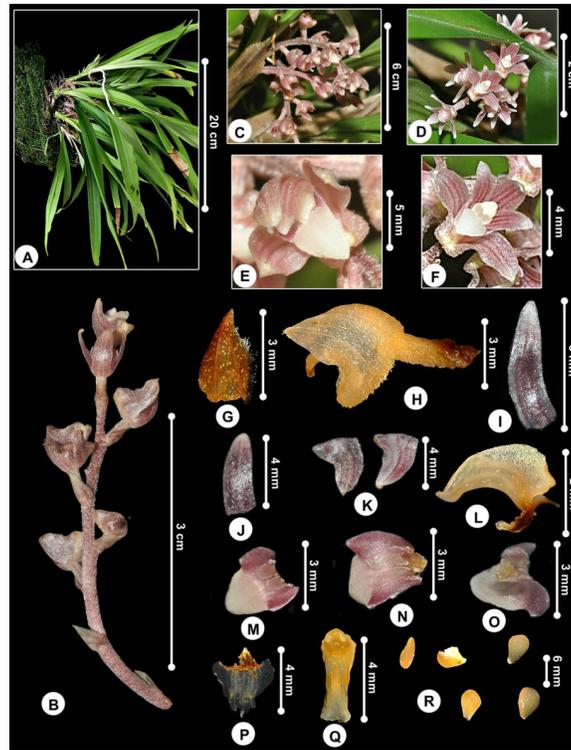
**Fig 9. Distribution of *Habenaria rostelifera*.**

<https://doi.org/10.1371/journal.pone.0267485.g009>

**Species reference.** *Habenaria rostelifera* Rchb.f. [57]; *Habenaria roseata* Ridl. [58]; *Habenaria hancockii* Rolfe [59].

**Additional specimens examined.** MALAYSIA. Peninsular Malaysia, Terengganu, Rantau Abang, 1903, *Down* SING0139971 (SING-photo!); THAILAND. Siam. Tung Song, 19 July 1929, *Rabil* L.1516480 (NHN-photo!); Northeast Thailand, Loie, Sitan, 16 August 1948, *Royal Forest Department* P00370734 (MNHN-photo!); Chanburi, Makham, 3 June 1965, *Phengkklai* L.1516481 (NHN-photo!); Surat, North of Chumphon, 11 August 1966, 50 m elev., *Larsen, Smitinand, Warncke* L.1516479 (NHN-photo!); Unknown locality, 17 August 1984, *Godefroy-Lebeuf* K000364319 (K-photo!); Songkla, Haad Yai, Klong Hoy Kong, 21 November 1984, *Maxwell* AMES01946805 (AMES-photo!); Chiang Mai, Wieng Haeng, Ban Jong village area, 18 September 1989, 975 m elev., *Maxwell* L.1516483 (NHN-photo!); Chiang Mai, Muang, Gukao Falls area, 4 October 1989, 525 m elev., *Maxwell* L.1516482 (NHN-photo!); Trang, 29 June 1906, *Haniff* 4300 (SING-photo!); VIETNAM. Rùng Bbon Phu, August 1967, *Dournes* P00439735 (MNHN-photo!); CAMBODIA. *Godefroy* 14432 (RENZ-photo!); CHINA. Mengtze (Mengzi), Yunnan, June 1983, 1676–1829 m elev., *Hancock* K000827011 (K-photo!); Yunnan, Kunming, 17 August 1984, *Bartholomew & Boufford* AMES00140709 (AMES-photo!); Yunnan, Yangpi, *Rock* AMES00140671 (AMES-photo!); Yunnan, Mengzi, *Henry* AMES00140669 (AMES-photo!); June 1983, *Godefroy-Lebeuf* K000364319 (K-photo!).

***Bryobium cordiferum* subsp. *borneense*** (J.J.Wood) Schuit., Y.P.Ng & H.A.Pedersen, Bot. J. Linn. Soc. 186: 193 (2018); Fig 10.



**Fig 10.** *Bryobium cordiferum* subsp. *borneense*. A. Plant. B, C, D. Inflorescence from lateral and front view. E, F. Flowers showing whitish ovate labellum. G. Floral bract. H. Flower from lateral view. I. Petal. J. Dorsal sepal. K. Lateral sepals. L. Labellum from lateral view. M. Labellum from top view showing midlobe. N. Labellum from top view showing two lateral keels. O. Labellum from top view showing basal part. P. Flattened labellum. Q. Gymnostemium. R. Pollinia.

<https://doi.org/10.1371/journal.pone.0267485.g010>

Homotypic synonym:—*Eria cordifera* subsp. *borneensis* J.J.Wood, Kew Bull. 39: 84 (1984).  
Type: MALAYSIA. Sarawak, Gunung Mulu National Park, Rib Anderson Camp, 14 march 1978, Nielsen 652 (holotype AAU-Photo!).

Specimen examined:—MALAYSIA. Sarawak, Kapit, ca. 50 m elev., 2 December 2019, Besi *et al.* EDW068 (UPM!).

**Description.** *Plants* epiphytic, up to 20 cm high. *Rhizome* very short. *Pseudobulbs* caespitose, cylindrical, 2-leaved, 2–3 cm long, covered in pale brown, ovate-lanceolate, apex acute to acuminate, membranous sheaths. *Leaves blades* 13–20 × 1.1–1.8 cm, green above, light green below, erect, linear-lanceolate, apex attenuate and unequally bilobulate, conduplicate towards base. *Inflorescence* 6- to 8-flowered, lax, much shorter than leaves; peduncle and rachis pubescent, covered by short white indumentum; peduncle 1.8 cm long, with sterile bract; rachis 3.5 cm long. *Floral bracts* ovate, subacute, minutely puberulus, 3.2 × 1.8 mm. *Pedicel-with-ovary* sessile, terete, densely pubescent, 3.5 mm long. *Flowers* 8 × 8 mm, pubescent dorsally, reddish, veins darker, petals and lateral sepals reflexed. *Mentum* 3 mm long. *Dorsal sepal* oblong, obtuse, concave, 5.3 × 2 mm. *Lateral sepals* obliquely ovate, falcate, obtuse, cucullate, 5-veined, 4.4 × 3.5 mm. *Petals* linear-oblong, obtuse, falcate, glabrous, 4.6 × 1.2 mm. *Labellum* 3-lobed, strongly recurved, glabrous, 2.6 × 2.8 mm, 4.5 × 3.5 mm when flattened; side lobes erect, widely rounded, ca. 0.9 mm long; midlobe triangular-ovate, acute, fleshy, with widely ovate callus, ca. 1.2 mm long; disc with a median keel, 2 parallel and oblong fleshy lamellae extending from near the base to the base of midlobe, ca. 1.5 mm long; base cuneate. *Gymnostemium* 4.5 × 1.5 mm, clavate, apex 1.5 mm long, foot 3 mm

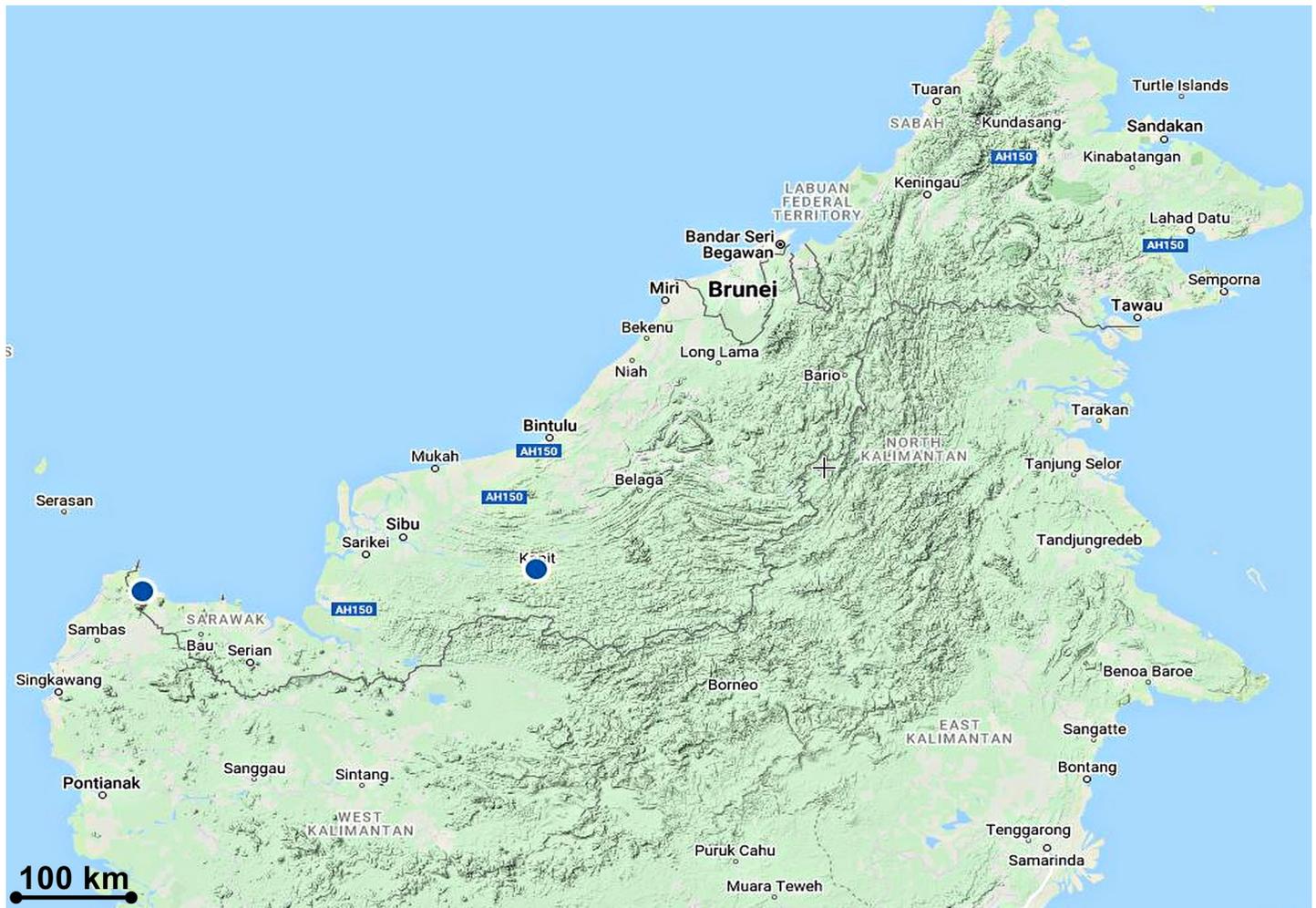


Fig 11. Distribution of *Bryobium cordiferum* subsp. *borneense*.

<https://doi.org/10.1371/journal.pone.0267485.g011>

long, dorsal lobe tooth-like, base lobate, stigma  $1 \times 0.6$  mm, anther cucullate, ovate; pollinia 8, ovate,  $0.6 \times 0.5$  mm.

**Distribution.** The first specimen was collected from the 4<sup>th</sup> Division, Gunung Mulu National Park by Nielsen in 1978 [60]. Since then, there was no further record on its recollection, until now. Our specimen was collected from Kapit, Sarawak (Fig 11).

**Etymology.** In Greek, *bryon* means moss and *bios* as in the English 'bios' means life [43]. The species epithet *cordiferum* (latin) means cordate, heart-shaped, with the notch at the base, referring to the heart-shaped labellum [61].

**Habitat and ecology.** Mixed forest on sandy soil with scattered limestone rock [60], and along the riverine forest with alluvial vegetation (Fig 12).

**Taxonomic notes.** According to J. J. Wood in his paper [60], *Bryobium cordiferum* subsp. *borneense* differs from *B. cordiferum* subsp. *cordiferum* from Papua New Guinea in having shorter pseudobulbs and leaves, much smaller floral bracts and less hairy flowers [60]. Though our specimen has leaves much wider than Wood's specimen of *B. cordiferum* subsp. *borneense* from Gunung Mulu National Park and Schlechter's specimen of *B. cordiferum* subsp. *cordiferum* (Table 2). But, presumably, both Wood's and Schlechter's descriptions were based on dried



**Fig 12.** The plants growing as epiphyte on a tree in a riverine forest in Kapit, Sarawak.

<https://doi.org/10.1371/journal.pone.0267485.g012>

specimens, hence, the reduced sizes of the specimens. Also, our specimen showing the vegetative structure is very much similar to the subsp. *cordiferum* rather than the subsp. *borneense* (Table 2). However, the bracts and flowers showing affinity to the subsp. *borneense*, especially on the tepals sizes and widely ovate callus on the midlobe (Table 2). *Bryobium cordiferum* differs from the other two species of *Bryobium* species found in Peninsular Malaysia, *B. hyacinthoides*

**Table 2.** Comparison of morphological characters of *B. cordiferum* subsp. *borneense* found in Kapit, *B. cordiferum* subsp. *borneense* found in Gunung Mulu National Park, and *B. cordiferum* subsp. *cordiferum* found in Papua New Guinea.

Characters	<i>B. cordiferum</i> subsp. <i>borneense</i> found in Kapit	<i>B. cordiferum</i> subsp. <i>borneense</i> found in Gunung Mulu National Park [55]	<i>B. cordiferum</i> subsp. <i>cordiferum</i> found in Papua New Guinea [57]
Pseudobulbs size	2–3 cm long	0.8–1.4 cm long	2.5–5 cm long
Leaves shape	linear-lanceolate, apex attenuate	linear-lanceolate, apex acute to attenuate	linear, apex acute
Leaves sizes	13–20 × 1.1–1.8 cm	10–14 × 0.5–0.7 cm	17–25 × 0.5–0.8 cm
Floral bracts shape	ovate, apex subacute	ovate, apex subacute	elliptic, apex obtuse
Floral bracts sizes	3.2 mm long	2.5 mm long	
Dorsal sepal shape	oblong, apex obtuse	oblong, apex obtuse	oblong, apex obtuse
Dorsal sepal size	5.3 mm long	5 mm long	6.5 mm long
Lateral sepals size	4.4 mm long	5 mm long	2.8 mm long
Petals shapes	linear-oblong, apex obtuse	linear-oblong, apex obtuse to acute	obliquely elliptic to strap-shaped, apex obtuse
Labellum size	2.6 × 2.8 mm	4.5 × 3 mm	6.5 × 6.5 mm
Labellum midlobe	widely ovate callus	widely ovate callus	large heart-shaped callus
Labellum lateral lobes	widely rounded	rounded	divergent, triangular, obtuse

<https://doi.org/10.1371/journal.pone.0267485.t002>

(Blume) Y.P.Ng & P.J.Cribb and *B. pudicum* (Ridl.) Y.P.Ng & P.J.Cribb, by having pseudobulbs small and inconspicuous, completely covered by rather thick and triangular sheaths.

### Artificial key to *Bryobium* from Malaysia with caespitose pseudobulbs

1	Pseudobulbs conspicuous, 6–11 cm long. .... <i>B. hyacinthoides</i>
	Pseudobulbs caespitose, 1–3 cm long. .... 2
2	Pseudobulbs conical bearing single leaf; flowers scented; labellum midlobe with irregular callus. .... ... <i>B. pudicum</i>
	Pseudobulbs inconspicuous, covered by triangular and alternate sheaths, bearing two leaves; flowers unscented; labellum midlobe with prominent ovate callus. ... ... <i>B. cordiferum</i> subsp. <i>borneense</i>

**Species reference.** *Eria cordifera* Schltr. [62]; *Eria cordifera* subsp. *borneensis* J.J.Wood [60].

**Additional specimens examined.** MALAYSIA. Sarawak, Gunung Mulu National Park, Rib Anderson Camp, 14 march 1978, *Nielsen* 652 (holotype AAU-Photo!); PAPUA NEW GUINEA. Kani Gebirges, 10 May 1908, ca. 1000 m elev., *Schlechter* L.0058744 (isotype NHN-photo!); Kani Gebirges, 10 May 1908, ca. 1000 m elev., *Schlechter* K000827429 (isotype K-photo!).

***Taeniophyllum rugulosum*** Carr, Gard. Bull. Straits Settlem. 7: 72 (1932); Fig 13.

Type: MALAYSIA. Peninsular Malaysia, Pahang, Sat River, August 1929, *Carr* K000942486 (unknown type K-photo!).

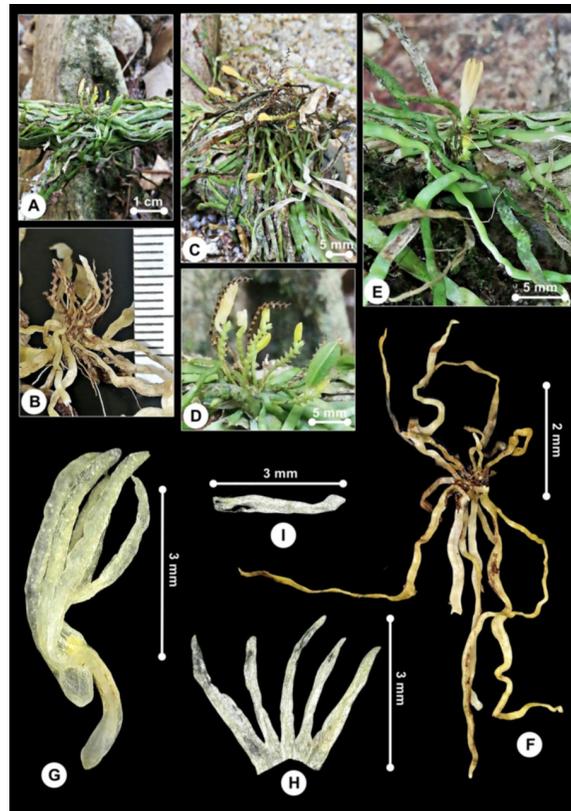
Specimen examined:—MALAYSIA. Perak, Lenggong, ca. 100 m elev., 3 April 2021, *Besi et al.* HS107 (UPM!).

**Description.** *Plants* leafless epiphytic herb forming tangled colonies, often several joined together in a chain, culminates more than 10 inflorescences when flowering. *Roots* thin, flattened, wrinkled, 3–15 × 0.1–0.3 cm, green. *Stems* 1–3 mm long. *Leaves* absent. *Inflorescence* an axillary raceme, ca. 1–1.5 cm long, peduncle filiform, glabrous, apex with alternate and sinuous bracts, green; rachis 5–10 mm long, flattened. *Flowers* 1 or 2 per inflorescence, resupinate, porrect, tubular, 5 × 2 mm, yellowish green, borne successively, spur 1 mm long, tubular; buds, open flowers and capsules often present simultaneously; sepals, petals and labellum almost having the same length, barely distinguishable. *Pedicel-with-ovary* 3 mm long, cylindrical. Sepals and petals somewhat fleshy, basally fused, spreading only in upper half, triangular. *Dorsal sepal* free part ca. 3.3 × 0.9 mm, narrowly triangular, apex acute. *Lateral sepals* free part ca. 3.2 × 0.5 mm, triangular, wider at base, apex acute, longer than petals. *Petals* free part ca. 3 × 0.5 mm, narrowly triangular, apex acute. *Labellum* ca. 3 × 0.7 mm, unlobed, pyriform when flattened; apex small, obtuse, upcurved, falcate; spur 1 mm long. *Gynostemium* porrect, at slight angle to ovary, less than 1 mm long. *Capsules* porrect, ellipsoid, ca. 7 mm long.

**Distribution.** So far, the species has only been recorded in Peninsular Malaysia and Borneo [25, 41] (Fig 14). However, the occurrence is still not well-known. Due to the inconspicuous appearance of these plants, small, recurrently occurring high in the forest canopy with small short-lived flowers, they are easily overlooked in the field and often preserved in poor conditions [63].

**Etymology.** In Greek, *tainia* means fillet and *phyllon* means leaf, and *Taeniophyllum* referring to the long filamentous leaves of the plant [43]. Meanwhile, the species epithet, *rugulosum*, in Latin, *ruga* means finely rugose, referring to the roots having many small wrinkles.

**Habitat and ecology.** The plant was growing as epiphytes in a lowland riverine forest, on a common riverine tree. Plants were growing on twigs about 3 cm thick.



**Fig 13. *Taeniophyllum rugulosum*.** A. Plant growing on a fallen twig of *Neonauclea* sp. (Rubiaceae) tree in a riverine forest. B, C, D, E. Inflorescence from lateral and front view. F. Plant's top view showing wrinkled roots (spirit-preserved). G. Flower's lateral view (spirit-preserved). H. Sepals and petals (spirit-preserved). I. Labellum's lateral view (spirit-preserved).

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**Taxonomic notes.** *Taeniophyllum rugulosum* is belonging to subg. *Codonosepalum* sect. *Sepalocodon*, a group characterised by having sepals and petals adnate at base and bracts alternate [64]. Our specimen is characterised by the flattened roots, flattened 2-ranked and alternate bracts, yellowish-green and flowers 5 mm long, triangular tepals and labellum, sepals and petals basally fused into a tube, and the free part of sepals always longer than tube. Some of these characters are also shared with the closely-related species, *T. campanulatum* Carr, *T. intermedium* Carr, and *T. stella* Carr. The absence of incurved spine on the labellum and the wrinkled roots differentiate *T. rugulosum* from *T. stella* [63].

**Artificial key to *Taeniophyllum* subg. *Codonosepalum* sect. *Sepalocodon* from Peninsular Malaysia**

1	Rachis short, 3 mm long. .... 2
	Rachis long, 5–10 mm long. .... 3
2	Flowers campanulate; free parts of petals and sepals shortly triangular, shorter than the fused part, 1 mm long. .... ..... <i>T. campanulatum</i>
	Flowers conical; free parts of petals sepals subulate, adnate at the middle in to a tube, spreading and reflexed, ca. 5 mm long. .... ..... <i>T. stella</i>
3	Sepals and petals shortly adnate at the base into a tube for a 1 mm long. .... ..... <i>T. intermedium</i>
	Sepals and petals adnate at the middle into a tube for a 2.5 mm long. .... ..... <i>T. rugulosum</i>

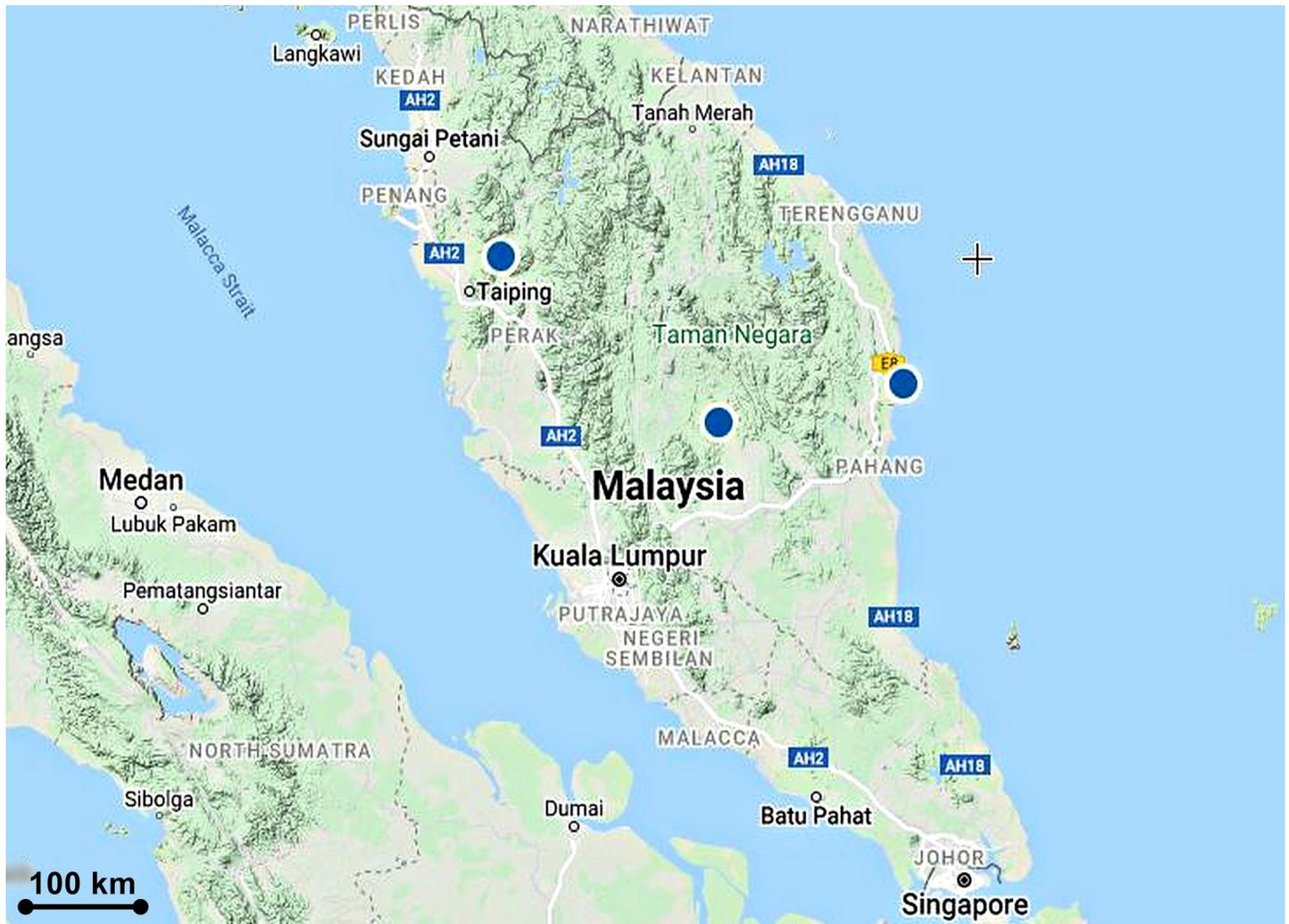


Fig 14. Distribution of *Taeniophyllum rugulosum*.

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**Species reference.** *Taeniophyllum campanulatum* Carr [64], *Taeniophyllum intermedium* Carr [64], *Taeniophyllum stella* Carr [64].

**Additional specimens examined.** MALAYSIA. Pahang, Tembeling, Sat River, August 1929, ca. 152 m elev., Carr K000942486 (K-photo!).

## Supporting information

**S1 File. Comparison on distinctive morphological characters.** A. *Paphiopedilum* Subgenus *Paphiopedilum* from Peninsular Malaysia, with usually single flowers (or at most 2 flowers) per plant. B. *Calanthe* Sect. *Monophylla* from Peninsular Malaysia. C. *Luisia* from Peninsular Malaysia with small flowers ca. 5 mm wide and petals shorter or same length as sepals. D. *Habenaria* from Peninsular Malaysia, has leaves linear and acute, and a labellum with three linear lobes. E. *Bryobium* from Malaysia with caespitose pseudobulbs. F. *Taeniophyllum* Subgenus *Codonosepalum* Section *Sepalocodon* from Peninsular Malaysia. (DOCX)

**S2 File. List of specimens examined, including information on localities, collectors, date of collection, and habitat.** A. *Paphiopedilum exul* (Ridl.) Rolfe. B. *Calanthe chrysoglossoides* J.J. Sm.. C. *Luisia brachystachys* (Lindl.) Blume. D. *Habenaria rostellifera* Rchb.f.. E. *Bryobium cordiferum* subsp. *borneense* (J.J.Wood) Schuit. F. *Taeniophyllum rugulosum* Carr. (DOCX)

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## References

1. Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J. Biodiversity hotspots for conservation priorities. *Nature* 2000; 403(6772): 853–858. <https://doi.org/10.1038/35002501> PMID: 10706275
2. Jin XH, Tan YH, Quan RC. Taxonomic discoveries bridging the gap between our knowledge and biodiversity. *PhytoKeys* 2018; 94: 1–2. <https://doi.org/10.3897/phytokeys.94.23887> PMID: 29416414
3. Sodhi NS, Koh LP, Brook BW, Ng PKL. Southeast Asian biodiversity: an impending disaster. *Trends Ecol. Evol.* 2004; 19(12): 654–660. <https://doi.org/10.1016/j.tree.2004.09.006> PMID: 16701328
4. Wood JJ, Cribb PJ. A checklist of the Orchids of Borneo. United Kingdom, Kew: Royal Botanical Gardens; 1994. 409 pp.
5. Sharma D. The survey of fauna, flora and geological features at the Mata Ayer Forest Reserve and the proposed Bukit Wang Mu Forest Reserve, Perlis. Project No. MYS 277/92 and MYS 241/92. Malaysia, Selangor: World Wildlife Fund; 1992. 122 pp.

6. Mathew D, Sharma D. Biodiversity in Peninsular Malaysia Transfrontier Forests: A study case at Mata Ayer Forest Reserve and proposed Bukit Wang Mu Forest Reserve, Perlis. Project No. MYS 277/92 and MYS 241/92. Malaysia, Selangor: World Wildlife Fund; 1992. 9 pp.
7. Kiew R. A flora survey of limestone hills in Perlis. Project No. 272/93. Malaysia, Selangor: World Wildlife Fund; 1993.
8. Latiff A, Osman K, Faridah-Hanum I, Rahimatsah A. Perlis State Park at Wang Kelian: An introduction. In: Faridah-Hanum I, Osman K, Latiff A, editors. *Kepelbagaian Biologi and Pengurusan Taman Negeri Perlis: Persekitaran Fizikal dan Biologi Wang Kelian*. Malaysia, Perlis: Forest Department of Perlis; 2001. pp. 19–27.
9. Rahimatsah A, Osman K. The administration and management of Perlis State Park. In: Faridah-Hanum I, Osman K, Yusoff AR., Latiff A, editors. *Biodiversity and management of Perlis State Park (Physical, Biological and Social Environments of Wang Mu)*. Forest Department of Perlis, Kangar, Perlis, Malaysia; 2002. pp. 23–43.
10. Liew TS, Price L, Clements R. Using Google Earth to improve the management of threatened limestone karst ecosystems in Peninsular Malaysia. *Trop. Conserv. Sci.* 2016; 9(2): 903–920. <https://doi.org/10.1177/194008291600900219>
11. Go R, Lim MYL, Phoon SN, Yong WSY, Tang CH, Khor HE, et al. Malaysian limestone orchids status: diversity, threat and conservation. *Blumea* 2009; 54(1–2): 109–116. <https://doi.org/10.3767/000651909X474168>
12. Kiew R, Rahman RA. Plant diversity assessment of karst limestone, a case study of Malaysia's Batu Caves. *Nat. Conserv.* 2021; 44: 21–49. <https://doi.org/10.3897/natureconservation.44.60175>
13. Go R, Hamzah KA. *Orchids of peat swamp forests in Peninsular Malaysia*. Malaysia, Serdang: Forest Research Institute Malaysia (FRIM); 2008. 136 pp.
14. Go R, Yong WSY, Unggang J, Ridzuan S. *Orchids of Perlis, jewels of the forest*. Revised edition. Malaysia, Perlis: Jabatan Perhutanan Perlis, and Malaysia, Selangor: Universiti Putra Malaysia; 2010.
15. Kiew R, Chung RCK, Saw LG, Soepadmo E. Seed plant families in Peninsular Malaysia. In: Kiew R, Chung RCK, Saw LG, Soepadmo E, Boyce PC, editors. *Flora of Peninsular Malaysia, Series II: Seed Plants*, Malaysia, Kepong: Forest Research Institute Malaysia (FRIM); 2010. Volume 1. pp. 3–20.
16. Ong PT, O'Byrne P, Saw LG, Chung RCK. *Checklist of orchids of Peninsular Malaysia*. Malaysia, Kuala Lumpur: Perpustakaan Negara Malaysia; 2017. 169 pp.
17. Besi EE, Nikong D, Mustafa M, Go R. Two new species of *Dendrobium* Sect. *Calcarifera* (Orchidaceae) from Terengganu, Peninsular Malaysia. *Malay. Nat. J.* 2018; 70(3): 251–259.
18. Besi EE, Nikong D, Mustafa M, Go R. A New Species of *Bromheadia* Sect. *Aporodes* (Orchidaceae) from Terengganu, Peninsular Malaysia. *Pak. J. Bot.* 2020a; 52(3): 1019–1023. [https://doi.org/10.30848/PJB2020-3\(21\)](https://doi.org/10.30848/PJB2020-3(21))
19. Besi EE, Nikong D, Mustafa M, Yong CSY, Go R. Taxonomic placement of four confusable *Crepidium* species (Orchidaceae, Malaxidinae) based on macro-and micro-morphological analyses, including a note on two new records to Peninsular Malaysia. *Phytotaxa* 2020b; 454(1): 31–44. <https://doi.org/10.11646/phytotaxa.454.1.3>
20. Holttum RE. *A revised Flora of Malaya Vol I Orchids of Malaya*. Singapore: Government Printing Office Singapore; 1957. 759 pp.
21. Ridley HN. An enumeration of all Orchideae hitherto recorded from Borneo. *Bot. J. Linn. Soc.* 1986; 31 (215): 261–306. <https://doi.org/10.1111/j.1095-8339.1896.tb00808.x>
22. Smith JJ. *Icones orchidacearum Malayensium*. Meded. Rijks-Herb. 1930; 2: 1–50.
23. Vermeulen J. *Orchids of Borneo Vol. 2: Bulbophyllum*. United Kingdom, Kew: Royal Botanic Gardens; 1991.
24. Turner IM. A catalogue of the vascular plants of Malaya: Orchidaceae. *Garden's Bulletin Singapore* 1995; 47(1): 559–620.
25. Seidenfaden G, Wood JJ. *The orchids of Peninsular Malaysia and Singapore*. United Kingdom, Kew: Royal Botanical Garden; 1992. 779 pp.
26. Yong WSY, Go R, Tang CH, Abdullah JO, Osman K. Orchids of Perlis: New records and distribution. *Pertanika J. Trop. Agric. Sci.* 2005; 28(2): 135–146.
27. Ong PT. Limestone orchids of Peninsular Malaysia. *The Orchid Rev.* 2015; 123(1309): 28–36.
28. Go R, Pungga RS. *Sarawak Limestone Forests Orchids*. Malaysia, Selangor: University Putra Malaysia Press; 2018.
29. Go R, Khor HE, Mustafa M, Abdullah JO, Naruddin AA, Lee NS, et al. An assessment of orchids' diversity in Penang Hill, Penang, Malaysia after 115 years. *Biodivers. Conserv.* 2011; 20(10): 2263–2272. <https://doi.org/10.1007/s10531-011-0087-z>

30. Go R, Nordin FA. Orchids of Penang Hill, an updated checklist. *Folia Malaysiana* 2017; 18(1): 21–50.
31. Go R, Dahalan MP, Abdul Manaf MB. *Orchidèa Selangoreana* (Wild Orchids of Selangor). Malaysia, Selangor: Selangor State Forestry Department, in association with Malaysia, Selangor: Selangor State Department; 2014. 207 pp.
32. Ng YJ, Go R, Nulit R, Khor HE, Tan MC, Nordin FA, et al. Orchids of cloud forest in Genting Highlands, Pahang, Malaysia. *Sains Malays.* 2012; 41(5): 505–526.
33. Go R, Abdullah JO, Nordin FA, Md Isa SF. 2015. Orchids in the Montane Forests of Peninsular Malaysia. Malaysia, Selangor: Universiti Putra Malaysia Press; 2015. 216 pp.
34. Auyob NA, Zulkifli SZ, Nordin FA, Yong CS, Go R. Notes on new record of orchids on the summit of Gunung Jerai, Kedah, Peninsular Malaysia. *Malay. Nat. J.* 2016; 68(1&2): 49–55.
35. Besi EE, Nikong D, Pungga RS, Go R. Wild Orchid Diversity of Highland Forest in The Heart of Borneo: Long Banga and Tama Abu, Sarawak. *Nat. Conserv. Res.* 2020c; 5(Suppl.1): 1–11.
36. Md Isa SF, Yong CSY, Abdullah JO, Go R. Annotated Checklist of Orchids Found in Merapoh Trail (Gunung Tahan, Malaysia). *Pertanika J. Trop. Agric. Sci.* 2018; 41(3): 1245–1259.
37. Md Isa SF, Go R, Mohd Salim J, Yong CSY. 2015. Orchid in coastal heath forest of Terengganu. In: Mohamad F, Mohd Salim J, Mohd Jani J, Shahrudin R, editors. *Setiu wetlands: Species, ecosystem and livelihood*. Malaysia, Terengganu: Universiti Malaysia Terengganu Publications; 2015. pp. 51–66.
38. Besi EE, Nikong D, Mustafa M, Go R. Orchid diversity in antropogenic-induced degraded tropical rainforest, an extrapolation towards conservation. *Lankesteriana* 2019; 19(2): 107–124. <https://doi.org/10.15517/lank.v19i2.38775>
39. Go R, Besi EE. The Fate of Orchids in Logged Forests and Rescuing Efforts: Terengganu's case study. *Orchid Review* 2020; 1331(September 2020): 162–167.
40. Bridson D, Forman L. *The Herbarium Handbook* (3rd ed.). United Kingdom, Kew: Royal Botanical Gardens; 2000.
41. Govaerts R, Bernet P, Kratochvil K, Gerlach G, Carr G, Alrich P, et al. *World Checklist of Orchidaceae*. United Kingdom, Kew: Royal Botanical Gardens; 2021. Available: <http://apps.kew.org/wcsp/>
42. Koopowitz H. *Tropical Slipper Orchids: Paphiopedilum and Phragmipedium Species and Hybrids*. United States, New York: Timber Press; 2008. 412 pp.
43. Schultes RE, Peace AS. 1963. *Generic names of orchids: their origin and meaning*. New York and London: Academic Press; 1963. 331 pp.
44. Leong PKF. Flora of Peninsular Malaysia—Cypripedioideae. *Malesian Orchid J.* 2014; 13: 113–127.
45. Cribb P, Robbins S. *Paphiopedilum exul*. *Orchidaceae*. The Kew Magazine 1993; 10(1): 5–8. Available: <http://www.jstor.org/stable/45067134>
46. Rolfe RA. *Cypripedium exul*. *The Orchid Review* 1896a; 4(42–45): 162–364. Available: <https://www.biodiversitylibrary.org/item/123752#page/1/mode/1up>
47. Pfitzer EHH. *Orchidaceae-Pleonandrae* (No. 12). In: Engelmann W, editor. *Pflanzenr.* 1903; 4(50): 4–75.
48. Cribb PJ. *The Genus Paphiopedilum*. Collingridge, in association with United Kingdom, Kew: Royal Botanical Gardens; 1987. 222 pp.
49. Cribb PJ. *The Genus Paphiopedilum*. 2nd ed. Malaysia, Kota Kinabalu: Natural History Publications; 1998. 427 pp.
50. Ridley HN. New or Noteworthy Plants. *Gard. Chron.*, n.s. 1891; 3(10): 94. Available: <https://www.biodiversitylibrary.org/item/83801#page/7/mode/1up>
51. Clayton D, Cribb P. *The Genus Calanthe*. Malaysia, Kota Kinabalu: Natural History Publications; 2013. 409 pp.
52. Comber JB. *Orchids of Sumatra*. Malaysia, Kota Kinabalu: Natural History Publications (Borneo); 2001. 1026 pp.
53. Pridgeon AM, Cribb PJ, Chase MC, Rasmussen FN. *Genera Orchidacearum*, Vol. 2 (Orchidoideae, Part 1). United Kingdom, Oxford: Oxford University Press; 2001. 416 pp. PMID: 21669661
54. Sulistiarini D. The orchid genus *Luisia* in Indonesia. *Reinwardtia* 2014; 10(4): 383–398. <https://doi.org/10.14203/reinwardtia.v10i4.276>
55. Kurzweil H. The genus *Habenaria* (Orchidaceae) in Thailand. *Thai For. Bull. (Bot.)* 2009; 37: 7–105. Available: <https://li01.tci-thaijo.org/index.php/ThaiForestBulletin/article/view/24359>
56. Seidenfaden G. Orchid genera in Thailand V. *Orchidoideae*. *Dansk Bot. Ark.* 1977; 31: 1–149.
57. Reichenbach HG. *Orchidoideae Godefroyanae cambodiana*. *Otia Bot. Hamburg.* 1878; 1: 34. Available: <https://www.biodiversitylibrary.org/item/9237#page/1/mode/1up>

58. Ridley HN. New or Rare Malayan Plants. J. Straits Branch Roy. Asiat. Soc. 1908; 49: 42. Available: <https://www.biodiversitylibrary.org/item/130394#page/11/mode/1up>
59. Rolfe RA. New Orchid-Decades. Bull. Misc. Inform. Kew 1896b; 534(17–20): 202. Available: <https://www.biodiversitylibrary.org/item/127161#page/1/mode/1up>
60. Wood JJ. New orchids from Gunung Mulu national park, Sarawak. Kew Bull. 1984; 39(1): 73–98. <https://doi.org/10.2307/4107856>
61. Harris JG, Harris MW. Plant identification terminology (an illustrated glossary). United States, Utah: Spring Lake Publishing; 1994. 197 pp.
62. Schlechter R. Die Orchidaceen von Deutsch-Neu-Guinea. Repert. Spec. Nov. Regni Veg. Beih. 1914; 1: 664. Available: <https://www.biodiversitylibrary.org/item/28953#page/6/mode/1up>
63. Rice R. Photo Intro to: Vandoid Orchid Genera in Asia. Revised edition. Australia: Nature and Travel Books Australia; 2018. 200 pp.
64. Carr CE. The Genus *Taeniophyllum* in the Malay Peninsula. Gard. Bull. Straits Settlements. 1932; 7: 61–82. Available: <https://www.biodiversitylibrary.org/item/148124#page/7/mode/1up>