PhytoKeys 160: 1–6 (2020)
doi: 10.3897/phytokeys.160.54459
http://phytokeys.pensoft.net

RESEARCH ARTICLE

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# *Henckelia siangensis* (Gesneriaceae): a remarkable new species from Northeast India

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Academic editor: Eric Roalson | Received 19 May 2020 | Accepted 16 July 2020 | Published 8 September 2020

**Citation:** Taram M, Borah D, Taku O, Tag H (2020) *Henckelia siangensis* (Gesneriaceae): a remarkable new species from Northeast India. PhytoKeys 160: 1–6. https://doi.org/10.3897/phytokeys.160.54459

**Abstract**

*Henckelia siangensis*, a new species from Arunachal Pradesh of Northeast India, is described and illustrated here. The new species is remarkably different from all other allied species by its 5-winged calyx and elliptic-ovate calyx segments. It superficially resembles *H. calva* in glabrous stem and petioles, but differs from it in having persistent bracts, a campanulate 5-winged calyx and a style with glandular indumentum. A detailed morphological description, photographic illustration, and distribution of the new species are presented.

**Keywords**

Arunachal Pradesh, flora of India, Himalaya, morphology, new taxon

## Introduction

*Henckelia* Spreng. is a tropical genus of the family Gesneriaceae, comprising about 70 species (Kanthraj et al. 2020). The genus is distributed in the India, Bangladesh, Nepal, Bhutan, China, Myanmar, Sri Lanka, Thailand, Laos and Vietnam (Kanthraj et al. 2020). In India, the genus is so far represented by 35 species, 19 of them occurring in the Himalayas and Northeast India (Krishna and Lakshminarasimhan 2018; Borah et al. 2019; Kanthraj et al. 2020). The species of Northeast India along with others found in Sri Lanka were formerly attributed to *Chirita* sect. *Chirita* (Möller et al. 2017). They are all characterized by a caulescent habit, leaves in whorls of 2 or 3, orthocarpic

capsules dehiscing along both the upper and lower sutures and unappendaged seeds (Möller et al. 2017). During our trips to the East Siang district of Arunachal Pradesh in April of 2019, a few interesting specimens of *Henckelia* were collected. They were critically studied, consulting the type specimens housed in several herbaria and scrutiny of relevant literature. The studies revealed that our specimen is remarkably different from all other species of *Henckelia* and led us to conclude that it represents a new species. The striking yellow flowers found in this species are fairly uncommon as only three other species of *Henckelia* with yellow flowers are known from NE India (*H. pathakii*, *H. calva* and *H. dimidiata*) and two others from China (*H. shuii* and *H. xinpingensis*). But as stated by Wood (1974), corolla color in *Henckelia* can vary considerably within a single species due to edaphic factors, hence much emphasis on the corolla color is not given here. A diagnostic key to the yellow flowered species of *Henckelia* in Northeast India is presented below for easy identification. Comparison of this peculiar new species was made with a superficially allied species *H. calva,* in the glabrous nature of the stem and petioles and lanceolate bracteoles. This new species is described and illustrated here.

## Methods

Flowering stems were collected from the field and photographed using a digital camera (Nikon COOLPIX B600, Nikon India Pvt. Ltd). GPS coordinates were recorded using Garmin GPS (Etrex 10 device, Asim Navigation India Pvt. Ltd). All collected specimens were processed using standard herbarium methods (Jain and Rao 1977) and voucher specimens were deposited in ASSAM and ARUN. Morphological observations and measurements of the new species were made on both freshly collected and dried specimens. The micro morphological characters were studied with a stereomicroscope (Leica S8APO, Leica Microsystems Inc., Germany) and were compared with those reported in the relevant literature (Clarke 1874; Clarke 1883; Hooker 1885; Chatterjee 1948; Wood 1974; Burtt et al. 1988; Weitzman et al. 1997; Wang et al. 1998; Weber et al. 2011; Middleton et al. 2013; Sinha and Datta 2016; Möller et al. 2017; Krishna and Lakshminarasimhan 2018; Borah et al. 2019; Cai et al. 2019; Sirimongkol et al. 2019; Yang et al. 2019; Bui et al. 2020; Janeesha and Nampy 2020; Kanthraj et al. 2020) and digital images of type specimens present at K, E and PE, as well as actual sheets housed at ASSAM, ARUN and CAL.

## Taxonomic treatment

***Henckelia siangensis*** **Taram, D.Borah & Tag, sp. nov.**
urn:lsid:ipni.org:names:77211420-1

**Type.** India. Arunachal Pradesh: East Siang District, Pasighat, 28°13'54"N, 95°13'19"E; 375 m asl., 26 April 2019, *Ojar Taku* and *Momang Taram* 05001 (holotype: ASSAM; isotype: ARUN). (Fig. 1)

**Diagnosis.** The species is remarkably different from all other species of *Henckelia* by its 5-winged calyx and elliptic-ovate calyx segments. It is superficially similar to *H. calva* (C.B.Clarke) D.J.Middleton & Mich.Möller in glabrous stem and petiole as well as lanceolate bracts, but can be easily distinguished by ovate to lanceolate lamina with denticulate to serrulate margins (vs. elliptic to oblong- elliptic with entire to sub-entire and ciliate margin), peduncle 0.4–0.8 cm, glabrous (vs. 2–3 cm long, glabrescent), bracts persistent (vs. deciduous), calyx segments elliptic to ovate, raised at margins forming wings (vs. narrowly triangular to lanceolate), corolla glandular pubescent inside (vs. glabrous) and glandular hairy style (vs. puberulent).

Erect perennial herb, caulescent, 15–40 cm high, stems branched; mature stem terete, ca. 0.5 cm across, glabrous, young stem reddish brown, cylindrical. Leaves decussate; petiole terete, glabrous, slightly ridged at base, 1–6 × 0.1 cm, fleshy; lamina ovate to lanceolate, 7–10 × 2.5–4.5 cm, oblique–obtuse base, acute to shortly acuminate at apex, margin denticulate–serrulate, sparsely hirsute on both surfaces, hairs hyaline, dark green above, pale green below; secondary veins 6–10 pairs, sub-opposite, obscure above, raised beneath. Inflorescence axillary, 1 flowered cymes; peduncle 0.4–0.8 cm long, glabrous; pedicel glabrous 1.8–2.3 long, ca. 0.1cm thick; bracteoles 2, glabrous, green, opposite to sub opposite, ovate to lanceolate, 4–7 × 2–4 mm, apex acute, margin entire to sub entire. Calyx green, campanulate, 5 winged, raised at the fusion of the lobes, splitting with maturity, later turning 5 lobed up to below middle of the tube, glabrous, veins obscure, tube 0.6–0.7 cm long; calyx segments 2.0–2.3 × 0.6–1.1 cm, elliptic–ovate, margin entire, apex acute. Corolla 4.5–5 × 1.4–1.8 cm, bright yellow with three dark yellow and maroon stripes per lobe near throat, more prominent on lower lip, glabrescent outside, glandular pubescent inside (dense within tube), distinctly 2 lipped, lips divergent; upper lip 2-lobed, equal, broadly ovate, 0.4–0.6 cm × 0.5–0.7 cm, apex round, margin entire; lower lip 3-lobed, lobes sub-equal, broadly ovate, 0.7–1 × 0.5–0.6 cm, apex round, margin entire; tube 2.8–3.5 × 1.3–1.7 cm. Stamens 2, inserted 2–2.3 cm above corolla base, anthers and top of filaments maroon, glandular pubescent; anthers 0.2–0.3 × 0.1–0.2 cm, cohering face to face; filaments 0.8–1.5 × 0.1 cm, geniculate near base, knee dark pink-maroon. Staminodes 3, lateral staminodes 2, divergent (sometimes coiled), 0.4–0.7 cm long, hirsute, maroon, central staminode white, antherodes white-green, 0.2–0.3 cm long. Pistil 2.8–3.6 cm long; style glandular hairy, 1.5– 1.9 cm long; stigma chiritoid, lower lip 2 lobed, lobe apex acute to obtuse; disc yellow, undulate–annular, ca. 0.1 cm high. Ovary green, glabrous to glabrescent, 1.6–2 × 0.15 cm. Capsules not seen.

**Phenology.** Flowering: April and fruiting: September.

**Etymology.** The species is named after the type locality, the Siang valley.

**Vernacular name (assigned here).** *Libe lirak Appun* (in Adi language)

**Distribution.** So far only known from East Siang district of Arunachal Pradesh, India.

**Habitat and ecology.** It grows in moist shady places in rock crevices in association with *Henckelia mishmiensis* (Debb. ex Biswas) D.J.Middleton & Mich.Möller, *Aeschynanthus superbus* C.B.Clarke, *Begonia josephii* A.DC., *B. burkillii* Dunn., *Elatostema sessile* J.R.Forst. & G.Forst., *Pilea umbrosa* Blume, *Nephrolepis cordifolia* (L.) C.Presl., *Selaginella* sp. etc.

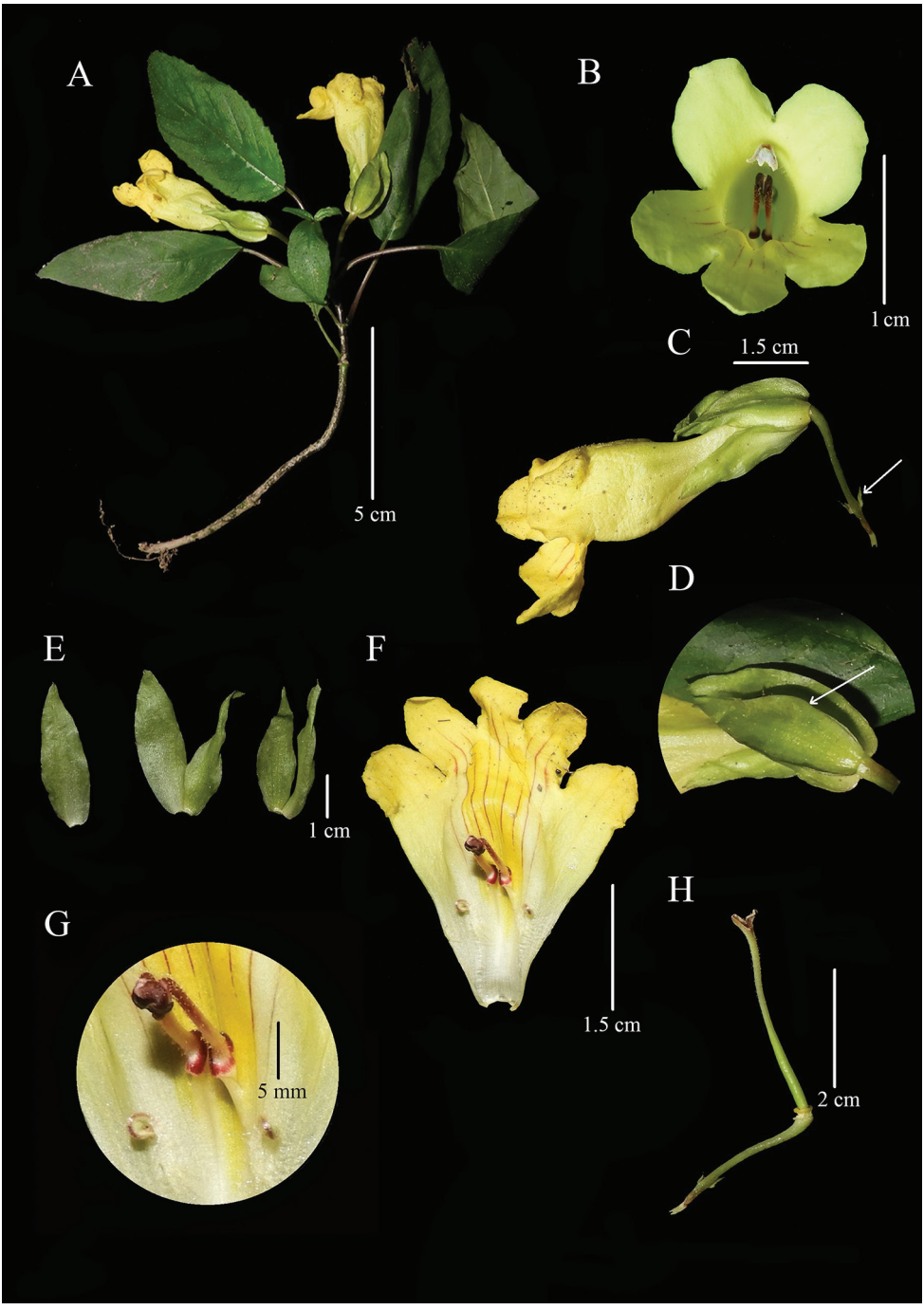


**Figure 1.** *Henckelia siangensis*. **A** flowering stem **B** flower front view **C** flower side view (arrow indicates the bracteoles) **D** winged calyx (arrow indicates the wings) **E** dissected calyx segments **F** dissected corolla **G** stamens and staminodes **H** pistil (Photographs by Momang Taram).

Key to yellow species of *Henckelia* in Northeast India

| | | |
|---|---|---|
| 1 | Bracts cupular, concealing pedicel of flower buds | ***H. pathakii*** |
| – | Bracts free, not concealing pedicel of flower buds | **2** |
| 2 | Bracts denticulate, calyx sub-equal and acuminate | ***H. dimidiata*** |
| – | Bracts entire, calyx equal and acute | **3** |
| 3 | Bracts deciduous, calyx tubular, not-winged, triangular to lanceolate, style pubescent | ***H. calva*** |
| – | Bracts persistent, calyx campanulate, winged, segments elliptic – ovate, style glandular hairy | ***H. siangensis*** |

## Acknowledgments

The authors are grateful to Department of Botany, Rajiv Gandhi University, for providing necessary facilities to carry out the work. They are also thankful to Gyan Taram for his kind help during the field work, Cai Lei, Han Meng-Qi and Yin-Zheng Wang for confirming the identity of the species and Ritesh Kr. Choudhary, Michael Möller for improving the content of the manuscript.

## References

Borah D, Taram M, Joe A, Neelamkavi SV (2019) *Henckelia collegii-sancti-thomasii*: A new species of *Henckelia* (Gesneriaceae) from Northeastern India. Phytotaxa 415(4): 247–251. https://doi.org/10.11646/phytotaxa.415.4.10

Bui HQ, Nuraliev MS, Möller M, Kuznetsov AN, Kuznetsova SP, Middleton DJ, Wen F (2020) *Henckelia longisepala* (Gesneriaceae), a new record for Vietnam. Rheedea 30(1): 176–186. https://doi.org/10.22244/rheedea.2020.30.01.12

Burtt BL, Srivastava SK, Mehrotra BN (1988) A new species of Chirita from NE India. Notes from the Royal Botanic Garden Edinburgh 45: 469–470.

Cai L, Liu DT, Zhang P, Dao ZL (2019) Two new species of Henckelia (Gesneriaceae) from southeastern Yunnan, China. PhytoKeys 130: 151–160. https://doi.org/10.3897/phytokeys.130.33988

Chatterjee D (1948) New Plants from India and Burma. Kew Bulletin 3(1): 57–65. https://doi.org/10.2307/4118920

Clarke CB (1874) Commelynaceae et Cyrtandraceae Bengalenses. Spink and Co.

Clarke CB (1883) Cyrtandreae In: de Candolle A, de Candolle C (Eds) Monographiae Phanerogamarum 5: 137. G. Masson, Masson & Amp., Parisiis.

Hooker JD (1885) The flora of British India. Vol. 4. L. Reeve & Co, London.

Jain SK, Rao RR (1977) A handbook of field and herbarium methods. Today's & tomorrow's printer and publishers, New Delhi.

Janeesha AP, Nampy S (2020) A taxonomic revision of *Henckelia* (Gesneriaceae) in South India with a new species, one new combination and seven lectotypifications. Rheedea 30(1): 48–95. https://doi.org/10.22244/rheedea.2020.30.01.03

Kanthraj AS, Rana TS, Nair KN (2020) *Henckelia umbellata* (Gesneriaceae), a new species from the eastern Himalaya of India. Rheedea 30: 143–149. https://doi.org/10.22244/rheedea.2020.30.01.08

Krishna G, Lakshminarasimhan P (2018) A new species of *Henckelia* (Gesneriaceae) from Arunachal Pradesh, India. Taiwania 63(4): 397–401.

Middleton DJ, Weber A, Yao TL, Sontag S, Möller M (2013) The current status of the species hitherto assigned to *Henckelia* (Gesneriaceae). Edinburgh Journal of Botany 70(3): 385–403. https://doi.org/10.1017/S0960428613000127

Möller M, Nampy S, Janeesha M, Weber A (2017) The Gesneriaceae of India: Consequences of updated generic concepts and new family classification. Rheedea 71: 23–41.

Sinha BK, Datta S (2016) Taxonomic account of the family Gesneriaceae in northeast India. Nelumbo 58(0): 1–43. https://doi.org/10.20324/nelumbo/v58/2016/105932

Sirimongkol S, Parnell JAN, Hodkinson TR, Middleton DJ, Puglisi C (2019) Five new species of Henckelia (Gesneriaceae) from Myanmar and Thailand. Thai Forest Bulletin (Botany) 47(1): 38–54. https://doi.org/10.20531/tfb.2019.47.1.08

Wang WC, Pan KY, Li ZY, Weitzman AL, Skog LE (1998) Gesneriaceae. In: Wu ZY, Raven PH (Eds) Flora of China. Vol.18. Science Press; Missouri Botanical Garden Press, 244–401.

Weber A, Middleton DJ, Forrest A, Kiew R, Lim CL, Rafidah AR, Sontag S, Triboun P, Wei YG, Yao TL, Möller M (2011) Molecular systematics and remodelling of Chirita and associated genera (Gesneriaceae). Taxon 60(3): 767–790. https://doi.org/10.1002/tax.603012

Weitzman AL, Skog LE, Wang W, Pan K, Li Z (1997) New taxa, New Combinations, and Notes on Chinese Gesneriaceae. Novon 7(4): 423–435. https://doi.org/10.2307/3391777

Wood D (1974) A revision of *Chirita* (Gesneriaceae). Notes from the Royal Botanic Garden Edinburgh 33: 123–205.

Yang B, Ding HB, Fu KC, Yuan YK, Yang HY, Li JW, Zhang LX, Tan YH (2019) Four new species of Gesneriaceae from Yunnan, Southwest China. PhytoKeys 130: 183–203. https://doi.org/10.3897/phytokeys.130.34001

PhytoKeys 160: 7–43 (2020)
doi: 10.3897/phytokeys.160.52946
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CHECKLIST

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# A checklist of vascular plants and uses of some species for livelihood-making in Setiu Wetlands, Terengganu, Malaysia

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Academic editor: Ricarda Riina | Received 11 April 2020 | Accepted 3 July 2020 | Published 8 September 2020

**Citation:** Jamilah MS, Lee GE, Salam MR, Shahimi S, Pesiu E, Jani JM, Horsali NAI, Shahrudin R, Nor SMM, Chong JL, Mohamad F, Raffi A, Nikong D (2020) A checklist of vascular plants and uses of some species for livelihood-making in Setiu Wetlands, Terengganu, Malaysia. PhytoKeys 160: 7–43. https://doi.org/10.3897/phytokeys.160.52946

## Abstract

The Setiu Wetlands, a unique area with nine interconnected habitats, comprises a considerable fraction of the total Peninsular Malaysia's wetland flora. Although botanical collecting in the area has been active in the past 10 years, only a few studies dealing with the wetland flora have been published. Thus, a detailed checklist of this area is urgently needed to ensure the continuity of its inter-relating flora and fauna, as well as the livelihood of the local people. In this work we conducted a survey of the vascular plant flora of Setiu Wetlands and investigated the most important plants used by the local communities. Our checklist accounts for 406 taxa from 277 genera and 106 families, including 24 (6%) species of ferns and lycophytes, three gymnosperms, 257 (64%) dicotyledons and 122 (30%) monocotyledons. This comprehensive plant checklist will be a primary reference for the management of the newly gazetted Setiu Wetlands State Park covering more than 400 hectares of lands and water bodies.

## Keywords

coastal ecosystem, diversity, flora, local community, Malesia, useful plants

## Introduction

Wetlands are not only among the most productive and complex ecosystems (Costanza et al. 1997), but are also known to benefit humans with significant economic and ecological values (Barbier et al. 2011). The importance of wetlands has increased tremendously following the 2004 catastrophic tsunami which affected many places severely in the Asian region. The Setiu Wetlands (SW) constitutes the largest wetland complex in the east coast of Peninsular Malaysia which is located in an arbitrary but exclusive zone referring to the larger Setiu district in Terengganu. The coastal lagoon is the largest part of the SW, stretching approximately 14 km, parallel to the coastline, from Lembah Bidong in the south up to Beting Lintang to the north, while the wetland basin covers about 23,000 ha of lands and 880 ha of water bodies (Nakisah and Fauziah 2003). In 2018, in lieu of protecting vital catchment areas and their natural heritage, the state government of Terengganu gazetted two new state parks, one of which was in the Setiu district. Driven by its importance for the local economy and the dire need to wisely manage SW for the sustainability, efforts to legally protect SW were initiated more than 20 years ago. However, it was not until recently that the state authority of Terengganu passed the Terengganu State Park Enactment 2017, under which, 432 ha of SW were gazetted as State Park in Phase 1 covering mainly the SW brackish lagoon and estuary (Fig. 1). In the near future, the gazettement for three more phases of this State Park will cover possibly one of the largest coastal freshwater lakes in Peninsular Malaysia, locally known as Tasik Berombak. Tasik Berombak is hydrologically important by supplying the primary source of freshwater into the brackish lagoon of SW (Sathiamurthy 2015) which is a hub for economic and livelihood activities of the SW local community. In addition, phases 3 and 4 of the gazettement intend to cover mostly mangrove islands in SW, but many issues and challenges, primarily related to land title, need to be addressed.

SW supports major wetlands ecosystem of marine, coastal vegetation, brackish and freshwater swamps with nine interconnected habitats of sea, beach, mudflats, lagoons, estuaries, rivers, islands, coastal and mangrove vegetation (Mohd Lokman and Sulong 2001; Nakisah and Fauziah 2003; Jamilah et al. 2014). The nine vegetation types (Fig. 2) including the beach-ridge vegetation or BRIS soil vegetation are lowland forest, mangrove swamp forest, peat swamp forest, freshwater swamp forest, riparian vegetation, beach vegetation, heath vegetation (coastal dunes forest), and disturbed vegetation. Each of the habitats is characterised by a unique yet intricate physical environment, supporting its biological entities. Intimate and complex interaction between wetlands, people and the environment could clearly be observed in Setiu district where most of the natural resources harvested from SW are vital for supporting local livelihoods (Faridah et al. 2015). Similar to other wetlands, SW integrity critically depends on the physical and biological environments. Vegetation or flora are the vital biological entity of the SW with many efforts conducted to document this entity (for example, Jamilah et al. 2014; Siti Fatimah et al. 2015; Razali et al. 2017; Rohani et al. 2017). Furthermore, the SW flora is edaphically adapted, for example, the BRIS soil vegetation which is largely confined to the sandy environment of Terengganu narrow coastal

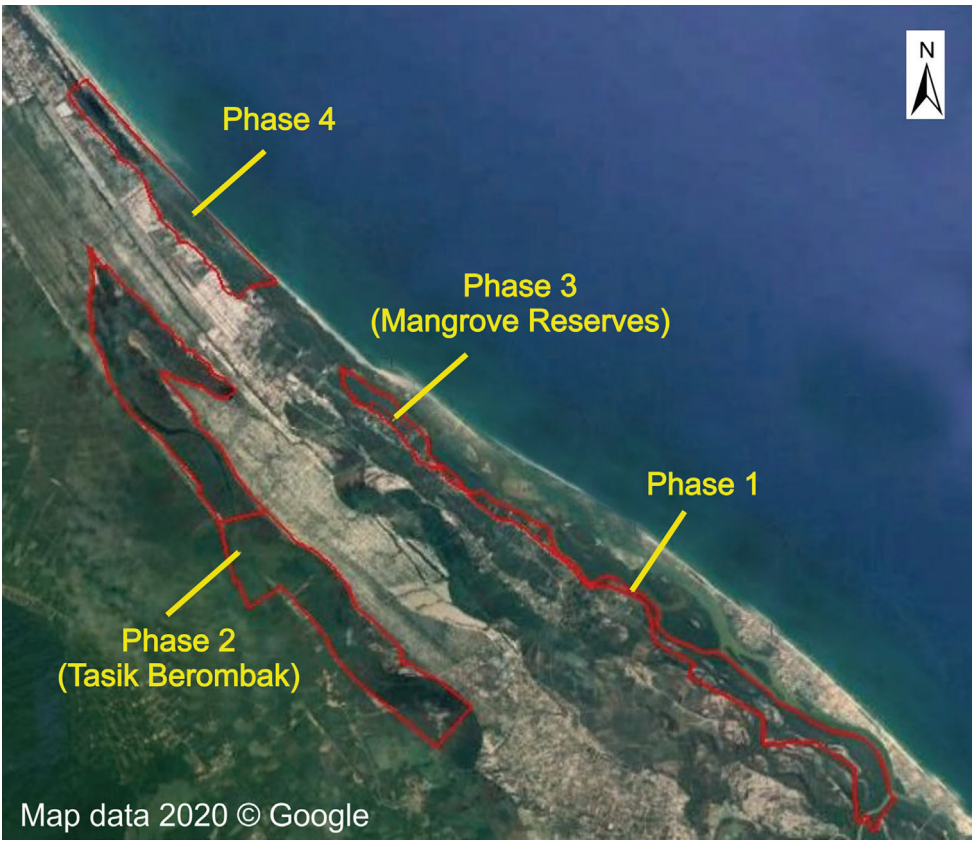


**Figure 1.** The boundaries (red line) of the forest to be gazetted in Setiu Wetlands as state park. Map courtesy of the Terengganu State Parks.

stripe and such unique vegetation is not found on the west coast of Peninsular Malaysia (Jamilah et al. 2014).

Setiu lagoon supports several islets within the lagoon with healthy mangrove vegetation. However, the mangrove ecosystem here is also characterised by a relatively sandier habitat as compared to the typical mangroves on the west coast of Peninsular Malaysia such as the Matang mangroves. Setiu mangroves are not only supporting the three classes of common mangrove vegetation, namely exclusive, non- exclusive and associate (Japar 1994), but also additional vegetation associated with sand ridges. This vegetation, including vascular plants, offers significant ecosystem services, such as providing food and shelter to animals residing in the area, with many being economically important. Furthermore, Setiu lagoon, which is the longest brackish wetlands in Terengganu, includes several patches of sandy-mudflats which support a healthy community of bivalves [including *Scapharca cornea* (local name: kepah bulu) and *Meretrix meretrix* (kepah minyak)] (Wan Bayani and Zaleha 2015) that are harvested by the Setiu locals for sale (Faridah et al. 2016). Two species of seagrasses (*Halodule pinifolia* and *Halophila minor*) are recorded to thrive well here (Syarifah et al. 2008). This

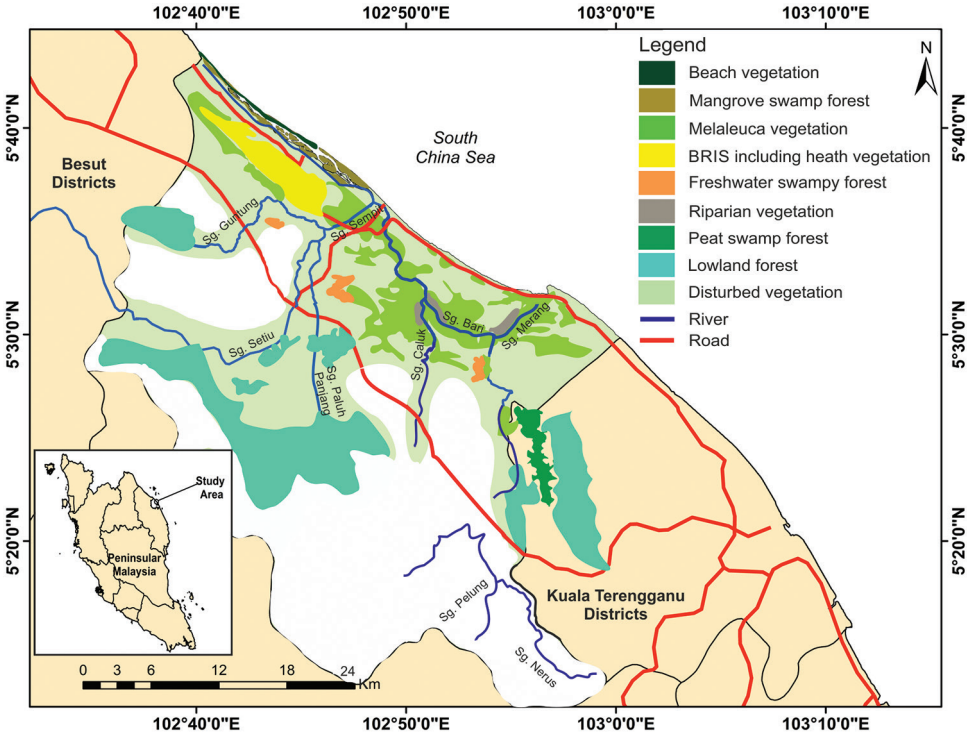


**Figure 2.** The locality of Setiu Wetlands and the nine vegetation types.

seagrass-mangrove continuum is reported to be an important nursery ground for the juveniles of fishes such as grouper, and pink ear emperor fish, *Lethrinus lentjan* (Le et al. 2018). The mangroves of Setiu, and its lagoon, are also an important habitat for highly demanded mangrove crabs, *Scylla* spp. (Ikhwanuddin et al. 2010), and is the source of income for many local fishermen in the area. The geography and the vegetation cover of the area support it as a hub for aquaculture activities, covering brackish water cage culture, pond culture, pen culture especially on groupers, and also oyster farming (Suratman et al. 2014).

In terms of soil origin, the Setiu coastal plain originated from marine-based deposit, arranged in a series of ridges and depressions parallel to the shoreline (Ali and Mohamed 2007; Sathiamurthy 2015) known as BRIS (Beach Ridges Interspersed with Swales). BRIS is oligotrophic or infertile and unsuitable for agriculture (Lim 2002) partly due to extreme water retention capacity and comprises 90% sand (Mohd Ekhwan et al. 2009). However, BRIS soil supports a distinct natural vegetation formation which is different from a typical evergreen rainforest (Jamilah et al. 2013). The ridge part supports heath-like ecosystem plants, while the depression site is usually a pocket of seasonal wetland with adapted vegetation (Jamilah et al. 2011).

The nine habitats in SW are increasingly being exposed to various anthropogenic and natural pressures. This could threaten the integrity and ability of those natural ecosystems to fulfil their ecological roles for the benefit of the local community and the coastal environment. As vegetation is the most important entity of the wetlands that supports other important life forms, it is essential to highlight the diversity of flora in SW. The aims of this paper are to provide the first comprehensive checklist of vascular plants of SW, and to understand the use of wild plants for livelihood continuity and sustainability in SW. The latter also further aims to understand how the local community's utilisation affects the plants' sustainability, so that sustainable resource management and conservation policy for SW can be achieved.

## Materials and methods

The checklist is based on the plant collections carried out by JMS, EP, SMMN and DN with the help of field assistant, MRS. More than 30 different localities were visited after 2010 in the nine different ecosystems of SW. Specimens were deposited at the Herbarium of Universiti Malaysia Terengganu (UMTP). In addition, the checklist is also based on a search of the literature (e.g., Mohd Lokman and Sulong 2001; Jamilah et al. 2014; Siti Fatimah et al. 2015; Razali et al. 2017; Rohani et al. 2017; Pesiu 2018) as well as herbaria that store collections of specimens collected from SW, such as the Herbarium of Forest Research Institute of Malaysia, Kepong (KEP) and the Herbarium of Universiti Kebangsaan Malaysia, Bangi (UKMB). The checklist includes family, species and local names, and life forms. It also provides the conservation status according to the IUCN Red List of Threatened species (IUCN 2020), Malaysia Plant Red List, Peninsular Malaysia Dipterocarpaceae (Chua et al. 2010), Malaysia Biodiversity Information System (MyBIS) and Convention on International Trade on Endangered Species of Wild Fauna and Flora (CITES).

A total of 188 houses from six villages, i.e. Beting Lintang, Gong Batu, Pengkalan Gelap, Fikri, Mangkok and Penarek, were opportunistically selected for a rapid livelihood survey to determine their dependence on SW wild flora resources. In addition to that, a stratified sampling of 10 households belonging to identified resource users was later conducted in Beris Tok Ku, to provide a better representation of wild flora resource utilisation in the area.

## Results and discussion

### Families, genera and species diversity

We recorded 406 taxa (400 species, three varieties and three hybrids) from 277 genera and 106 families of vascular plants in the nine habitats of SW, including 24 species of ferns and lycophytes, three species of gymnosperms (*Cycas edentata*, *Gnetum cuspidatum*

**Table 1.** Number of families, genera and species from Setiu Wetlands, Terengganu.

| | Families | Genera | Species |
|---|---|---|---|
| Ferns and lycophytes | 12 | 16 | 24 |
| Gymnosperms | 2 | 2 | 3 |
| Dicotyledons | 73 | 191 | 257 |
| Monocotyledons | 19 | 70 | 122 |
| Total | 106 | 277 | 406 |

and *G. gnemon*), with 257 being dicotyledons, and 122 monocotyledons (Table 1). This represents 19% of 2168 species recorded growing in wetlands of Peninsular Malaysia (Said and Zakaria 1992) and also illustrates the fact that SW flora is relatively species rich. The most speciose family recorded from SW is Orchidaceae (56 species/28 genera), followed by Rubiaceae (24 species/20 genera) and Fabaceae (22 species/17 genera) (Fig. 3), while there are 43 families represented only by a single species e.g., Amaryllidaceae, Commelinaceae, Cycadaceae, Dioscoreaceae, Flagellariaceae and Pittosporaceae (see Appendix 1 for other families). Among the genera that contribute most to the total number of species are *Dendrobium* (11 species), *Bulbophyllum* and *Syzygium* with 10 species, while *Bruguiera*, *Cyperus* and *Sonneratia* have five species each. In terms of the life forms (Table 2), trees have the highest percentage (39.7%) followed by terrestrial herbs and epiphytes with 16.5% and 13.3% of the taxa, respectively. Apart from the trees, the herbaceous species which can be terrestrial, epiphytic or climbing, are represented by 27.8% of the species, which implies that trees and herbaceous flora are the most important components of the SW areas.

The Orchidaceae (Fig. 4) are well represented in SW, representing 23% of 245 orchid species recently reported in Terengganu (Besi et al. 2019). Thus, to date, there are 56 species of orchids found in SW from which 14 species were recorded by Siti Fatimah et al. (2015) and 42 represent new records in SW, mostly being recent collections by Dome Nikong. The highest number of orchid species in SW, as expected, are in the widespread genera *Bulbophyllum* and *Dendrobium*, similar to the results of Besi et al. (2019) in Tasik Kenyir logging sites. Both genera are found to be most abundant epiphytic orchids growing in disturbed and logged forests in which the weather and microclimate are favourable for growth and reproductive processes. However, orchid density is due in part to the severity of the disturbance in which highly disturbed logging sites harbour lower density than somewhat disturbed sites (Besi et al. 2019). Among the species recorded in SW, there are some that are exceptional. The orchid diversity in SW is enriched with the sighting of the uncommon *Papilionanthe hookeriana* that is confined to the freshwater swamp area of Tasik Berombak in SW. It usually coexists with shrubs and tall grasses for support (Pridgeon et al. 2014). On the other hand, the discovery of *Vanilla griffithii* in its uncharacteristic habitat of the BRIS forest signified its capability to thrive in xeric environment and supported its local genus distribution pattern suggested by Mohd Raffi et al. (2014) which was best described as constantly sparse, widespread and in many habitats.

As for the mangroves, there are about 33 exclusive mangrove species including three hybrids i.e. *Sonneratia* × *hainanensis*, *Bruguiera* × *rhynchopetala*,

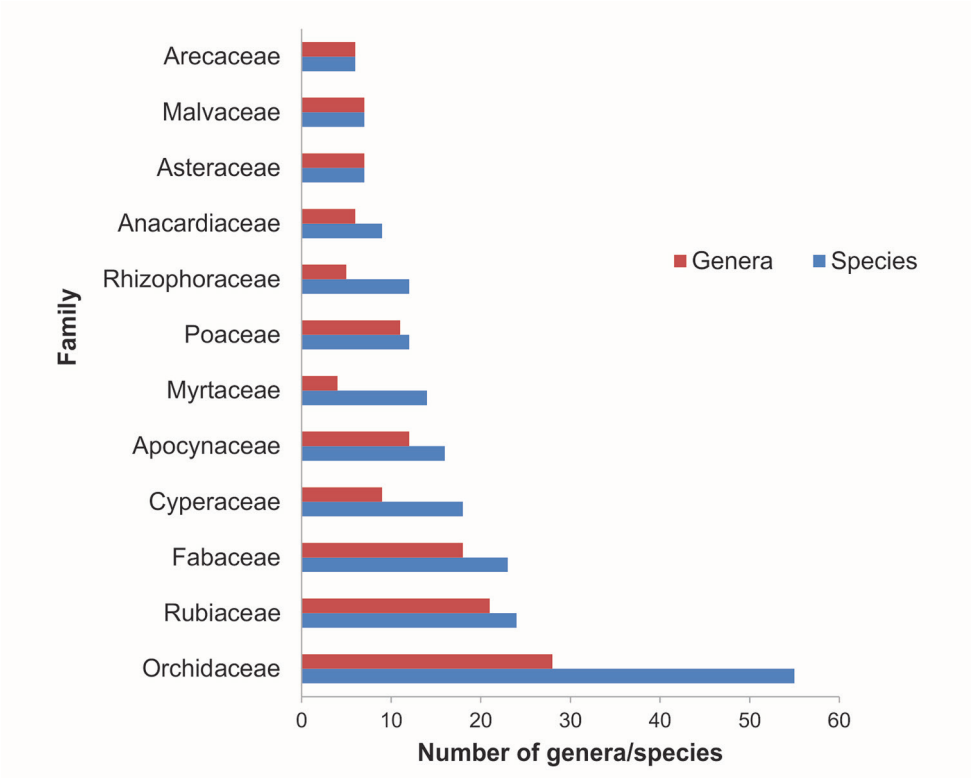


**Figure 3.** The 12 largest families and genera of the vascular plants of Setiu Wetlands.

**Table 2.** Number of species from Setiu Wetlands according to their life form.

| Life form | No. of species | Percentage (%) |
|---|---|---|
| Trees | 161 | 39.7 |
| Terrestrial herbs | 67 | 16.5 |
| Epiphytic herbs and shrubs | 54 | 13.3 |
| Shrubs | 39 | 9.6 |
| Climbing herbs and shrubs | 33 | 8.1 |
| Ferns | 23 | 5.7 |
| Aquatic herbs | 15 | 3.7 |
| Palms | 5 | 1.2 |
| Parasitic herbs and shrubs | 5 | 1.2 |
| Palm-like (*Pandanus* spp.) | 4 | 1 |
| Total | 406 | 100 |

*Rhizophora* × *annamalayana* and four individuals of *Bruguiera hainesii* located at Pulau Layat (Razali et al. 2017). However, the mangroves in SW and on the east coast of Peninsular Malaysia, in general, are not so diverse and widely distributed as compared to the west coast because the former are exposed to the lagoons and rivers (Latiff and

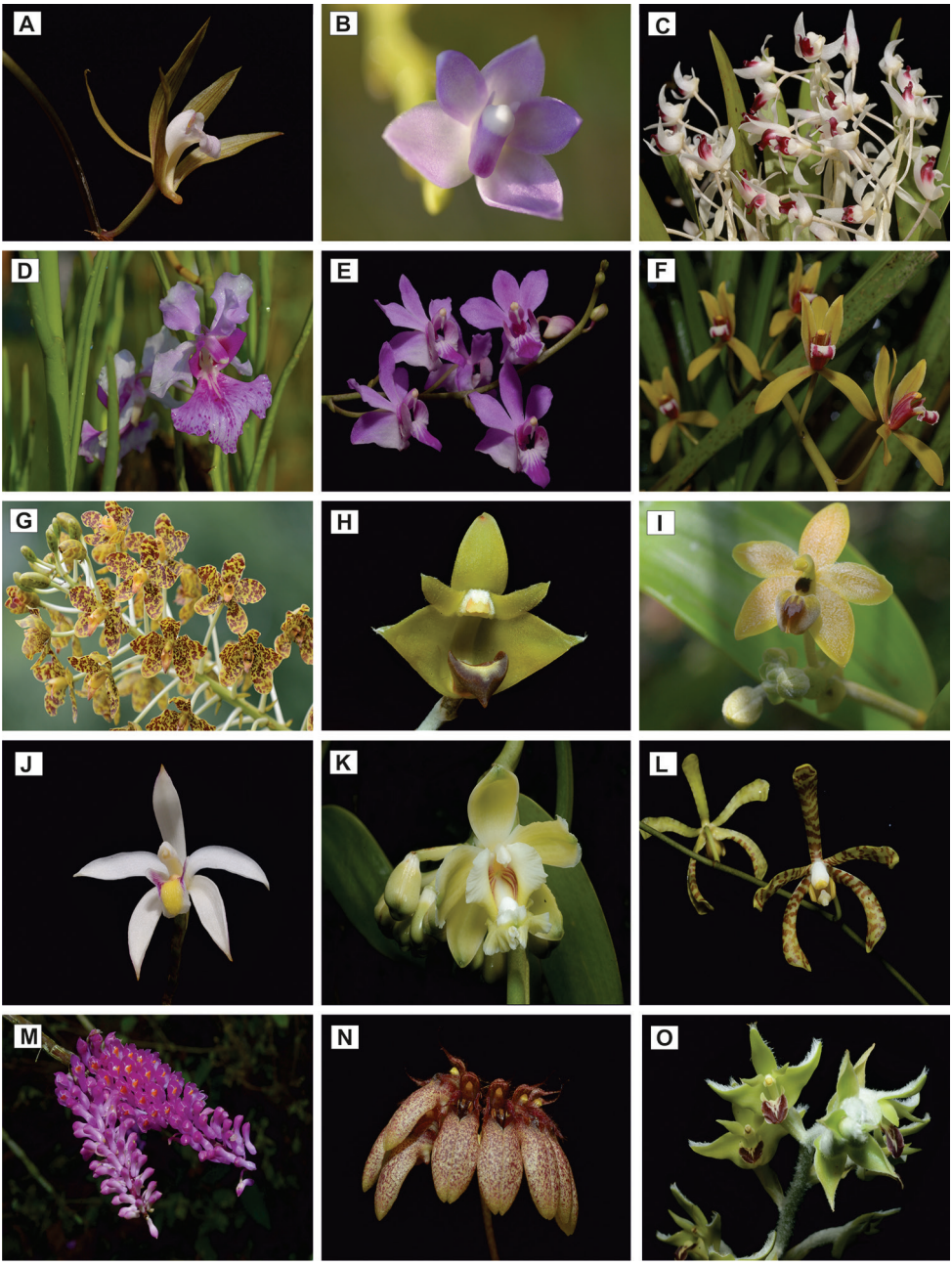


**Figure 4.** A selection of Orchidaceae species from Setiu Wetlands. **A** *Ania penangiana* **B** *Thrixspermum amplexicaule* **C** *Pinalia atrovinosa* **D** *Papilionanthe hookeriana* **E** *Phalaenopsis pulcherrima* **F** *Cymbidium finlaysonianum* **G** *Grammatophyllum speciosum* **H** *Strongyleria pannea* **I** *Callostylis pulchella* **J** *Bromheadia finlaysoniana* **K** *Vanilla griffithii* **L** *Arachnis flos-aeris* **M** *Dendrobium secundum* **N** *Bulbophyllum trigonopus* **O** *Dendrolirium lasiopetalum*.

Faridah-Hanum 2014), and are also threatened by strong waves during monsoon months as well as anthropogenic activities e.g., many mangroves in SW had been uprooted to make way for aquaculture, shrimp ponds and constructions of infrastructures.

The relatively species rich profile of SW reflects on the interconnected forest types in SW which consists of different plant communities (Fig. 5) including beach, mangroves, peat swamp and freshwater swamp plants. Beach vegetation includes Casuarinaceae and Convolvulaceae and mixed mangroves plants such as the families Avicenniaceae, Lythraceae and Rhizophoraceae. Peat swamp plants can be found behind the mangrove belt and further inland, *Melaleuca* swamp forest dominates the waterlogged area associated with BRIS soil (Jamilah et al. 2015). On the other hand, the heath-like dune landscape established on the ridge areas of Setiu coast is characterised by stunted and low stature vegetation growing in a clumping pattern (Jamilah et al. 2014).The vegetation on the sandy and dry ridge is dominated by Myrtaceae family (*Melaleuca cajuputi*, *Baeckea frutescens*, *Rhodomyrtus tomentosa* and *Syzygium* spp.). Woody epiphytic shrubs (e.g., *Ficus deltoidea*) and herbaceous species such as orchids are adapted to grow underneath the clump on BRIS soil dune landscape (Jamilah et al. 2014). However, the natural ecosystem on BRIS soil ridge and swamps is becoming scarce and smaller in coverage due to various threats faced by the coastal ecosystem of SW. It has become more scattered and fragmented, resulting in difficulty in finding an area that could be a good representative of BRIS soil flora. Fragmentation and degradation also expose this natural ecosystem to the invasion of exotic invasive alien species, such as *Acacia mangium*, *A. auriculiformis* and their hybrids (Jamilah et al. 2014). It is predicted that without legal protection and authority commitment to conserve BRIS soil natural vegetation, it will soon be replaced by these alien species, particularly *Acacia* spp. Although the gazettement of BRIS soil habitat is still underway, land conversion in BRIS is rampant and to prevent further land uses, ecotourism activity is recommended. Therefore, the hope is that in the near future, BRIS soil habitat would be included in the next phases of State Park gazettement which will likely have a significant effect in ensuring the conservation of this unique habitat.

As for the wetland or swamp, a rainfed swamp with a water table is highest during the monsoon months. The swamp is dominated by *Melaleuca cajuputi* trees with larger diameter of *M. cajuputi* trees relative to trees growing on the drier ridge of BRIS soil, as it grows better in waterlogged conditions as compared to dry sites (Suzuki 1999). This *Melaleuca* swamp harbours carnivorous species of pitcher plants (*Nepenthes* spp.), sundews (*Drosera burmannii* in particular) and *Utricularia bifida* which are adapted to freshwater swamp. The hydrological contribution of patches of *Melaleuca* swamp as a seasonal wetland is worth exploring and the wetlands may provide a critical ecosystem service of mitigating floods, particularly in monsoon months in Terengganu (Jamilah et al. 2015). In addition, SW also harbours a large freshwater lake, locally known as Tasik Berombak. The water is contributed by rain and a few small river tributaries (Sathiamurthy 2015) and comprises BRIS soil with heath-like vegetation on its ridge, but is less rich than natural BRIS ecosystem. The lake is invaded by thick bush of *Hanguana malayana* and other aquatic and semi aquatic non vascular plants.

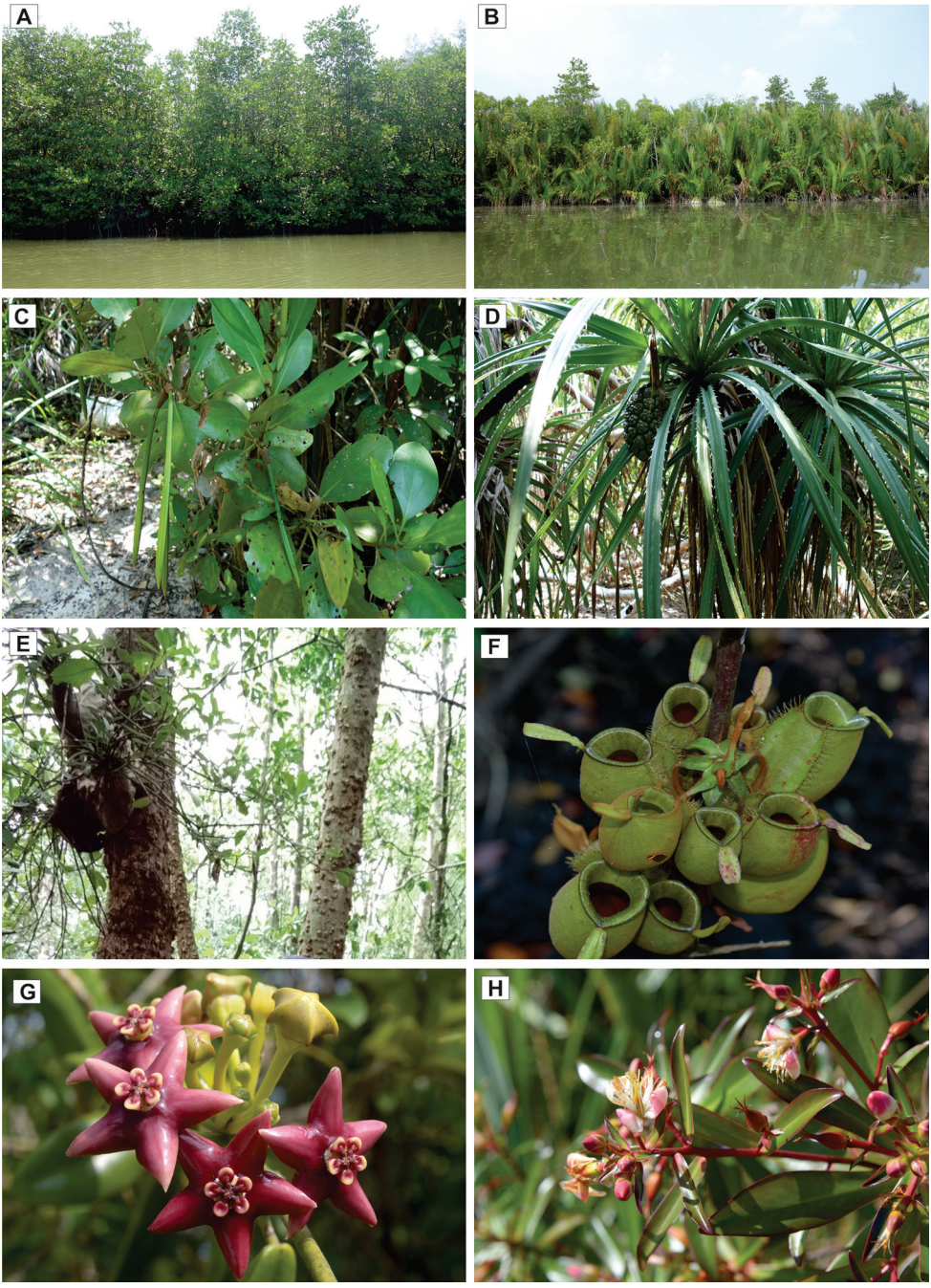


**Figure 5.** Different plant communities in Setiu Wetlands. **A** Mangrove plants **B** Nipa palm (*Nypa fruticans*) population **C** *Ceriops zippeliana* **D** *Pandanus tectorius* **E** Ant plant, *Hydnophytum formicarum* attached to *Bruguiera hainesii* **F** *Nepenthes ampullaria* **G** *Hoya coronaria* **H** *Ploiarium alternifolia.*

The high diversity of wild orchids and other potentially useful plant species on coastal habitat of SW is indeed a natural capital for SW State Park and furthermore, the habitat supports an option value, which could be tapped in the future as outlined in Total Economic Value (TEV) (Costanza et al. 1997). The biodiversity resources in SW can be managed sustainably to support the local community green economy as an alternative to unsustainable economic activities such as sand mining. The SW State Park will also be crucial to protect the critically endangered Painted Terrapin (*Batagur borneoensis* (Schlegel & Muller, 1844)) and to serve as a refuge for some 29 mammals, 161 birds and 36 reptiles and amphibians (WWF-Malaysia). Furthermore, it is also classified as an Important Bird Area (IBA) by Birdlife International.

## Conservation status

Eight species have been classified as threatened species including one Critically Endangered (CR), *Bruguiera hainesii*, two Endangered (EN), *Anisoptera marginata* and *Pterocarpus indicus*, and five Vulnerable (VU) (*Avicennia rumphiana*, *Halophila beccarii*, *Intsia bijuga*, *Ternstroemia wallichiana* and *Vatica pauciflora*). The Critically Endangered, *B. hainesii* is only found in several localities in Southeast Asia including SW, and the lower estimates of mature individuals probably due to the low rates of propagation and germination (Polidoro et al. 2010). However, recent molecular analyses revealed that *B. hainesii* did not merit recognition of species as it has no unique haplotype/allele of its own but instead shared nuclear allele with *B. cylindrica* and *B. gymnorhiza*, and thus indicating the hybrid origin of *B. hainesii* (Ono et al. 2016). Five species partially met the classification thresholds under the threatened species category and therefore were listed as Near Threatened i.e. *Cycas edentata*, *Myristica lowiana*, *Olax scandens*, *Phoenix paludosa*, *Sonneratia ovata*, while 155 species are regarded either as Least Concern (LC) or Data Deficient (DD). However, about half of the vascular plants (59%) occurring in SW have not been assessed and categorised under the IUCN Red List of Threatened Species.

For the Malaysia Plant Red List, two species have been classified as threatened species, namely *Anisoptera marginata* (EN) and *Anodendron candolleanum* (VU). There were nine species listed as Near Threatened i.e. *Cycas edentata*, *Cerbera odollam*, *Cerbera manghas*, *Vatica pauciflora*, *Drosera burmannii*, *Xylocarpus moluccensis*, *Horsfieldia irya*, *Myristica lowiana*, *Olax scandens* while 32 species were listed as Least Concern (LC). The other 369 species have not been assessed and categorised under the Malaysia Plant Red List but are available in MyBIS. On the other hand, there were 55 species (13%) listed under CITES of which 49 species were from Orchidaceae, three from Nepenthaceae, two from Ebenaceae and one from Cycadaceae. Almost all the orchids recorded (89%) in SW are listed in CITES. About 30,000 plant species have been listed and protected by CITES against over-exploitation through international trade of which more than half of the species assessed are orchids and cacti.

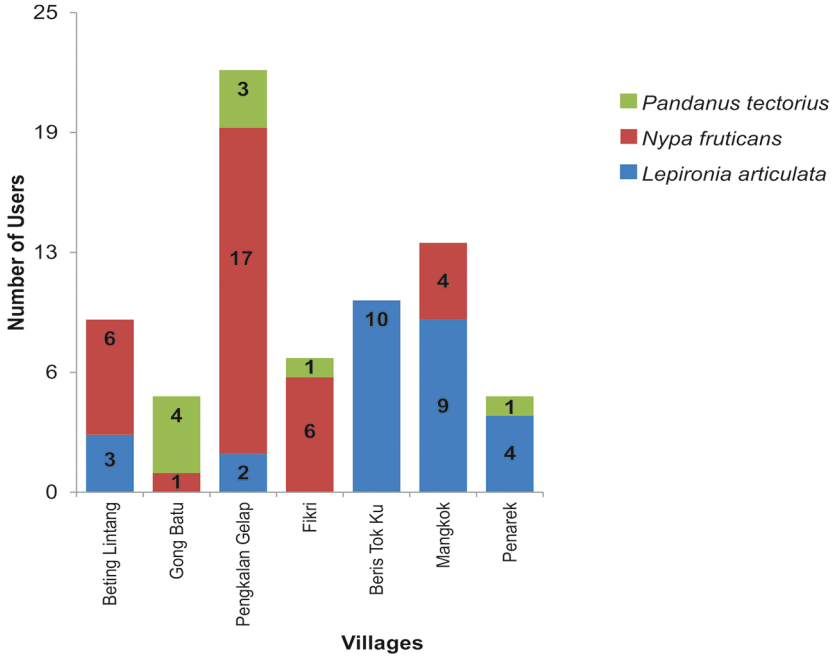


**Figure 6.** Number of various wild flora species users according to villages.

## Wild flora based livelihoods in SW

We found that in the SW, the local households' utilisation mainly focused on three species, namely *Nypa fruticans* (nypa), *Lepironia articulata* (Blue-grey sedge) and *Pandanus tectorius* (Sea Pandan, Sea screwpine). Figure 6 shows the number of flora user households based on the species utilised in each village. *Nypa fruticans* records the highest number of users with 34 households from five out of seven villages. *Lepironia articulata* is a close second, with recorded utilisation in 28 households in five villages as well. Meanwhile *P. tectorius* is the least utilised of the three species with only nine user households in total from four villages. The wide use of *N. fruticans* coincides with the highest variety of products that can be made using its various plant parts (see Fig. 7). The nypa palm is the most versatile wild plant among the three as different parts of the plant are used to make different kinds of products. For example, the young leaves are used to make tobacco wrappers, its dried midrib is weaved into baskets, while mature fronds with leaves are used to make roof-thatch. The midribs of the nypa, which are unsuitable for weaving lekar baskets, are used to make brooms. Due to this, nypa is the most preferred plant species used in SW. Its utilisation is well documented in Malaysia (see Latiff 2009; Tsuji et al. 2011). It is not only an important wild resource for the Malays but also for indigenous tribes such as the Mah Meri who use nypa leaves to produce decorative items for spirit huts, altars, homes and dancers (Baba et al. 2013).

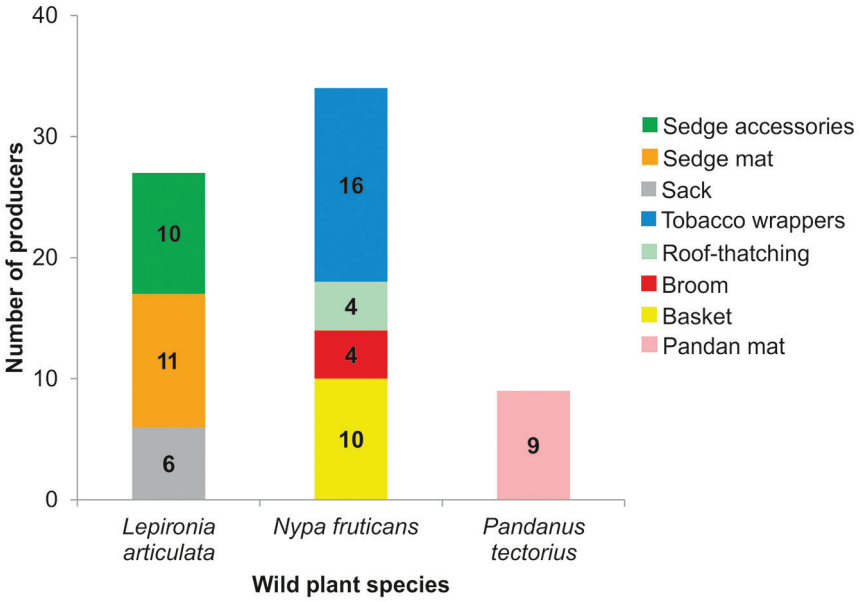


**Figure 7.** Number of producers based on type of products made from wild flora.

As for *Lepironia articulata*, although it can be used to make similar types of products as those made using *Pandanus tectorius*, i.e. mats and bags, its livelihood-based utilisation in Malaysia appears less recorded compared to the latter. Instead, there appears to be more documentation on its utilisation in grey water treatment (see Sim et al. 2008; Wurochekke et al. 2014). However, its utilisation is significant for the users in SW, as it supplemented up to 45% of their monthly household income and represents a strong cultural link to the local tradition for the users who are mostly exclusive (not using other flora resource) users of this resource. The 11 users from SW produced mats, six users made sacks, while 10 users made accessories' items such as hats and bags. Our findings suggest that current utilisation is at a sustainable level thanks to the user's knowledge about the ecology of these plants. Its use therefore poses no threat to the integrity of the state park. According to MacDonald (2009), *L. articulata* is listed among eight major species that are commonly used for weaving activities by the Plant Resources of South-East Asia (PROSEA) (Brink and Escobin 2003) due to their high suitability as a raw material for weaving activities, in particular their toughness, plasticity, sustainable strength and impermeability after being dried (Truyen et al. 2014).

The utilisation of *L. articulata* has been documented in other countries like Indonesia, Vietnam, Thailand and China where this plant is used to make handicraft or household materials such as bags, mats, baskets, and hats (Domyos and Te-Chato 2013; Truyen et al. 2014). Whereas *P. tectorius* is only used to make one type of product, i.e. mats by nine users in SW, although other types of handicrafts used to be made in the


**Figure 8.** Utilisation of *Lepironia articulata* (**A1–3**), *Pandanus tectorius* (**B1–3**), and *Nypa fruticans* (**C1–3ii**) in Setiu Wetlands. From left to right **1** Harvesting **2** Part used **3** Finished products.

past. Indeed, while pandan mats are produced in various parts of Malaysia (Ismail and Nawawi 2011; Baba et al. 2013) the quality of pandan mats produced by Terengganu weavers is of excellent quality (Ismail and Nawawi 2013). Therefore, it is highly probable that the weavers in SW could also produce a variety of products (Fig.8), just as the weavers of Mah Meri tribe who are well known for producing varied, exquisite handicrafts such as purses, pouches, mats and baskets in Pulau Carey, Selangor (Baba et al. 2013). However, there needs to be a steady market demand that guarantees a good income stream, which is provided to the Mah Meri weavers by the Gerai OA, an NGO that helps market their products through fairs and online marketing.

## Conclusions

Our survey indicates that the nine connected habitats in SW are relatively rich in vascular plants, harbouring nearly 20% of Peninsular Malaysia wetland flora. The current checklist is far from complete as additional species will likely be found with wider sampling coverage and additional systematic inventories. The utilisation of plant resources for the livelihood of coastal communities in SW is still significant for the three main species used in the area (*Nypa fruticans*, *Lepironia articulata* and *Pandanus tectorius*). Local communities play an important role in the sustainability of SW, so it is essential to understand their dependence on the intricate network of wetland ecosystems and their plant species to ensure that they are not overlooked in the management plans of the Setiu Wetlands State Park.

## Acknowledgements

We are grateful to the Director of Terengganu State Parks, Muhammad Aizat Mohd Rashid and Nabila Husna Mohd Zohuri for providing and helping with the map, and Universiti Malaysia Terengganu for the facilities and utilities used during this study. Part of this paper is based on a research project awarded to JMJ (53131) undertaken for Universiti Malaysia Terengganu's Niche Research Grant Scheme (NRGS) programme through funding by the Malaysian Ministry of Education. We are also grateful to the subject editor Ricardia Riina and two anonymous reviewers for providing very useful comments and also for suggesting substantial improvements to earlier drafts of this manuscript.

## References

Ali CA, Mohamed KR (2007) Fragile Environment under Threat-The Study Lagoon Case Study. Geological Heritage of Malaysia, 457–469.

Baba S, Chan HT, Aksornkoae S (2013) Useful Products from Mangrove and Other Coastal Plants. ISME Mangrove Educational Book Series No. 3, International Society for Mangrove Ecosystems (ISME) and International Tropical Timber Organization (ITTO), Japan, 1–111. http://www.mangrove.or.jp/img/publications/book_pdf/EB03-Educational_3.pdf

Barbier EB, Sally D, Hacker SD, Kennedy C, Koch EW, Stier AC, Silliman BR (2011) The Value of Estuarine and Coastal Ecosystem Services. Ecological Monographs 201(2): 169–193. https://doi.org/10.1890/10-1510.1

Besi EE, Nikong D, Mustafa M, Go R (2019) Orchid diversity in anthropogenic-induced degraded tropical rainforest, an extrapolation towards conservation. Lankesteriana 19(2): 107–124. https://doi.org/10.15517/lank.v19i2.38775

Brink M, Escobin RP (2003) Plant Resources of South-East Asia No. 17 Fibre Plants. Prosea Foundation, Backhuys, 1–459.

Chua LSL, Suhaida M, Hamidah M, Saw LW (2010) Malaysia Plant Red List. Peninsular Malaysian Dipterocarpaceae, Forest Research Institute Malaysia, 1–210.

Costanza R, d'Arge R, de-Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neil R, Paruelo J, Raskin R, Sutton P, van den Belt J (1997) The value of the world's ecosystem services and natural capital. Nature 387(6630): 253–260. https://doi.org/10.1038/387253a0

Domyos P, Te-chato S (2013) In vitro propagation of *Lepironia articulata* in Kuan Kreng Peat lands, Nakhon Si Thammarat. Journal of Agricultural Technology 6: 1595–1605. http://www.ijataatsea.com/pdf/v9_n6_13_November/21_IJAT_2013_9(6)_Plant%20Science_Premrudee%20%20Domyos%20and%20Sompong%20Te-chato.pdf

Faridah M, Jamilah MS, Jarina MJ, Rohani S (2015) Setiu Wetlands Species, Ecosystem and Livelihoods. Universiti Malaysia Terengganu Publishing, 1–228. https://www.e-sentral.com/book/info/269181/Setiu-Wetland-Species-Ecosystems-and-Livelihoods

Faridah M, Yusof Shuaib I, Nursalwa B, Allyza Azura ARA, Muhammad Hafiz B (2016) The Invertebrates of Setiu Wetlands. Universiti Malaysia Terengganu Publishing, 1–211. http://bookstore.umt.edu.my/index.php?route=product/product&product_id=292

Ikhwanuddin M, Bachok Z, Hilmi MG, Ghazali A, Zakaria MZ (2010) Species diversity, carapace width-body weight relationship, size distribution and sex ratio of mud crab, genus *Scylla* from Setiu Wetlands of Terengganu coastal waters, Malaysia. Journal of Sustainability Science and Management 5: 97–109. http://www.myjurnal.my/public/article-view.php?id=4857

Ismail NH, Nawawi NM (2011) Design motive and pattern in screwpine and pandan plaiting from Peninsular Malaysia. In IEEE Colloquium on Humanities, Science and Engineering, 137–142. https://doi.org/10.1109/CHUSER.2011.6163703

Ismail NH, Nawawi NM (2013) *Pandanus*, Pattern and Design. International Journal of Literature and Art 1: 1–6.

IUCN (2020) IUCN Red List of Threatened Species. Version 2020-1. http://www.iucnredlist.org [accessed 30.3.2020]

Jamilah MS, Norhayati Y, Kasawani I, Nursalwa B, Razali MS (2011) Brief floristic descriptions of Jambu Bongkok Forest Reserve, BRIS ecosystem, *Melaleuca* Swamp of Terengganu. In: Jamilah MS, Faridah M (Eds) A Biological Assessment of Jambu Bongkok Forest Reserve, Terengganu and Nearby Ecosystem, Universiti Malaysia Terengganu Publishing, Terengganu, 1–24.

Jamilah MS, Umairah H, Nur-Hanani AJ, Risnayati L, Razali MS (2013) Natural vegetation of BRIS soil ecosystem on coastal dune of Terengganu. Paper presented at the Seminar Kebangsaan Pemuliharaan Hutan Pesisir Pantai Negara; Universiti Malaysia Terengganu, Malaysia.

Jamilah MS, Nur-Faiezah AG, Siti Kehirah A, Siti Mariam MN, Razali MS (2014) Woody plants on dune landscape of Terengganu, Peninsular Malaysia. Journal of Tropical Forest Science 26(2): 267–274.

Jamilah MS, Faridah M, Rohani S (2015) Setiu: More than a Wetlands in Setiu Wetland. In: Faridah M, Jamilah MS, Jarina MJ, Rohani S (Eds) Species, Ecosystem and Livelihood, Setiu Wetland: Species, Ecosystem and Livelihoods. Universiti Malaysia Terengganu Publishing, Terengganu, 87–100. https://www.e-sentral.com/book/info/269181/Setiu-Wetland-Species-Ecosystems-and-Livelihoods

Japar SB (1994) Mangrove plant resources in the ASEAN region. In: Wilkinson CR, Sudara S, Chou LM (Eds) Proceedings of the third ASEAN-Australia Symposium on living coastal resources vol. 1: Status Reviews, AIMS, Townsville, 123–138.

Latiff A (2009) Malaysian nipah: An appraisal of its scientific, economic potential and future. In: Abd. Rahman AR, et al. (Eds) Prosiding Seminar Pengurusan dan Pemuliharaan Hutan Nipah 2008. Jabatan Perhutanan Semenanjung Malaysia, Kerajaan Negeri Pulau Pinang & Kementerian Sumber Asli & Alam Sekitar, 49–58.

Latiff A, Faridah-Hanum I (2014) Mangroves ecosystem of Malaysia: Status, challenges and management strategies. In: Faridah-Hanum I, Latiff A, Hakeem KR, Ozturk M (Eds) Mangrove Ecosystems of Asia. Springer publishing, New York, 1–22. https://doi.org/10.1007/978-1-4614-8582-7_1

Le DQ, Tanaka K, Hii YS, Sano Y, Nanjo K, Shirai K (2018) Importance of seagrass-mangrove continuum as feeding grounds for juvenile pink ear emperor *Lethrinus lentjan* in Setiu Lagoon, Malaysia: Stable isotope approach. Journal of Sea Research 135: 1–10. https://doi.org/10.1016/j.seares.2018.02.004

Lim JS (2002) National Report for the UNCCD Implementation: Combating Land Degradation and Promoting Sustainable Land Management in Malaysia. Department of Agriculture, Kuala Lumpur.

MacDonald EM (2009) Guidelines for the Rehabilitation of degraded peat swamp forests in Central Kalimantan. Master Plan for the Conservation and Development of the Ex-Mega Rice Project Area in Central Kalimantan. Government of Indonesia/Royal Netherlands Embassy, Jakarta, 1–66. https://edepot.wur.nl/175467

Mohd Ekhwan HT, Mazlin BM, Muhammad Barzani G, Nor Azlina AA (2009) Analysis of the Physical Characteristics of BRIS Soil in Coastal Kuala Kemaman, Terengganu. Research Journal of Earth Sciences 1: 1–6.

Mohd Lokman H, Sulong I (2001) Mangrove of Terengganu, Mangrove Reserch Unit, Institute of Oceanography. A joint publication between Kolej Universiti Sains dan Teknologi Malaysia and Forestry Department Peninsular Malaysia, 1–135.

Mohd Raffi MA, Abdullah NAP, Go R, Abdullah TL, Saleh G (2014) *Vanilla*. In: Abdullah NAP, Ding P, Wan Daud WN (Eds) Recent advances in crop science Vol. 2. Universiti Putra Malaysia Press, Selangor, 300–329.

Nakisah MA, Fauziah AB (2003) Setiu Wetlands: Tranquility amidst plenty. Kolej Universiti Sains dan Teknologi Malaysia, Terengganu, 1–105.

Ono J, Yong JWH, Takayama K, Mohd Nazre S, Wee AKS, Asakawa T, Yllano OB, Salmo AG III, Suleiman M, Tung NX, Soe KK, Meenakshisundaram SH, Watano Y, Webb EL, Kajita T (2016) *Bruguiera hainesii*, a critically endangered mangrove species, is a hybrid between *B. cylindrica* and *B. gymnorhiza* (Rhizophoraceae). Conservation Genetics 17(5): 1137–1144. https://doi.org/10.1007/s10592-016-0849-y

Pesiu E (2018) Tree community structure and above ground biomass in off-coast islands, Setiu Wetlands and Hulu Terengganu, Terengganu. MSc. Thesis, Universiti Malaysia Terengganu, Malaysia.

Polidoro BA, Carpenter KE, Collins L, Duke NC, Ellison AM, Ellison JC, Farnsworth EJ, Fernando ES, Kathiresan K, Koedam NE, Livingstone SR, Miyagi T, Moore GE, Nam

VN, Ong JE, Primavera JH, Salmo SG III, Sanciangco JC, Sukardjo S, Wang Y, Yong JWH (2010) The loss of species: Mangrove extinction risk and geographic areas of global concern. PLoS One 5(4): e10095. https://doi.org/10.1371/journal.pone.0010095

Pridgeon AM, Cribb PJ, Chase MW, Rasmussen FN (2014) Genera Orchidacearum, Volume 6: Epidendroideae, Part 3. Oxford University Press, Oxford, 1–576.

Razali MS, Muhammad Khairul FZ, Wan Juliana WA (2017) Distribution and rarity of mangrove and coastal plants in developing indicators of hotspots in Setiu Wetlands. In: Abdullah DM, Nasir MZ, Mohd Mazlan N, Wan Faridah AWK (Eds) Prosiding seminar ekspedisi saintifik Tanah Bencah Setiu 2016. World Wildlife Fund-Malaysia, Selangor, 14–23.

Rohani S, Jamilah MS, Abdul Shukor Y (2017) Plant Diversity of Gelam Forest at Setiu Wetlands, Terengganu. In: Abdullah DM, Nasir MZ, Mohd Mazlan N, Wan Faridah AWK (Eds) Prosiding seminar ekspedisi saintifik Tanah Bencah Setiu 2016. World Wildlife Fund-Malaysia, Selangor, 70–77.

Said IM, Zakaria R (1992) An updated list of wetland plant species of Peninsular Malaysia, with particular reference to those having socio-economic value. Asian Wetland Bureau No. 67a, 1–109.

Sathiamurthy E (2015) Setiu River Basin: A brief account of the hydrologic connections of Setiu Wetlands. In: Faridah M, Jamilah MS, Jarina MJ, Rohani S (Eds) Setiu Wetlands: Species, Ecosystem and Livelihood. Universiti Malaysia Terengganu Publishing, Terengganu, 101–107. https://www.e-sentral.com/book/info/269181/Setiu-Wetland-Species-Ecosystems-and-Livelihoods

Sim CH, Yusoff MK, Shutes B, Ho SC, Mansor M (2008) Nutrient removal in a pilot and full scale constructed wetland, Putrajaya city, Malaysia. Journal of Environmental Management 88(2): 307–317. https://doi.org/10.1016/j.jenvman.2007.03.011

Siti Fatimah MI, Rusea G, Jamilah MS, Yien CYS (2015) Orchids in Coastal Heath Forest of Terengganu. In: Faridah M, Jamilah MS, Jarina MJ, Rohani S (Eds) Setiu Wetlands Species, Ecosystem and Livelihood. Universiti Malaysia Terengganu Publishing, Terengganu, 51–56. https://www.e-sentral.com/book/info/269181/Setiu-Wetland-Species-Ecosystems-and-Livelihoods

Suratman S, Hussein ANAR, Latif MT, Weston K (2014) Reassessment of physico-chemical water quality in Setiu Wetland, Malaysia. Sains Malaysiana 43(8): 1127–1131. http://journalarticle.ukm.my/7507/

Suzuki K (1999) An ecological study of *Melaleuca* communities in littoral swamps. Eco-Habitat 6: 133–141.

Syarifah NTB, Shazili NAM, Abdullah SA, Mamat AS (2008) Experimental and Field Study on Accumulation of Heavy Metals in Seagrasses (*Halodule pinifolia* and *Halophila minor*) in Setiu Wetland, Terengganu. Journal of Sustainability Science and Management 3(1): 41–73.

Truyen DM, Le HT, Manshor M (2014) Conservation and exploitation of bang grass effective in Phu My village, Vietnam. International Journal of GEOMATE, Geotechnique, Construction Materials and Environment, Tsu, Mie, Japan 7(2): 1096–1100. https://doi.org/10.21660/2014.14.4117

Tsuji K, Ghazalli MNF, Ariffin Z, Nordin MS, Khaidizar MI, Dulloo ME, Sebastian LS (2011) Biological and ethnobotanical characteristics of Nipa palm (*Nypa fruticans* Wurmb.): A review. Sains Malaysiana 40(12): 1407–1412.

Wan Bayani WO, Zaleha K (2015) Biodiversity of Mollusc in Setiu Wetlands by Using Molecular Markers for Characterization and Conservation. In: Faridah M, Jamilah MS, Jarina MJ, Rohani S (Eds) Setiu Wetlands Species, Ecosystem and Livelihood. Universiti Malaysia Terengganu Publishing, Terengganu, 27–37. https://www.e-sentral.com/book/info/269181/Setiu-Wetland-Species-Ecosystems-and-Livelihoods

Wurochekke AA, Harun NA, Mohamed RMSR, Kassim AHBM (2014) Constructed Wetland of *Lepironia articulata* for household greywater treatment. APCBEE Procedia 10: 103–109. https://doi.org/10.1016/j.apcbee.2014.10.025

## Appendix 1

Checklist of vascular plants from Setiu Wetlands, Terengganu, Malaysia. The habitat for all species are abbreviated as MSF = Mangrove Swamp Forest; PSF = Peat Swamp Forest; RV = Riparian Vegetation; LF = Lowland Forest; HV= Heath vegetation including CDF= Coastal Dunes Forest; BV = Beach Vegetation; DV = Disturbed Vegetation; FSF = Freshwater Swamp Forest; and BRIS including *Melaleuca* vegetation (MV=*Melaleuca* vegetation). Six categories in the conservation status, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, DD: Data Deficient, NE: Never Evaluated.

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| **LYCOPHYTES** | | | | | | |
| Lycopodiaceae | *Lycopodiella cernua* (L.) Pic.Serm. | Sorok-sorok | Fern | RV, DV | LC | NE |
| **FERNS** | | | | | | |
| Aspleniaceae | *Asplenium longissimum* Blume | - | Fern | LF | NE | NE |
| | *Asplenium nidus* L. | Paku Sarang Burung, Daun Semun, Paku Langsuir, Paku Langsuyar, Paku Pandan, Paku Sakat, Rumah Langsuyar | Fern | LF | NE | NE |
| Blechnaceae | *Blechnum indicum* Burm.f. | - | Fern | CDF | NE | NE |
| | *Stenochlaena palustris* (Burm.f.) Bedd. | Paku Miding | Fern | LF | NE | NE |
| Davalliaceae | *Davallia denticulata* (Burm.f.) Mett. ex Kuhn. | Paku Tertutup, Paku Terutup | Fern | FSF, RV, DV | NE | LC |
| | *Davallia solida* (Forst.) Sw. | - | Fern | BV | NE | NE |
| Dennstaedtiaceae | *Pteridium esculentum* (G.Forst.) Cockayne | - | Fern | LF | NE | NE |
| Lygodiaceae | *Lygodium flexuosum* (L.) Sw. | Paku Ribu-ribu, Akar Sidin, Darai Paya | Fern | LF | LC | LC |
| | *Lygodium microphyllum* (Cav.) R.Br. | Paku Ribu-ribu, Selada | Fern | DV | LC | LC |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Nephrolepidaceae | *Nephrolepis auriculata* (L.) Trimen | Paku Hitam | Fern | DV | DD | NE |
| | *Nephrolepis biserrata* (Sw.) Schott | Paku Hitam, Paku Larat, Paku Uban | Fern | DV | LC | LC |
| Polypodiaceae | *Drynaria quercifolia* (L.) J.Sm. | Paku Sakat Tupai, Sakat Laipang, Daun Kelapa Tupai, Daun Kepala Tupai | Fern | LF | LC | LC |
| | *Goniophlebium percussum* (Cav.) Wagner & Grether | Paku Pakis | Fern | LF | LC | LC |
| | *Phymatosorus cuspidatus* (D.Don) Pic.Serm. | Paku Pakis | Fern | LF, DV | DD | NE |
| | *Phymatosorus scolopendria* (Burm.f.) Pic.Serm. | Paku Wangi, Sakat Hitam | Fern | LF, DV | DD | NE |
| | *Pyrrosia lanceolata* (L.) Farw. | Bulu Ayam, Sakat Batu, Tetumpang | Fern | BV,CDF | LC | LC |
| | *Pyrrosia piloselloides* (L.) M.G.Price | Duit-duit, Sakat Ribu-ribu, Sisik Naga | Fern | LF, MSF | LC | LC |
| | *Pyrrosia longifolia* (Burm.f.) C.V.Morton | Sakat, Suloi | Fern | LF, FSF, DV | LC | LC |
| Psilotaceae | *Psilotum nudum* (L.) P.Beauv. | - | Fern | CDF | NE | NE |
| Pteridaceae | *Acrostichum aureum* L. | Piai Raya, Paku Larat, Paku Laut | Fern | MSF | LC | LC |
| | *Acrostichum speciosum* Willd. | Piai Lasa | Fern | MSF | LC | LC |
| Salviniaceae | *Salvinia molesta* D.S.Mitch. | Kiambang | Fern | FSF | NE | NE |
| Schizaeaceae | *Schizaea dichotoma* (L.) Sm. | Janggut keli, Payung Ali, Misai Rimau, Paku Cakar Ayam | Fern | CDF | LC | NE |
| **GYMNOSPERMS** | | | | | | |
| Cycadaceae | *Cycas edentata* De Laub. | Pokok Sakat | Tree | CDF | NT | NT |
| Gnetaceae | *Gnetum cuspidatum* Blume | Melinjau akar | Climbing Shrub | LRW | LC | NE |
| | *Gnetum gnemon* L. | Melinjau/Cokok | Tree | BV | LC | NE |
| **DICOTYLEDONS** | | | | | | |
| Acanthaceae | *Acanthus ebracteatus* Vahl | Jeruju Putih | Shrub | MSF, RV, LF | LC | NE |
| | *Acanthus ilicifolius* L. | Jeruju Hitam | Shrub | MSF | LC | NE |
| | *Ruellia tuberosa* L. | - | Terrestrial herb | DV | NE | NE |
| | *Thunbergia fragrans* Roxb. | Akar Patuk Tuau, Akar Sebiak, Kacang Akar, Kelemai Merah, Sambung Nyawa, Tunbergia Putih | Terrestrial herb | DV | NE | NE |
| Anacardiaceae | *Anacardium occidentale* L. | Gajus, Jambu Golok, Jambu Monyet, | Tree | CDF | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Anacardiaceae | *Buchanania arborescens* (Blume) Blume | Otak Udang Tumpul, Otak Udang, Katak Udang, Ketak Udang, Puah Pipit, Puan, Terentang Tikus | Tree | RV, CDF | NE | NE |
| | *Buchanania sessilifolia* Blume | Otak Udang Tumpul | Tree | LF | DD | NE |
| | *Campnosperma coriaceum* (Jack) Hallier f. ex Steenis | Terentang, Terentang Kelintang | Tree | SF, FSF | NE | NE |
| | *Campnosperma squamatum* Ridl. | Terentang, Terentang Daun Kecil, | Tree | SF | NE | NE |
| | *Gluta velutina* Blume | Rengas, Rengas air | Tree | SF, RV, CDF | NE | NE |
| | *Mangifera griffithii* Hook.f. | Asam Raba, Asam Rawa, Rawa | Tree | LF | NE | NE |
| | *Mangifera pentandra* Hook.f. | Pauh, Mangga, Mangga Air, Mangga Dodol, Mempelam Bemban | Tree | LF | DD | NE |
| | *Gluta wallichii* (Hook.f) Ding Hou | Rengas | Tree | PSF | DD | NE |
| Annonaceae | *Annona glabra* L. | Nona Licin | Tree | MSF | NE | NE |
| Ancistrocladaceae | *Ancistrocladus tectorius* (Lour.) Merr. | Akar Julong Hitam, Jejulong Akar | Shrub | LF | NE | LC |
| | *Alyxia reinwardtii* Blume | Palusari | Climbing shrub | LF, PSF | NE | LC |
| | *Anodendron candolleanum* Wight | Akar kikat, Akar nirwali | Climbing shrub | PSF, RV | NE | VU |
| | *Calotropis gigantea* (L.) W.T.Aiton | Remingu | Shrub | CDF, BV | NE | NE |
| | *Cerbera odollam* Gaertn. | Pong-pong, Buta-buta | Tree | SF | NE | NE |
| | *Cerbera manghas* L. | Pong-pong, Pong Pong Pong, Buta-buta, Nyan | Tree | MSF, BV | NE | NT |
| | *Dischidia major* (Vahl) Merr. | Akar Bano, Akar Kul | Epiphytic herb | BV | NE | NE |
| | *Dischidia nummularia* R.Br. | Daun Pitis Kecil | Epiphytic herb | FSF | NE | NE |
| | *Finlaysonia obovata* Wall. | Kalak kambing, Pelir Kambing | Climbing shrub | MSF | NE | NE |
| | *Hoya carnosa* (L.f.) R.Br. | Akar Banok Jantan | Climbing shrub | BV | NE | NT |
| | *Hoya coronaria* Blume | Akar Setebal | Epiphytic shrub | MSF | NE | NE |
| | *Hoya coriacea* Blume | Akar Setebal | Epiphytic shrub | MSF | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Ancistrocladaceae | *Hoya diversifolia* Blume | Akar Setebal | Epiphytic shrub | MSF | NE | NE |
| | *Hoya verticillata* (Vahl) G.Don | Akar Setebal | Epiphytic shrub | MSF | NE | NE |
| | *Parsonsia alboflavescens* (Dennst.) Mabb. | - | Climbing shrub | MSF, PSF, BV | NE | NE |
| | *Tylophora flexuosa* R.Br. | Akar Banok Jantan | Climbing shrub | MSF | NE | NE |
| Aquifoliaceae | *Ilex cymosa* Blume | Mensirah, Mensirah Puteh | Tree | MSF | NE | NE |
| Araliaceae | *Arthrophyllum diversifolium* Blume | Tumbuh Kelapa | Tree | LF | NE | NE |
| | *Schefflera elliptica* (Blume) Harms. | Cenama Gajah | Climbing shrub | MSF | NE | NE |
| Apocynaceae | *Alstonia pneumatophora* Baker ex Den Berger | Pulai Paya | Tree | FSF | LC | NE |
| | *Catharanthus roseus* (L.) G.Don | Kemunting Cina | Shrub | CDF, MSF | NE | NE |
| | *Sarcolobus globosus* Wall. | Buah Pitis | Climbing shrub | MSF | NE | NE |
| | *Secamone elliptica* R.Br. | - | Shrub | DV | NE | NE |
| Asteraceae | *Melanthera biflora* (L.) Wild | Serenai Laut, Seremai, Serenah, Sunai Laut | Climbing herb | MSF, BV | NE | NE |
| | *Mikania micrantha* Kunth | Selaput Tunggul | Climbing herb | DV | NE | NE |
| | *Pluchea indica* (L.) Less | Beluntas | Shrub | MSF | NE | NE |
| | *Sphagneticola trilobata* (L.) Pruski | - | Terrestrial herb | DV | NE | NE |
| | *Synedrella nodiflora* (L.) Gaertn. | - | Terrestrial herb | DV | NE | NE |
| | *Tridax procumbens* L. | Butang Baju | Terrestrial herb | DV | NE | NE |
| Avicenniaceae | *Avicennia alba* Blume | Api-api Putih, Api-api Hitam | Tree | MSF, RV | LC | NE |
| | *Avicennia officinalis* L. | Api-api Ludat, Api-api, Api-api Sudu | Tree | MSF | LC | NE |
| | *Avicennia rumphiana* Hallier f. | Api-api Bulu | Tree | MSF | VU | NE |
| Bignoniaceae | *Dolichandrone spathacea* (L.f.) K.Schum. | Tui, Poko Kulo, Tuj, Kulok | Tree | MSF | LC | NE |
| Bonnetiaceae | *Ploiarium alternifolium* (Vahl) Melchior | Riang-riang | Tree | FSF, DV | NE | LC |
| Calophyllaceae | *Calophyllum inophyllum* L. | Bintangor laut | Tree | CDF | LC | NE |
| | *Calophyllum rupicola* Ridl. | Bintangor | Tree | MSF, CDF | NE | NE |
| | *Calophyllum sclerophyllum* Vesque | Bitangor Jangkang | Tree | PSF | NE | NE |
| | *Mesua ferruginea* (Pierre) Kosterm. | Sembawang | Tree | PSF | NE | NE |
| Casuarinaceae | *Casuarina equisetifolia* L. | Rhu, Ru | Tree | CDF, BV | NE | NE |

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|---|---|---|---|---|---|---|
| Celastraceae | *Gymnosporia littoralis* (Backer) Jordaan | - | Shrub | CDF | NE | NE |
| | *Salacia chinensis* L. | Akar pelanduk | Climbing shrub | MSF | NE | NE |
| Chrysobalanaceae | *Licania splendens* (Korth.) Prance | Nyalas | Tree | PSF, LF | LC | LC |
| | *Parastemon urophyllus* (Wall.ex A.DC.) A.DC. | Malas Siangus | Tree | CDF, BV | NE | NE |
| Clusiaceae | *Garcinia hombroniana* Pierre | Beruas | Tree | CDF, BV | NE | NE |
| | *Garcinia nigrolineata* Planch.ex T.Anderson | Beruas | Tree | CDF | NE | NE |
| | *Garcinia brevirostris* Scheff. | Lulai, Kandis | Tree | CDF | NE | NE |
| | *Garcinia parvifolia* (Miq.) Miq. | Beruas | Tree | FSF | NE | NE |
| Combretaceae | *Lumnitzera littorea* (Jack) Voigt | Teruntum Merah | Tree | MSF | LC | NE |
| | *Lumnitzera racemosa* Willd. | Teruntum Putih, Teruntum Bunga Putih | Tree | MSF | LC | NE |
| | *Combretum tetralophum* C.B.Clarke | - | Climbing shrub | PSF | NE | NE |
| | *Terminalia catappa* L. | Ketapang | Tree | MSF, CDF, BV | NE | NE |
| Convolvulaceae | *Ipomoea cairica* (L.) Sweet | Seri pagi jalar | Terrestrial herb | CDF,BV | LC | NE |
| | *Ipomoea pes-caprae* (L.) R.Br | Tapak Kuda, Seri pagi | Terrestrial herb | CDF, DV, BV | NE | NE |
| Dilleniaceae | *Dillenia suffruticosa* (Griff.) Martelli. | Simpoh Air | Tree | LF,DV | NE | NE |
| | *Tetracera indica* (Christm. & Panz.) Merr. | Akar Mempelas Licin, Akar Mempelas, Mempelas, Mempelas Minyak, Mempelas Paya | Climbing shrub | LF,DV | NE | NE |
| | *Tetracera scandens* (L.) Merr. | Akar Mempelas | Climbing shrub | LF,DV,BV | NE | NE |
| Dioscoreaceae | *Tacca leontopetaloides* (L.) Kuntze | Lekir Pasir | Terrestrial herb | CDF, BV | LC | NE |
| Dipterocarpaceae | *Anisoptera marginata* Korth. | Mersawa Paya | Tree | PSF | EN | EN |
| | *Vatica pauciflora* Blume | Resak raya | Tree | MSF | VU | NT |
| Droseraceae | *Drosera burmannii* Vahl | - | Terrestrial herb | LF | LC | NT |
| Ebenaceae | *Diospyros ferrea* (Willd.) Bakh. | Buey, Kayu Arang, Kayu Arang | Tree | MSF | NE | NE |
| | *Diospyros lanceifolia* Roxb. | Arang | Tree | LF | NE | NE |
| | *Diospyros maingayi* (Hiern) Bakh. | Kayu Arang, Siangus, Merpinang Daun Besar | Tree | PSF, LF | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Elaeocarpaceae | *Elaeocarpus macrocerus* (Turcz.) Merr. | Mendong | Tree | FSF | NE | NE |
| | *Elaeocarpus mastersii* King | Mendong | Tree | LF, FSF, PSF | NE | LC |
| | *Elaeocarpus petiolatus* (Jack) Wall | Mendong | Tree | LF | NE | LC |
| Ericaceae | *Styphelia malayana* (Jack) Spreng. | Choreng atap, Chuchur Atap, Maki China, Tasek Timbul | Tree | CDF,BV | NE | NE |
| | *Vaccinium littoreum* Miq. | Inai batu | Tree | BV | NE | NE |
| Erythroxylaceae | *Erythroxylum cuneatum* (Miq.) Kurz. | Cinta Mula | Tree | CDF, BV | NE | NE |
| Euphorbiaceae | *Excoecaria agallocha* L. | Buta-buta, Buta-buta, Bebuta, Betak-betak | Tree | MSF | LC | NE |
| | *Macaranga hypoleuca* (Rchb.f. & Zoll.) Müll. Arg. | Mahang Putih | Tree | LF,DV | NE | NE |
| | *Macaranga laciniata* Whitmore & Airy Shaw. | Mahang | Tree | LF,DV | NE | NE |
| | *Shirakiopsis indica* (Willd.) Esser | Gurah | Tree | MSF | LC | NE |
| | *Suregada multiflora* (A.Juss.) Baill. | Merlimau, Limau Hantu | Tree | LF | NE | NE |
| Fabaceae | *Aganope heptaphylla* (L.) Polhill | Ketui Besar, Omis omis | Climbing shrub | MSF, BV | NE | NE |
| | *Archidendron clypearia* (Jack) I.C.Nielsen | Petai Kera | Tree | PSF, DV | NE | NE |
| | *Caesalpinia bonduc* (L.) Roxb. | Gorek | Climbing shrub | CDF, BV | NE | NE |
| | *Caesalpinia crista* L. | Akar Kuku Tupai | Climbing shrub | MSF | NE | NE |
| | *Canavalia rosea* (Sw.) DC. | Kekacang Laut | Terrestrial herb | BV | NE | NE |
| | *Cynometra ramiflora* L. | Katak Puru | Tree | MSF | NE | NE |
| | *Dalbergia candenatensis* (Dennst.) Prain | Akar Kait, Api-api Jambu, | Climbing shrub | MSF | NE | NE |
| | *Dendrolobium umbellatum* (L.) Benth. | Petai laut, Dedulang, Petai belalang, Petai laut | Shrub | MSF | NE | NE |
| | *Derris trifoliata* Lour. | Ketui, Tuba laut, Ketui, Salang, Selang, Setui | Climbing shrub | MSF | NE | NE |
| | *Desmodium adscendens* (Sw.) DC. | Sisik Naga | Terrestrial herb | PSF, DV | LC | NE |
| | *Desmodium heterophyllum* (Willd.) DC. | Sisik Naga | Terrestrial herb | LF, DV | NE | NE |
| | *Desmodium triflorum* (L.) DC. | Sisik Naga | Terrestrial herb | DV | LC | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Fabaceae | *Intsia bijuga* (Colebr.) Kuntze | Ipil, Merbau Ipil, Merbau Changkat, Merbau laut | Tree | MSF | VU | NE |
| | *Mimosa pudica* L. | Semalu | Terrestrial herb | DV | LC | NE |
| | *Ormosia sumatrana* (Miq.) Prain | Sepit-sepit | Tree | LF | NE | NE |
| | *Peltophorum pterocarpum* (DC.) K.Heyne | Jemerlang | Tree | MSF, BV | NE | NE |
| | *Pongamia pinnata* (L.) Pierre | Mempari | Tree | MSF, BV | LC | NE |
| | *Pongamia pinnata* (L.) Pierre var. *xerocarpa* (Hassk.) Alston | Malapari | Tree | RV,LF | | |
| | *Pterocarpus indicus* Willd. | Angsana | Tree | CDF | VU | NE |
| | *Senna alata* (L.) Roxb. | Gelenggang | Shrub | LSF,DV | NE | NE |
| | *Senna occidentalis* (L.) Link | Gelenggang Pasir | Shrub | DV | NE | NE |
| | *Tamarindus indica* L. | Asam Jawa | Tree | LF | LC | NE |
| Gentianaceae | *Cyrtophyllum fragrans* (Roxb.) DC. | Tembusu | Tree | FSF, DV | NE | NE |
| | *Fagraea auriculata* Jack | Pelir Musang | Tree | CDF | NE | NE |
| | *Fagraea racemosa* Jack | Kahwa Hutan | Tree | LSF,DV | NE | NE |
| | *Fagraea fragrans* Roxb. | Tembusu | Tree | FSF, DV | LC | NE |
| Goodeniaceae | *Scaevola taccada* (Gaertn.) Roxb. | Ambong-ambong | Shrub | BV | NE | LC |
| Hemerocallidaceae | *Dianella ensifolia* (L.) DC. | Siak-siak, Akar Siak, Benjuan, Jamaka, Lenjuang, Meroyan Bangkai, Setagit, Senjuang | Terrestrial herb | LF | NE | NE |
| Hypericaceae | *Cratoxylum arborescens* (Vahl) Blume | Geronggang | Tree | PSF, DV | LC | LC |
| Lamiaceae | *Volkameria inermis* L. | Lampin Budak, Gambir Laut, Pawan, Tulang-tulang | Shrub | MSF | NE | NE |
| | *Gmelina elliptica* Sm. | Bulangan | Shrub | DV | NE | NE |
| | *Premna serratifolia* L. | Buas-buas, Bangkung Kayu, Sarunai, | Shrub | MSF, BV | NE | NE |
| | *Vitex pinnata* L. | Leban | Tree | DV | NE | NE |
| | *Vitex rotundifolia* L.f. | Langundi | Shrub | BV | NE | NE |
| | *Vitex trifolia* L. | Halban, Lagundi | Tree | MSF | NE | NE |
| Lauraceae | *Cassytha filiformis* L. | Cemar batu | Parasitic herb | CDF, BV | NE | NE |
| | *Neolitsea zeylanica* (Nees) Merr. | Teja pasir | Tree | CDF | NE | NE |
| | *Phoebe grandis* (Nees) Merr. | Medang | Tree | LF | NE | NE |
| Lentibulariaceae | *Utricularia bifida* L. | - | Herbaceous | PSF | LC | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Loranthanceae | *Dendrophthoe pentandra* (L.) Miq. | Dedalu | Parasitic shrub | LF | NE | NE |
| Lecythidaceae | *Barringtonia asiatica* (L.) Kurz. | Putat Laut, Butong, Butun, Butung | Tree | BV | LC | LC |
| | *Barringtonia racemosa* (L.) Spreng. | Putat Sungai, Putal Kedul, Putat Air, Putat Ayam, Putat Darat, Putat Kampung, Putat Padi, Putat Rambai, Putat Sawah | Tree | MSF | NE | NE |
| Linaceae | *Indorouchera griffithiana* (Planch.) Hallier f. | Akar Ipoh | Climbing shrub | LF, PSF | NE | NE |
| Lythraceae | *Lagerstroemia speciosa* (L.) Pers. | Bungor, Bungor Biru, Bungor Rya, Tibabah | Tree | DV | NE | NE |
| | *Sonneratia alba* Sm. | Perepat, Pauh Kijang | Tree | MSF | LC | NE |
| | *Sonneratia caseolaris* (L.) Engl. | Berembang, Perapat, Perapat Laut, Perepat | Tree | MSF | LC | NE |
| | *Sonneratia* x *hainanensis* W.C.Ko | Gedabu Hibrid | Tree | MSF | DD | NE |
| | *Sonneratia lanceolata* Blume | Berembang Putih, | Tree | MSF | LC | NE |
| | *Sonneratia ovata* Backer | Gedabu, Kedabu, Rogam | Tree | MSF | NT | NE |
| Malpighiaceae | *Tristellateia australasiae* A.Rich. | - | Climbing shrub | MSF | NE | NE |
| Malvaceae | *Brownlowia argentata* Kurz. | Durian Laut | Tree | MSF,BV | DD | NE |
| | *Commersonia bartramia* (L.) Merr. | Angkut Besi | Tree | LF,DV | LC | NE |
| | *Heritiera littoralis* Aiton | Dungun, Bayur Laut, Buah Pelir Kambing, Atun Laut | Tree | MSF | LC | NE |
| | *Talipariti tiliaceum* (L.) Fryxell | Baru-baru Laut, Bebaru, Bebaru Laut | Tree | MSF | LC | NE |
| | *Thespesia populnea* (L.) Sol. ex Correa | Bebaru, Baru Laut, Buah Keras Laut | Tree | MSF | LC | NE |
| | *Sida acuta* Burm.f. | Kelulut Putih | Terrestrial herb | DV | NE | NE |
| | *Urena lobata* L. | Pulut-pulut, Pepulut, Pulut Lembu | Terrestrial herb | DV | DD | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Melastomataceae | *Melastoma malabathricum* L. | Senduduk, Kenduduk | Shrub | LF | DD | NE |
| | *Memecylon caeruleum* Jack | Dali Dedali, Delek Jambu | Tree | LF | LC | LC |
| | *Memecylon edule* Roxb. | Delek Air, Nipis Kulit, Delek Ayer | Tree | LF | LC | LC |
| Meliaceae | *Xylocarpus granatum* J.Koenig | Nyireh Bunga, Nyireh | Tree | MSF | LC | LC |
| | *Xylocarpus moluccensis* (Lam.) M.Roem. | Nyireh Batu | Tree | MSF | LC/NT | LC |
| Menyanthaceae | *Nymphoides indica* (L.) Kuntze | Telipot | Aquatic herb | DV | LC | NE |
| Moraceae | *Ficus deltoidea* Jack | Mas Cotek, Ara, Serapat Angin, Telinga Beruk | Shrub | LF | DD | NE |
| | *Ficus microcarpa* L.F. | Beringin, Ara Jejawi, Jawi Jawi | Tree | MSF | LC | NE |
| | *Ficus sundaica* Blume | Ara Bertih, Ara Punai | Tree | LF | DD | NE |
| Myrtaceae | *Baeckea frutescens* L. | Cucur Atap, Tuturun Atap, Rempah Rempah | Tree | PSF | LC | NE |
| | *Melaleuca cajuputi* Powell | Gelam Putih, Kayu Putih | Tree | PSF, MSF | LC | NE |
| | *Rhodamnia cinerea* Jack | Mempoyan, Mempoyan Bukit, Mengkoyan Pinang | Tree | LF | LC | NE |
| | *Rhodomyrtus tomentosa* (Aiton) Hassk. | Kemunting, Lidah Katak Laut | Shrub | BV | LC | NE |
| | *Syzygium antisepticum* (Blume) Merr. & L.M.Perry | Kelat Tikus, Gelam Tikus, Kelat Gelam | Tree | LF | NE | NE |
| | *Syzygium densiflora* var. *angustifolia* Ridl. | - | Tree | LF | DD | NE |
| | *Syzygium grande* (Wight) Walp. & Wight | Jambu laut, Jambu Air Laut, Kelat Jambu Laut | Tree | CDF | NE | NE |
| | *Syzygium oblatum* (Roxb.) Wall. ex A.M. Cowan & Cowan | Kelat Kecham | Tree | LF, PSF | DD | NE |
| | *Syzygium incarnatum* (Elmer) Merr. & L.M.Perry | Kelat Kertas, Kulat Gelam | Tree | LF, PSF | DD | NE |
| | *Syzygium leucoxylon* Korth. | Kelat Putih | Tree | PSF | DD | NE |
| | *Syzygium pyrifolium* (Blume) DC. | Kelat Putih, Kelat Lapis | Tree | LF, PSF | NE | NE |
| | *Syzygium palembanicum* Miq. | Jambu, Kelat | Tree | LF | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Myrtaceae | *Syzygium syzygioides* (Miq.) Merr. & L.M.Perry | Kelat Hitam | Tree | LF | NE | NE |
| | *Syzygium zeylanicum* (L.) DC. | Kelat Gelam, Jambu, Gelam Tikus, Kelat Nenasi, Ubah Gelam | Tree | LF, FSF | NE | NE |
| Myricaceae | *Morella esculenta* (Buch.-Ham. ex D.Don) I.M.Turner | Telur Cicak, Kesami, Keteng, Lenketing | Tree | FSF | LC | LC |
| Myrisinaceaae | *Aegiceras corniculatum* (L.) Blanco | Teruntun, Kacang Kacang, Kuku Helang | Tree | MSF | LC | NE |
| | *Rapanea porteriana* (Wall. ex A.DC.) Mez | Dedahruang | Tree | MSF | NE | NE |
| Myristicaceae | *Horsfieldia irya* (Gaertn.) Warb. | Pianggu, Penarahan | Tree | MSF, FSF | LC | NT |
| | *Knema conferta* (King) Warb. | Penarahan Hitam | Tree | LF | LC | NE |
| | *Knema globularia* (Lamk.) Warb. | Penarahan Padi, Chendarah Padi | Tree | LF | NT | NE |
| | *Myristica lowiana* King | Penarahan arang, Penarah Arang Gambut | Tree | PSF | NT | NT |
| Nepenthaceae | *Nepenthes ampullaria* Jack | Periok Kera | Climbing shrub | LF, FSF | LC | NE |
| | *Nepenthes gracilis* Korth. | Periok Kera | Climbing shrub | PSF | LC | NE |
| | *Nepenthes mirabilis* (Lour.) Druce | Periok Kera | Climbing shrub | PSF,LF | LC | NE |
| Ochnaceae | *Brackenridgea hookeri* (Planch.) A.Gray | Bunga Kelat Merah, Mata Ketam, Kayu Luru | Tree | LF | LC | NT |
| Olacaceae | *Olax scandens* Roxb. | Kodak Aching, Meribut | Shrub | DV | NT | NE |
| Oleaceae | *Olea brachiata* (Lour.) Merr. | Menserah | Tree | BV | NE | NE |
| Opiliaceae | *Champereia manillana* (Blume) Merr. | Chemperai | Tree | FSF | LC | NE |
| | *Cansjera rheedei* J.F.Gmel. | Chemperai Akar | Shrub | BV | NT | NE |
| Passifloraceae | *Passiflora foetida* L. | Buah Letup, Buah Tikus, Pokok Lang Bulu, Timun Denfdang, Timun Hutan | Climbing herb | RV, DV | NE | NE |
| Peraceae | *Chaetocarpus castanocarpus* (Roxb.) Thwaites | Membatu, Bebatu, Bedik | Tree | LF, PSF | LC | NE |
| Pentaphylacaceae | *Adinandra sarosanthera* Miq. | Tetiup, Kelat Pamah, Petuta Bukit, Pongpong Raya, Samak | Tree | LF | NE | NE |
| | *Ternstroemia wallichiana* (Griff.) Engl. | Medang Bunga Lawang | Tree | LF | VU | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Phyllanthaceae | *Antidesma cuspidatum* Müll.Arg. | Beruni, Berunai, Sebasah Bukit | Tree | LF, FSF | NE | NE |
| | *Antidesma ghaesembilla* Gaertn. | Beruni, Balong Ayam, Guncak | Tree | LF, PSF | LC | NE |
| | *Breynia racemosa* (Blume) Müll.Arg. | Hujan panas, Ambin Kera, Peringat, Saga, Sumbar | Tree | LF, BV | LC | NE |
| | *Glochidion littorale* Blume | Jambu Kera | Tree | BV, MSF | LC | NE |
| Pittosporaceae | *Pittosporum ferrugineum* W.T.Aiton. | Belalang Puak, Cemperai Ikan, Chabek Hantu | Tree | BV | LC | LC |
| Primulaceae | *Aegiceras corniculatum* (L.) Blanco | Kuku Lang, Kacang-kacang, Teruntun | Tree | MSF | LC | NE |
| | *Ardisia crenata* Sims. | Mata ayam, Akar Bebuluh, Mata Pelandok, Sirih Puyuh | Shrub | | NE | NE |
| | *Ardisia elliptica* Thunb. | Mata pelanduk, Buah Letus, Daun Bisa Hati, Jambulan Pantai, Jangkang, Kayu Lampilan, Mempenai | Tree | FSF | NE | E |
| | *Embelia ribes* Burm.f. | - | Shrub/ Climbing shrub | LF | NE | NE |
| | *Rapanea porteriana* (Wall. ex A.DC.) Mez. | Kicar, Dedahruang | Tree | MSF | NE | NE |
| Rhizophoraceae | *Bruguiera cylindrica* (L.) Blume | Berus-berus, Bakau Putih, Berus Putih | Tree | MSF | LC | NE |
| | *Bruguiera gymnorhiza* (L.) Lam. ex Savigny | Tumu Merah, Lenggadai | Tree | MSF | LC | NE |
| | *Bruguiera sexangula* (Lour.) Poir | Tumu Putih, Tumu Berau, Mata Buaya, Putut | Tree | MSF | LC | NE |
| | *Bruguiera hainesii* C.G.Rogers | Berus Mata Buaya | Tree | MSF | CR | NE |
| | *Bruguiera* x *rhynchopetala* (W.C.Ko) N.C.Duke & X.J.Ge | Tumu Hibrid | Tree | MSF | DD | NE |
| | *Carallia brachiata* (Lour.) Merr. | Sisik Puyu, Merpuing, Meransi | Tree | LF, MSF, BV | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Rhizophoraceae | *Ceriops tagal* (Pers.) C.B.Rob. | Tengar, Tengar Samak | Tree | MSF | LC | NE |
| | *Ceriops zippeliana* Blume | Tengar | Tree | MSF | LC | NE |
| | *Gynotroches axillaris* Blume | Mata Keli, Bulu Bulu, Kandis Batu | Tree | | NE | NE |
| | *Rhizophora apiculata* Blume | Bakau Minyak, Bakau Akik, Bakau Tandok, Bangkita | Tree | MSF | LC | NE |
| | *Rhizophora mucronata* Lam. | Bakau Kurap, Bakau Belukap, Bakau Gelukap, Bakau Jankar | Tree | MSF | LC | NE |
| | *Rhizophora* x *annamalayana* Kathir. | Bakau Hibrid | Tree | MSF | DD | NE |
| Rhamnaceae | *Colubrina asiatica* (L.) Brongn. | Bidara Laut , Peria Pantai | Shrub | BV | NE | NE |
| Rubiaceae | *Canthium confertum* Korth. | Kemuning Jantan | Tree | BV,LF | NE | NE |
| | *Catunaregam spinosa* (Thunb.) Tirveng. | Duri Timbang Tahil | Tree | CDF | NE | NE |
| | *Catunaregam tomentosa* (Blume ex DC.) Tirveng. | Duri Timbang Tahil | Tree | BV | NE | NE |
| | *Gardenia tubifera* Wall. ex Roxb. | Mentiong Paya, Chempaka Hutan, Delima Hutan | Tree | LF | DD | NE |
| | *Guettarda speciosa* L. | Selar Malam, Bebaru Laut, Katapang Pasir | Tree | BV | NE | NE |
| | *Gynochthodes sublanceolata* Miq. | Akar sulong, Akar Lampai Hitam | Shrub | LF | NE | NE |
| | *Oldenlandia herbacea* (L.) Roxb. | Siku-siku | Terrestrial herb | BV | DD | NE |
| | *Hydnophytum formicarum* Jack | Kepala Berok, Sarang Semut | Epiphytic shrub | PSF, BV | NE | NE |
| | *Hypobathrum racemosum* (Roxb.) Kurz. | Empawang Putih | Tree | LF | NE | NE |
| | *Ixora concinna* R.Br.ex Hook.f. | Jenjarum | Shrub | LF | NE | NE |
| | *Ixora grandifolia* Zoll. & Moritzi | Jenjarum, Jarum Hutan | Shrub | LF | DD | NE |
| | *Kailarsenia tentaculata* (Hook.f.) Tirveng. | Kecubong Paya, Kepayang Air | Shrub | RV | NE | NE |
| | *Morinda citrifolia* L. | Mengkudu Daun Kecil, Noni, Mengkudu, Mengkudu Besar | Tree | DV | NE | NE |
| | *Morinda umbellata* L. | Mengkudu akar, Mengkudu Hutan | Climbing shrub | BV,LF | NE | NE |
| | *Ixora congesta* Roxb. | Pecah Periok, Bunga Penaga Riam, Jarum Saluang | Shrub | LF | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Rubiaceae | *Ixora umbellata* var. *multibracteata* (H.Pearson ex King & Gamble) Corner | Pecah Periok | Shrub | LF | DD | NE |
| | *Mussaenda glabra* Vahl | Balik Adap | Shrub | FSF, DV | NE | NE |
| | *Myrmecodia tuberosa* Jack | Periok Hantu | Shrub | MSF, FSF | NE | NE |
| | *Oxyceros longiflorus* (Lam.) T.Yamaz. | Akar Kekait, Akar Bedara Laut, Akar Duri | Climbing shrub | MSF | DD | NE |
| | *Psychotria sarmentosa* Blume | Akar Daldaru, Kaum Kopi | Climbing shrub | LF, FSF | NE | NE |
| | *Scyphiphora hydrophyllacea* C.F.Gaertn. | Chengam | Shrub | MSF | LC | NE |
| | *Tarenna fragrans* (Blume) Koord. & Valeton | Julong-julong Jantan | Tree | LF,RV | DD | NE |
| | *Timonius flavescens* (Jacq.) Baker | Kurau, Kaum Kopi | Tree | LF,PSF | LC | NE |
| | *Uncaria acida* (W.Hunter) Roxb. | Gambir-gambir | Climbing shrub | LF | NE | NE |
| Rutaceae | *Acronychia pedunculata* (L.) Miq. | Jenjagong | Tree | LF | LC | NE |
| | *Melicope lunu-ankenda* (Gaertn.) T.G.Hartley | Tenggek burung, Pepauh, Chabang Tiga | Shrub | LF | LC | NE |
| Salicaceae | *Flacourtia rukam* Zoll. & Moritzi | Rukam | Tree | RV | NE | NE |
| | *Scolopia macrophyll*a (W.& A.) Clos | Rukam Hutan | Tree | MSF, RV | NE | NE |
| Santalaceae | *Dendrotrophe buxifolia* (Blume) Miq. | Setong Jundor | Parasitic shrub | BV | DD | NE |
| | *Viscum orientale* Willd. | Dedalu | Parasitic shrub | MSF | DD | NE |
| | *Viscum ovalifolium* DC. | Dedalu Emping, Api-api | Parasitic shrub | MSF | LC | LC |
| Sapotaceae | *Palaquium obovatum* (Griff.) Engl. | Taban Putih, Nyatoh, Nyatoh Putih | Tree | LF, FSF | LC | NE |
| | *Planchonella obovata* (R.Br.) Pierre | Nenasi, Misi, Nyatoh Laut, Nyatoh Kuning | Tree | MSF, BV | NE | NE |
| Sapindaceae | *Allophylus cobbe* (L.) Raeusch | Buah Penancang, Congkol, Cungkil, Kasai, Kasai Daun Kecil | Shrub | LF, MSF, BV | NE | NE |
| | *Dodonaea viscosa* (L.) Jacq. | Serengan laut, Kayu Bertih | Tree | RV, BV | LC | NE |
| | *Guioa bijuga* (Hiern) Radlk. | Senyamok | Tree | LF | NE | NE |
| | *Guioa pleuropteris* (Blume) Radlk. | Senyamok, Samak, Kelentit, Nyamuk Laut, Pena-pena, Sempayan Ular | Tree | LF, RV | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Sapindaceae | *Lepisanthes rubiginosa* (Roxb.) Leenh. | Mertajam, Kelat Layu, Terajah | Tree | RV | LC | NE |
| | *Mischocarpus sundaicus* Blume | Suji | Tree | LF | NE | NE |
| Simaroubaceae | *Eurycoma longifolia* Jack | Tongkat Ali, Bidara Merah, Lempedu Pahit, Pasak Bumi, Setunjang Bumi | Tree | LF, BV | NE | NE |
| | *Quassia indica* (Gaertn.) Noot. | Kayu Pahit, Gatip pahit, Kacang-kacang | Tree | PSF, MSF | NE | NE |
| Symplocaceae | *Symplocos adenophylla* Wall. ex G.Don | Semugum, Jiak | Tree | LF | DD | NE |
| Thymelaeaceae | *Wikstroemia indica* (L.) C.A.Mey | Depu | Shrub | DV | NE | NE |
| Vitaceae | *Cayratia trifolia* (L.) Domin | Galing-galing, Lakum | Shrub | LF, DV | NE | NE |
| | *Cissus hastata* Miq. | Akar Asam Riang, Akar Kerayong | Shrub | LF | NE | NE |
| Ximeniaceae | *Ximenia americana* L. | Bedara laut | Tree | BV | LC | NE |
| **MONOCOTYLEDONS** | | | | | | |
| Aizoaceae | *Sesuvium portulacastrum* (L.) L. | Gelang Laut, Gelang Pasir, Saruni Air | Terrestrial herb | MSF, CDF | NE | LC |
| Amaryllidaceae | *Crinum asiaticum* L. | Bakong, Tembaga Suasa | Terrestrial herb | RV, LF, FSF | NE | NE |
| Araceae | *Cryptocoryne ciliata* (Roxb.) Schott. | Keladi Payau | Aquatic herb | MSF | LC | NE |
| | *Cryptocoryne cordata* Griff. | - | Aquatic herb | RV | LC | NE |
| | *Cryptocoryne griffithii* Schott. | - | Aquatic herb | PSF | NE | NE |
| | *Lasia spinosa* (L.) Thw. | Geli-geli | Terrestrial herb | PSF | LC | NE |
| | *Scindapsus hederaceus* (Zoll. & Moritizi) Miq. | Akar Lebang Aleh | Climbing herb | PSF | NE | NE |
| Arecaceae | *Calamus erinaceus* (Becc.) J.Dransf. | Rotan Bakau | Palm | MSF | NE | NE |
| | *Licuala spinosa* Wurmb. | Palas, Palas Duri | Palm | MSF | NE | NE |
| | *Nypa fruticans* Wurmb. | Nipah | Palm | MSF | LC | NE |
| | *Oncosperma tigillarium* (Jack) Ridl. | Nibong, Ibas, Linau, Nibung, Nibong | Palm | MSF | NE | NE |
| | *Phoenix paludosa* Roxb. | Kedangsa, Dangsa | Palm | MSF | NT | NE |
| Asparagaceae | *Dracaena porteri* Baker | Jarum-jarum | Shrub | LF, FSF | NE | NE |
| Commelinaceae | *Cyanotis cristata* D.Don | Petungan | Terrestrial herb | BV | LC | NE |
| Cymodoceaceae | *Halodule pinifolia* (Miki) Hartog | - | Aquatic herb | FSF | LC | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Cyperaceae | *Bulbostylis barbata* (Rottb.) C.B.Clarke | Rumput rusiga | Terrestrial herb | FSF | NE | NE |
| | *Cyperus distans* L.f. | Rumput rusiga | Aquatic herb | RV,PSF | LC | NE |
| | *Cyperus digitatus* Roxb. | Rumput rusiga | Aquatic herb | PSF | LC | NE |
| | *Cyperus javanicus* Houtt. | Rumput rusiga | Terrestrial herb | MSF | NE | NE |
| | *Cyperus rotundus* L. | Rumput rusiga | Terrestrial herb | RV,BV | LC | NE |
| | *Cyperus stoloniferus* Retz. | Rumput rusiga | Terrestrial herb | BV | LC | NE |
| | *Eleocharis geniculata* (L.) Roem. & Schult. | Rumput rusiga | Terrestrial herb | RV | LC | NE |
| | *Eleocharis ochrostachys* Steud. | Rumput rusiga | Terrestrial herb | PSF | LC | NE |
| | *Eleocharis retroflexa* (Poir.) Urb. | Rumput rusiga | Terrestrial herb | RV | LC | NE |
| | *Fimbristylis acuminata* Vahl | Rumput rusiga | Terrestrial herb | RV | LC | NE |
| | *Fimbristylis cymosa* R.Br. | Rumput rusiga | Terrestrial herb | MSF | LC | NE |
| | *Fimbristylis pauciflora* R.Br. | Rumput rusiga | Terrestrial herb | LF | NE | NE |
| | *Fuirena umbellata* Rottb. | Rumput rusiga | Terrestrial herb | RV | LC | NE |
| | *Lepironia articulata* (Retz.) Domin | Kercut/Kerchut | Aquatic herb | FSF | NE | NE |
| | *Rhynchospora brownii* Roem. & Schult. | Rumput rusiga | Terrestrial herb | HV, BRIS | NE | NE |
| | *Remirea maritima* Aubl. | Rumput rusiga | Terrestrial herb | CDF,BV | NE | NE |
| | *Scleria levis* Retz. | Rumput rusiga | Terrestrial herb | FSF,DV | NE | NE |
| | *Scleria poaeformis* Retz. | Rumput rusiga | Terrestrial herb | FSH,DV | NE | NE |
| Eriocaulaceae | *Eriocaulon truncatum* Buch.-Ham. ex Mart. | - | Aquatic herb | DV | LC | NE |
| | *Eriocaulon willdenovianum* Moldenke | - | Aquatic herb | DV | NE | NE |
| Flagellariaceae | *Flagellaria indica* L. | Rotan Dini, Rotan Tikus, Rotan Kera | Climbing shrub | MSF, FSF | NE | NE |
| Hanguanaceae | *Hanguana malayana* (Jack) Merr. | Bakong | Aquatic herb | RV, FSF | LC | NE |
| Hydrocharitaceae | *Blyxa aubertii* Rich. | - | Aquatic herb | FSF | LC | NE |
| | *Halophila beccarii* Aschers. | - | Aquatic herb | MSF | VU | NE |
| | *Halophila minor* (Zollinger) den Hartog | - | Aquatic herb | BV | LC | NE |
| | *Halophila ovalis* (R.Brown) J.D.Hooker | - | Aquatic herb | BV | LC | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Orchidaceae | *Acriopsis liliifolia* (J. Koenig) Ormerod | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Appendicula cornuta* Blume | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Appendicula uncata* Ridl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Ania penangiana* (Hook.f.) Summerh. | Orkid | Terrestrial herb | BRIS | NE | NE |
| | *Arachnis flos-aeris* (L.) Rchb.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Arachnis hookeriana* (Rchb.f.) Rchb.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bromheadia finlaysoniana* (Lindl.) Miq | Orkid | Terrestrial herb | BRIS | LC | NE |
| | *Bulbophyllum acuminatum* (Ridl.) Ridl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum apodum* Hook.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum clandestinum* Lindl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum fenestratum* J.J.Sim | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum macranthum* Lindl. | Orkid | Epiphytic herb | BRIS | LC | NE |
| | *Bulbophyllum patens* King ex Hook.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum planibulbe* (Ridl.) Ridl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum purpurascens* Teijsm. & Binn. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum trigonopus* (Rchd.f) P.T.Ong | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Bulbophyllum vaginatum* (Lindl.) Rchb.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Callostylis pulchella* (Lindl.) S.C.Chen & Z.H.Tsi | Orkid | Epiphytic herb | HV, BRIS | NE | NE |
| | *Ceratostylis subulata* Blume | Orkid | Epiphytic herb | BRIS | LC | NE |
| | *Claderia viridiflora* Hook.f. | Orkid | Terrestrial herb | BRIS | NE | NE |
| | *Cleisostoma teretifolium* Teijsm. & Binn. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Coelogyne foerstermannii* Rchb.f. | Orkid | Epiphytic herb | HV, BRIS | LC | NE |
| | *Cymbidium finlaysonianum* Lindl. | Orkid | Epiphytic herb | HV, BRIS | NE | NE |
| | *Cymbidium rectum* Ridl. | Orkid | Epiphytic herb | HV, BRIS | NE | NE |
| | *Dendrobium acerosum* Lindl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrobium aloifolium* (Blume) Rchb.f. | Orkid | Epiphytic herb | BRIS | LC | NE |

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|---|---|---|---|---|---|---|
| Orchidaceae | *Dendrobium angustifolium* (Blume) Lindl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrobium clavator* Ridl. | Orkid Merpati | Epiphytic herb | MSF, BRIS | NE | NE |
| | *Dendrobium crumenatum* Sw. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrobium lamellatum* (Blume) Lindl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrobium leonis* (Lindl.) Rchb.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrobium pachyphyllum* (Kuntze) Bakh.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrobium rhodostele* Ridl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrobium secundum* (Blume) Lindl. ex Wall. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Dendrolirium lasiopetalum* (Willd.) S.C.Chen & J.J.Wood | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Eulophia graminea* Lindl. | Orkid | Terrestrial herb | BRIS | NE | NE |
| | *Grammatophyllum speciosum* Blume | Orkid Harimau | Epiphytic/ Terrestrial herb | BRIS | NE | NE |
| | *Liparis ferruginea* Lindl. | Orkid | Terrestrial herb | FWF | NE | NE |
| | *Luisia jonesii* J.J.Sm. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Oberonia padangensis* Schltr. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Papilionanthe hookeriana* (Rchb.f.) Schltr. | Orkid | Epiphytic herb | FWF | NE | NE |
| | *Phalaenopsis pulcherrima* (Lindl.) J.J.Sm. | Orkid | Terrestrial herb | HV, BRIS | NE | NE |
| | *Pinalia atrovinosa* (Carr) Schuit., Y.P.Ng & H.A.Pedersen | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Pinalia floribunda* (Lindl.) Kuntze | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Pinalia tenuiflora* (Ridl.) J.J.Wood | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Plocoglottis lowii* Rchb.f. | Orkid | Terrestrial herb | BRIS | NE | NE |
| | *Polystachya concreta* (Jacq.) Garay & H.R.Sweet | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Renanthera elongata* (Blume) Lindl. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Strongyleria pannea*(Lindl.) Schuit., Y.P.Ng & H.A.Pedersen | Orkid | Terrestrial herb | BRIS | NE | NE |
| | *Taeniophyllum pusillum* (Willd.) Seidenf. & Ormerod | Orkid hantu | Epiphytic herb | MSF,BRIS | NE | NE |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Orchidaceae | *Thrixspermum amplexicaule* (Blume) Rchb.f. | Orkid | Epiphytic herb | FSF | NE | NE |
| | *Thrixspermum calceolus* (Lindl.) Rchb.f. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Thrixspermum centipeda* Lour. | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Thrixspermum scopa* (Rchb.f. ex Hook.f.) Holttum | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Thrixspermum trichoglottis* (Hook.f.) Kuntze | Orkid | Epiphytic herb | BRIS | NE | NE |
| | *Vanilla griffithii* Rchb.f. | Telinga Kerbau | Terrestrial/ Epiphytic herb | BRIS | NE | NE |
| Pandanaceae | *Pandanus atrocarpus* Griff. | Mengkuang Paya | Palm-like | LF | NE | NE |
| | *Pandanus helicopus* Kurz ex Miq. | Mengkuang Paya, Rasau | Palm-like | LF | NE | NE |
| | *Pandanus tectorius* Parkinson | Mengkuang Laut, Pandan Duri, Pandan Laut | Palm-like | MSF | LC | NE |
| | *Pandanus yvanii* Solms. | Mengkuang Paya | Palm-like | LF | NE | NE |
| Philydraceae | *Philydrum lanuginosum* Banks & Sol. ex Gaertn. | Rumput Kipas | Terrestrial herb | FWS | NE | NE |
| Poaceae | *Chloris barbata* Sw. | Rumput Jari Kembong | Terrestrial herb | CDF,BV | NE | NE |
| | *Chrysopogon aciculatus* (Retz.) Trin. | Kemuncup | Terrestrial herb | CDF,BV | NE | NE |
| | *Chrysopogon serrulatus* Trin. | Kemuncup Besar | Terrestrial herb | CDF, BV | NE | NE |
| | *Cynodon dactylon* (L.) Pers. | Rumput Minyak | Terrestrial herb | BV, DV | NE | NE |
| | *Eleusine indica* (L.) Gaertn. | Sambau | Terrestrial herb | DV | LC | NE |
| | *Eriachne pallescens* R.Br. | - | Terrestrial herb | BV, DV | NE | NE |
| | *Imperata cylindrica* (L.) P.Beauv. | Lalang | Terrestrial herb | BV | LC | NE |
| | *Ischaemum muticum* L. | Rumput Tembaga Jantan, Rumput Terutus Tembaga | Terrestrial herb | BV | LC | NE |
| | *Leersia hexandra* Sw. | - | Terrestrial herb | FSF | LC | NE |
| | *Paspalum orbiculare* G.Forst. | - | Terrestrial herb | FSF | NE | NE |
| | *Sacciolepis indica* (L.) Chase | - | Terrestrial herb | CDF,FSF | DD | NE |
| | *Zoysia matrella* (L.) Merr. | - | Terrestrial herb | BV | NE | NE |
| Restionaceae | *Dapsilanthus disjunctus* (Mast.) B.G.Briggs – & L.A.S.Johnson | Terrestrial herb | BV | NE | NE | |

| Family | Species | Local Name | Life Form | Habitat | IUCN Status | Malaysia Red List/ MyBIS |
|---|---|---|---|---|---|---|
| Xyridaceae | *Xyris complanata* R.Br. | - | Terrestrial herb | RV | LC | NE |
| | *Xyris pauciflora* Willd. | - | Terrestrial herb | RV | LC | NE |
| Zingiberaceae | *Alpinia aquatica* (Retz.) Roscoe | Munkanang | Terrestrial herb | FSF, RV | NE | NE |
| | *Alpinia conchigera* Griff. | Lengkuas Ranting, Lengkuas Geting, Lengkuas Kecil, Lengkuas Padi | Terrestrial herb | FSF, DV | NE | NE |
| | *Alpinia galanga* (L.) Willd. | Lengkuas | Terrestrial herb | LF | NE | NE |
| | *Alpinia javanica* Blume | Lengkuas Hutan | Terrestrial herb | LF | LC | NE |
| | *Alpinia oxymitra* K.Schum. | - | Terrestrial herb | LF | NE | NE |

PhytoKeys 160: 45–97 (2020)
doi: 10.3897/phytokeys.160.54193
http://phytokeys.pensoft.net

REVIEW ARTICLE

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# Continental diatom biodiversity discovery and description in China: 1848 through 2019

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Academic editor: Kalina Manoylov | Received 12 May 2020 | Accepted 29 July 2020 | Published 8 September 2020

**Citation:** Kociolek JP, You Q, Liu Q, Liu Y, Wang Q (2020) Continental diatom biodiversity discovery and description in China: 1848 through 2019. PhytoKeys 160: 45–97. https://doi.org/10.3897/phytokeys.160.54193

## Abstract

In this paper we inventory the continental diatom taxa described from inland waters in China, from the first species descriptions dating back to 1848 through 2019. China's geography and hydrography are complex, including the world's highest mountains, many large rivers, salty lakes, and large karst regions. From this area, a total of 1128 taxa have been described from China over this time period. We examine the number of taxa described in ca. 20-year intervals and note the periods of time of no to few descriptions, versus time intervals with many taxon descriptions. Early on, taxon descriptions of freshwater diatoms from China were done by mostly by Europeans working alone, and the time frame of 1948 to 1967 had few descriptions, as a devasting famine and the cultural revolution impacted scientific work and productivity. B.V. Skvortzov produced a large number of taxon descriptions, during his time in residence in Harbin, later while in Sao Paulo, Brazil, and even posthumously. More recently, a wide range of labs and collaborations across China, and with a diverse array of international partners, is ushering in a new, robust era of research on the biodiversity of continental diatoms. A few areas of research and work for the future are discussed.

## Keywords

new taxa, diatoms, Bacillariophyta, Skvortzov, China, continental

## Introduction

Asia has received considerable attention in the context of biodiversity discovery, biogeography and resolving the evolutionary history of a variety of lineages (Gower et al. 2012). It is an area harboring many endemic species and broader lineages (López-Pujol et al. 2011; Lu et al. 2018), relicts (Wu et al. 2007; López-Pujol and Ren 2009; Li et al. 2012a) as well as extinct taxa (Fu et al. 2019; Proust et al. 2020; Zhang 2020). Many diverse lineages have originated, radiated and gone extinct in China. This is true for many groups of organisms, including continental diatoms (see Skvortzov 1937; Hustedt 1938a, b, 1939; Williams 2004; Williams and Reid 2006; Kulikovskiy et al. 2012, 2015; Hamsher et al. 2014; Kociolek 2019).

Within China, there has been a long history and much recent attention on the description of many new species and even genera from continental ecosystems across the country. Interest in continental diatoms of China extends beyond biodiversity discovery to a rich array of work related to water quality and bioassessment (e.g. Ouyang et al. 2015), impacts of eutrophication and the creation of dams (Wang and Zhang 2004; Shen et al. 2018), paleoenvironmental reconstructions (Rioual and Wang 2009) and the development of many products with diatoms (Zhang et al. 2012; Wang and Seibert 2017; Zhang 2019).

The work on biodiversity discovery, as well as ecological work and more applied studies, depends on a working knowledge of the flora that has already been documented. We have compiled and present here a listing of the continental diatoms described from China to provide these descriptive and practical projects with a historical context and a baseline against future work can be compared. This compilation of new taxa described from China, and the publications in which they were presented, can also help interpret the history and development of diatom studies in China, from the middle of the 19$^{th}$ century to the present.

## Methods

In our work developing this compilation of names of the continental diatoms described from China, we used the current geo-political circumscription of the country recognized by the United Nations. Our definition of "continental" refers to a variety of inland waters bodies, including freshwaters as well as those with high conductivity and, to some extent, 'salty' waters. But we have excluded taxa described from estuaries and marine localities from our review.

The bases of this compilation are the major resources for diatom nomenclature, including Catalogue of Diatom Names (Fourtanier and Kociolek 2011), DiatomBase (Kociolek et al. 2020) and AlgaeBase (Guiry and Guiry 2020). In addition, we reviewed several of the compilations of diatoms of China ("*Flora Algarum Sinicarum Aquae Dulcis*") and some primary literature that escaped the notice of these comprehensive works and summative projects. An important reference for this work is Jin

(1951), in which the knowledge of diatoms reported from China from 1848 to 1946, noting over 1000 taxa had been reported from marine and freshwater ecosystems, is summarized. The paper lists the taxa described from China (mostly by Skvortzov up to 1946). Although Jin (1951) did not document most of the other descriptions by European authors, both prior to and concurrent with Skvortzov, and his list obviously does not include post-1946 names, it is a great (but under cited) reference from which to develop a list of diatoms from China. The Skvortzov names were checked against the check list of his taxa compiled by Gololobova (2012). All of the names documented in this work have been included in DiatomBase.

## Results

### Continental diatoms described from China: An overview

In the 170-year history of continental diatom discovery in China, 1128 taxa have been described at the level of species and below (Table 1). This was not a smooth, equal accumulation of species over time, and if we examine the overall time period in groups of 20-year intervals, we can see there were times when significant numbers of taxa were described. For example, the time interval of 1928 to 1947 there were 355 taxa described in 16 publications, and between 1968 and 1987, 189 taxa were described in only 13 publications. In both instances, most of the publications were by a single author (See Appendices 1 and 2). On the other hand, in the more recent period of 2000 to 2019, the highest number of taxa were described (421), and published in 99 separate publications. Many of these papers were multi-authored. Periods of low publication of new species can be found in the earliest periods (1848–1887) and in the period 1948–1967 (Fig. 1).

In the next sections, we break down the work of continental diatom discovery in China into two periods, the initial period (1848–1999) and more recent period of continental diatom discovery (2000–2019). We examine the changes in approach and productivity during these time periods and compile a list of the taxa described and the references in which they were published.

### The initial period: 1848–1999

Studies on the continental diatoms of China date back to the mid 1800's, to the work of Ehrenberg. From these initial works through ¾ of the 20$^{th}$ century, there were many studies that documented continental diatom taxa in China, with a few genera and many species and subspecific taxa being proposed. The majority of taxa described was at the subspecific level. In Appendix 1 we document the new genera, species and subspecific continental diatoms described from China in this time period. This list, based on more than 50 publications only, shows that there were 2 genera described from continentals of China (*Amphiraphia* Chen and Zhu 1983 and *Porosularia* Skvortzov

**Table 1.** Number of taxa described, Cumulative number of described taxa and number of publications in which new taxa were described from freshwaters in China, 1848–2019.

| | Number of Taxa | Cumulative | Publications |
|---|---|---|---|
| 1848–1867 | 9 | 9 | 2 |
| 1868–1887 | 0 | 9 | 0 |
| 1888–1907 | 28 | 37 | 1 |
| 1908–1927 | 57 | 94 | 2 |
| 1928–1947 | 355 | 449 | 16 |
| 1948–1967 | 8 | 457 | 2 |
| 1968–1987 | 189 | 646 | 13 |
| 1988–1999 | 61 | 707 | 17 |
| 2000–2019 | 421 | 1128 | 99 |

1976b). Neither of these genera have been reported since they were first described, and neither of these names are in use today.

Table 1 and Appendix 1 show that from 1848 until 1999, a total of 707 taxa were described from continental in China. Of these, 218 were recognized as separate species, while 489 were described as varieties and forms. These taxa were included across 48 genera. Genera with the most taxa described include *Pinnularia* (138), *Navicula sensu lato* (98), *Cymbella sensu lato* (56) and *Nitzschia* (43) and *Gomphonema* (39).

The data for this period were organized into 20-year intervals (except the last period) and show some interesting trends. The first works in which new taxa were described were penned by Europeans working alone. This included Ehrenberg being the first in 1848 and then again in 1854, but after that more than 50 years went by before another publication that included a new species described was produced. In 1906 Mereschkowsky studies diatoms from Tibet, and in 1922 Hustedt worked on diatoms from Tibet and the northwestern part of China. Starting in the late 1920's, through the 1940's, the description of continental diatom taxa was dominated by Boris V. Skvortzov. Williams et al. (2016) have provided insights into the life and work of Skvortzov, and Gololobova (2012) has created a checklist of the taxa described by him. Unlike his predecessors who described continental diatoms from China, Skvortzov actually lived and worked in China (though he studied from many parts of Asia, from the Philippines, Russia and to India, and further afield, and received samples from many individuals). His base was in Harbin, in Heilongjiang Province, in the northeastern part of the country. Thus, while species he described were from many areas and diverse ecosystems across China, many of the taxa described were from the northeastern part of the country. Skvortzov trained students in Harbin, and later work on diatom taxonomy in China has been carried out by three generations of scientists who can trace their academic lineages back to him. During the same time period as Skvortzov was describing many taxa, some Europeans also contributed to our knowledge of new continental diatoms, such as Skuja (1937) and Voigt (1942a, b).

In the period following Skvortzov's large work published in 1946, only one other publication appeared (in which 8 taxa were described), until another large work on the continental diatoms of China was published by Skvortzov in 1976. From 1950 to 1976

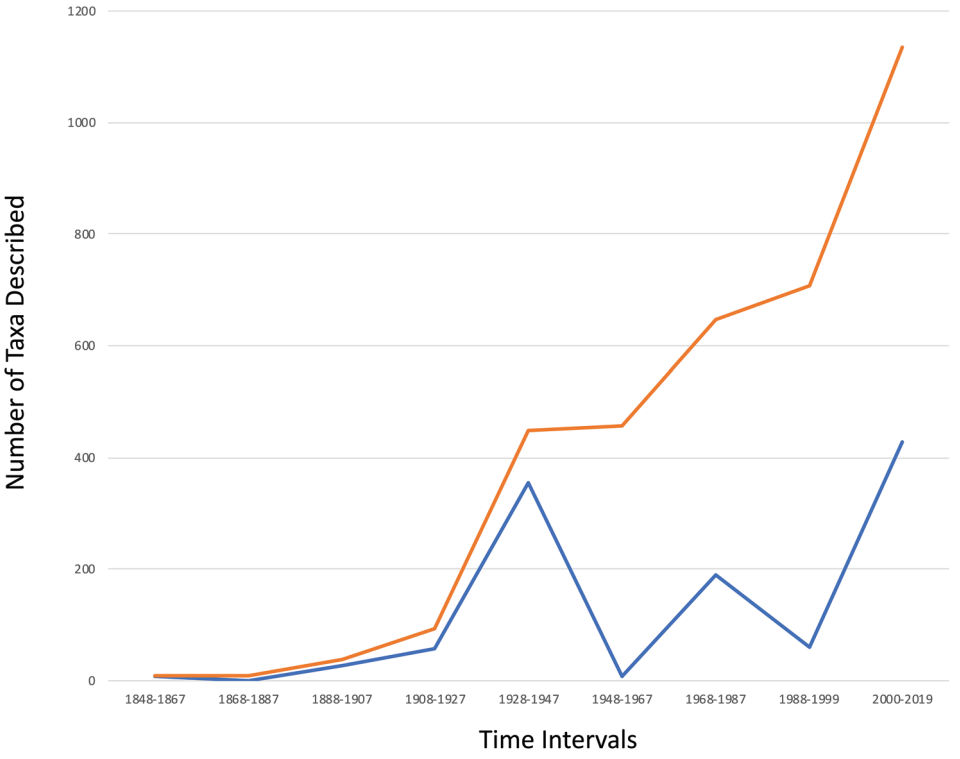


**Figure 1.** Number of species, varieties and forms described from freshwaters China, 1848–2019. The blue line represents the number of taxa described for each time interval. The orange line represents the cumulative number of taxa described over the entire period.

was a period of dramatic challenges and cultural change in China. The first occurred with the severe famine that hit the country in 1950, lasting three years. The impacts of that famine led to the deaths of tens of millions of people, and this had lasting impacts on society for many years afterwards. In addition, the Cultural Revolution, in part a reaction to the great famine, also had negative impacts on life in China, and those impacts on academics are well-documented. Thus, with the few publications produced in this time period within the narrow discipline of diatom taxonomy and biodiversity discovery, we can see the impacts of natural disasters, economic decline and political and cultural change on the output and continuation of scientific research and training.

Skvortzov left China during the cultural revolution, and ended up in Sao Paulo, Brazil. While there, he published two large works in which nearly 140 taxa were described from Chinese continental (Skvortzov 1976a, b). These were to be his last works on the topic of continental diatoms from China while he was alive. His collections have never been found (See Williams et al. 2016).

Despite his death, and the uncertainty regarding his collections, Skvortzov's legacy lives on with the works of his students, especially Professor Bao (who is currently in Harbin) and Professor Qi (who is currently in Guangzhou), both of whom are officially retired, as well as Professor Zhang, previously of Jinan University in Guangzhou (now deceased). All of these scientists ended up forming collaborations with scientists in the USA, with C.W. Reimer at the Academy of Natural Sciences of Philadelphia (who visited Harbin and hosted Bao, Qi and Zhang in Philadelphia) and E.F. Stoermer at the University of Michigan. Professor Qi visited Reimer at the Academy in Philadelphia while attending the International Diatom Symposium there in 1982 and stayed with Stoermer at his home in Ann Arbor, while on an extended trip to the USA in 1984. These connections yielded published collaborative works (Qi et al. 1984; Stoermer et al. 1986; Bao and Reimer 1992).

In the latter part of the 20th century, we see important floristic works being published on the diatoms from Tibet, Yunnan and other localities, and some emphasis on freshwater fossil diatoms by Chinese researchers. In these books and papers, a new generation of scientists had come on the scene, and there was the initiation of an important series focused on documenting the freshwater diatom flora of the country ("Flora Algarum Sinicarum Aquae Dulcis" Qi 1995; Qi and Li 2004; Li and Qi 2010; Shi 2004, 2013; Wang and You 2018).

## The recent period (2000–2019)

In the 20-year time period, from 2000 to 2019, a total of 421 taxa, consisting of 252 species and 169 subspecific taxa across 67 genera have been described from continental waters in China (Appendix 2; Table 2). In addition, 6 new genera have been described. The breadth of lineages represented in these works during this period is remarkable, since several groups of "centric" and "araphid" diatoms have been described, as well as taxa among the major raphid lineages (Eunotiales, Bacillariales, Naviculales, Cymbellales, Rhopalodioid and Surirellales) are all included. For example, new genera of centric diatoms include *Edtheriotia* and the new genus of araphid diatoms is represented by *Tibetiella*. Raphid genera are included in the Eunotiales (*Sinoperonia*), Naviculales (*Sichuaniella*, *Pseudofallacia*) and Cymbellales (*Gomphosinica*). New species can be found among the centrics (in the genera *Cyclotella*, *Edtheriotia*, *Urosolenia*, *Orthoseira*, and *Melosira*), araphids (*Fragilaria*, *Tabularia*, *Diatoma* and *Tetracyclus*) and across the raphid diatoms, including the Eunotiales (*Eunotia*), Bacillariales (*Simonsenia*, *Achnanthes*), Monoraphids (*Achnanthidium*, *Platessa*), Naviculoids (*Germainiella*, *Neidium*, *Pinnularia. Muelleria*), Cymbelloids (*Cymbella*, *Delicata*), Rhopalodioids (*Epithemia*) and Surirelloids (*Cymatopleura*, *Surirella*). Please note that *Achnanthes*, though monoraphid, has been shown to be more closely related to members of the Bacillariales (Bruder and Medlin 2008); the monoraphid condition has evolved several times in the raphid diatom lineage (Kociolek et al. 2019a). Genera with the most species described in this period include *Pinnularia* (76), *Gomphonema*, (57), *Cymbella* (36), *Neidium* (22), *Amphora* (23).

**Table 2.** Number of taxa described, cumulative number of taxa, and number of publications in which taxa were described of freshwater diatoms in China, 2000–2019.

| Year | Number of taxa described | Cumulative number of described taxa | Number of Publications |
|---|---|---|---|
| 2000 | 2 | 2 | 1 |
| 2001 | 0 | 2 | 0 |
| 2002 | 1 | 3 | 1 |
| 2003 | 8 | 11 | 3 |
| 2004 | 10 | 21 | 2 |
| 2005 | 1 | 22 | 1 |
| 2006 | 1 | 23 | 1 |
| 2007 | 1 | 24 | 1 |
| 2008 | 1 | 25 | 1 |
| 2009 | 4 | 29 | 3 |
| 2010 | 8 | 37 | 6 |
| 2011 | 1 | 38 | 1 |
| 2012 | 209 | 247 | 3 |
| 2013 | 28 | 275 | 7 |
| 2014 | 17 | 292 | 7 |
| 2015 | 14 | 306 | 9 |
| 2016 | 11 | 317 | 9 |
| 2017 | 36 | 353 | 13 |
| 2018 | 38 | 391 | 15 |
| 2019 | 30 | 421 | 15 |
| TOTAL | 421 | | 99 |

There is also great geographic breadth represented in these studies, with taxa being described in the northwestern portion of the country, Tibet and Yunnan, across the biodiverse regions of the karst belt extending from Yunnan to Guizhou, the central part of China, and from Hainan to the extreme Northeast.

Since 2000, there have been floristic studies that have yielded description of new taxa, such as Zhu and Chen's (2000) tome on the diatoms of Tibet, as well as revisionary work, such as Shi's (2004) study on gomphonemoid diatoms. While these were published in Chinese, the trend has been in more recent years for works to be published in English-language journals, such as Phytotaxa, Phycologia, Fottea, Cryptogamie: Algologie, Nova Hedwigia, and Diatom Research. Some research continues to be published in several Chinese-language journals as well.

In 2012, Kulikovskiy et al. included a paper offered by Gololobova and Kulikovskiy where they traced a manuscript submitted in the 1960's by Skvortzov to Dr. Proschkina-Lavrenko in Moscow for publication. but the paper was, for unknown reasons, never published. In this paper, which has been published in the 23rd volume of Iconographia Diatomologica, Skvortzov presents 445 taxa, that represent either new names, transfers or new taxon descriptions. This work includes taxa from India, China, Philippines, Japan, Korea, Australia and even Cuba. For the purposes of the current work, 208 of the taxa were newly described from China, and recorded for the year of publication (2012) even though the work was submitted 4 decades previously. These new taxon descriptions were not validly published (they lacked designation of type

specimens) but are included here since they represent the identification and publication of new taxa in China.

In total, since 2000, the 421 described taxa were included in nearly 100 published books and papers (Table 2), nearly twice the number of publications than was published in the preceding 150 years. In some of the recent studies, observations have verified the continued presence of endemics described in earlier works (e.g. *Gomphonema eminens* Skuja in Yunnan; Liu et al. 2020; several species of *Pinnularia* from the Great A'er Mountains; Liu et al. 2018; and species of centric diatoms from Yunnan), though the population sizes of these endemic taxa are reported to be declining (Li et al. 2012b).

The degree of collaboration between Chinese researchers within and between institutions, and the inclusion of students in these works, are both striking and a demonstration that this area of research will have a fruitful period of work ahead. Amongst the senior and corresponding authors of these papers we see the impact of Skvortzov, whose academic grandchildren and great-grandchildren working on freshwater diatoms are now in Shanghai, Taiyuan, and Harbin. There are also well-established labs in Beijing, Shanghai, Kunming, Nanjing, and Jishou, whose focus may include the study of ecological and palaeoecological interpretation, as well as biodiversity discovery and description. Collaborations with non-Chinese scientists is also hallmark of this most recent era, with partners joining in these works from the U.K., Spain, Macedonia, Germany, Luxembourg, Belgium, Canada, and the USA.

## Discussion: A look ahead

While there has been a tremendous amount of work done to document the freshwater diatom flora of China, there are still many areas across the country that await initial or additional in-depth study. Some of these areas include, Yunnan Province, the vast karst region across Yunnan/Guangxi/Guizhou provinces, the subtropical southern part of the country, Xinjiang Autonomous Region, and Tibet, to name a few. In these regions are the two biodiversity hotspots the are fully in China (Myers et al. 2000; CEPF 2019). Also, the two longest rivers in China, The Yangtze River and Yellow River, have had isolated studies, but not comprehensive analyses. There exist specialized habitats such as also high mountain ranges, waterfalls, and hot springs, to name a few, where more intensive studies are warranted.

Perhaps one of the most challenging projects, with the potential of having the least "impact" (in the way most universities or state labs would assess that notion), but the greatest impact on the discipline, would be the typification of the diatom taxa described by Skvortzov. With the location of his collection uncertain (several generations of curators have attempted to track the collection to universities and institutes in China, Russia, Brazil, and Scandanavia), it seems likely that the collection has been lost. The challenge would not only be the large number of taxa he described. There would be a huge challenge to find specimens to designate as neotypes for his taxa, or to designate illustrations of his as epitypes. If neotypification was chosen, it would present

many challenges, especially in situations where several varieties or forms were dissected from the same species, or for the large number of taxa described in his 1976 and 2012 papers, where the illustrations are of a quality that might not facilitate making positive identifications. It also appears that the collections of Chen and Zhu have been lost, and typification of their taxa will also be an important activity for taxonomists.

The loss of several important collections in China is not restricted to that country. Collections have been discarded by many universities and research institutes across the world. Currently, China does not have a national diatom collection. Such a repository might be useful in the future, as the significant, current activities of collection-building and biodiversity discovery and description, which appears to still be in a log growth phase (see Fig. 1). The fate of the collections that have been established and blossomed in a single generation in Shanghai, Harbin, Taiyuan, Beijing and other labs will always be tenuous. Having a national collection would potentially provide a repository for the country to serve future generations of scientists.

Although there is tremendous described diversity in the continental diatom flora of China, and it is likely that there is still much to do to achieve a more comprehensive knowledge of that flora, the number of strains of continental diatoms in GenBank traceable to a source in China is modest. In fact, this is all the more surprising since some groups of continental diatoms have a tremendous diversity in China, and some endemic genera in Asia have representatives in the Chinese flora (Kociolek 2019). Some of these groups include the Thalassiosiraceae and Cymbellales. In the latter group, the only endemic genera known for that lineage worldwide are from Asia and include species from China (e.g. Zhang et al. 2018). Workflows and resources will need to be developed so that the number of molecular sequences generated from Chinese taxa are commensurate with the diversity and unique nature of the flora.

## Acknowledgements

This paper is dedicated to Profs. Bao and Qi, for all of their hard work and support of students in the study of diatoms in China. This work was funded in part by the One-hundred Talent Program of Shanxi Province and the Shanxi '1331' Project. We appreciate the comments of the reviewers and editors, and communications with Dr. David Williams regarding nomenclature and typification.

## References

Bao W-M, Reimer CW (1992) New taxa of the diatoms from Changbaishan Mountain, China. Bulletin of Botanical Research 12(4): 357–361.

Bruder K, Medlin LK (2008) Morphological and molecular investigations of naviculoid diatoms. II. Selected genera and families. Diatom Research 23(2): 283–329. https://doi.org/10.1080/0269249X.2008.9705759

Cao Y, Yu P, You Q, Lowe RL, Williams DM, Wang Q-X, Kociolek JP (2018) A new species of *Tabularia* (Kützing) Williams & Round from Poyang Lake, Jiangxi Province, China, with a cladistic analysis of the genus and their relatives. Phytotaxa 373(3): 169–183. https://doi.org/10.11646/phytotaxa.373.3.1

CEPF [Critical Ecosystem Partnership Fund] (2019) The biodiversity hotspots. https://www.cepf.net/our-work/biodiversity

Chen J (1980) Shui Sheng Sheng Wu Hsueh Bao 7(2): 253–256. [Notes on some new species and variety of the genus *Melosira* (Bacillariophyta)]

Chen J (1987) A new variety of the *Cyclotella asterocostata* (Bacillariophyta). Shui Sheng Sheng Wu Hsueh Bao 11(4): 1.

Chen J, Zhu H (1983) Amphiraphisales, a new order of the pennatae, Bacillariophyta. Zhiwu Fenlei Xuebao 21(4): 449–457.

Chen J, Zhu H (1985) Studies on the freshwater centricae of China. Shui Sheng Sheng Wu Hsueh Bao 9(1): 80–83.

Cheng Y, Liu Y, Kociolek JP, You Q, Fan Y (2018) A new species of *Gomphosinica* (Bacillariophyta) from Lugu Lake, Yunnan Province, SW China. Phytotaxa 348(2): 118–124. https://doi.org/10.11646/phytotaxa.348.2.6

Ehrenberg CG (1848) Mittheilung über vor Kurzem vom dem Preufs. Seehandlungs Schiffe, der Adler, aus Canton mitgebrachte verkäufliche, chinesische Blumen-Cultur-Erde, wiefs deren reiche Mischung mit mikroskopischen Organismen und verzeichniss 124 von ihm selbst beobachteten Arten chinesischer kleinster Lebensformen. Bericht über die zur Bekanntmachung geeigneten Verhandlungen der Königlich-Preussischen Akademie der Wissenschaften zu Berlin 1847: 476–485.

Ehrenberg CG (1854) Mikrogeologie. Einundvierzig Tafeln mit über viertausend grossentheils colorirten Figuren, Gezeichnet vom Verfasser. [Atlas]. Leopold Voss, Leipzig.

Fan Y, Shi Z, Bao W, Wang Q-X (2004) A New combination and Two varieties of Polystigmate *Gomphonema* (Gomphonemaceae Bacillariophyta) from Heilongjiang Province, China. Chinese Journal of Oceanology and Limnology 22(2): 198–200. https://doi.org/10.1007/BF02842593

Fourtanier E, Kociolek JP (2011) Catalogue of Diatom Names, California Academy of Sciences, On-line Version. http://research.calacademy.org/research/diatoms/names/index.asp

Fu D, Tong G, Dai T, Liu W, Yang Y, Zhang Y, Cui L, Li L, Yun H, Wu Y, Sun A, Liu C, Pei W, Gaines RR, Zhang X (2019) The Qingjiang biota-A Burgess Shale-typeee fossil Lagerstätte from the early Cambrian of South China. Science 363(6433): 1338–1342. https://doi.org/10.1126/science.aau8800

Gololobova MA (2012) Checklist of Boris V. Skvortsow's diatom taxa. Iconographia Diatomologica 23: 611–742.

Gong Z, Li Y (2011) *Cymbella fuxianensis* Li and Gong sp. nov. (Bacillariophyta) from Yunnan Plateau, China. Nova Hedwigia 92(3–4): 551–556. https://doi.org/10.1127/0029-5035/2011/0092-0551

Gong Z, Li Y (2012) *Gomphonema yaominae* sp. nov. Li, a new species of diatom (Bacillariophyta) from lakes near Yangtze River, China. Phytotaxa 54(1): 59–64. https://doi.org/10.11646/phytotaxa.54.1.6

Gong Z, Li Y, Metzeltin D, Lange-Bertalot H (2013) New species of *Cymbella* and *Placoneis* (Bacillariophyta) from late Pleistocene fossil, China. Phytotaxa 150(1): 29–40. https://doi.org/10.11646/phytotaxa.150.1.2

Gong Z, Metzeltin D, Li Y, Edlund M (2015) Three new species of *Navicula* (Bacillariophyta) from lakes in Yunnan Plateau (China). Phytotaxa 208(2): 135–146. https://doi.org/10.11646/phytotaxa.208.2.2

Gower D, Johnson K, Richardson J, Rosen B, Rüber L, Williams S (Eds) (2012) Biotic Evolution and Environmental Change in Southeast Asia. Systematics Association Special Volume. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511735882

Guiry MD, Guiry GM (2020) AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. https://www.algaebase.org

Guo Y-Q, Xie S-Q, Li J-S (1997) (A new species of the genus *Amphor* (Bacillariophyta).). Zhiwu Fenlei Xuebao 35(3): 273–274.

Hamsher SE, Graeff CL, Stepanek JG, Kociolek JP (2014) Variation in valve and girdle band morphology in freshwater *Denticula* (Bacillariophyceae) species: Implications for the systematic position of the genus including the description of *Tetralunata* gen. nov. (Epithemiaceae, Rhopalodiales). Plant Ecology and Evolution 147: 346–365. https://doi.org/10.5091/plecevo.2014.990

Hu Z, Li Y, Metzeltin D (2013) Three new species of Cymbella (Bacillariophyta) from high altitude lakes, China. Acta Botanica Croatica 72(2): 359–374. https://doi.org/10.2478/botcro-2013-0005

Huang C, Liu S, Chen Z (1998) Atlas of Limnetic Fossil Diatoms of China. China Ocean Press, Beijing. [in Chinese]

Hustedt F (1922) Bacillariales aus Innerasien. Gesammelt von Dr. Sven Hedin. In: Hedin S (Ed.) Southern Tibet, discoveries in former times compared with my own researches in 1906–1908. Lithographic Institute of the General Staff of the Swedish Army, Stockholm 6(3): 107–152. https://doi.org/10.5962/bhl.title.64226

Hustedt F (1938a) Systematische und ökologische Untersuchungen über die Diatomeen-Flora von Java, Bali und Sumatra nach dem Material der Deutschen Limnologischen Sunda-Expedition. Allgemeiner Teil. I. Übersicht über das Untersuchengsmaterial und Charakteristik der Diatomeen flora der einzelnen Gebiete. “Tropische Binnengewässer, Band VII. Archiv für Hydrobiologie (Supplement, 15): 638–790.

Hustedt F (1938b) Systematische und ökologische Untersuchungen über die Diatomeen-Flora von Java, Bali und Sumatra nach dem Material der Deutschen Limnologischen Sunda-Expedition. Allgemeiner Teil. II. Die Diatomeenflora der untersuchtn Gewässertypen. "Tropische Binnengewässer, Band VII". Archiv für Hydrobiologie. Supplement 16(1): 1–155.

Hustedt F (1939) Systematische und ökologische Untersuchungen über die Diatomeen-Flora von Java, Bali und Sumatra nach dem Material der Deutschen Limnologischen Sunda-Expedition. Allgemeiner Teil. III. Die ökologischen Faktoren und ihr Einfluß auf die Diatomeenflora. "Tropische Binnengewässer, Band VII". Archiv für Hydrobiologie. Supplement 16(1): 274–394.

Jao C (1964) Some fresh-water algae from southern Tibet. Oceanologia et Limnologia Sinica 6(2): 169–192.

Jao C, Zhu H, Lee Y (1974) The fresh-water algae from Mount Qomolangma district (in Tibet). Report of the Scientific Survey of Mount Qomolangma district, 1966–1968: 92–126.

Jiang Z, Liu Y, Kociolek JP, Fan Y (2018) One new *Gomphonema* (Bacillariophyta) species from Yunnan Province, China. Phytotaxa 349(3): 257–264. https://doi.org/10.11646/phytotaxa.349.3.6

Jin TG (1951) A list of Chinese diatoms, from 1847 to 1946. Amoy Fisheries Bulletin 1: 41–143.

Kociolek JP (2019) A worldwide listing and biogeography of freshwater diatom genera: A phylogenetic perspective. Diatom Research 33(4): 509–534. https://doi.org/10.1080/0269249X.2019.1574243

Kociolek JP, You Q-M, Wang Q-X, Liu Q (2015) Consideration of some interesting freshwater gomphonemoid diatoms from North America and China, and the description of *Gomphosinica* gen. nov. Nova Hedwigia. Beiheft 144: 175–198.

Kociolek JP, You Q-M, Stepanek J, Lowe RL, Wang Q-X (2016a) A new freshwater diatom genus, *Edtheriotia* gen. nov. of the Stephanodiscaceae Glezer & Makarova (Bacillariophyta) from south-central China. Phycological Research 64(4): 274–280. https://doi.org/10.1111/pre.12145

Kociolek JP, You Q-M, Stepanek J, Lowe RL, Wang Q-X (2016b) A new *Eunotia* C.G. Ehrenberg (Bacillariophyta: Bacillariohyceae: Eunotiales) species from karst formations of southern China. Phytotaxa 265: 285–293. https://doi.org/10.11646/phytotaxa.265.3.10

Kociolek JP, Ector L, Coste M (2018) Nomenclatural corrections and clarifications for names of diatoms (Bacillariophyta) in two volumes of Bibliotheca Diatomologica. Notulae algarum 77: 1–3.

Kociolek JP, Williams DM, Stepanek J, Liu Q, Liu Y, You Q-M, Karthick B, Kulikovskiy M (2019a) Rampant homoplasy and adaptive radiation in pennate diatoms. Plant Ecology and Evolution 152(2): 131–141. https://doi.org/10.5091/plecevo.2019.1612

Kociolek JP, You Q-M, Lou F, Yu P, Lowe RL, Wang Q-X (2019b) First report and new freshwater species of the genus *Germainiella* from China, based on collections from the Maolan Nature Reserve, Guizhou Province. Phytotaxa 393: 35–46. https://doi.org/10.11646/phytotaxa.393.1.3

Kociolek JP, Balasubramanian K, Blanco S, Coste M, Ector L, Liu Y, Kulikovskiy M, Lundholm N, Ludwig T, Potapova M, Rimet F, Sabbe K, Sala S, Sar E, Taylor J, Van de Vijver B, Wetzel CE, Williams DM, Witkowski A, Witkowski J (2020) DiatomBase. http://www.diatombase.org

Kulikovskiy MS, Lange-Bertalot H, Metzeltin D, Witkowski A (2012) Lake Baikal: Hotspot of endemic diatoms I. Iconographia Diatomologica 23: 7–608.

Kulikovskiy MS, Lange-Bertalot H, Kuznetsova I (2015) Lake Baikal: Hotspot of endemic diatoms II. Iconographia Diatomologica 26: 1–656.

Krammer K (2002) Cymbella. Diatoms of Europe. 3: 1–584.

Krammer K (2003) Cymbopleura, Delicata, Navicymbula, Gomphocymbellopsis, Afrocymbella. Diatoms of Europe. 4: 1–529.

Lei G, Liu Y, Kociolek JP, Fan Y (2014a) New *Gomphonema* (Bacillariophyta) species from Xingkai Lake, China. Phytotaxa 175: 249–255. https://doi.org/10.11646/phytotaxa.175.5.2

Lei G, Liu Y, Kociolek JP, Fan Y (2014b) Newly recorded species in *Pinnularia* (Bacillariophyta) from Xingkai Lake, China. Acta Hydrobiologia Sinica 38: 669–674.

Li JY (1982). Acta Botanica Sinica 24(5): 456–467. [Miocene diatom assemblage of Shanwang, Shandong Sheng]

Li JY (1984) Zhiwu Fenlei Xuebao 22(3): 231–236. [Some new species and varieties of the genus *Tetracyclus* Ralfs (Bacillariophyta)]

Li JY (1988) A new fossil (diatom) recorded and its significance. Bulletin of Botanical Research 8: 129–132.

Li YL (1999) Some new fossil species and varieties of the genus *Tetracyclus* Ralfs. Acta Geoscientica Sinica. 20: 439–446.

Li Y, Gong Z (2013) *Eucocconeis lichunhaii* Li, sp. nov. (Bacillariophyta) from high mountain lakes, China. Algological Studies 141(1): 29–36. https://doi.org/10.1127/1864-1318/2012/0002

Li JY, Qi YZ (2010) Flora Algarum Sinicarum Aquae Dulcis. Tomus XIV. Bacillariophyta. Naviculaceae (I). Science Press, Beijing, 177 pp.

Li N, Shi ZX, Lei AP (1999) New taxa of *Gomphonema* (Bacillariophyta) from Hubei. Shui Sheng Sheng Wu Hsueh Bao 23(2): 192–193.

Li YL, Shi ZX, Xie P, Rong KW (2003) New varieties of *Gomphonema* and *Cymbella* (Bacillariophyta) from Qinghai province. Shui Sheng Sheng Wu Hsueh Bao 27(2): 147–148.

Li YL, Gong ZJ, Xie P, Shen J (2005) New species and new records of fossil diatoms from the late Pleistocene of the Jianghan Plain, Hubei Province. Acta Micropalaeontologica Sinica 22(3): 304–310.

Li Y, Gong Z, Xie P, Shen J (2006) Distribution and morphology of two endemic gomphonemoid species, *Gomphonema kaznakowi* Mereschkowsky and *G. yangtzensis* Li, nov. sp. in China. Diatom Research 21(2): 313–324. https://doi.org/10.1080/0269249X.2006.9705672

Li YL, Gong ZJ, Xie P, Shen J (2007) New species and new records of fossile diatoms from China. Shui Sheng Sheng Wu Hsueh Bao 31(3): 319–324.

Li YL, Gong ZJ, Wang CC, Shen J (2010a) New species and new records of diatoms from Lake Fuxian, China. Journal of Systematics and Evolution 48(1): 65–72. https://doi.org/10.1111/j.1759-6831.2009.00059.x

Li Y, Kociolek JP, Metzeltin D (2010b) *Gomphonema sichuanensis* Li and Kociolek sp. nov. and *Gomphonema laojunshanensis* Li, Kociolek and Metzeltin sp. nov. from two high mountain lakes, China. Diatom Research 25(1): 87–98. https://doi.org/10.1080/0269249X.2010.9705831

Li Y, Metzeltin D, Gong Z (2010c) Two new species of *Sellaphora* (Bacillariophyta) from a deep oligotrophic plateau lake, Lake Fuxian in subtropical China. Chinese Journal of Oceanology and Limnology 28(6): 1160–1165. https://doi.org/10.1007/s00343-010-9028-z

Li YL, Williams DM, Metzeltin D, Kociolek JP (2010d) *Tibetiella pulchra* gen. nov. et sp. nov., a new freshwater epilithic diatom from River Nujiang in Tibet, China. Journal of Phycology 46(2): 325–330. https://doi.org/10.1111/j.1529-8817.2009.00776.x

Li JK, Nel A, Zhang XP, Fleeck G, Gao MX, Lin L, Zhou J (2012) A third species of the relict family Epiophlebiidae discovered in China (Odonta: Epiproctophora). Systematic Entomology 37(2): 408–412. https://doi.org/10.1111/j.1365-3113.2011.00610.x

Li YL, Gong ZJ, Shen J (2012) Effects of eutrophication and temperature on *Cyclotella rhomboideo-elliptica* Skuja, endemic diatom to China. Phycological Research 60(4): 288–296. https://doi.org/10.1111/j.1440-1835.2012.00659.x

Li YL, Metzeltin D, Gong ZJ (2013) Two new species of *Sellaphora* (Bacillariophyta) from a deep oligotrophic plateau lake, Lake Fuxian in subtropical China. Chinese Journal of Oceanology and Limnology 28(6): 1160–1165. https://doi.org/10.1007/s00343-010-9028-z

Li Y, You Q-M, Kociolek JP, Wang L-Q, Zhang W (2019) *Gomphosinica selincuoensis* sp. nov., a new gomphonemoid species (Bacillariophyceae) from North Tibet, China. Phytotaxa 423: 195–205. https://doi.org/10.11646/phytotaxa.423.3.8

Liao M-N, Li YL (2018) One new *Gomphonema* Ehrenberg (Bacillariophyta) species from a high mountain lake in Yunnan Province, China. Phytotaxa 361(1): 123–130. https://doi.org/10.11646/phytotaxa.361.1.11

Liu Y, Fu C, Wang Q-X, Stoermer EF (2010a) A new species, *Diatoma rupestris*, from the Great Xing'an Mountains, China. Diatom Research 25(2): 337–347. https://doi.org/10.1080/0269249X.2010.9705854

Liu Y, Fu C, Wang Q-X, Stoermer EF (2010b) Two new species of *Pinnularia* from Great Xing'an Mountains, China. Diatom Research 25(1): 99–109. https://doi.org/10.1080/0269249X.2010.9705832

Liu Y, Kociolek JP, Fan Y, Wang Q-X (2012) *Pseudofallacia* gen. nov., a new freshwater diatom (Bacillariophyceae) genus based on *Navicula occulta* Krasske. Phycologia 51(6): 620–626. https://doi.org/10.2216/11-098.1

Liu Y, Kociolek JP, Wang Q-X (2013) Six new species of *Gomphonema* Ehrenberg (Bacillariophyceae) from the Great Xing'an Mountains, Northeastern China. Cryptogamie. Algologie 34(4): 301–324. https://doi.org/10.7872/crya.v34.iss4.2013.301

Liu Q, Kociolek JP, Wang Q-X, Fu C (2014a) Valve morphology of three species of *Neidiomorpha* (Bacillariophyceae) from Zoigê Wetland, China, including description of *Neidiomorpha sichuaniana* nov. sp. Phytotaxa 166(2): 123–131. https://doi.org/10.11646/phytotaxa.166.2.3

Liu Y, Kociolek JP, Wang Q-X, Fan Y (2014a) A new species of *Neidium* (Bacillariophyceae) and a checklist of the genus from China. Diatom Research 29(2): 165–173. https://doi.org/10.1080/0269249X.2013.872192

Liu Q, Kociolek JP, Wang Q-X, Fu C (2014b) Two new *Prestauroneis* Bruder & Medlin (Bacillariophyceae) species from Zoigê Wetland, Sichuan Province, China, and comparison with Parlibellus E.J. Cox. Diatom Research 30(2): 133–139. https://doi.org/10.1080/0269249X.2014.988292

Liu Y, Kociolek JP, Wang Q-X, Fan Y (2014b) Two new species of monoraphid diatom (Bacillariophyceae) from South of China. Phytotaxa 188(1): 31–37. https://doi.org/10.11646/phytotaxa.188.1.4

Liu B, Blanco S, Huang B (2015a) Two new *Nitzschia* species (Bacillariophyceae) from China, possessing a canal-raphe-conopeum system. Phytotaxa 231(3): 260–270. https://doi.org/10.11646/phytotaxa.231.3.4

Liu B, Sterrenburg F, Huang B (2015b) *Gyrosigma xiamenense* sp. nov. (Bacillariophyta) from the middle intertidal zone, Xiamen Bay, southern China. Phytotaxa 222(4): 259. https://doi.org/10.11646/phytotaxa.222.4.3

Liu B, Williams DM, Huang B (2015c) *Gyrosigma rostratum* sp. nov. (Bacillariophyta) from the low intertidal zone, Xiamen Bay, southern China. Phytotaxa 203(3): 254–262. https://doi.org/10.11646/phytotaxa.203.3.4

Liu B, Blanco S, Long H, Xu J, Jiang X (2016) *Achnanthidium sinense* sp. nov. (Bacillariophyta) from the Wuling Mountains Area, China. Phytotaxa 284(3): 194. https://doi.org/10.11646/phytotaxa.284.3.4

Liu Y, Kociolek JP, Fan Y (2016) *Urosolenia* and *Acanthoceras* species from Hainan Province, China. Phytotaxa 244(2): 161. https://doi.org/10.11646/phytotaxa.244.2.4

Liu Q, Kociolek JP, Li B, You Q-M, Wang Q-X (2017) The diatom genus *Neidium* Pfitzer (Bacillariophyceae) from Zoige Wetland, China. Bibliotheca Diatomologica 63: 1–120.

Liu B, Williams DM, Blanco S, Jiang XY (2017a) Two new species of *Luticola* (Bacillariophyta) from the Wuling Mountains Area, China. Nova Hedwigia. Beiheft 146: 197–208. https://doi.org/10.1127/1438-9134/2017/197

Liu B, Williams DM, Ou Y (2017b) *Adlafia sinensis* sp. nov. (Bacillariophyceae) from the Wuling Mountains Area, China, with reference to the structure of its girdle bands. Phytotaxa 298(1): 43–54. https://doi.org/10.11646/phytotaxa.298.1.4

Liu B, Williams DM, Tan L (2017c) Three new species of *Ulnaria* (Bacillariophyta) from the Wuling Mountains Area, China. Phytotaxa 306(4): 241–258. https://doi.org/10.11646/phytotaxa.306.4.1

Liu Q, Yang L, Nan F, Feng J, Lv J, Kociolek JP, Xie S (2018a) A new diatom species of *Aneumastus* D. G. Mann & Stickle ((Bacillariophyta, Bacillariophyceae, Mastogloiales, Mastogloiaceae) from Tibet, China. Phytotaxa 373(3): 231–235. https://doi.org/10.11646/phytotaxa.373.3.6

Liu Y, Kociolek JP, Wang Q-X, Fan Y (2018b) The diatom genus *Pinnularia* from Great Xing'an Mountains, China. Bibliotheca Diatomologica 65: 1–298.

Liu B, Blanco S, Qing-Yan L (2018a) Ultrastructure of *Delicata sinensis* Krammer et Metzeltin and *D. williamsii* sp. nov. (Bacillariophyta) from China. Fottea 18(1): 30–36. https://doi.org/10.5507/fot.2017.009

Liu Y, Kociolek JP, Glushchenko A, Kulikovskiy M, Fan Y (2018b) A new genus of Eunotiales (Bacillariophyta, Bacillariophyceae: Peroniaceae), *Sinoperonia*, from Southeast Asia, exhibiting remarkable phenotypic plasticity with regard to the raphe system. Phycologia 57(2): 147–158. https://doi.org/10.2216/17-21.1

Liu B, Williams DM, Ector L (2018c) *Entomoneis triundulata* sp. nov. (Bacillariophyta), a New Freshwater Diatom Species from Dongting Lake, China. Cryptogamie. Algologie 39(2): 239–253. https://doi.org/10.7872/crya/v39.iss2.2018.239

Liu B, Williams DM, Liu Q (2018d) A new species of *Cymbella* (Cymbellaceae, Bacillariophyceae) from China, possessing valves with both uniseriate and biseriate striae. Phytotaxa 344(1): 39–46. https://doi.org/10.11646/phytotaxa.344.1.5

Liu B, Williams DM, Liu Q, Yang X (2019a) Three species of *Ulnaria* (Bacillariophyceae) from China, with reference to the valve central area and apices. Diatom Research 34(1): 49–65. https://doi.org/10.1080/0269249X.2019.1577761

Liu Q, Glushchenko A, Kulikovskiy M, Maltsev Y, Kociolek JP (2019a) New *Hannaea* Patrick (Fragilariaceae, Bacillariophyta) Species from Asia, with Comments on the Biogeography of the Genus. Cryptogamie. Algologie 40(5): 41–61. https://doi.org/10.5252/cryptogamie-algologie2019v40a5

Liu B, Williams DM, Blanco S, Liu ZX, Liu D (2019b) Three new species of *Ulnaria* (Kützing) Compere (Bacillariophyta) from China, with reference to the fine structure of their valvocopula. Cryptogamie. Algologie 40(11): 119–139. https://doi.org/10.5252/cryptogamie-algologie2019v40a11

Liu Q, Li J, Nan F, Feng J, Lv J, Xie S, Kociolek JP (2019b) New and interesting diatoms from Tibet: I. Description of a new species of *Clipeoparvus* Woodbridge et al. Diatom Research 34(1): 33–38. https://doi.org/10.1080/0269249X.2019.1578697

Liu B, Blanco S, Ector L, Liu ZX, Ai J (2019c) *Surirella wulingensis* sp. nov. and fine structure of *S. tientsinensis* Skvortzov (Bacillariophyceae) from China. Fottea 19(2): 151–162. https://doi.org/10.5507/fot.2019.006

Liu Y, Kociolek JP, Fan Y (2020) Valve ultrastructure of two species of the diatom genus *Gomphonema* Ehrenberg (Bacillariophyta) from Yunnan Province, China. Fottea 20(1): 25–35. https://doi.org/10.5507/fot.2019.012

Liu Q, Li B, Wang Q-X (2018) *Muelleria pseudogibbula*, a new species from a newly recorded genus (Bacillariophyceae) in China. Journal of Oceanology and Limnology 36: 556–558. https://doi.org/10.1007/s00343-018-6194-x

López-Pujol J, Ren MX (2009) China: A hot spot of relict plant taxa. In: Rescigno V, et al. (Eds) Biodiversity Hotspots. Nova Science Publishers, 1–20.

López-Pujol J, Zhang FM, Sun HQ, Ying TS, Ge S (2011) Mountains of southern China as "Plant Museums" and "Plant Cradles": Evolutionary and conservation insights. Mountain Research and Development 31(3): 261–269. https://doi.org/10.1659/MRD-JOURNAL-D-11-00058.1

Lowe RL, Kociolek JP, You Q-M, Wang Q-X, Stepanek J (2017) Diversity of the diatom genus *Humidophila* in karst areas of Guizhou, China. Phytotaxa 305: 269–284.

Lu L-M, Mao L-F, Yang T, Ye J-F, Liu B, Li H-L, Sun M, Miller JT, Mathews S, Hu H-H, Niu Y-T, Peng D-X, Chen Y-H, Smith SA, Chin M, Xiang K-L, Le C-T, Dang V-C, Lu A-M, Soltis PS, Soltis DE, Li J-H, Chen Z-D (2018) Evolutionary history of the angiosperm flora of China. Nature 554: 234–238. https://doi.org/10.1038/nature25485

Luo F, You Q-M, Yu P, Pang W, Wang Q (2019) *Eunotia* (Bacillariophyta) biodiversity from high altitude, freshwater habitats in the Mugecuo Scenic Area, Sichuan Province, China. Phytotaxa 394(2): 133–147. https://doi.org/10.11646/phytotaxa.394.2.2

Mereschkowsky C (1906) Diatomées du Tibet. Imperial Russkoe geograficheskoe obshchestvo. St. Petersburg, 40 pp.

Metzeltin D, Lange-Bertalot H, Nergui S (2009) Diatoms in Mongolia. In: Lange-Bertalot H (Ed.) Iconographia Diatomologica. Annotated Diatom Micrographs 20: 3–686.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GA, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403(6772): 853–858. https://doi.org/10.1038/35002501

Ouyang L, Pan Y, Huang C, Tang YJ, Xiao W (2015) Water quality assessment of benthic diatom communities for water quality in the subalpine karstic lakes of Jiuzhaigou, a world heritage site in China. Journal of Mountain Science 13. https://doi.org/10.1007/s11629-014-3392-7

Peng Y, Rioual P, Jin Z, Sterrenburg FAS (2016) *Gyrosigma peisonis* var. *major* var. nov., a new variety of *Gyrosigma peisonis* (Bacillariophyta) from Lake Qinghai, China. Phytotaxa 245(2): 119–128. https://doi.org/10.11646/phytotaxa.245.2.3

Peng Y, Rioual P, Williams DM, Zhang Z, Zhang F, Jin Z (2017) *Diatoma kalakulensis* sp. nov. – a new diatom (Bacillariophyceae) species from a high-altitude lake in the Pamir Mountains, Western China. Diatom Research 32(2): 175–184. https://doi.org/10.1080/0269249X.2017.1335239

Proust AW, Gao C, Varricchio DJ, Wu J, Zhang F (2020) A new microraptorine theropod from the Jehol biota and growth in early Dromaeosaurids. The Anatomical Record 303(4): 963–987. https://doi.org/10.1002/ar.24343

Qi Y (1995) Flora Algarum Sinicarum Aquae Dulcis. Tomus IV. Bacillariophyta. Centricae. Science Press, Beijing, 104 pp.

Qi YZ, Li JY (2004) Flora Algarum Sinicarum Aquae Dulcis. Tomus X. Bacillariophyta. Araphidales & Raphidionales. Science Press, Beijing, 161 pp.

Qi YZ, Yang JR (1985) New data on the early Pleistocene fossil diatoms from Miyi, Sichuan, China. Acta Micropalaeontologica Sinica 2: 283–288.

Qi YZ, Reimer CW, Mahoney RK (1984) Taxonomic studies of the genus *Hydrosera*. I. Comparative morphology of *H. triquetra* Wallich and *H. whampoensis* (Schwarz)Deby, with ecological remarks. In: Mann DG (Ed.) Proceedings of the 7th International Diatom Symposium. O. Koeltz, Koenigstein, 231–224.

Rioual P, Wang L (2009) Environmental and climatic changes inferred from lake deposits in China: A review of recent progress. PAGES News 17(3): 110–112. https://doi.org/10.22498/pages.17.3.110

Rioual P, Gao Q, Peng Y, Chu G (2013) *Stauroneis lacusvulcani* sp. nov. (Bacillariophyceae), a new diatom from volcanic lakes in northeastern China. Phytotaxa 148(1): 47–56. https://doi.org/10.11646/phytotaxa.148.1.3

Rioual P, Morales EA, Chu GQ, Han JT, Li D, Liu JQ, Liu Q, Mingram J, Ector L (2014) *Staurosira longwanensis* sp. nov., a new araphid diatom (Bacillariophyta) from Northeast China. Fottea 14(1): 91–100. https://doi.org/10.5507/fot.2014.007

Rioual P, Flower RJ, Chu G, Lu Y, Zhang Z, Zhu B, Yang X (2017a) Observations on a fragilarioid diatom found in inter-dune lakes of the Badain Jaran Desert (Inner Mongolia, China), with a discussion on the newly erected genus *Williamsella* Graeff, Kociolek & Rushforth. Phytotaxa 329(1): 28–50. https://doi.org/10.11646/phytotaxa.329.1.2

Rioual P, Jewson D, Liu Q, Chu G, Han J, Liu J (2017b) Morphology and ecology of a new centric diatom belonging to the *Cyclotella comta* (Ehrenberg) Kützing complex: *Lindavia khinganensis* sp. nov. from the Greater Khingan Range, Northeastern China. Cryptogamie. Algologie 38(4): 349–377. https://doi.org/10.7872/crya/v38.iss4.2017.349

Shen R, Ren H, Yu P, You Q-M, Pang W, Wang Q-X (2018) Benthic diatoms of the Ying River (Huaihe River Basin, China) and their application in water trophic status assessment. Water (Basel) 10(8): 1013. https://doi.org/10.3390/w10081013

Shi Z-X (1991) Acta Micropalaeontologica Sinica 8(4): 449–459. [New taxa of fossil diatoms from borehole 47 in the Jianghan Plain, Hubei]

Shi Z-X (2004) Flora Algarum Sinicarum Aquae Dulcis. Tomus XII. Bacillariophyta. Gomphonemaceae. Science Press, Beijing, 147 pp.

Shi Z-X (2013) Flora Algarum Sinicarum Aquae Dulcis. Tomus XVI. Bacillariophyta. Cymbellaceae. Science Press, Beijing, 217 pp.

Shi Z-X, Li N, Li YL (2003) New species of Gomphocymbella from Hubei Province, China. Shui Sheng Sheng Wu Hsueh Bao 27(4): 405–407.

Skuja H (1937) Algae. Symbolae Sinicae: botanische Ergebnisse der Expedition der Akademie der Wissenschaften in Wein nach Sudwest-China, 1914–1918. Wien. 1:1–105.

Skvortzov BV (1927) Diatoms from Tientsin North China. Le Journal de Botanique 65(772): 102–109.

Skvortzov BV (1928a) Diatoms from ponds of Peking. The Peking Society of Natural History Bulletin 3: 43–48.

Skvortzov BV (1928b) Diatoms of Khingan, North Manchuria, China. Philippine Journal of Science 35(1): 39–51.

Skvortzov BV (1928c) Ein Beitrag zur Bacillariaceen-Flora der Nordostlichen Mongolei. Hedwigia 68: 311–314.

Skvortzov BV (1929a) Alpine Diatoms from Fukien Province, South China. Philippine Journal of Science 41(1): 39–49.

Skvortzov BV (1929b) Freshwater Diatoms from Amoy, South China. The China Journal. Shanghai 2 (11)(1):40–44.

Skvortzov BV (1929c) A Contribution to the Algae, Primorsk District of Far East, U.S.S.R. Diatoms of Hanka Lake. Memoirs of the Southern Ussuri Branch of the State Russian Geographical Society. Vladivostok, 66 pp.

Skvortzov BV (1930) Diatoms from Dalai-Nor Lake, Eastern Mongolia. Philippine Journal of Science 41(1): 31–37.

Skvortzov BV (1937) Subaerial diatoms from Hangchow, Chekiang province, China. Bulletin of the Fan Memorial Institute of Biology (Botany) 7(6): 219–230.

Skvortzov BV (1938a) Subaerial diatoms from Pin-Chiang-Sheng Province, Manchoukuo. Philippine Journal of Science 65(3): 263–281.

Skvortzov BV (1938b) Diatoms from a mountain bog, Kaolingtze, Pinchiang-Sheng Province, Manchoukuo. Philippine Journal of Science 66(3): 343–362.

Skvortzov BV (1938c) Diatoms from Chengtu, Szechwan, Western China. Philippine Journal of Science 66(4): 479–496.

Skvortzov BV (1938d) Diatoms from Argun River, Hsing-An-Pei Province, Manchoukuo. Philippine Journal of Science 66(1): 43–72.

Skvortzov BV (1938e) Diatoms from a peaty bog in Lianchicho River Valley, Eastern Siberia. Philippine Journal of Science 66(2): 161–182.

Skvortzov BV (1946) Species novae et minus cognitae Algarum, Flagellatarum et Phycomicetarum Asiae, Africae, Ameriae et Japoniae nec non Ceylon anno 1931–1945, descripto et illustrato per tab. 1–18. Proceedings of the Harbin Society of Natural History and Ethnography, Harbin, 2: 1–34.

Skvortzov BV (1976a) Moss diatom flora from River Gan in the northern part or Great Khingan Mountains, China, with description of a new genera Porosularia gen. nov. from Northern and Southern China. (First Part). Quarterly Journal of the Taiwan Museum 29(1–2): 111–152.

Skvortzov BV (1976b) Moss diatoms flora from River Gan in the northern part of Great Khingan Mts, China. With descriptions of a new genera Porosularia gen. nov. from northern and southern China, The Second Part. Quarterly Journal of the Taiwan Museum 29(3–4): 397–439.

Skvortzov BV (2012) New and little known fresh- and brackish water diatoms chiefly from Eastern part of Asia and their geographical distribution with a map and 499 figures. Iconographia Diatomologica 23: 749–861.

Stachura-Suchoples K, Jahn R (2009) Middle Miocene record of *Pliocaenicus changbaiense* sp. nov. from Changbai (Jilin Province, China). Acta Botanica Croatica 68(2): 211–220.

Stoermer EF, Qi YZ, Ladewski TB (1986) A quantitative investigation of shape variation in *Didymosphenia* (Lyngb.). M. Schmidt. Phycologia 25(4): 494–502. https://doi.org/10.2216/i0031-8884-25-4-494.1

Voigt M (1942a) Notes sur quelques espèces chinoises du genre *Cymbella*. Musée Heude, Université l'Aurore, Changhai. Notes de Botanique Chinoise 5: 1–46.

Voigt M (1942b) Les Diatomées du parc de Koukaza dans la Concession Française de Changhi. Musée Heude, Université l'Aurore, Changhai. Notes de Botanique Chinoise 3: 1–126.

Wang J-W, Seibert M (2017) Prospects for commercial production of diatoms. Biotechnology for Biofuels 10(1): 16. https://doi.org/10.1186/s13068-017-0699-y

Wang Q-X, You Q-M (2018) Flora algarum sinicarum aquae dulcis. Tomus XXII. Bacillariophyta-Aulonoraphidinales. Science Press, Beijing.

Wang C, Zhang J (2004) Studies on DCCA of the attached diatom community in headwater streams of Fenhe Reservoir. Zhongguo Huanjing Kexue 24: 28–31.

Williams DM (2004) On diatom endemism and biogeography. *Tetracyclus* and Lake Baikal's endemic species. In: Poulin M (Ed.) Proceedings of the 17th International Diatom Symposium. Biopress, Ltd., Bristol, 433–459.

Williams DM, Li J (1990) Observations on the diatom genus *Tetracyclus* Ralfs (Bacillariophyta). III. Description of two new species from Chinese fossil deposits. British Phycological Journal 25(4): 335–338. https://doi.org/10.1080/00071619000650371

Williams DM, Reid G (2006) *Amphorotia* nov. gen., a new genus in the family Eunotiaceae (Bacillariophyceae), based on *Eunotia clevei* Grunow in Cleve et Grunow. Diatom Monographs 6: 1–153.

Williams DM, Gololobova M, Glebova M (2016) Boris Vasil'evich Skvortzov (1896–1980): Notes on his life, family and scientific studies. Diatom Research 31(3): 313–321. https://doi.org/10.1080/0269249X.2016.1211556

Wu Z, Sun H, Zhou Z, Peng H, Li D (2007) Origin and differentiation of endemism in the flora of China. Frontiers of Biology in China 2(2): 125–143. https://doi.org/10.1007/s11515-007-0020-8

Xie S-Q, Cai S-S (1981) Journal of the University of Shanxi 3: 14–32. [A contribution to inland water centric diatoms of Shanxi, Hebei, Inner Mongolia and Henan provinces]

Xie S-Q, Li T (1994) A new diatom species of salt lake from Shanxi Province. Zhiwu Fenlei Xuebao 32(3): 273–274.

Xie S-Q, Qi YZ (1984) Light, scanning and transmission electron microscopic studies on the morphology and taxonomy of *Cyclotella shanxiensis* sp. nov. In: Mann DG (Ed.) Proceedings of the Seventh International Diatom Symposium, Philadelphia, August 22–27, 1982. Koeltz Science Publishers, Koenigstein, 185–196.

Xie S-Q, Lin B, Cai S-S (1985) Zhiwu Fenlei Xuebao 23(6): 473–475. [Studies by means of LM and EM on a new species, *Cyclotella asterocostata* Lin, Xie et Cai]

Xu J-X, You Q-M, Kociolek JP, Wang Q-X (2017) Taxonomic studies of the centric diatom from the lake Changhai, Jiuhaigou Valley, China, including the description of a new species. Shui Sheng Sheng Wu Hsueh Bao 41: 1140–1148.

Yang JG (1990) New material of the diatoms from China. Bulletin of Botanical Research 10(4): 11–12.

Yang JG (1994) New materials of *Navicula* (Naviculaceae) from Anhui, China. Zhiwu Fenlei Xuebao 32(4): 378–379.

Yang J (1995) A new species of *Eunotia* (Bacillariophyta) from Anhui, China. Zhiwu Fenlei Xuebao 33(2): 206–207.

Yang J-R, Stoermer EF, Kociolek JP (1994) *Aulacoseira dianchiensis* sp. nov., a new fossil diatom from China. Diatom Research 9(1): 225–231. https://doi.org/10.1080/026924 9X.1994.9705298

Yang L, You Q-M, Kociolek JP, Wang L-Q, Zhang W (2019) *Gomphosinica selincuoensis* sp. nov., a new gomphonemoid species (Bacillariophyceae) from North Tibet, China. Phytotaxa 423: 195–205. https://doi.org/10.11646/phytotaxa.423.3.8

You Q-M, Liu Y, Wang Y, Wang Q-X (2008) *Synedra ulna* var. *repanda*, a new variety of *Synedra* (Bacillariophyta) from Xinjiang, China. Chinese Journal of Oceanology and Limnology 26(4): 419–420. https://doi.org/10.1007/s00343-008-0419-3

You Q-M, Liu Y, Wang Y, Wang Q-X (2009) Taxonomy and distribution of diatoms in the genera *Epithemia* and *Rhopalodia* from the Xinjiang Uygur Autonomous Region, China. Nova Hedwigia 89(3): 397–430. https://doi.org/10.1127/0029-5035/2009/0089-0397

You Q-M, Kociolek JP, Wang X-X (2013) New *Gomphoneis* Cleve (Bacillariophyceae) species from Xinjiang Province, China. Phytotaxa 103: 1–24. https://doi.org/10.11646/phytotaxa.103.1.1

You Q-M, Kociolek JP, Wang Q-X (2015a) The diatom genus *Hantzschia* (Bacillariophyta) in Xinjiang province, China. Phytotaxa 197(1): 1–14. https://doi.org/10.11646/phytotaxa.197.1.1

You Q-M, Wang Q-X, Kociolek JP (2015b) New *Gomphonema* Ehrenberg (Bacillariophyceae: Gomphonemataceae) species from Xinjiang Province, China. Diatom Research 30(1): 1–12. https://doi.org/10.1080/0269249X.2014.952783

You Q-M, Kociolek JP, Wang Q-X (2015c) Taxonomic studies of the diatom genus *Halamphora* (Bacillariophyceae) from the mountainous regions of southwest of China, including the description of two new species. Phytotaxa 205(2): 75–89. https://doi.org/10.11646/phytotaxa.205.2.1

You Q-M, Kociolek JP, Yu P, Cai M, Lowe RL, Wang Q-X (2016) A new species of *Simonsenia* from a karst landform, Maolan Nature Reserve, Guizhou Province, China. Diatom Research 31(3): 269–275. https://doi.org/10.1080/0269249X.2016.1227377

You Q-M, Kociolek JP, Cai M-J, Lowe RL, Liu Y, Wang Q-X (2017a) Morphology and ultrastructure of *Sellaphora constrictum* sp. nov. (Bacillariophyta), a new diatom from southern China. Phytotaxa 327(3): 261–268. https://doi.org/10.11646/phytotaxa.327.3.5

You Q-M, Kociolek JP, Cai M, Yu P, Wang Q-X (2017b) Two new *Cymatopleura* taxa (Bacillariophyta) from Xinjiang, China with slightly twisted frustules. Fottea 17(2): 291–300. https://doi.org/10.5507/fot.2017.014

You Q-M, Cao Y, Yu P, Kociolek JP, Zang L, Wu B, Lowe RL, Wang Q-X (2019a) Three new subaerial *Achnanthidium* (Bacillariophyta) species from a karst landform in the Guizhou Province, China. Fottea 19(2): 138–150. https://doi.org/10.5507/fot.2019.005

You Q-M, Yu P, Kociolek JP, Wang Y, Luo F, Lowe RL, Wang Q-X (2019b) A new species of *Achnanthes* (Bacillariophyceae) from a freshwater habitat in a karst landform from south-central China. Phycological Research 67(4): 303–310. https://doi.org/10.1111/pre.12381

Yu P, You Q-M, Kociolek JP, Lowe RL, Wang Q-X (2017) *Nupela major* sp. nov., a new diatom species from Maolan Nature Reserve, south-central China. Phytotaxa 311(3): 245–254. https://doi.org/10.11646/phytotaxa.311.3.4

Yu P, Kociolek JP, You Q-M, Wang Q-X (2019a) *Achnanthidium longissimum* sp. nov. (Bacillariophyta), a new diatom species from Jiuzhai Valley, Southwestern China. Diatom Research: 1–10. https://doi.org/10.1080/0269249X.2018.1545704

Yu P, You Q-M, Kociolek JP, Wang Q-X (2019b) Three new freshwater species of the genus *Achnanthidium* (Bacillariophyta, Achnanthidiaceae) from Taiping Lake, China. Fottea 19(1): 33–49. https://doi.org/10.5507/fot.2018.015

Yu P, You Q-M, Pang W, Cao Y, Wang Q-X (2019c) Five new Achnanthidiaceae species (Bacillariophyta) from Jiuzhai Valley, Sichuan Province, Southwestern China. Phytotaxa 405(3): 147–170. https://doi.org/10.11646/phytotaxa.405.3.5

Zhang YX (2019) Current Diatom Research in China. In: Seckbach J, Gordon R (Eds) Diatoms: Fundamentals and Applications. Scrivener Publishing, Hoboken, NJ, 43–98. https://doi.org/10.1002/9781119370741.ch4

Zhang ZA, Qi YZ (1994) Some new taxa and records of the order Araphidinaies from China. Journal of Jinan University 15(1): 125–129. [Natural Science]

Zhang D, Wang Y, Cai J, Pan JF, Jiang XG, Jiang YG (2012) Bio-manufacturing technology based on diatom micro- and nanostructure. Chinese Science Bulletin 57(30): 3836–3849. https://doi.org/10.1007/s11434-012-5410-x

Zhang W, Li YL, Kociolek JP, Zhang RL, Wang L-Q (2015) *Oricymba tianmuensis* sp. nov., a new cymbelloid species (Bacillariophyceae) from Tianmu Mountain in Zhejiang Province, China. Phytotaxa 236(3): 257. https://doi.org/10.11646/phytotaxa.236.3.6

Zhang W, Pereira AC, Kociolek JP, Liu C, Xu X, Wang L (2016) *Pinnularia wuyiensis* sp. nov., a new diatom (Naviculales, Bacillariophyceae) from the north region of Wuyi Mountains, Jiangxi Province, China. Phytotaxa 267(2): 121–128. https://doi.org/10.11646/phytotaxa.267.2.4

Zhang W, Wang L-Q, Kociolek JP, Zhang R-L (2016a) *Oricymba xianjuensis* sp. nov., a new freshwater diatom (Bacillariophyceae) from Xianju National Park in Zhejiang Province, China. Phytotaxa 272(2): 134–140. https://doi.org/10.11646/phytotaxa.272.2.4

Zhang W, Xu X-Y, Kociolek JP, Wang L-Q (2016b) *Gomphonema shanghaiensis* sp. nov., a new diatom species (Bacillariophyta) from a river in Shanghai, China. Phytotaxa 278(1): 29–38. https://doi.org/10.11646/phytotaxa.278.1.3

Zhang ZG, Rioual P, Peng YM, Yang XP, Jine ZD, Ector L (2017) *Cymbella pamirensis* sp. nov. (Bacillariophyceae) from an alpine lake in the Pamir Mountains, Northwestern China. Phytotaxa 308(2): 249–258. https://doi.org/10.11646/phytotaxa.308.2.6

Zhang W, Shang G-X, Kociolek JP, Wang L-Q, Zhang R-L (2018) *Oricymba rhynchocephala* sp. nov., a new cymbelloid species (Bacillariophyceae) from Xianju National Park in Zhejiang Province, China. Phytotaxa 340(1): 63–70. https://doi.org/10.11646/phytotaxa.340.1.4

Zhang W, Du C, Kociolek JP, Zhao T-T, Wang L-Q (2018a) *Gomphonema wuyiensis* sp. nov., a new freshwater species (Bacillariophyceae) from Wuyi Mountains, China. Phytotaxa 375(1): 113–120. https://doi.org/10.11646/phytotaxa.375.1.8

Zhang W, Shang G, Kociolek JP, Wang L, Tan H (2018b) *Gomphonema bicepiformis* sp. nov., a new diatom species (Bacillariophyta) from a stream in Zhejiang, China. Phytotaxa 375(4): 274–282. https://doi.org/10.11646/phytotaxa.375.4.3

Zhang W, Shang G-X, Kociolek JP, Wang L-Q, Zhang R-L (2018c) *Oricymba rhynchocephala* sp. nov., a new cymbelloid diatom (Bacillariophyceae) from Xianju National Park in Zhejiang Province, China. Phytotaxa 340(1): 63–70. https://doi.org/10.11646/phytotaxa.340.1.4

Zhang W, Wang T, Levkov Z, Jüttner I, Ector L, Zhou Q-C (2019) *Halamphora daochengensis* sp. nov., a new freshwater diatom species (Bacillariophyceae) from a small mountain lake, Sichuan Province, China. Phytotaxa 404(1): 12–22. https://doi.org/10.11646/phytotaxa.404.1.2

Zhang H, Jaric I, Roberts DL, He Y, Du H, Wu J, Wang C, Wei Q (2020) Extinction of one of the world's largest freshwater fishes: Lessons for conserving the endangered Yangtze fauna. The Science of the Total Environment 710: 136242. https://doi.org/10.1016/j.scitotenv.2019.136242

Zhu HZ, Chen JY (1994) Study on the diatoms of the Wuling Mountain Region. Compilation of reports on the survey of algal resources, 405pp.

Zhu HZ, Chen JY (1995) New taxa of diatom (Bacillariophyta) from Xizang (Tibet) (I). Zhiwu Fenlei Xuebao 33(5): 516–519.

Zhu HZ, Chen JY (1996) New taxa of diatom (Bacillariophyta) from Xizang (Tibet). (II). Zhiwu Fenlei Xuebao 34(1): 102–104.

Zhu HZ, Chen JY (2000) Bacillariophyta of the Xizang Plateau. Science Press, Beijing, 353 pp.

## Appendix 1

Taxa of continental diatoms described from China, 1848–1999.

*Achnanthes affinis* var. *biseriata* Skvortzov 1938c
*Achnanthes cucurbita* Skvortzov 1935
*Achnanthes fragilis* Skvortzov 1938b
*Achnanthes fukiensis* Skvortzov 1929a
*Achnanthes girinensis* Skvortzov 1935
*Achnanthes guizhouensis* Chen and Zhu 1994
*Achnanthes hedini* Hustedt 1922
*Achnanthes hankensis* Skvortzov 1929c
*Achnanthes himalayensis* Jao and Zhu in Jao, Zhu and Lee 1974
*Achnanthes inflata* var. *sinica* Skvortzov 1929a
*Achnanthes kansouensis* Skvortzov 1935
*Achnanthes linearis* var. *kankouensis* Skvortzov 1935
*Achnanthes linearis* f. *minuta* Skvortzov 1935
*Achnanthes medioconvexa* Zhu and Chen 1996
*Achnanthes mesoconstricta* Zhu and Chen 1996
*Achnanthes minutissima* var. *constricta* Skvortzov 1935
*Achnanthes pamirensis* Hustedt 1922
*Achnanthes pinnata* Hustedt 1922
*Achnanthes schmidtiana* var. *tibetica* Jao and Zhu in Jao, Zhu and Lee 1974
*Achnanthes sublinearis* Skvortzov 1938c
*Achnanthes sublinearis* var. *complexa* Skvortzov 1938c
*Achnanthes sublinearis* var. *elliptica* Skvortzov 1938c
*Achnanthes tibetica* Jao 1964
*Actinella brasiliensis* var. *curta* Skvortzov 1929c
*Actinella miocenica* Li 1988
*Amphiprora medulica* var. *sinensis* Skvortzov 1927
*Amphiraphia* Chen and Zhu 1983
*Amphiraphia xizangensis* Chen and Zhu 1983
*Amphiraphia xizangensis* var. *major* Chen and Zhu 1983
*Amphora angusta* var. *sinensis* Skvortzov 1927
*Amphora asiatica* Skvortzov 1935
*Amphora dalaica* var. *hinganica* Skvortzov 1976b
*Amphora dalaica* var. *oculata* Skvortzov 1976b
*Amphora delicatissima* f. *sinica* Skvortzov 1935
*Amphora geniculata* Hustedt 1922
*Amphora ostenfeldii* Hustedt 1922
*Amphora ovalis* f. *mongolica* Skvortzov 1930
*Amphora reniformis* Guo, Xie and Li 1997

*Anomoeoneis polygramma* var. *rhomboides* Jao 1964
*Anomoeoneis polygramma* var. *tibetica* Jao 1964
*Aulacoseira dianchiensis* Yang, Stoermer and Kociolek 1994
*Caloneis bacillum* f. *latilanceolatum* Zhu and Chen 1995
*Caloneis chansiensis* Skvortzov 1935
*Caloneis fasciata* var. *pekinensis* Skvortzov 1928a
*Caloneis holstii* var. *tibetica* Jao 1964
*Caloneis hunanensis* Chen and Zhu 1989
*Caloneis lepidula* var. *angustata* Skvortzov 1976a
*Caloneis patagonica* var. *sinica* Skvortzov 1938c
*Caloneis schroderi* var. *densestriata* Skvortzov 1976a
*Caloneis schumanniana* var. *biconstricta* f. *minor* Zhu and Chen 1995
*Caloneis silicula* var. *hankensis* Skvortzov 1929c
*Caloneis schumanniana* f. *gracilis* Skvortzov 1935
*Caloneis silicula* var. *hinganica* Skvortzov 1976a
*Caloneis sphagnicola* Skvortzov 1938b
*Ceratoneis arcus* var. *orientalis* Skuja 1937
*Cocconeis placentula* var. *rotunda* Skvortow 1928a
*Coscinodiscus sinicus* Skvortzov 1946
*Cyclotella asterocostata* Lin, Xie & Cai in Xie et al. 1985
*Cyclotella asterocostata* var. *borealis* Xie and Cai 1985
*Cyclotella asterocostata* var. *striata* Chen 1987
*Cyclotella curvistriata* Chen and Zhu 1985
*Cyclotella florida* Voigt 1942
*Cyclotella hinganica* Skvortzov 1976a
*Cyclotella hubeiana* Chen and Zhu 1985
*Cyclotella kuetzingiana* var. *hankensis* Skvortzov 1929b
*Cyclotella lacunarum* Hustedt 1922
*Cyclotella meneghiniana* var. *hankiensis* Skvortzov 1929b
*Cyclotella meneghiniana* var. *hinganica* Skvortzov 1976a
*Cyclotella miyiensis* Qi and Yang 1985
*Cyclotella obliquata* Qi and Yang 1985
*Cyclotella rhomboideo-elliptica* Skuja, 1937
*Cyclotella rhomboideo-elliptica* var. *rounda* Qi and Yang 1985
*Cyclotella shanxiensis* Xie and Qi 1984
*Cyclotella tibetana* Hustedt 1922
*Cymatopleura sinensis* Skvortzov 1927
*Cymatopleura solea* var. *hankensis* Skvortzov 1929c
*Cymbella affinis* var. *elegans* Mereschkowsky 1906
*Cymbella amphioxys* var. *asiatica* Skvortzow 1938e
*Cymbella amoyensis* Voigt 1942
*Cymbella angustata* var. *hinganica* Skvortzov 1976b
*Cymbella aspera* var. *elongata* Skvortzov 1928b

*Cymbella aspera* var. *fossilis* Skvortzov 1937
*Cymbella aspera* var. *intermedia* Skvortzov 1929c
*Cymbella aspera* var. *manschurica* Skvortzov 1928b
*Cymbella aspera* var. *shantungensis* Voigt 1942
*Cymbella australica* var. *hankensis* Skvortzov 1929c
*Cymbella austriaca* var. *hankensis* Skvortzov 1929c
*Cymbella cantonensis* Voigt 1942
*Cymbella cantonensis* var. *obtusa* Voigt 1942
*Cymbella cesatii* var. *asiatica* Skvortzov 1938b
*Cymbella cistula* var. *asiatica* Mereschkowsky 1906
*Cymbella cistula* var. *heterostriata* Mereschkowsky 1906
*Cymbella cistula* var. *hinganensis* Skvortzov 1928b
*Cymbella cistula* var. *manschurica* Skvortzov 1928b
*Cymbella cistula* var. *recta* Shi 1991
*Cymbella cistula* var. *rotundata* Voigt 1942
*Cymbella cistula* var. *woosungensis* Voigt 1942
*Cymbella delicatula* var. *capitata* Skvortzov 1935
*Cymbella delicatula* var. *fasciata* Voigt 1942
*Cymbella delicatula* var. *magna* Chen & Zhu in Zhu & Chen, 1994
*Cymbella ehrenbergii* var. *apiculata* Skvortzov 1976b
*Cymbella ehrenbergii* var. *hankensis* Skvortzov 1929c
*Cymbella globosa* Voigt 1942
*Cymbella gracilis* var. *arcuata* Voigt 1942
*Cymbella gracilis* var. *arcuata* Skvortzov 1976b
*Cymbella gracilis* f. *crassiostriata* Skvortzov 1976b
*Cymbella gracilis* var. *kansouensis* Skvortzov 1935
*Cymbella gracilis* f. *sphagnicola* Skvortzow 1938e
*Cymbella heteropleura* var. hinganica Skvortzov 1976b
*Cymbella lanceolata* var. *grossepunctata* Skvortzov 1976b
*Cymbella jianghanensis* Shi 1991
*Cymbella jilinensis* Huang in Huang et al, 1983
*Cymbella jolmolungenesis* C.C. Jao & Y.Y. Lee in C.C. Zao, H.Z. Zhu & Y.Y. Lee 1974
*Cymbella lacustris* var. *subtropica* Voigt 1942
*Cymbella lata* var. *sinica* Skvortzov 1935
*Cymbella muralis* Skvortzov 1937
*Cymbella naviculiformis* f. *constricta* Skvortzov 1938d
*Cymbella naviculiformis* var. *stauroptera* Voigt 1942
*Cymbella pavlovi* Skvortzov 1938b
*Cymbella perpusilla* f. *elongata* Skvortzow 1938e
*Cymbella ruttneri* var. *liaotungensis* Skvortzov 1946
*Cymbella signata* var. *chinensis* Skvortzov 1929a
*Cymbella sinica* Skvortow 1938c
*Cymbella sinica* var. *miyiensis* Qi and Yang 1985

*Cymbella stuxbergii* var. *tumida* Skvortzov 1938c
*Cymbella tenuistriata* Shi 1991
*Cymbella tibetana* Hustedt 1922
*Cymbella tumidula* f. *recta* Skvortzov 1938c
*Cymbella turgida* var. *hinganica* Skvortzov 1976b
*Cymbella ventricosa* var. *major* Skvortzov 1929c
*Cymbella ventricosa* var. *pekinensis* Skvortzov 1929a
*Cymbella ventricosa* f. *major* Mereschkowsky 1906
*Denticula elegans* var. *hinganica* Skvortzov 1976b
*Diatoma shenonngia* Zhang and Qi 1994
*Diploneis elliptica* var. *hankae* Skvortzov1929b
*Diploneis elliptica* var. *mongolica* Mereschkowsky 1906
*Diploneis finnica* var. *sinica* Skvortzov 1929a
*Diploneis lijingensis* Huang in Huang et al. 1998
*Diploneis rupestris* Skvortzov 1938a
*Discoplea atmosphaerica* Ehrenberg 1848
*Discoplea sinensis* Ehrenberg 1848
*Epithemia hyndmanii* var. *chinensis* Skvortzov 1929a
*Epithemia zebra* var. *hankensis* Skvortzov 1929c
*Eucocconeis hinganica* Skvortzov 1976a
*Eunotia anhuiensis* J.Yang 1995
*Eunotia arcus* var. *bindulata* Skvortzov 1976a
*Eunotia arcus* var. *crassistriata* Skvortzov 1976a
*Eunotia arcus* var. *hinganica* Skvortzov 1976a
*Eunotia arcus* var. *triundulata* Skvortzov 1976a
*Eunotia asiatica* Skvortzow 1938e
*Eunotia asiatica* var. *interrupta* Skvortzow 1938e
*Eunotia bigibba* var. *rupestris* Skvortzov 1938a
*Eunotia clevei* var. *sinica* Skvortzov 1929a
*Eunotia faba* var. *lunata* Skvortzov 1976a
*Eunotia faba* var. *minor* Skvortzov 1976a
*Eunotia formica* var. *elongata* Skvortzov 1929c
*Eunotia fragilariodes* var. *elongata* Skvortzov 1929b
*Eunotia gracilis* var. *densestriata* Skvortzov 1976a
*Eunotia hainanensis* Zhang et Qi 1993
*Eunotia hinganica* Skvortzov 1976a
*Eunotia lunaris* var. *undulata* Skvortzov 1976a
*Eunotia major* var. *asiatica* Skvortzov 1929a
*Eunotia major* var. *hankensis* Skvortzov 1929b
*Eunotia monodon* var. *asiatica* Skvortzov 1936
*Eunotia asiatica* var. *interrupta* Skvortzow 1938e
*Eunotia parallela* f. *asiatica* Skvortzov 1938b
*Eunotia parallela* var. *hinganica* Skvortzov 1976a

*Eunotia pectinalis* var. *chinensis* Skvortzov 1929b
*Eunotia plicata* Jao 1964
*Eunotia praerupta* var. *tibetica* Mereschkowsky 1906
*Eunotia sudetica* var. *hankensis* Skvortzov 1929b
*Eunotia suecica* f. *hankensis* Skvortzov 1929c
*Eunotia suecica* var. *hinganica* Skvortzov 1976a
*Eunotia suecica* var. *simplex* Skvortzov 1976a
*Eunotia tautoniensis* var. *hankensis* Skvortzov 1929b
Eunotia tautoniensis var. *undulata* Skvortzov 1929c
*Fragilaria asiatica* Hustedt 1922
*Fragilaria brevistriata* var. *bigibba* Jao 1964
*Fragilaria brevistriata* var. *tibetica* Mereschkowsky 1906
*Fragilaria curvata* Skvortzov 1935
*Fragilaria hainanensis* Zhang et Qi 1994
*Fragilaria hinganensis* Skvortzov 1928b
*Fragilaria hinganensis* var. *longissima* Skvortzov 1928b
*Fragilaria indigema* Skvortzov 1976a
*Fragilaria lapponica* var. *lanceolata* Zhang and Qi 1994
*Fragilaria leptostauron* var. *hainanensis* Zhang in Zhang and Qi 1994
*Fragilaria mesotyla* Ehrenberg 1848
*Fragilaria shangdongensis* Li 1982
*Fragilaria subtriundulata* Li 1999
*Fragilaria virescens* var. *acicularis* Skvortzov 1976a
*Fragilaria virescens* var. *obtusa* Skvortzov 1976a
*Fragilaria virescens* var. *restratus* Skvortzov 1976a
*Frustulia chinensis* Skvortzov 1929b
*Frustulia vulgaris* var. *asiatica* Skvortzov 1928b
*Frustulia vulgaris* var. *constricta* Skvortzov 1929b
*Frustulia vulgaris* var. *muscosa* Skvortzov 1937
*Frustulia vulgaris* var. *rupestris* Skvortzov 1938a
*Gloeonema sinense* Ehrenberg 1848
*Gomphonema acuminatum* f. *elongatum* Skvortzov 1929c
*Gomphonema acuminatum* var. *sinica* Skvortzov 1935
*Gomphonema acuminatum* var. *tibeticum* Jao 1964
*Gomphonema augur* f. *hankensis* Skvortzov 1929c
*Gomphonema augur* f. *orientalis* Skvortzov 1929c
*Gomphonema augur* var. *sinica* Skvortzov 1946
*Gomphonema changyangicum* Li et al 1999
*Gomphonema clevei* f. *heterovalvata* Voigt 1942
*Gomphonema clevei* var. *sinensis* Voigt 1942
*Gomphonema constrictum* var. *amphicephala* Mereschkowsky 1906
*Gomphonema constrictum* var. *elongata* Skvortzov 1929c
*Gomphonema constrictum* var. *hankensis* Skvortzov 1929c

*Gomphonema eminens* Skuja 1937
*Gomphonema hinganicum* Skvortzov 1976b
*Gomphonema hinganicum* var. *apiculatum* Skvortzov 1976b
*Gomphonema hedini* Hustedt 1922
*Gomphonema heideni* var. *sinica* Skvortzov 1938c
*Gomphonema hubeicum* Li et al. 1999
*Gomphonema instabilis* f. *wangii* Bao and Reimer 1992
*Gomphonema interruptum* Chen and Zhu 1994
*Gomphonema kasnakowi* Mereschkowsky 1906
*Gomphonema kasnakowi* var. *distincta* Skvortzov 1938c
*Gomphonema laojunshanensis* Li, Kociolek and Metzeltin 2010b
*Gomphonema licenti* Skvortzov 1935
*Gomphonema licenti* var. *curta* Skvortzov 1935
*Gomphonema longiceps* var. *australica* Skvortzov 1976b
*Gomphonema longiceps* f. *minuta* Skvortzow 1938e
*Gomphonema montanum* f. *hankensis* Skvortzov 1929c
*Gomphonema olivaceum* var. *tibetica* Mereschkowsky 1906
*Gomphonema parvulum* var. *deserta* Skvortzov 1935
*Gomphonema parvulum* var. *sinica* Skvortzov 1935
*Gomphonema puiggarianum* var. *sinica* Skvortzov 1929b
*Gomphonema ruttneri* var. *liaotungensis* Skvortzov 1946
*Gomphonema sinica* Skvortzov 1929b
*Gomphonema sphaerophorum* var. *asiatica* Skvortzov 1929a
*Gomphonema sphaerophorum* var. *densestriatum* Zhu & Chen, 1994
*Gomphonema subclavatum* var. *hankensis* Skvortzov 1929c
*Gomphonema tergestinum* var. *shantungensis* Skvorttzow 1937
*Gomphonema tropicale* var. *nonpunctatum* Shi 1991
*Gomphonema xiphoidea* Skvortzov 1976b
*Gyrosigma attenuatum* var. *asiatica* Skvortzov 1938c
*Gyrosigma hankensis* Skvortzov 1929c
*Gyrosigma spencerii* var. *sinica* Skvortzov 1929b
*Hantzschia amphioxys* var. *compacta* Hustedt 1922
*Hantzschia amphioxys* f. *hankensis* Skvortzov 1929c
*Hantzschia amphioxys* var. *hinganensis* Skvortzov 1928b
*Hantzschia amphioxys* var. *sinica* Skvortzov 1946
*Hantzschia elongata* var. *curta* Skvortzov 1976b
*Hantzschia elongata* var. *densestriata* Skvortzov 1976b
*Hantzschia elongata* var. *obtusa* Skvortzov 1976b
*Hantzschia elongata* var. *tenua* Skvortzov 1976b
*Mastogloia braunii* var. *sinensis* Skvortzov 1927
*Mastogloia grevillei* var. *sinica* Skvortzov 1927
*Mastogloia bruni* var. *sinensis* Skvortzov 1927
*Melosira bruni* var. *sinensis* Skvortzov 1927

*Melosira cuculleta* Chen 1980
*Melosira hunanica* Chen & Zhu in Huang et al. 1998
*Melosira irregularis* var. *hankensis* Skvortzov 1929b
*Melosira italica* var. *hankensis* Skvortzov 1929b
*Melosira radiato-sinuata* Chen 1980
*Melosira radiato-sinuata* var. *yunnanica* Chen 1980
*Melsoria roseana* var. *asiatica* Skvortzov 1938a
*Melosira roeseana* var. *epidendron* f. *spinosa* Skvortzov 1938a
*Melosira roseana* f. *spinosa* Skvortzov 1938a
*Melosira roeseana* var. *xizangensis* Chen in Chen and Zhu 1995
*Melosira sinensis* Chen 1980
*Melosira soochowensis* Skvortzov 1946
*Melosira young*i var. *tenuissima* Skvortzov 1937
*Meridion circulare* var. *subcapitatum* Skvortzov 1976a
*Navicula aktinoides* Skuja 1937
*Navicula americana* f. *hankensis* Skvortzov 1929c
*Navicula amphibola* var. *manschurica* Skvortzov 1928b
*Navicula anhuiensis* Yang 1994
*Navicula argunensis* Skvortzov 1938d
*Navicula bacillum* var. *elongata* Skvortzov 1929c
*Navicula bacillum* var. *hankensis* Skvortzov 1929c
*Navicula bacillum* var. *parallela* Skvortzov 1938d
*Navicula barentsii* var. *capitata* Bao and Reimer 1992
*Navicula bigibba* Chen and Zhu 1994
*Navicula brockmannii* var. *undulata* Zhu and Chen 1996
*Navicula bryophila* var. *paucistriata* Zhu and Chen 1996
*Navicula cantonensis* Ehrenberg 1848
*Navicula cari* var. *rostrata* Skvortzov 1935
*Navicula chansiensis* Skvortzov 1935
*Navicula chinensis* Skvortow 1929b
*Navicula cincta* var. *kansouensis* Skvortzov 1935
*Navicula cincta* var. *minuta* Skvortzov 1937
*Navicula cincta* var. *sphagnicola* Skvortzow 1938e
*Navicula cryptocephala* var. *australis* Skuja 1937
*Navicula cryptocephala* var. *hankensis* Skvortzov 1929c
*Navicula cuspidata* f. *craticularis* Skvortzov 1929c
*Navicula cuspidata* var. *hankae* Skvortzov 1929c
*Navicula cuspidata* var. *tibetica* Jao 1964
*Navicula exigua* var. *signata* Skvortzov 1935
*Navicula exigua* var. *sinica* Skvortzov 1935
*Navicula fukiensis* Skvortzov 1929b
*Navicula gastrum* var. *hankensis* Skvortzov 1929c
*Navicula gastrum* var. *limnetica* Skvortzov 1929c

*Navicula gastrum* var. *mongolica* Skvortzov 1928c
*Navicula hangchowensis* Skvortzov 1937
*Navicula hankae* Skvortzov 1929c
*Navicula hedini* Hustedt 1922
*Navicula hunanensis* Chen and Zhu 1994
*Navicula incerta* f. *asiatica* Skvortzov 1935
*Navicula jkarii* Skvortzov 1929c
*Naviculaa kalganica* Skvortzov 1935
*Navicula kotschyi* f. *hinganica* Skvortzov 1976a
*Navicula kotschyi* var. *rupestris* Skvortzov 1938a
*Navicula kovalchookiana* Skvortzov 1937
*Navicula laevissima* var. *lanceolata* Skvortzov 1938a
*Navicula laevissima* var. *ovata* Skvortzov 1937
*Navicula laevissima* var. *robusta* Skvortzov 1938a
*Navicula lagerheimii* var. *capitata* Skvortzov 1937
*Navicula lagerheimii* var. *lanceolata* Skvortzov 1938a
*Navicula lagerheimii* var. *ovata* Skvortzov 1937
*Navicula lagerheimii* var. *robusta* Skvortzov 1938a
*Navicula lambda* var. *recta* Skvortzov 1929b
*Navicula lambda* var. *sinica* Skvortzov 1935
*Navicula licenti* Skvortzov 1935
*Navicula menisculus* var. *sinica* Skvortzov 1935
*Navicula mongolica* Skvortzov 1935
*Navicula multipunctata* Chen and Zhu 1994
*Navicula muscosa* Skvortzow 1938e
*Navicula mutica* var. *rhombica* Skvortzov 1938a
*Navicula mutica* var. sinica Yang 1994
*Navicula nivalis* var. *chinensis* Skvortzov 1929b
*Navicula oblonga* var. *linearis* Mereschkowsky 1906
*Navicula ocellata* Skvortzov 1938a
*Navicula ocellata* var. *polymorpha* Skvortzov 1938a
*Navicula parva* Skvortzov 1935
*Navicula peregrina* var. *asiatica* Skvortzov 1929c
*Navicula peregrina* f. *curta* Skvortzov 1929c
*Navicula peregrina* var. *hankensis* Skvortzov 1929c
*Navicula peregrina* var. *lanceolata* Skvortzov 1929c
*Navicula peregrina* var. *minuta* Skvortzov 1929c
*Navicula peregrina* var. *sinica* Skvortzov 1938c
*Navicula perpusilloides* Chen and Zhu 1994
*Navicula praegnans* Skuja 1937
*Navicula pseudolinearis* Hustedt 1922
*Navicula pseudoseminulum* Skvortzov 1935
*Navicula puncticulata* Skvortzov 1976a

*Navicula pupula* var. *elongata* Skvortzov 1976a
*Navicula pupula* var. *sinica* Skvortzov 1935
*Navicula radiosa* var. *hankensis* Skvortzov 1929c
*Navicula radiosa* var. *manschurica* Skvortzov 1928b
*Navicula rhynchocephala* var. *hankensis* Skvortzov 1929c
*Navicula rhynchocephala* f. *hankensis* Skvortzov 1929c
*Navicula rhynchocephala* var. *tenua* Skvortzov 1938c
*Navicula semen* var. *lineata* Skvortzov 1976a
*Navicula seminuda* C. Jao & Y.Y.Lee in Jao, Zhu and Lee 1974
*Navicula seposita* var. *major* Zhu and Chen 1994
*Navicula setchwanensis* Skuja 1937
*Navicula siberica* Skvortzov 1929c
*Navicula sinensis* Ehrenberg 1848
*Navicula soehrensis* var. *parallela* Skvortzow 1938e
*Navicula soochowensis* Skvortzov 1946
*Navicula soodensis* var. *mongolica* Skvortzov 1935
*Navicula stagna* Chen and Zhu 1994
*Navicula subrhombica* Hustedt 1922
*Navicula subvitrea* var. *maxima* Skvortzov 1938c
*Navicula tientsinensis* Skvortzov 1927
*Navicula tytthocephala* Skvortzov 1976a
*Navicula viridula* var. *alisoviana* Skvortzov 1929c
*Navicula viridula* var. *hankensis* Skvortzov 1929c
*Navicula viridula* var. *pamirensis* Hustedt 1922
*Navicula viridula* var. *rostrata* Skvortzov 1938d
*Navicula viridula* var. *pamirensis* Hustedt 1922
*Neidium affine* f. *manschurica* Skvortzov 1928b
*Neidium affine* var. *amphirhynchus* f. *manchuria* Skvortzov 1928b
*Neidium affine* f. *hankensis* Skvortzov 1929
*Neidium bigibborum* Zhu and Chen 1995c
*Neidium bisulcatum* f. *hankensis* Skvortzov 1929c
*Neidium bisulcatum* f. *latior* Skvortzov 1976a
*Neidium bisulcatum* f. *longissima* Skvortzov 1976a
*Neidium bisulcatum* var. *notata* Mereschkowsky 1906
*Neidium bisulcatum* f. *subcapitatum* Skvortzov 1976a
*Neidium constrictum* Zhu and Chen 1995
*Neidium didelta* Hustedt 1922
*Neidium dilatatum* var. angustatum Skvortzov 1976a
*Neidium ellipticis* Zhu and Chen 1995
*Neidium ellipticum* Voigt 1942
*Neidium hankensis* Skvortzov 1929
*Neidium hitchcockii* f. *hankensis* Skvortzov 1929c
*Neidium hitchcockii* var. obliquestriatum Skvortzov 1935

*Neidium iridis* var. *dissimilia* Jao & Zhu in Jao, Zhu and Lee 1974
*Neidium iridis* f. *hanganica* Skvortzov 1976a
*Neidium iridis* var. *orochenicum* Skvortzov 1976a
*Neidium kozlowi* var. *amphicephala* Mereschkowsky 1906
*Neidium kozlowi* var. *elliptica* Mereschkowsky 1906
*Neidium kozlowi* var. elpatievskyi f. majus Zhu and Chen 1995
*Neidium kozlowi* var. *hankensis* Skvortzov 1929c
*Neidium kozlowi* var. *parva* Mereschkowsky 1906
*Neidium kozlowii* Mereschkowsky 1906
*Neidium manshuricum* Skvortzov 1946
*Neidium maximum* var. *hankensis* Skvortzov 1929c
*Neidium mirabile* Hustedt 1922
*Neidium oblongum* Zhu and Chen 1995
*Neidium punctulatum* Hustedt 1922
*Neidium radiosum* Voigt 1942
*Neidium rectum* Hustedt 1922
*Nitzschia acuta* var. *hinganica* Skvortzov 1976b
*Nitzschia amoyensis* Skvortzov 1929a
*Nitzschia amphibia* var. *curta* Skvortzov 1928a
*Nitzschia bacillariaeformis* Hustedt 1922
*Nitzschia bacilliformis* Hustedt 1922
*Nitzschia bacilliformis* var. *elongata* Skvortzov 1935
*Nitzschia bacillum* Hustedt 1922
*Nitzschia bremensis* var. *sinica* Skvortzov 1935
*Nitzschiaa capitellata* var. *mongolica* Skvortzov 1935
*Nitzschia capitellata* var. *montana* Skvortzov 1938b
*Nitzschia chinensis* Hustedt 1922
*Nitzschia denticula* var. *elongata* Mereschkowsky 1906
*Nitzschia denticulata* Skvortzov 1935
*Nitzschia denticulata* var. *undulata* Skvortzov 1935
*Nitzschia filia* Skvortzov 1976b
*Nitzschia filia* var. *apiculata* Skvortzov 1976b
*Nitzschia frustulum* var. *asiatica* Hustedt 1922
*Nitzschia frustulum* var. *mongolica* Skvortzov 1935
*Nitzschia gradifera* Hustedt 1922
*Nitzschia grigoriewi* Mereschkowsky 1906
*Nitzschia hankensis* Skvortzov 1929c
*Nitzschia heufleriana* var. *asiatica* Skvortzov 1929c
*Nitzschia ignorata* var. *asiatica* Skvortzov 1938b
*Nitzschia heidenii* var. *pamirensis* Boye Peterson 1930
*Nitzschia iugiformis* Hustedt 1922
*Nitzschia jugiformis* Hustedt 1922
*Nitzschia mongolica* Skvortzov 1935

*Nitzschia ostenfeldi* Hustedt 1922
*Nitzschia palea* var. *gracilis* Skvortzov 1935
*Nitzschia palea* var. *hinganica* Skvortzov 1976b
*Nitzschia pamirensis* Hustedt 1922
*Nitzschia pekinensis* Skvortzov 1928a
*Nitzschia pseudolinearis* Hustedt 1922
*Nitzschia regula* Hustedt 1922
*Nitzschia regula* f. *pekinensis* Skvortzov 1928a
*Nitzschia rigida* var. *sinensis* Skvortzov 1927
*Nitzschia sigma* var. *serpentina* Skvortzov 1927
*Nitzschia sinuata* var. *constricta* Chen and Zhu 1989
*Nitzschia subvitrea* Hustedt 1922
*Nitzschia tibetana* Hustedt 1922
*Nitzschia tingrica* Jao & Lee in Jao, Zhu and Lee 1974
*Nitzschia yunchengensis* Xie and Li 1994
*Nitzschia zabelini* var. *hinganica* Skvortzov 1976b
*Pliocaenicus cathayanus* G.Wang 1999
*Pliocaenicus jilinensis* G.Wang 1999
*Pinnularia acrosphaeria* f. *hankensis* Skvortzov 1929c
*Pinnularia aestuari* var. *hinganica* Skvortzov 1976b
*Pinnularia alpina* f. *symmetrica* Mereschkowsky 1906
*Pinnularia archaica* Skvortzov 1976a
*Pinnularia bogotensis* var. *asiatica* Skvortzov 1938b
*Pinnularia bogotensis* var. *hankensis* Skvortzov 1929a
*Pinnularia brebissonii* f. *curta* Skvortzov 1929a
*Pinnularia cardinalis* var. *constricta* Skvortzov 1976b
*Pinnularia cardinalis* var. *fenestrata* Skvortzov 1976b
*Pinnularia cardinalis* f. *angustior* Skvortzov 1976b
*Pinnularia cardinalis* f. *hankensis* Skvortzov 1929c
*Pinnularia cardinalis* var. *hinganica* Skvortzov 1976b
*Pinnularia cardinalis* f. *minuta* Skvortzov 1976b
*Pinnularia centropuncta* Skvortzov 1976a
*Pinnularia centropuncta* var. *lineata* Skvortzov 1976a
*Pinnularia cheng* Skvortzov 1946
*Pinnularia chinensis* Skvortzov 1929a
*Pinnularia cholnokyi* Skvortzov 1976b
*Pinnularia cholnokyi* var. *unilateralis* Skvortzov 1976b
*Pinnularia congeri* Skvortzov 1976b
*Pinnularia distinguenda* var. *asiatica* Skvortzov 1938b
*Pinnularia distinguenda* f. *striolata* Skvortzov 1938b
*Pinnularia distinguenda* var. *sphagnalis* Skvortzow 1938e
*Pinnularia divergens* var. *continua* Mereschkowsky 1906
*Pinnularia divergens* var. *tumida* Skvortzov 1976a

*Pinnularia divergentissima* var. *capitata* Hustedt 1922
*Pinnularia divergentissima* var. *lata* Skvortzow 1938e
*Pinnularia dorgogostaiskii* var. *latior* Skvortzov 1976b
*Pinnularia episcopalis* var. *hankensis* Skvortzov 1929c
*Pinnularia episcopallis* var. *lineata* Skvortzov 1976a
*Pinnularia episcopalis* var. *manschurica* Skvortzov 1928b
*Pinnularia esox* var. *hinganica* Skvortzov 1976b
*Pinnularia essentialis* Skvortzov 1976a
*Pinnularia fonticola* Hustedt 1922
*Pinnularia fritschiana* Skvortzov 1976b
*Pinnularia gibba* f. *constricta* Skvortzov 1938b
*Pinnularia gibba* f. *polymorpha* Skvortzow 1938e
*Pinnularia gracillima* var. *hinganica* Skvortzov 1976a
*Pinnularia hartleyana* f. *minor* Skvortzov 1946
*Pinnularia hedini* Hustedt 1922
*Pinnularia hinganica* Skvortzov 1976b
*Pinnularia interrupta* f. *hankensis* Skvortzov 1929c
*Pinnularia interrrupta* var. *sinica* Skvortzov 1935
*Pinnularia isostauron* var. *orientalis* Skvortzow 1938e
*Pinnularia karelica* var. *subcapitata* Skvortzow 1938e
*Pinnularia kisselewii* Skvortzov 1976b
*Pinnularia kisselewii* var. *hinganica* Skvortozw 1976b
*Pinnularia kisselewii* var. *intermedia* Skvortzov 1976b
*Pinnularia kisselewii* var. *parallela* Skvortzov 1976b
*Pinnularia kisselewii* var. *subacuta* Skvortzov 1976b
*Pinnularia lacushankae* Skvortzov 1946
*Pinnularia lata* var. *hinganica* Skvortzov 1976a
*Pinnularia lata* var. *intermedia* Skvortzov 1976a
*Pinnularia latofasciata* Skvortzov 1946
*Pinnularia legumen* var. *hinganica* Skvortzov 1976a
*Pinnularia leptosoma* var. *hinganica* Skvortzov 1976a
*Pinnularia liouana* var. *hinganica* Skvortzov 1976a
*Pinnularia major* Skvortzov 1928b
*Pinnularia major* f. *hankensis* Skvortzov 1929c
*Pinnularia major* f. *hinganica* Skvortzov 1976a
*Pinnularia major* var. *shantungensis* Skvortzov 1937
*Pinnularia mesolepta* var. *angusta* f. *sinica* Skvortzov 1929a
*Pinnularia mesolepta* f. *hankensis* Skvortzov 1929c
*Pinnularia mesolepta* f. *hinganica* Skvortzov 1976a
*Pinnularia mesolepta* f. *sinica* Skvortzov 1929a
*Pinnularia mesolepta* f. *subundulata* Skvortzov 1929c
*Pinnularia meyerii* var. *hinganica* Skvortzov 1976b
*Pinnularia microstauron* f. *curta* Skvortzov 1929c

*Pinnularia molaris* var. *asiatica* Skvortzov 1938b
*Pinnularia molaris* var. *constricta* Skvortzov 1976a
*Pinnularia molaris* var. *hinganica* Skvortzov 1976a
*Pinnularia mongolica* Skvortzov 1935
*Pinnularia mongolica* var. *lanceolata* Skvortzov 1946
*Pinnularia montana* var. *sinica* Skvortzov 1929a
*Pinnularia nobilis* var. *constricta* Skvortzov 1976b
*Pinnularia nobilis* var. *densestriata* Skvortzov 1976b
*Pinnularia nobilis* var. *distincta* Skvortzow 1938e
*Pinnularia nobilis* var. *gracillima* Skvortzov 1976b
*Pinnularia nobilis* var. *manschurica* Skvortzov 1928
*Pinnularia nobilis* f. *minor* Skvortzov 1976b
*Pinnularia nobilis* var. *obesa* Skvortzov 1976b
*Pinnularia nobilis* var. *soochowensis* Skvortzov 1946
*Pinnularia nobilis* var. *triundulata* Skvortozw 1946
*Pinnularia nodosa* var. *hankensis* Skvortzov 1929c
*Pinnularia nodosa* var. *maakii* Skvortzov 1929c
*Pinnularia patrickii* Skvortzov 1976b
*Pinnularia patrickii* var. *angustata* Skvortzov 1976b
*Pinnularia patrickii* var. *interrupta* Skvortzov 1976b
*Pinnularia patrickii* var. *pandurinifomis* Skvortzov 1976b
*Pinnularia polyonca* var. *hinganica* Skvortzov 1976a
*Pinnularia polyonca* var. *major* Skvortzov 1929c
*Pinnularia polyonca* var. *sublinearis* Skvortzov 1976a
*Pinnularia prima* Skvortzov 1976a
*Pinnularia prima* var. *subcapitata* Skvortzov 1976b
*Pinnularia reimerii* Skvortzov 1976b
*Pinnularia reimerii* var. *interrupta* Skvortzov 1976b
*Pinnularia savanensis* var. *hinganica* Skvortzov 1976a
*Pinnularia savanensis* var. *ignota* Skvortzov 1976a
*Pinnularia secunda* Skvortzov 1976b
*Pinnularia selengensis* var. *hinganica* Skvortzov 1976a
*Pinnularia sinomongolica* Skvortzov 1976a
*Pinnularia sinomongolica* var. *angustior* Skvortzov 1976a
*Pinnularia sphagnicola* Skvortzow 1938e
*Pinnularia spitzbergensis* var. *hinganica* Skvortzov 1976a
*Pinnularia stauroptera* var. *chinensis* Skvortzov 1929a
*Pinnularia stauroptera* f. *hankensis* Skvortzov 1929c
*Pinnularia stauroptera* var. *recta* Skvortzov 1929c
*Pinnularia stauroptera* f. *subcapitata* Skvortzov 1929c
*Pinnularia stomatophora* var. *hinganica* Skvortzov 1976a
*Pinnularia streptoraphe* var. *asiatica* Skvortzov 1938b
*Pinnularia streptoraphe* var. *muscicola* Skvortzov 1976b

*Pinnularia subborealis* Hustedt 1922
*Pinnularia subcapitata* f. *constricta* Skvortzov 1938b
*Pinnularia subcapitata* var. *sinica* Skvortzov 1935
*Pinnularia subcapitata* f. *tenua* Skvortzov 1938e
*Pinnularia subsolaris* var. *asiatica* Skvortzow 1938e
*Pinnularia subsolaris* var. *interrupta* Skvortzov 1935
*Pinnularia tibetana* Hustedt 1922
*Pinnularia tibetana* var. *argunensis* Skvortzov 1938d
*Pinnularia tibetana* var. *stauroneiformis* Skvortzov 1946
*Pinnularia tibetana* var. *truncata* Skvortzov 1946
*Pinnularia tibetica* Mereschkowsky 1906
*Pinnularia turizaninow* Skvortzov 1976b
*Pinnularia viridis* f. *argunensis* Skvortzov 1938d
*Pinnularia viridis* var. *fasoiata* Skvortzov 1976b
*Pinnularia viridis* f. *hankensis* Skvortzov 1929c
*Pinnularia viridis* var. *hinganica* Skvortzov 1976b
*Pinnularia viridis* f. *hinganica* Skvortzov 1976b
*Pinnularia viridis* var. *jenisseyensis* Skvortzov 1976b
*Pinnularia viridis* f. *muscicola* Skvortzov 1976b
*Pinnularia viridis* var. *orientalis* Skvortzow 1938e
*Pinnularia viridis* var. *sinica* Skvortzov 1946
*Pinnularia viridis* var. *ussuriensis* Skvortzov 1929c
*Pinnularia zabelini* Skvortzov 1976b
*Pinnularia zabelini* var. *amurensis* Skvortzov 1976b
*Pinnularia zabelini* var. *dimidia* Skvortzov 1976b
*Pinnularia zabelini* var. *zeaana* Skvortzov 1976b
*Pinnularia zabelini* var. *interrupta* Skvortzov 1976b
*Pleurosigma spenceri* var. *sinensis* Skvortzov 1927
*Pleurosigma spenceri* var. *tientsinensis* Skvortzov 1927
*Porosularia* Skvortzov 1976b
*Porosularia amoyensis* Skvortzov 1976b
*Porosularia borgei* Skvortzov 1976b
*Porosularia calawayi* Skvortzov 1976b
*Porosularia calawayi* var. *undulata* Skvortzov 1976b
*Porosularia chowyiliangi* Skvortzov 1976b
*Porosularia handel-mazzettii* Skvortzov 1976b
*Porosularia jurilyi* Skvortzov 1976b
*Porosularia jurilyi* var. *striata* Skvortzov 1976b
*Porosularia kolbei* Skvortzov 1976b
*Porosularia lackeyi* Skvortzov 1976b
*Porosularia liouningyanii* Skvortzov 1976b
*Porosularia meisteri* Skvortzov 1976b
*Porosularia merrilli* Skvortzov 1976b

*Porosularia poretskyi* Skvortzov 1976b
*Poroularia poroidea* Skvortzov 1976b
*Porosularia pseudoviridis* Skvortzov 1976b
*Porosularia pulchra* Skvortzov 1976b
*Porosularia scheschukewii* Skvortzov 1976b
*Porosularia skujae* Skvortzov 1976b
*Porosularia skujae* var. *unilateralis* Skvortzov 1976b
*Porosularia striata* Skvortzov 1976b
*Porosularia subsalsa* Skvortzov 1976b
*Porosularia wislouchi* Skvortzov 1976b
*Rhopalodia gibba* var. *gracilis* Skvortzov 1976b
*Rhopalodia gibba* var. *major* Skvortzov 1928b
*Rhopalodia gibberula* f. *mongolica* Mereschkowsky 1906
*Rhopalodia gibberula* f. *tibetica* Mereschkowsky 1906
*Rhopalodia pseudogibba* Skvortzov 1976b
*Rhopalodia tibetica* Mereschkowsky 1906
*Schizostauron sorokninii* Mereschkowsky 1906
*Scoliopleura pavlovi* Skvortzov 1930
*Stauroneis anceps* var. *hankensis* Skvortzov 1929c
*Stauroneis anceps* var. *oblonga* Skvortzov 1929c
*Stauroneis anceps* var. *orientalis* Skvortzov 1929c
*Stauroneis anceps* var. *hinganica* Skvortzov 1976a
*Stauroneis anceps* var. *kansouensis* Skvortzov 1935
*Stauroneis anceps* var. *ussuriensis* Skvortzov 1929c
*Stauroneis chinensis* Skvortzov 1929b
*Stauroenis gregori* var. *hankensis* Skvortzov 1929c
*Stauroneis jimeiensis* Lin 1989
*Stauroneis laticeps* Hustedt 1922
*Stauroneis okamurae* Skvortzov 1929c
*Stauroneis parvula* var. *rupestris* Skvortzov 1937
*Stauroneis phoenicenteron* f. *curta* Skvortzov 1929c
*Stauroneis phoenicenteron* var. *genuina* Skvortzov 1928b
*Stauroneis phoenicenteron* var. *hankensis* Skvortzov 1929c
*Stauroneis phoenicenteron* f. *hankensis* Skvortzov 1929c
*Stauroneis phoenicenteron* var. *oblongella* Skvortzov 1929c
*Stauroneis rupestris* Skvortzov 1938a
*Stauroneis tibetica* Mereschkowsky 1906
*Stauroptera granulata* Ehrenberg 1848
*Stenopterobia sigmoidea* Skvortzov 1976
*Stephanodiscus sinensis* Ehrenberg 1854
*Stephanodiscus soochowensis* Skvortzov 1946
*Surirella alisoviana* Skvortzov 1929c
*Surirella angusta* var. *amoyensis* Skvortzov 1929b

*Surirella angusta* var. *constricta* Skvortzov 1929c
*Surirella angusta* var. *curta* Skvortzov 1929c
*Surirella angusta* var. *elongata* Skvortzov 1929c
*Surirella angusta* var. *hankensis* Skvortzov 1929b
*Surirella angusta* f. *ovata* Skvortzov 1929c
*Surirella biseriata* var. *orientalis* Skvortzov 1929c
*Surirella biseriata* var. *ussuriensis* Skvortzov 1929c
*Surirella borscowi* Mereschkowsky 1906
*Surirella capronii* var. *hankensis* Skvortzov 1929c
*Surirella chachinae* Skvortzov 1929c
*Surirella didyma* var. *hinganica* Skvortzov 1976b
*Surirella elegans* var. *hankensis* Skvortzov 1929c
*Surirella elliptica* Ehrenberg 1848
*Surirella engleri* var. *hankensis* Skvorttzow 1929c
*Surirella fukiensis* Skvortzov 1929a
*Surirella hinganica* Skvortzov 1976b
*Surirella linearis* var. *vermifera* Skvortzov 1938c
*Surirella ovalis* var. *hankensis* Skvortzov 1929c
*Surirella ovalis* f. *tientsinensis* Skvortzov 1927
*Surirella ovata* f. *curta* Skvortzov 1930
*Surirella ovata* f. *mongolica* Skvortzov 1930
*Surirella patella* var. *hankensis* Skvortzov 1929c
*Surirella robusta* var. *hankensis* Skvortzov 1929c
*Surirella robusta* var. *manschurica* Skvortzov 1928b
*Surirella saxonica* var. *sinica* Skvortzov 1929a
*Surirella splendida* var. *hankensis* Skvortzov 1929c
*Surirella tenera* var. *hinganica* Skvortzov 1976b
*Surirella tibetica* Mereschkowsky 1906
*Surirella tientsinensis* Skvortzov 1927
*Surirella ussuriensis* Skvortzov 1929c
*Surirella ussuriensis* var. *elegans* Skvortzov 1929c
*Surirella ussuriensis* var. *elongata* Skvortzov 1929c
*Synedra affinis* var. *sinica* Skvortzov 1935
*Synedra amphicephala* var. *asiatica* Skvortzov 1935
*Synedra licenti* Skvortzov 1935
*Synedra mazamaensis* var. *changbaiensis* Bao and Reimer 1992
*Synedra rumpens* var. *sinica* Skvortzov 1935
*Synedra tenera* var. *sinica* Skvortzov 1935
*Synedra ulna* f. *constricta* Skvortzov 1938c
*Synedra ulna* f. *curta* Skvortzov 1928c
*Synedra ulna* var. *anhuiensis* Yang 1990
*Synedra ulna* var. *intermedia* Mereschkowsky 1906
*Synedra ulna* var. lanceolata f. *constricta* Skvortzov 1938c

*Synedra ulna* var. *mongolica* Skvortzov 1928c
*Synedra ulna* var. *tenuirostris* Skvortzov 1938c
*Synedra vaucheriae* var. *capitata* Skvortzov 1938c
*Tetracyclus celatom* var. *minor* Li 1999
*Tetracyclus dunhuanensis* Li 1984
*Tetracyclus ellipticus* var. *austrochinensis* Zhang 1994
*Tetracyclus ellipticus* var. *ovaliformis* Li 1984
*Tetracyclus ellipticus* var. *rostrata* Li 1984
*Tetracyclus jaoi* Li 1984
*Tetracyclus minutus* Li 1999
*Tetracyclus mucronatus* Li 1999
*Tetracyclus navicularis* Li 1984
*Tetracyclus ovaliformis* Li 1984
*Tetracyclus radiatus* Li 1999
*Tetracyclus rupestris* var. *subclypeatus* Li 1999
*Tetracyclus shangduensis* Li 1984
*Tetracyclus sinensis* Li 1984
*Tetracyclus subclypeus* Li and Williams 1990
*Tetracyclus subdivisium* Williams and Li 1990
*Tetracyclus subdivisium* var. *ellipticus* Li 1999
*Thalassiosira lacustris* var. *crassiospinua* Cai et Xie in Xie and Cai 1981
*Tropidoneis maxima* var. *sinensis* Skvortzov 1927
*Tryblionella debilis* var. sinensis Skvortzov 1927
*Tryblionella hantzschiana* f. *sinensis* Skvortzov 1927
*Tryblionella tryblionella* Skvortzov 1929c
*Tryblionella tryblionella* f. *hankensis* Skvortzov 1929c

## Appendix 2

Listing of New Taxa Described from continental waters of China, 2000–2019. Genera are in bold.

*Achnanthes chinii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes coarctata* subsp. *fukinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes drepanocladoides* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes drepanocladoides* var. *fukinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes gracillima* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Achnanthes hankiana* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes kansouensis* var. *septentrionalis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes kryophila* subsp. *distincta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes kryophila* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes lanceolata* var. *argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes lanceolata* var. *elliptica* f. *asiatica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes linearis* var. *szechwanica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes minutissima* var. *bistriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes maolanensis* P.Yu, Kociolek, & Q-M.You in Q-M.You et al. 2019b
*Achnanthes montana* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes pseudoexigua* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes pseudoexigua* var. *unilateralis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes radiata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes rarissima* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthes striatella* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Achnanthidium epilithica* P.Yu, Q-M.You & Q-X Wang in Yu et al. 2019c
*Achnanthidium guizhouensis* P.Yu, You & Kociolek in You et al. 2019a
*Achnanthidium jiuzhaienis* P.Yu, Q-M.You & Q-X Wang in Yu et al. 2019c
*Achnanthidium lacustre* P.Yu, Q-M. You et Kociolek in Yu et al. 2019b
*Achnanthidium limosua* P.Yu, Q-M. You & Q-X Wang in Yu et al. 2019c
*Achnanthidium longissimum* P.Yu, Q-M.You & Kociolek in Yu et al. 2019a
*Achnanthidium mediolanceolatum* P.Yu, Q-M.You & Kociolek in You et al. 2019a
*Achnanthidium parvulum* You, Q-M.You & Kociolek in You et al. 2019a
*Achnanthidium sinense* B.Liu & S.Blanco in B. Liu et al. 2016
*Achnanthidium sublanceolatum* P.Yu, Q-M.You et Kociolek in Yu et al. 2019b
*Achnanthidium subtilissimum* P.Yu, Q-M.You & Q-X Wang in Yu et al. 2019c
*Achnanthidium taipingensis* P.Yu, Q-M.You et Kociolek in Yu et al. 2019b
*Adlafia sinensis* B.Liu & D.M.Williams in B.Liu et al. 2017
*Amphora chu-yin-changii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora dalaica* var. *bistriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Amphora dalaica* var. *latostriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora dalaica* var. *oculata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora delicatissima* var. *dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora delicatissima* var. *pekinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora epithemiformis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora jao* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora liouiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora meyeri* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora normanii* var. *alkalina* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora normanii* var. *curta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora normanii* var. *curta* f. *mongolica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora normanii* var. *interrupta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora normanii* var. *pekinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora normanii* var. *poyangi* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora perpusilla* var. *mongolica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora perpusilla* var. *pekinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora perpusilla* var. *subelliptica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora subsalina* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora wangchanii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Amphora wang-wei* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Aneumastus yamdrokensis* Q.Liu & S.L. Xie in Q.Liu et al. 2018
*Caloneis clevei* var. *parallela* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Clipeoparvus tibeticus* Q.Liu, Kociolek & Xie in Q.Liu et al. 2019b
*Cocconeis pediculus* var. *cruciata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cocconeis pediculus* var. *emarginata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Coscinodiscus rothii* var. *sibirica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Coscinodiscus sinicus* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cyclotella changhai* J.-X. Xu & J.P. Kociolek in Xu et al. 2017
*Cyclotella glomerata* var. *argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cyclotella kutzingiana* subsp. *densestriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cyclotella kutzingiana* var. *dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cyclotella meneghiniana* var. *pumila* fo. *sibirica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymatopleura elliptica* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymatopleura aquastudia* Kociolek & You in You et al. 2017b
*Cymatopleura xinjiangiana* You & Kociolek in You et al. 2017b
*Cymbella chow-yi-liangii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella cistuloides* var. *angulata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella cistuloides* var. *angulata* f. *corni-caprae* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella cistuloides* var. *angulata* f. *minor* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella cistuloides* var. *bilateralis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella cistuloides* var. *truncata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella cistuloides* var. *undulata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella gracilis* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella distalebiseriata* B.Liu & D.M.Williams in B.Liu et al. 2018d
*Cymbella fuxianensis* Y.Li & Gong in Gong and Li 2011
*Cymbella hechiensis* Y.Li & W.Zhang in Zhang et al. 2019
*Cymbella heihainensis* Y.Li & Gong in Hu et al. 2013
*Cymbella hubeiensis* Y.Li Y. in Gong et al. 2013
*Cymbella jianghanensis* Y.Li in Gong et al. 2013 (nomen nudum)
*Cymbella khokhensis* Metzeltin, Lange-Bertalot & Li in Metzeltin et al. 2009
*Cymbella liyangensis* Zhang, Jüttner & E.J. Cox, 2018
*Cymbella moelleriana* var. *argunica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella pekinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Cymbella paenetruncata* Y.Li & Z.Gong in Gong et al. 2013
*Cymbella pamirensis* Z.Zhang & Rioual in Z.Zhang et al. 2017
*Cymbella pseudotumida* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella pseudotumida* var. *pseduoborealis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella rupicola* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella semicircularis* var. *dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella sinica* var. *rostrata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella sinuata* var. *argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella tumida* var. *convergentistriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella tungtingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Cymbella pulchra* Y.Li & Lange-Bertalot in Gong et al. 2013
*Cymbella shii* Y.Li in Gong et al. 2013
*Cymbella shudunensis.* YLi & Metzeltin in Hu et al. 2013
*Cymbella sinensis* Metzeltin & Krammer in Krammer 2002
*Cymbella xingyunnensis* Y.Li & Gong in Hu et al. 2013
*Cymbella yabe* var. *punctata* Y.Li & Shi in Li et al. 2003
*Cymbella yangtzensis* Y.Li & D.Metzeltin in Gong et al. 2013
*Cymbopleura pseudokuelbsii* Shi 2013
*Delicata changqingensis* W.Zhang, S.Q.Yang & S. Blanco in Zhang et al. 2019
*Delicata sinensis* Krammer and Metzeltin 2003
*Delicata williamsii* B.Liu & S. Blanco in Bing Liu et al. 2018b
*Diatoma kalakulensis* Peng, Rioual & D.M. Williams, 2017
*Diatoma rupestris* Y.Liu & Wang in Y.Liu et al. 2010
*Diploneis barbatula* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Diploneis parma* var. *sinoborealis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Diploneis pseudoovalis* var. *tiensinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Diploneis smithii* var. *denseareolata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

***Edtheriotia*** Kociolek, Q.You, Stepanek, R.L.Lowe & Q-X.Wang, 2016a

*Edtheriotia guizhoiana* Kociolek, You, Stepanek, R.L.Lowe & Q-X.Wang 2016a
*Entomoneis triundulata* B.Liu & D.M.Williams in B.Liu et al. 2018c

*Epithemia arguiformis* Q-M.You & Q-X.Wang, 2009
*Eucocconeis lichunhaii* Y.Li in Y.Li and Gong 2013
*Eunotia arcus* var. *undulata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia bigibba* var. *subcapitata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia diodon* var. *fukinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia filiformis* Luo et al. 2019
*Eunotia monodon* var. *amoyensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia pectinalis* var. *amoyensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia mugecuo* Luo et al. 2019
*Eunotia pectinalis* var. *bigibba* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia pectinalis* var. *curta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia pectinalis* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia praerupta* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia shantungensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia shantungensis* var. *linealata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia sudeticiformis* Kociolek et al. 2016b
*Eunotia tauntoniensis* var. *amoyensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia tridentula* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia valida* var. *densistriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Eunotia valida* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Fragilaria crenophila* var. *sinensis* Rioual in Rioual et al. 2017a
*Geissleria jianghanensis* Y.Li inY. Li et al. 2005
*Germainiella guizhouiana* Kociolek et al. 2019b
*Germainiella maolaniana* Kociolek et al. 2019b
*Germainiella sinica* Kociolek et al. 2019b
*Gomphocymbella asymmetrica* Shi & Y.Li in Shi et al. 2003
*Gomphocymbella laxistriata* Shi & Y.Li in Shi et al. 2003
*Gomphoneis distorta* Q-M.You & Kociolek in Q-M. You et al. 2013

*Gomphoneis pseudosubtiloides* Q-M.You & Kociolek in Q-M. You et al. 2013
*Gomphoneis qii* Q-M.You & Kociolek in Q-M. You et al. 2013
*Gomphoneis rostratoides* Q-M.You & Kociolek in Q-M. You et al. 2013
*Gomphoneis stoermeri* Q-M.You & Kociolek in Q-M. You et al. 2013
*Gomphoneis subtiloides* Q-M.You & Kociolek in Q-M. You et al. 2013
*Gomphoneis xinjiangiana* Q-M.You & Kociolek in Q-M. You et al. 2013
*Gomphonema acuminatum* var. *obtusum* Y.Fan & Bao in Fan et al. 2004
*Gomphonema argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema asiaticum* Y.Liu & Kociolek in Y.Liu et al. 2013
*Gomphonema augur* var. *poyangiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema clevei* var. *oryzae* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema constrictum* var. *tumidum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema gordejevi* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema heideni* var. *mingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema intricatum* var. *curvatum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema jao* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema kaznakowi* var. *mingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema bicepiformis* Zhang & Kociolek,2018b
*Gomphonema bigutianchnensis* Y.Li in Liao and Y.Li 2018
*Gomphonema chinense* Y.Liu & Kociolek in Y.Liu et al. 2013
*Gomphonema constrictum* var. *ellipticum* Z.X.Shi & J.Y.Chen in Shi 2004
*Gomphonema dichotiforme* Z.X.Shi, 2004
*Gomphonema genestoermeri* Y.Liu & Kociolek in Y.Liu et al. 2013
*Gomphonema heilongtanensis* Y.Li, Kociolek & D.Metzeltin, 2010
*Gomphonema instabilis* var. *rhombicum* S.Q.Xie & Z.H.Shi in Shi 2004
*Gomphonema intricatoides* Q-M.You & Kociolek, 2015
*Gomphonema intricatum* var. *mirum* Z.X.Shi & H.Z.Zhu, 2004
*Gomphonema jianghanense* Y.Li, Z.J.Gong, P.Xie & J.Shen, 2007
*Gomphonema kaznakowi* var. *cruciatum* Z.X.Shi & Y.Li in Shi 2014
*Gomphonema lanceolatum* var. *amuricum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema lanceolatum* var. *curtum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema longiceps* var. *rupestris* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Gomphonema mediocris* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema mediocris* var. *capitatum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema mereschkowskyii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema mereschkowskyii* subsp. *lancetulum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema olivaceum* var. *argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema metzeltinii* Q-M.You & Kociolek, 2015
*Gomphonema microlanceolatum* Q-M.You & Kociolek, 2015
*Gomphonema montanum* var. *multipunctatum* Z.X.Shi & H.Z.Zhu in Shi 2004
*Gomphonema olivaceum* var. *brevistriatum* Li & Shi in Y.Li et al. 2003
*Gomphonema olivaceum* var. *brevistriatum* Y.Li & Shi in Li et al. 2003
*Gomphonema olivaceum* var. *densostriatum* Z.X.Shi & H.Z.Zhu, 2004
*Gomphonema olivaceum* var. *punctatum* Z.X.Shi & N. Li in Shi 2004
*Gomphonema pygmaeoides* Q-M.You & Kociolek, 2015
*Gomphonema rexlowei* Y.Liu & Kociolek in Y.Liu et al. 2013
*Gomphonema shanghaiensis* Zhang & Kociolek, 2016b
*Gomphonema shangtungensis* var. *rostratum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema sichuanensis* Y.Li & Kociolek in Li et al. 2010b
*Gomphonema staurophorum* var. *oblongum* Li & Shi in Li et al. 2003
*Gomphonema subclavatum* var. *elongatum* Z.X.Shi, 2014
*Gomphonema subinsigniforme* L.Ge, Y.Liu & Kociolek, 2014
*Gomphonema turris* var. *elongatum* Z.X. Shi & H.Z. Zhu in Shi 2004
*Gomphonema turris* var. *latum* Y.Fan & Q-X.Wang in Fan et al. 2004
*Gomphonema wangii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Gomphonema williamsii* Kociolek & Y.Liu in Y.Liu et al. 2013
*Gomphonema witkowskii* Kociolek & Y. Liu in Y.Liu et al. 2013
*Gomphonema wuyiensis* W.Zhang & Kociolek in Zhang et al. 2018
*Gomphonema xiantaoicum* Z.X.Shi & N.Li in Z.X.Shi 2014
*Gomphonema xiantaoicum* Z.X.Shi & N.Li in Z.X.Shi 2014
*Gomphonema xinjiangianum* Q-M.You & Kociolek, 2015
*Gomphonema yangtzensis* Y.Li in Y.Li et al. 2006
*Gomphonema yaominae* Y.Li, in Gong and Li 2012
*Gomphosinica* Kociolek et al. 2015
*Gomphosinica capitata* Kociolek, Q-M.You & Q-X. Wang in Kociolek et al. 2015
*Gomphosinica lugunsis* Y.Liu et al. in Cheng et al. 2018
*Gomphosinica robusta* Kociolek, Q-M.You & Q-X. Wang in Kociolek et al. 2015
*Gomphosinica selincuoensis* Z.Zhang, Q-M.You & Kociolek in Yang et al. 2019
*Gomphosinica simsiae* Kociolek, Q-M.You & Q-X.Wang in Kociolek et al. 2015

*Gomphosinica subtilis* Kociolek, Q-M.You & Q-X.Wang in Kociolek et al. 2015
*Gyrosigma peisonis* var. *major* Peng, Rioual & Sterrenburg, 2016
*Halamphora daochengensis* Zhang, Jüttner & Levkov in Zhang et al. 2019
*Halamphora hezhangii* Q-M.You & Kociolek in Q-M. You et al. 2015c
*Halamphora subfontinalis* Q-M.You & Kociolek in Q-M. You et al. 2015c
*Hannaea tibetiana* Q.Liu, Glushchenko, Kulikovskiy & Kociolek in Q.Liu et al. 2019a
*Hantzschia lineolata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Hantzschia virgata* var. *dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Hippodonta qinghainensis* Peng & Rioual, 2014
*Humidophila cavernaphila* Lowe, Kociolek & Q-M.You in Lowe et al. 2017
*Humidophila minuta* Lowe, Kociolek & Q-M.You in Lowe et al. 2017
*Humidophila panduriformis* Lowe, Kociolek & Q-M.You in Lowe et al. 2017
*Humidophila potapovae* Lowe, Kociolek & Q-M.You in Lowe et al. 2017
*Humidophila undulocontenta* Lowe, Kociolek & Q-M.You in Lowe et al. 2017
*Kolbesia sichuanenis* P. Yu, Q-M. You & Q-X. Wang in Yu et al. 2019a
*Lindavia khinganensis* Rioual in Rioual et al. 2017
*Luticola hunanensis* B.Liu & D.M.Williams in B.Liu et al. 2017a
*Luticola wulingensis* B.Liu & S.Blanco in B.Liu et al. 2017a
*Melosira asiatica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Muelleria pseudogibbula* Q.Liu & Q-X.Wang in Liu et al. 2018
*Navicula craticuloides* Li & Metzeltin in Gong et al. 2015
*Navicula gongii* Metzeltin & Li in Gong et al. 2015
*Navicula ignorata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Navicula salinarum* f. *gracilis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Navicula subocculata* var. *parallelistriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Navicula wangii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Navicula wangii* f. *constricta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Navicula wangii* var. *obtusa* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Navicula wangii* var. *subcapitata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Navicula seposita* var. *major* Chen & Zhu in Zhu and Chen 2000
*Navicula subtilissima* var. *paucistriata* Chen & Zhu in Zhu and Chen 2000
*Navicula yunnanensis* Li & Metzeltin in Gong et al. 2015
*Neidiomorpha sichuaniana* Q.Liu, Q-X.Wang & Kociolek, in Q.Liu et al. 2014a
*Neidium angustatum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium apiculatoides* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium avenaceum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium bacillum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017

*Neidium chenii* Y.Liu & Kociolek in Y.Liu et al. 2014a
*Neidium convexum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium dicephalum* Q.Liu, Q.X.Wang & Kociolek in Liu et al. 2017
*Neidium hitchcockii* var. *obliquestriatum* f. *densestriatum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Neidium lacusflorum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium ligulatum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium limuae* Y.Liu & Kociolek, 2014 in Y.Liu et al. 2014a
*Neidium qia* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium rostellatum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium rostratum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium suboblongum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium suoxiyuae** Y.Liu & Kociolek in Y.Liu et al. 2014a
*Neidium tibetianum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium tibeticum** Y.Liu & J.P.Kociolek in Y.Liu et al. 2014a
*Neidium tortum* Q.Liu, Q-X.Wang & Kociolek in Q. Liu et al. 2017
*Neidium triundulatum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Neidium zhui** Y.Liu & J.P.Kociolek in Y.Liu et al. 2014a
*Neidium zoigeaeum* Q.Liu, Q-X.Wang & Kociolek in Q.Liu et al. 2017
*Nitzschia acuta* var. *argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia angustata* var. *dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia apiculata* var. *latostriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia fonticola* var. *acuta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia gracilis* var. *minuta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia hastata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia hastata* var. *obtusa* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia hastata* var. *parallelistriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia intermedia* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia kalganica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia linearis* var. *robustrior* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia obtusa* var. *minuta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia parvula* var. *recta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Nitzschia recta* var. *lanceolata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia recta* var. *tenuirostris* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia sheshukowae* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia sinuata* var. *undulata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia tryblionella* f. *obtusiuscula mongolica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia tryblionella* var. *tungtingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia tungtingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nitzschia wangtzianii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Nupela major* P.Yu, Q-M.You & Kociolek in Yu et al. 2017
*Oricymba rhynchocephala* Zhang & Kociolek in Zhang et al. 2018c
*Oricymba tianmuensis* Zhang & Li in Zhang et al. 2015
*Oricymba xianjuensis* Zhang & Kociolek in Zhang et al. 2016a
*Pinnularia amurensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia appendiculata* var. *densestriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia balfouriana* var. *brevicostata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia aquaedulcis* Y.Liu, Kociolek & Q-X.Wang in Kociolek et al. 2018
*Pinnularia borealis* var. *densestriata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia braunii* var. *angustata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia braunii* var. *curta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia ceylonica* var. *costulata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia ceylanica* var. *gigantea* Skvortzov, 2012 (original description)
*Pinnularia composita* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia composita* var. *acuta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia composita* var. *distincta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Pinnularia composita* var. *linearis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia dactylus* var. *convergentissima* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia dactylus* var. *mingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia dactylus* var. *semitropica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia clavata* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia crater-lapis* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia daerbinsis* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia dicephala* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia distans* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia elliptica* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a, accepted as *Pinnularia palidis* Y.Liu, Kociolek & Q-X.Wang in Kociolek et al. 2018
*Pinnularia episcopalis* var. *mingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia gibba* var. *mingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia gibba* var. *lata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia gigantea* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia gigantea* var. *interrupta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia gigantea* var. *minor* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia hartleyana* var. *amurensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia gracile* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia hemiptera* var. *longilineata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia interrupta* var. *tungtingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia jao* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia kolbei* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia krasskei* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia krasskei* var. *latior* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia lacushankae* var. *convergenda* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia lata* var. *amurensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012

*Pinnularia lata* var. *linearis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia legumen* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia liouniata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia major* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia meisteriana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia montium* Y.Liu, Kociolek & Q-X.Wang in Kociolek et al. 2018a
*Pinnularia palidis* Y.Liu, Kociolek & Q-X.Wang in Kociolek et al. 2018a
*Pinnularia paliobducta* Y.Liu, Kociolek & Q-X.Wang in Kociolek et al. 2018a
*Pinnularia paludosa* Y.Liu & Q-X.Wang, 2010 in Y.Liu et al. 2010b
*Pinnularia paludosa* Y.Liu & Q-XWang, 2010 in Y.Liu et al. 2010b
*Pinnularia parallela* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a, accepted as *Pinnularia shii* Y.Liu, Kociolek & Q-X.Wang in Kociolek et al. 2018a
*Pinnularia parvulum* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia platycephala* var. *nipponica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia polyonca* var. *nipponica* f. *australis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia pseudosinistra* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia qii* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a
*Pinnularia rectangularis* Y.Liu, Kociolek & Q-X.Wang in Y.Liu et al. 2018a
*Pinnularia shii* Y.Liu, Kociolek & Q.X.Wang in Kociolek et al. 2018a
*Pinnularia sinicorum* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia stauroptera* var. *mingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia stauroptera* var. *rostrata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia streptoraphe* var. *argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia streptoraphe* var. *tumida* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia subcapitata* var. *mingiana* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia subaldenii* Q-X.Wang & Y.Liu, 2010 in Y. Liu et al. 2010b
*Pinnularia subbrebissonii* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a
*Pinnularia submicrostauron* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a, accepted as *Pinnularia aquaedulcis* Y.Liu, Kociolek & Q.X.Wang in Kociolek et al. 2018
*Pinnularia subnotabilis* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a
*Pinnularia subobscura* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a

*Pinnularia subsalaris* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia tabellaria* var. *sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia tschangbaischanica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Pinnularia subsinistra* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a, accepted as *Pinnularia paliobducta* Y.Liu, Kociolek & Q.X.Wang in Kociolek et al. 2018
*Pinnularia wuyiensis* Zhang et al. 2016
*Pinnularia xianhensis* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a
*Pinnularia zebra* Y.Liu, Kociolek & Q.X.Wang in Y.Liu et al. 2018a
*Placoneis sinensis* Y.Li & D.Metzeltin in Gong et al. 2013
*Platessa guangzhouae* Y.Liu & Kociolek in Y.Liu et al. 2014b
*Pliocaenicus changbaiense* Stachura-Suchoples and Jahn 2009
*Prestauroneis lowei* Liu, Wang & Kociolek, 2014
*Prestauroneis nenwai* Liu, Wang & Kociolek, 2014
*Psammothidium hainanii* Kociolek & Y.Liu, in Liu et al. 2014
*Rhopalodia gibba* var. *dalaica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Rhopalodia pseudogibba* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Rhopalodia pseudogibba* var. *arcuata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Rhopalodia pseudogibba* var. *pseudoventricosa* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Stauroneis javanica* var. *truncata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Stenopterobia recta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Stephanodiscus argunensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Stephanodiscus argunensis* var. *simple* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Stephanodiscus hustedtii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Sellaphora constrictum* Kociolek & Q-M.You in Q-M.You et al. 2017a
*Sellaphora sinensis* Y.Li & Metzeltin in Y.Li et al. 2013
*Sellaphora yunnanensis* Y.Li & Metzeltin in Y.Li et al. 2013
*Sellaphora yunnanensis* Y.Li in Y.Li et al. 2010c
*Sellphora fuxianensis* Y.Li in Y.Li et al. 2010a

***Sichuania*** Y.Li, H. Lange-Bertalot & D. Metzeltin, 2009 accepted as *Sichuaniella* Li Yanling, Lange-Bertalot & Metzeltin, 2013

*Sichuania lacustris* Y.Li, H.Lange-Bertalot & D.Metzelin, 2009

***Sichuaniella*** Y.Li, Lange-Bertalot & Metzeltin, 2013

*Sichuaniella lacustris* (Y.Li, Lange-Bertalot & Metzeltin) Y.Li, Lange-Bertalot & Metzeltin, 2013
*Simonsenia maolaniana* Q-M.You & Kociolek, in Q-M.You et al. 2016

***Sinoperonia*** Kociolek, Y.Liu, Glushchenko & Kulikovskiy in Y.Liu et al. 2018b

*Sinoperonia polyraphiamorpha* Kociolek, Y.Liu, Glushchenko & Kulikovskiy in Y.Liu et al. 2018b
*Stauroneis lacusvulcani* P.Rioual, 2013
*Staurosira longwanensis* P.Rioual, Morales & Ector, 2014
*Surirella angustata* var. *apiculata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Surirella tientsinensis* var. *striolata* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Surirella wulingensis* B.Liu & Ector in B.Liu et al. 2019c
*Synedra amoyensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Synedra arguinensis* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Synedra chungii* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Synedra sinica* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Synedra sinica* var. *recta* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Synedra tenera* var. *subtenera* Skvortzov ex Gololobov & Kulikovskiy in Kulikovskiy et al. 2012
*Synedra ulna* var. *repanda* Wang & You in You et al. 2008
*Tabularia sinensis* Cao et al. 2018

***Tibetiella*** Y.Li, D.M.Williams & D.Metzeltin, 2010d

*Tibetiella pulchra* Y.Li, D.M.Williams & Metzeltin, 2010d
*Ulnaria dongtingensis* B.Liu in B.Liu et al. 2019b
*Ulnaria gaowangjiensis* B.Liu & D.M.Williams in B.Liu et al. 2017
*Ulnaria jinbianensis* S.Blanco & B.Liu in B.Liu et al. 2019b
*Ulnaria oxybiseriata* D.M.Williams & B.Liu In B.Liu et al. 2019b
*Ulnaria rhombus* D.M.Williams in B.Liu et al. 2019a
*Ulnaria sinensis* B.Liu & D.M.Williams in B.Liu et al. 2017
*Ulnaria ulnabiseriata* D.M.Williams & B.Liu in B.Liu et al. 2017
*Ulnaria wulingensis* B.Liu in B.Liu et al. 2019a
*Urosolenia subtenuis* Kociolek & Y.Liu in Y.Liu et al. 2016
*Urosolenia truncata* Y.Liu & Kociolek in Y.Liu et al. 2016
*Urosolenia yalongii* Kociolek & Y. Liu in Y.Liu et al. 2016

PhytoKeys 160: 99–107 (2020)
doi: 10.3897/phytokeys.160.54237
http://phytokeys.pensoft.net

RESEARCH ARTICLE

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# The rediscovery of *Uraria lacei* Craib (Leguminosae) after 67 years from India

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Academic editor: Clifford Morden | Received 13 May 2020 | Accepted 3 August 2020 | Published 8 September 2020

**Citation:** Gogoi J, Rana TS (2020) The rediscovery of *Uraria lacei* Craib (Leguminosae) after 67 years from India. PhytoKeys 160: 99–107. https://doi.org/10.3897/phytokeys.160.54237

**Abstract**

Manipur is one of the biodiversity-rich states in the North-Eastern region of India, and it is also part of the Indo-Burma biodiversity hotspot with rich plant diversity and endemism. Recent field exploration in the area has resulted in the rediscovery of *Uraria lacei* Craib after 67 years from its last collection in 1952. The rediscovery of this beautiful species fills a gap in the current distribution knowledge and should pave the way for its immediate conservation and propagation.

**Keywords**

Biodiversity hotspot, Fabaceae, Manipur, rediscovery, *Uraria*

## Introduction

The genus *Uraria* Desv. (Fabaceae-Papilionoideae-Desmodieae) contains about 20 species distributed in tropical Africa, South East Asia and Australia (Ohashi et al. 2006). In India, the genus has eight to 12 species predominantly found in tropical and sub-tropical regions (Baker 1879, Sanjappa 1992, Gaur 1999, Kirtikar and Basu 2001). *Uraria lacei* Craib is a beautiful species with dark blue inflorescence and is distributed in India, China, Laos, Myanmar, Thailand and Vietnam. The

panicle of *U. lacei* is similar to that of *U. oblonga* (Wall. ex Benth.) H. Ohashi & K. Ohashi (Ohashi et al. 2018). In India, *U. lacei* is reported from the states of Nagaland, Manipur, Mizoram and Bihar (Sanjappa 1992). However, published literature and herbarium data suggests that, although the species was mentioned in the recent floras of Manipur (Singh et al. 2000) and Mizoram (Singh et al. 2002), these records were based on older collections. During a field study in November 2019 by the first author to North East India, the species was collected in flowering and fruiting stages from a hillslope at the only floating National Park (Keibul Lamjao National Park, Bishnupur, Manipur) in the world. After compiling all the data available in the public domain and specimens in different herbaria, it was observed that the last collection was from 11 September 1952 (*D.B. Deb 585*, CAL!). In the past 67 years, the species was not recollected from its occurrence in India, therefore, this certainly raises questions about its current status, conservation and existence in nature. Detailed description, taxonomic notes and colour photographs of *U. lacei* are provided here.

## Methods

All the published literature were scrutinized for the probable localities or distribution of *Uraria* spp. in India. With that distribution data, a field survey was conducted during October–November 2019 in the states of Assam, Nagaland, Manipur and Meghalaya of India to collect plants of *Uraria* spp. Fresh specimens of *U. lacei* were collected in flowering and fruiting stages from Manipur. The flowering twigs were packed in airtight polybags, flowers and fruits were separately collected in collection tubes containing 70% ethanol for further studies. Field notes recorded included habit, habitat, number of individuals in the population, geo-coordinates, and elevation data. In transit camp, the specimens were pressed and dried on blotting sheets. Upon reaching the institute, they were processed in the herbarium following standard herbarium procedures (Jain and Rao 1977). All the collected samples were dissected and were examined under stereo microscope (LEICA S8 APO, Wetzler, Germany) and described. Taxonomic literature and protologues were studied and compared for identification (Hasskarl 1844; Clarke 1889; Lecomte 1920; Haines 1921; Deb 1961; Thuan et al. 1987; Sanjappa 1992; Sha 1994; Singh et al. 2000; Singh et al. 2002; Kumar and Sane 2003; Ohashi et al. 2006; Puhua et al. 2010).

Herbarium sheets were consulted which are available in GBIF as well as various Indian (AHMA, ARUN, APF, ASSAM, BSA, BSD, BSI, BSID, CAL, DD, FRC, LWG, MH and TBGT) and foreign digital herbaria (A, B, BM, BO, E, H, K, L, MO, NY, P and US) (acronym following Thiers 2018). The specimens of *U. lacei* were found in DD, CAL, K, P, E, MO, L, A and US. The collected voucher specimens have been deposited at LWG. The distribution map was prepared using QGIS 3.8.0- Zanzibar.

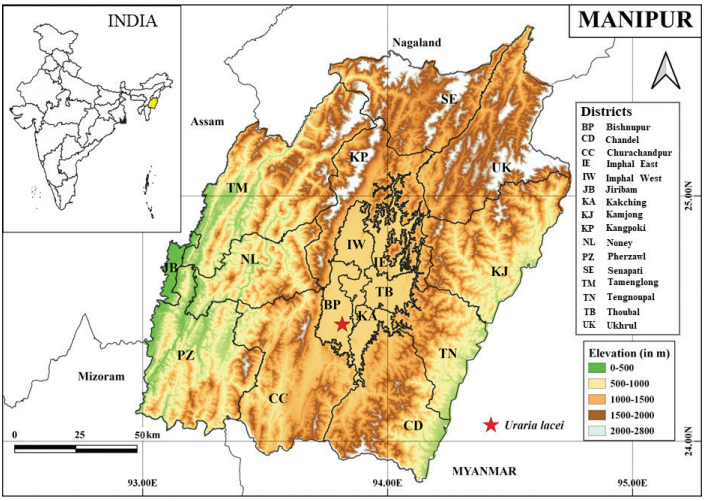


**Figure 1.** Map of Manipur showing the locality where *Uraria lacei* was rediscovered.

## Taxonomy

***Uraria lacei* Craib, Bull. Misc. Inform. Kew 1910(8): 276 (1910)**
Figs 1, 2

**Type.** Myanmar. Maymyo Plateau, 3500 ft, 12 Oct 1908, *J.H. Lace 4325* (lectotype, designated by Thuan et al. 1987, pg. 112: K! [K000858898]; isolectotypes: CAL! E! [E00301323, E00813650])

**Synonyms.** *U. paniculata* C.B. Clarke, J. Linn. Soc. Bot. 25: 15, tab. 4. 1889. *nom. illeg*. Type: India. Kohima, 3000 ft, 19 Oct 1885, *C.B. Clarke 40924* (K!). *U. clarkei* Gagnepain in Lecomte, Fl. Gen. Indoch. 2: 542. 1920. Type: Vietnam. Tonkin: Plateau de Kiendi, dans les paturages, 7 Oct 1891, *B. Balansa 4430* (Holotype: P [P02142551]). *U. pulchra* Haines, Bull. Misc. Inform. Kew 1921 (8): 308. 1921. Type: India. Bihar, Someshwar Hills, *H.H. Haines 3962* (ABD!). *U. guangxiensis* W.L. Sha in Guihaia 14: 23. 1994. Type: China. Guangxi, Nandan Xian, Yueli, 20 Sept 1977, Exped. *Nandan 4–5–073*; (Lectotype, designated by Ohashi et al. 2006, pg. 344: Herb. Guangxi Research Centre of Natural Materia Medica).

**Description.** Shrubs up to 3 m height. Roots taproot with lateral roots. Stems erect, solid, strong, striate, 0.5–0.9 cm wide with ferruginous hooked hairs (0.018–0.099 cm long) and straight hairs (0.008–0.045 cm long), internodes 0.7–3.0 cm long. Leaves trifoliolate, rarely 4-foliolate, 8.0–21.5 × 7–17 cm; petiole terete, 1.5–5.0 × 0.2 cm, scabrous, up to 0.1 cm long hairs; rachis 1.0–2.5 × 0.1–0.2 cm; petiolule densely scabrous, 0.2–0.4 cm long; terminal leaflets 3.7–13.2 × 2.1–7.5 cm, lateral leaflets smaller than terminal, 4.0–10.5 × 1.4–4.1 cm, leaflets elongated ovate, obtuse at both ends, margin entire to crenate, apex mucronate; lateral veins 9–14 pairs, up to margin, with dense

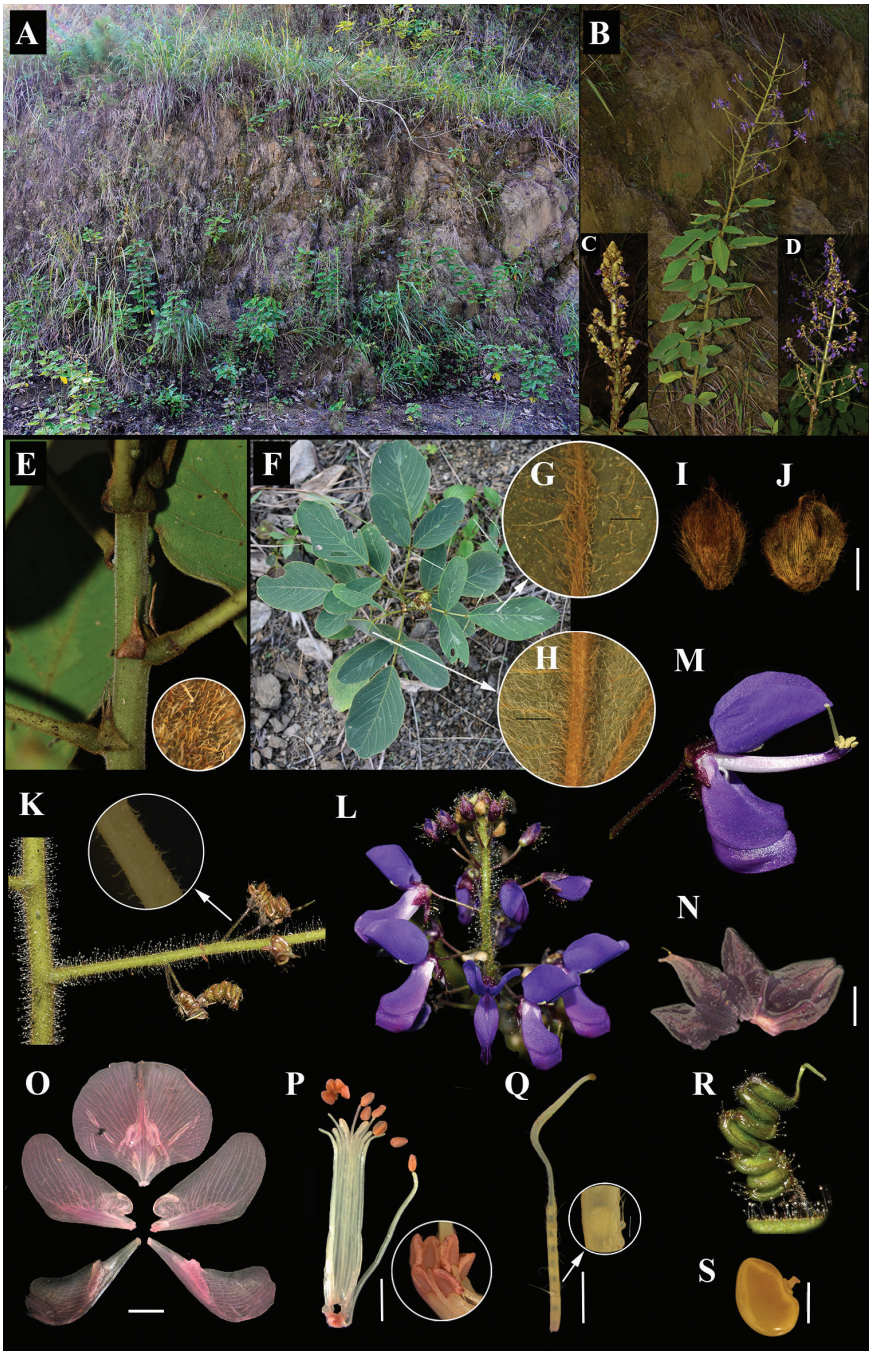


**Figure 2.** The first photographs of *Uraria lacei* Craib **A** habitat **B** habit **C** young panicle **D** mature panicle **E** stipules and magnified stem hairs **F** leaflets **G** upper surface of leaf **H** lower surface of leaf **I** abaxial surface of bract **J** adaxial surface of bract **K** rachis and fruit position with magnified hairs of pedicel **L** flower position on the panicle **M** single flower **N** calyx (Safranin stained) **O** petals–standard, wings, keel (Safranin stained) **P** androecium with magnified anthers (Safranin stained) **Q** gynoecium with magnified hairs **R** single pod **S** single seed. Scale bars: 2 mm (**J, N–Q**); 500 μm (**S**).

brown hairs underneath; midrib protruding underneath, with both dense long straight and hooked brown hairs; leaf blade adaxial (upper) surface pilose with both eglandular straight and hooked hairs, few scattered glandular straight hairs, blade with granular deposition; leaf blade abaxial (lower) surface tomentose soft hairs, shines white in sunlight. Stipules 2, not covering whole of stem width, triangular, caudate, 0.9–1.5 × 0.3–0.6 cm with scabrous hooked and straight hairs; stipels elongated triangular, 0.3–0.5 cm long with scattered scabrous hairs. Inflorescence a very lax panicle, 17–40 × 6–24 cm, ferruginous hairy, young panicle with many bracts and short secondary rachis, mature panicle with deciduous bracts and longer secondary rachis, panicle terminal, sometimes axillary; secondary rachis green, with yellowish-white glandular hairs and short hooked brown hairs; flowers in pairs; pedicels 0.8–1.0 cm long, violet-purple, minutely bent towards calyx, with short hooked white hairs (0.017 cm long). Calyx valvate, 0.3–0.5 cm long, violet-purple, sepals 5, persistent, upper two lobes completely joined together except slightly at the tooth, lower three free at teeth, joined at tube, both lobes almost of equal length, lobes abaxially glandular hairy. Corolla dark blue, petals 5, standard suborbicular, 0.87–0.88 × 0.97–1.02 cm, with two white spots adaxially towards base; wings dark blue, purple, towards base white, 0.81–0.86 × 0.38–0.48 cm, auricle slightly drooped, up to 0.12 cm long; keel-petals 0.99–1.04 × 0.44–0.51 cm, auricle minute, up to 0.04 cm long. Androecium 9 + 1, filament 1.04–1.08 cm long, filament sheath 0.83–0.88 cm × 0.14–0.15 cm, filament tips 0.05–0.14 cm long; anthers 0.07–0.08 × 0.04–0.06 cm. Gynoecium 1.15–1.27 × 0.05 cm, ovary 0.51–0.55 cm long, with 4–8 ovules, slightly appressed hairy, style ca. 0.62 cm long, bent. Pods coiled, 4–8 articles, 0.7–1.2 × 0.3–0.4 cm, green to brownish, with long glandular hairs (0.03–0.06 cm) and minute eglandular hooked (0.008–0.019 cm long) hairs on the joints; seeds yellowish, 0.23–0.25 × 0.18–0.20 cm.

**Phenology.** Flowering from October to November, fruiting from November to December.

**Specimens examined.** China. Yunnan: No locality, No altitude, 1897, *A. Henry 9144* (CAL); Szemoa, *A. Henry 9144A* (US02055945); Mengtze, *A. Henry 9144C* (MO-2331548, A00234907, A00234912); *A. Henry 9144* (US-02055943, 02055944); Puerh, *A. Henry 9144C* (K000858912); Southern Yunnan, Between Muang Hai and Keng Hung, 15–17 Feb 1922, *J.F. Rock 2492a* (US-02055941); West of Talifu, Mekong watershed, en route to Youngchang and Tengyueh, Sept.-Oct. 1922, *J.F. Rock 6615, 6585* (US-02055940, 02055942); India. Manipur: Manipur, Laimatak, 3–4000 ft, Nov 1907, *A. Meebold 6245* (CAL); Myring Naga Hills, 5000 ft, Dec 1907, *A. Meebold 9263* (CAL); Litan, 3000 ft, 12 Nov 1944, *N.L. Bor 18132* (CAL); Palel, 3000 ft, 13 Nov 1945, *A.H. Bullock 793* (L0477544); Karong, 3500 ft, 26 Sept 1950, *Walter N. Koelz 26287* (L0477545); Imphal, 11 Sept 1952, *D.B. Deb 585* (CAL); Bishnupur district, Keibul Lamjao National Park, 24.475687°N, 93.814391°E, 773 m, 17 Nov 2019, *Jahnabi Gogoi 327778, 327779* (LWG-106051, 106052, 106050, 106053); 24.475614°N, 93.814607°E, 758 m, *Jahnabi Gogoi 327780* (LWG-106054, 106054); 24.475590°N, 93.814555°E, 755 m, *Jahnabi Gogoi 327781* (LWG-106056); Nagaland: Kohima, 3000 ft, 19 Oct 1885, *C.B. Clarke 40924*; *S.N. Bal 513* (CAL); Naga Hills, Assam, 1935, *N.L. Bor 32* (DD); Myanmar. Maymyo Plateau, 3500 ft, 31 Oct 1911,

*J.H. Lace 5512* (DD, E00899264); Maymyo plateau, 3500 ft, 5 Oct 1912, *J.H. Lace 4325/ 5512?* (E00899265); Shwebo District, Kanza Laga Reserve, near Maukaw Forest Rest House, under 1000 ft, 16 Nov 1917, *C. Gilbert Rogers 670* (CAL, DD); Myit Kyi na District, Ka dw nan Pa law, 9 Nov 1930, *Maung Ba Pe 11834* (CAL, DD); Vietnam: Plateau de kiendi, dans les paturges, 7 Oct 1891, *B. Balansa 4430* (P02142551); N. du Tonkin, 900 m, 31 Dec 1937, *M. Poilane 26958* (P02996196, P03089173).

**Conservation status.** Based on the available literature in the public domain, and our recent field studies, we suggest that *U. lacei* can be provisionally considered under the 'Data deficient' category of IUCN (IUCN 2019). However, a further assessment of the threat operating on the species in question needs to be done as per IUCN guidelines.

## Discussion

*Uraria lacei* was first collected by C.B. Clarke on 19 Oct 1885 from Kohima, Nagaland, India. He published the novelty as *U. paniculata* C.B. Clarke in 1890, but was unaware of the fact that the same name exists for a different type *U. paniculata* Hassk. in 1844, thus making it as a later homonym. Gagnepain, in 1920, realised this and renamed it *U. clarkei* Gagnepain, giving credit to C.B. Clarke. In the meantime, Craib (1910) already published it as *U. lacei* Craib, thereby it became the accepted name with priority. *Uraria lacei* was named after the collector of the type specimen, John Henry Lace, a famous botanist and forester in India, Myanmar, Pakistan, etc. His collection period was from 1889 to 1912. There are many species named after him including *Styrax lacei* W.W. Smith (Styracaceae), *Parastyrax lacei* (W. W. Smith) W. W. Smith (Styracaceae), *Derris lacei* Dunn (Fabaceae), and *Euphorbia lacei* Craib (Euphorbiaceae).

*Uraria lacei* is completely different from other species of *Uraria* in its inflorescence. Although the panicle resembles *U. oblonga* (Wall. Ex Benth.) H. Ohashi & K. Ohashi, it differs in having trifoliolate leaves rather than the unifoliolate leaves of the latter. The field observation revealed that the rediscovered population had about 20 individual plants within 2 $m^2$ area on the slope of a small hill at Keibul Lamjao National Park, Bishnupur. There were both young saplings as well as mature 2–3 m tall plants. Most of the plants were in flowering and fruiting condition. The soil was sliding due to clearance for road and mostly consisted of small pieces of rocks. The plants were growing with grasses and pines.

While going through the protologue and various literature, it was observed that the species is uniformly described to have terminal inflorescence. However, we observed both terminal as well as axillary panicle during the field survey (Fig 3). The protologue also suggested the pods to be "fere glabrum" (i.e. almost smooth), which can also mean there might be scarce minute hairs that are not noticeable. On the plants that we collected, the glandular hairs were clearly visible with naked eyes, but were not very dense. Unlike the dense glandular haired pedicel described by Ohashi et al. 2006 from China, the specimens collected were observed to have minute hooked hairs on its pedicels. Thuan et al. (1987) described the calyx as glabrous while Ohashi et al. (2006) described the calyx as densely glandular hairy. Our specimens were neither glabrous

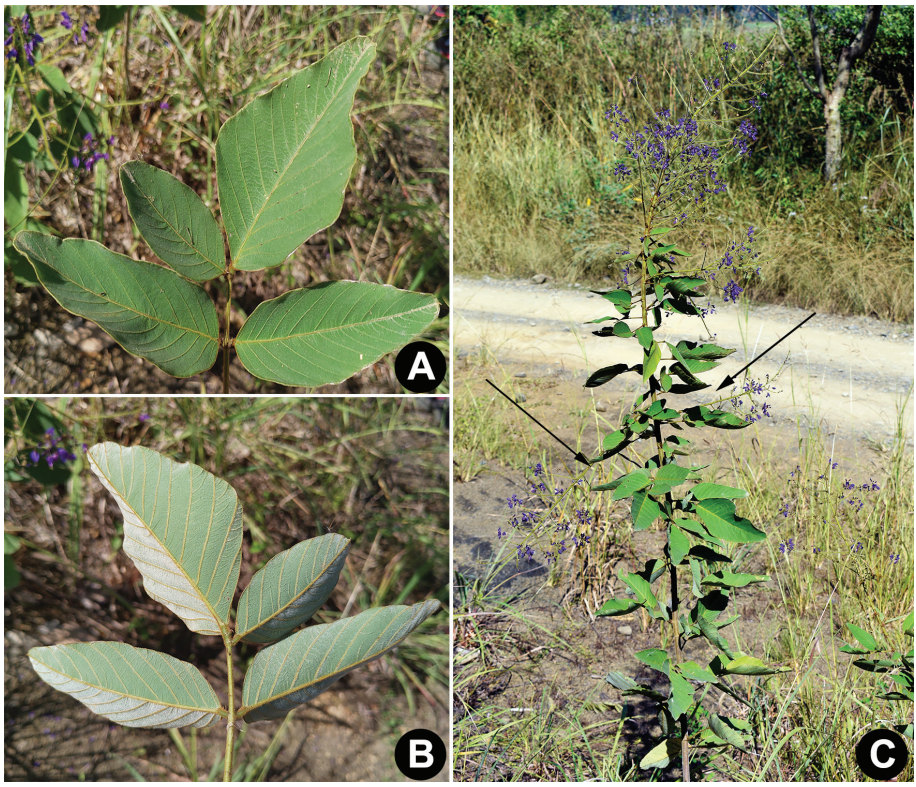


**Figure 3.** *Uraria lacei* Craib rare 4-foliolate leaflet **A** adaxial surface **B** abaxial surface **C** plant bearing axillary inflorescence (signified by arrows).

nor densely glandular hairy, but were scarcely glandular hairy. As observed in the field, the plants rarely have 4-foliolate leaflets (Fig 3).

As the plant has beautiful inflorescence and foliage, it would therefore be well-suited for domestication as an ornamental plant. Keibul Lamjao National Park, Manipur (India) is itself a protected area but anthropogenic activities like tourism is allowed in the buffer zone, therefore the vulnerability of *U. lacei* still cannot be ruled out. We could not locate any other population nearby to the present location and, given its rarity, there is an urgent need to conserve the population of this species in its present locale. Furthermore, species specific habitats need to be identified using ecological niche modelling (ENM) tools and saplings multiplied using both macro as well micro-propagation techniques, should be planted in the specific habitats to ensure the *in-situ* conservation of the species.

## Acknowledgements

The authors express their sincere thanks to the Forest Department of Manipur for allowing us to collect the plant material from its present location; to the herbarium curators of Harvard University, U.S.A. Massachusetts, Cambridge (A); University of Aber-

deen, U.K. Scotland, Aberdeen (ABD); Agharkar Research Institute-Pune, Maharashtra (AHMA); Botanical Survey of India, Itanagar, Arunachal Pradesh (ARUN); State Forest Research Institute, Arunachal Pradesh (APF); Botanical Survey of India-Eastern Circle, Shillong, Meghalaya (ASSAM); Botanischer Garten und Botanisches Museum Berlin, Zentraleinrichtung der Freien Universität Berlin, Germany, Berlin (B); Botanical Survey of India-Central Circle, Allahabad, Uttar Pradesh (BSA); Botanical Survey of India-Northern Circle, Dehradun, Uttarakhand (BSD); Botanical Survey of India-Western Circle, Pune, Maharashtra (BSI); Botanical Survey of India-Deccan Centre, Hyderabad, Telangana (BSID); The Natural History Museum, U.K., England, London (BM); Research Centre for Biology, Indonesia, Cibinong (BO); Central National Herbarium, Howrah, West Bengal (CAL); Forest Research Institute, Dehradun, Uttarakhand (DD); Royal Botanic Garden Edinburgh, U.K., Scotland, Edinburgh (E); Institute of Forest Genetics and Tree Breeding-Fischer Herbarium, Tamil Nadu (FRC); University of Helsinki, Finland, Helsinki (H); Royal Botanic Gardens, U.K., England, Kew (K); Naturalis, Netherlands, Leiden (L); CSIR-National Botanical Research Institute, Lucknow, Uttar Pradesh (LWG); Missouri Botanical Garden, U.S.A., Saint Louis (MO); Botanical Survey of India-Southern Circle, Coimbatore, Tamil Nadu (MH); The New York Botanical Garden, U.S.A. New York, Bronx (NY); Muséum National d'Histoire Naturelle, France, Paris (P); Tropical Botanic Garden and Research Institute, Trivandrum, Kerala (TBGT) and Smithsonian Institution, U.S.A., District of Columbia, Washington (US); and to the Director, CSIR-National Botanical Research Institute, Lucknow, India for facilities and encouragements. We extend our thanks to Mr A.S. Kanthraj, Ms Bhavya P. Mishra and Mr Ram Mohan for their help and support during the field survey; to Mr A.S. Kanthraj for helping in preparing the photo plate and map. Authors greatly acknowledge the financial support of the Science and Engineering Research Board (SERB), New Delhi (CRG/2019/003918) and Department of Science and Technology (DST), New Delhi to Ms Jahnabi Gogoi as DST-INSPIRE fellowship (IF170235).

Manuscript Number: CSIR-NBRI_MS/2020/05/05.

## References

Baker JG (1879) Leguminosae. In: Hooker JD (Ed.) The flora of British India. London: L. Reeve & Co. (2): 155–157.

Clarke CB (1889) On the plants of Kohima & Muneypore. Journal of the Linnean Society, Botany 25: 15–16. [Plate 4] https://doi.org/10.1111/j.1095-8339.1889.tb00793.x

Craib WG (1910) Decades Kewenses. Bulletin of Miscellaneous Information 276.

Deb DB (1961) Dicotyledonous plants of Manipur territory. Bulletin of the Botanical Survey of India 3: 271.

Gaur RD (1999) Flora of the District Garhwal North West Himalaya (with ethnobotanical notes). Transmedia Srinagar (Garhwal), U.P., India, 298–299.

Haines HH (1921) Decades Kewenses. Bulletin of miscellaneous information, Kew 1921(8): 308–309.

Hasskarl JC (1844) Catalogus plantarum in horto botanico bogoriensi cultarum alter 273. https://doi.org/10.5962/bhl.title.79159

Jain SK, Rao RR (1977) A Handbook of Field and Herbarium Methods. Today & Tommorrow's Printer & Publishers, New Delhi.

Kirtikar KR, Basu BD (2001) Indian medicinal plants with illustrations. Oriental Enterprises 3: 1048–1052.

Kumar S, Sane PV (2003) Legumes of South Asia (A Check-list). Royal Botanic Gradens Kew 218.

Lecomte MH (1920) Flora Generale de l'Indo-Chine, Paris 2: 542.

Ohashi H, Iokawa Y, Dy Phon P (2006) The Genus *Uraria* (Leguminosae) in China. Shokubutsu Kenkyu Zasshi 81(6): 332–361. http://www.jjbotany.com/pdf/JJB_081_332_361.pdf

Ohashi K, Ohashi H, Nemoto T, Ikeda T, Izumi H, Kobayashi H, Muragaki H, Nata K, Sato N, Suzuki M (2018) Phylogenetic Analyses for a New Classification of the Desmodium Group of Leguminosae Tribe Desmodieae. Shokubutsu Kenkyu Zasshi 93(3): 165–189.

Puhua H, Ohashi H, Iokawa Y (2010) Flora of China 10: 287. http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=242353446

Sanjappa M (1992) Legumes of India. Bishen Singh Mahendra Pal Singh, Dehradun 269.

Sha WL (1994) A new species of *Uraria* from Guangxi. Guihaia 14: 23–24.

Singh NP, Chauhan AS, Mondal MS (2000) Flora of Manipur. Director. Botanical Survey of India, Calcutta 1: 319.

Singh NP, Singh KP, Singh DK (2002) Flora of Mizoram. Director. Botanical Survey of India, Kolkata 1: 501.

IUCN [Standards and Petitions Committee] (2019) Guidelines for Using the IUCN Red List Categories and Criteria. Version 14. Prepared by the Standards and Petitions Committee. http://www.iucnredlist.org/documents/RedListGuidelines.pdf [accessed 03-07-2020]

Thiers B (2018) Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. http://sweetgum.nybg.org/ih/ [accessed 11.03.2020]

Thuan NV, Dy Phon P, Niyomdham C (1987) Legumineuses- Papilionoidees. Flore du Cambodge, du Laos et du Vietnam. Museum National d'Histoire Naturelle, Paris 23: 110–112.

PhytoKeys 160: 109–121 (2020)
doi: 10.3897/phytokeys.160.55603
http://phytokeys.pensoft.net

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# A new record of critically endangered *Saussurea bogedaensis* (Asteraceae) from Dzungarian Gobi, Mongolia

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Academic editor: A. Sukhorukov | Received 18 June 2020 | Accepted 13 August 2020 | Published 8 September 2020

**Citation:** Baasanmunkh S, Nyamgerel N, Bayarmaa G-A, Oyuntsetseg B, Oyundelger K, Choi HJ (2020) A new record of critically endangered *Saussurea bogedaensis* (Asteraceae) from Dzungarian Gobi, Mongolia. PhytoKeys 160: 109–121. https://doi.org/10.3897/phytokeys.160.55603

## Abstract

A species in the family Asteraceae, *Saussurea bogedaensis*, was newly described from Bogeda Mountain in Xinjiang, China and is a critically endangered species in China. Morphological and genetic characteristics confirm the presence of this species in Mongolia, as it was found in Baitag Bogd Mountain (in the Dzungarian Gobi). In addition, the distribution and conservation status of *S. bogedaensis* are provided.

## Keywords

Asteraceae, conservation status, distribution, Mongolia, *Saussurea*

## Introduction

*Saussurea* DC. is one of the largest genera in the tribe Cardueae (Asteraceae) and comprises ~500 species, classified into six subgenera and 20 sections (Lipschitz 1979; Raab-Straube 2017). The genus is distributed throughout the Northern Hemisphere, with diverse species in Central Asia (Wang et al. 2009). *Saussurea* spp. occur in a wide range of habitats, especially at higher altitudes with cold and dry conditions, but they also grow in lowlands. However, *Saussurea* spp. have a tendency towards habitat specificity (Butola

and Samant 2010). The highest number of *Saussurea* spp. is reported from China, with estimated 317 species (Chen and Yuan 2015). Sixty-one species are noted as native to India (Hajra 2000; Ahmad 2005), 54 species are mentioned in the flora of Siberia (Shurupova and Zverev 2017), 41 indigenous species are listed in the flora of Bhutan (Grierson and Springate 2001) and 23 species have been recorded in Pakistan (Ahmad 2005). To date, 53 species of *Saussurea* have been recorded in Mongolia (Gubanov 1996; Urgamal et al. 2014; Dariimaa 2017). Amongst these, five species, namely *S. catharinae* Lipsch., *S. gubanovii* Kamelin, *S. klementzii* Lipsch., *S. ramosa* Lipsch. and *S. saichanensis* Komarov ex Lipsch. are endemic to Mongolia (Urgamal and Oyuntsetseg 2017).

*Saussurea* is known for its wide array of uses, especially for medicinal and religious purposes (Mishra et al. 2018; Qureshi et al. 2018; Semwal and Painuli 2019). Additionally, the essential oils of several species are used in high-grade perfumes and as insecticides (Butola and Samant 2010). As a result of having a number of medicinal properties and economic uses, several *Saussurea* species are becoming threatened or endangered owing to over-exploitation and degradation of their habitats (Kamalpreet et al. 2019), as well as their natural rarity and small population size. These valued species include *S. involucrata* (Kar. & Kir.) Sch.Bip. and *S. orgaadayi* Khanm & Krasnob. which are listed as endangered species in the conservation list of Mongolia (Oyuntsetseg et al. 2018).

Our study initially aimed to clarify the taxonomic relationship between *S. involucrata* and *S. orgaadayi* in Mongolia and to assess the conservation status of these species. These two species are classified as endangered at the regional level and occur only in the western part of Mongolia (Grubov 1982; Gubanov 1996; Urgamal et al. 2014; Dariimaa 2017). Furthermore, both species have some morphological similarities, leading to misidentifications. Regarding their distribution range, *S. involucrata* is noted in four phytogeographical regions in western Mongolia: Mongolian Altai (MA), Dzungarian Gobi (DzG), Khovd and the Depression of Great Lakes (Grubov 1982; Dariimaa 2017). *Saussurea orgaadayi* is only noted in the MA region (Urgamal et al. 2014; Oyuntsetseg et al. 2017). *Saussurea involucrata* and *S. orgaadayi* belong to the *Saussurea* subg. *Amphilaena*, known for its taxonomic complexity (Raab-Straube 2017). However, *S. orgaadayi* can be differentiated from *S. involucrata* based on morphological characteristics of the capitula (Shi and Raab-Straube 2011; Raab-Straube 2017).

Recently, Chen and Wang (2018) discovered a new *Saussurea* species from Bogeda Mountain (Mt) in Xinjiang, China and named it *S. bogedaensis* Yu J.Wang & J.Chen. This newly-described species is closely related to *S. involucrata* and *S. orgaadayi*. This species had also been misidentified owing to its morphological similarity to *S. involucrata* and *S. orgaadayi.* Due to this confusion, Chen and Wang (2018) comprehensively investigated all three species and revealed some differences in their morphological characteristics, geographical distribution and phylogenetic positions. They also noted that *S. orgaadayi* was recorded in the Altai Mountains (Mts), and *S. involucrata* in the western part of the Chinese Tien-Shan Mts (Shi and Raab-Straube 2011; Chen and Wang 2018). *Saussurea involucrata* has been known to occur both in the DzG and MA regions of Mongolia (Urgamal et al. 2014). However, based on the distribution range indications of Chen and Wang (2018), the species recorded in the Mongolian

MA is likely to be *S. orgaadayi*. Thus, inconsistencies in the distribution range of these three *Saussurea* species, which could have been misidentified in Mongolia as well, motivated us to conduct an in-depth taxonomic assessment. In addition, Chen et al. (2019) recommended the use of nuclear ribosomal (nr) DNA ITS and chloroplast (cp) DNA regions of *rbcL* and *trnH-psbA* as candidate DNA barcode markers for species in the subg. *Amphilaena*. Using these three markers, it was possible to discriminate the *Saussurea* species that are morphologically similar and separated very recently.

The main objectives of the present study were to (1) re-identify the above mentioned *Saussurea* species recorded in western Mongolia and (2) newly report *S. bogedaensis* and describe its distribution and conservation status in the Mongolian flora.

## Materials and methods

### Herbarium and field research

The basic distribution data and photographs of the target *Saussurea* species, which had been known as *S. involucrata* and *S. orgaadayi* in Mongolia, were collected during our fieldwork from 2013 to 2019 in western Mongolia. We also included herbarium materials kept at UBA, UBU, OSBU and MW (abbreviations are according to Thiers 2019+).

### DNA barcoding

In this study, we investigated the application of combined nrDNA region of ITS and cpDNA regions of *trnK*, *trnH-psbA* and *rbcL* in barcoding analyses of two Mongolian *Saussurea* species. Additionally, a total of 36 sequences, based on four markers of three species (*S. bogedaensis*, *S. orgaadayi* and *S. involucrata*), which were used by Chen and Wang (2018) to evaluate the phylogenetic relationships between these species, were obtained from NCBI GenBank (Table 1). *Jurinea multiflora* (L.) B.Fedtsch. was selected as an outgroup based on Chen and Wang (2018) and Chen et al. (2019). Detailed information on sample collection, voucher specimens, Genbank accession numbers and references of each sample is provided in Table 1.

Total genomic DNA was extracted from silica gel-dried leaf materials following the CTAB method (Doyle and Doyle 1987). The PCR reaction was performed in a 50 µl volume, containing approximately 200 ng DNA, 1.5 mM $MgCl_2$, 0.2 mM dNTP, 1 µM of each primer and 0.75 units of Taq DNA polymerase. Initial template denaturation was programmed at 94 °C for 4 min and then followed by 30 cycles of 94 °C for 1 min, annealing at 50–56 °C for 1 min and extension at 72 °C for 1 min, with a final extension step of 72 °C for 7 min. Markers used for the amplification and sequencing are listed in Table 2. PCR products were sent to ZanaaSPX, Mongolia (www.hangal.mn) for commercial sequencing. Sequences were aligned using MEGA 7 (Kumar et al. 2016), with the default settings and

**Table 1.** Detailed information on taxa, sampled locations, voucher specimens, NCBI GenBank accession numbers and references of the samples used in this study.

| Taxon | Location & Herbarium accession number | Latitude (N) / Longitude (E) | Altitude (m) | GenBank accession number | | | | Reference |
|---|---|---|---|---|---|---|---|---|
| | | | | ITS | *rbcL* | *trnK* | *trnH-psbA* | |
| *S. bogedaensis* | Mongolia, Dzungarian Gobi; UBU20190698 | 45°13'14.52", 90°55'12.97" | 2742 | MT209829 | MT624048 | MT624054 | MT624060 | This study |
| *S. bogedaensis* | Mongolia, Dzungarian Gobi; UBU20190699 | 45°13'14.52", 90°55'12.97" | 2742 | MT210906 | MT624049 | MT624055 | MT624061 | This study |
| *S. bogedaensis* | Mongolia, Dzungarian Gobi; UBU20190700 | 45°13'14.52", 90°55'12.97" | 2742 | MT197331 | MT624050 | MT624056 | MT624062 | This study |
| *S. bogedaensis* | China, Xinjiang, Qitai; WYJ201308006 (38) | 43°27'11.56", 89°33'7.67" | 3471 | MH003708 | MH070873 | MH070999 | MH070746 | Chen et al. (2019) |
| *S. bogedaensis* | China, Xinjiang, Qitai; WYJ201308006 (39) | 43°27'11.56", 89°33'7.67" | 3471 | MH003709 | MH070874 | MH071000 | MH070747 | Chen et al. (2019) |
| *S. bogedaensis* | China, Xinjiang, Qitai; WYJ201308006 (40) | 43°27'11.56", 89°33'7.67" | 3471 | MH003710 | MH070875 | MH071001 | MH070748 | Chen et al. (2019) |
| *S. orgaadayi* | Mongolia, Mongolian Altai; UBU20180340 | 46°51'08.6", 91°45'27.3" | 2848 | MT209870 | MT624051 | MT624057 | MT624063 | This study |
| *S. orgaadayi* | Mongolia, Mongolian Altai; UBU20180341 | 46°51'08.6", 91°45'27.3" | 2848 | MT209871 | MT624052 | MT624058 | MT624064 | This study |
| *S. orgaadayi* | Mongolia, Mongolian Altai; UBU20180342 | 46°51'08.6", 91°45'27.3" | 2848 | MT210907 | MT624053 | MT624059 | MT624065 | This study |
| *S. orgaadayi* | China, Xinjiang, Altai; WYJ201308041 (11) | 47°13'6.46", 89°52'47.96" | 3541 | MH003773 | MH070934 | MH071060 | MH070807 | Chen et al. (2019) |
| *S. orgaadayi* | China, Xinjiang, Altai; WYJ201308041 (12) | 47°13'6.46", 89°52'47.96" | 3541 | MH003774 | MH070935 | MH071061 | MH070808 | Chen et al. (2019) |
| *S. orgaadayi* | China, Xinjiang, Altai; WYJ201308041 (360) | 47°13'6.46", 89°52'47.96" | 3541 | MH003775 | MH070936 | MH071062 | MH070809 | Chen et al. (2019) |
| *S. involucrata* | China, Xinjiang, Urumqi; WYJ20160725 (163) | 43°6'30.49", 86°50'31.92" | 3564 | MH003736 | MH070900 | MH071026 | MH070773 | Chen et al. (2019) |
| *S. involucrata* | China, Xinjiang, Urumqi; WYJ20160725 (165) | 43°6'30.49", 86°50'31.92" | 3564 | MH003737 | MH070901 | MH071027 | MH070774 | Chen et al. (2019) |
| *S. involucrata* | China, Xinjiang, Tekesi; WYJ201308184 (24) | 43°5'56.94", 86°50'31.92" | 3678 | MH003738 | MH0070902 | MH071028 | MH070775 | Chen et al. (2019) |
| *Jurinea multiflora* | China, Xinjiang, Tuoli; WYJ201308102 (377) | 45°44'8.3", 83°8'49.63" | 1753 | MH003704 | MH070869 | MH070995 | MH070742 | Chen et al. (2019) |

**Table 2.** List of the markers used for the DNA barcoding and phylogenetic analysis.

| Fragment | Marker | Sequence 5' → 3' | $T_a$ | Reference |
|---|---|---|---|---|
| ITS | *ITS4* | TCCTCCGCTTATTGATATGC | 50 °C | White et al. (1990) |
| | *ITS5A* | CCTTATCATTTAGAGGAAGG | | |
| *rbcL* | *rbcL_f* | ATGTCACCACAAACAGAGAC | 56 °C | Chase et al. (1993) |
| | *rbcL_r* | CTTCTGCTACAAATAAGAAT | | |
| *trnK* | *trnK(UUU)* | TTAAAAGCCGAGTACTCTACC | 50 °C | Sang et al. (1997) |
| | *rps16* | AAAGTGGGTTTTTATGATCC | | |
| *trnH-psbA* | *psbA* | GTTATGCATGAACGTAATGCTC | 56 °C | Olmstead et al. (1992) |
| | *trnH* | CGCGCATGGTGGATTCACAATCC | | |

manual adjustments were made using SnapGene Viewer 4.2.6. Sequences were edited manually using SnapGene Sequence Alignment Editor (GSL Biotech LLC). Ambiguous nucleotide bases were corrected using the corresponding base of the sequence that was obtained by the reverse primer. Multiple sequences were aligned using ClustalW with its default parameters (Thompson et al. 1994) and consensus sequences were created for each species. For the combined dataset, the genetic

divergences were calculated using DNASP v.6 (Julio et al. 2017) and used to determine whether a barcoding gap was present. The DNA sequences generated in this study have been deposited in GenBank (Table 1).

The phylogenetic analyses were conducted using Bayesian Inference (BI), Maximum Likelihood (ML) and Maximum Parsimony (MP). For BI analysis, the best close fit model of evolution for each partition neighbour joining (NJ) tree was estimated using MEGA 7 (Kumar et al. 2016). Posterior probability was determined by Markov Chain Monte Carlo sampling (MCMC) with the programme MrBayes v. 3.2.6 (Huelsenberk and Ronquist 2001; Ronquist and Huelsenberk 2003), as implemented in Geneious v. 10.2.2 (Kearse et al. 2012), using the estimated models of evolution. For each dataset, four simulation Markov chains were run for 1 million generations and trees were sampled every 100$^{th}$ generation. The ML analysis was performed using RAxML v. 8.2.11 (Stamatakis 2006, 2014) as implemented in Geneious v. 10.2.2 (Kearse et al. 2012), using the GTRGAMMA model with rapid bootstrapping and a search for the best-scoring ML tree algorithm, including 1,000 bootstrap replicates. The MP analyses were performed with MEGA 7 (Kumar et al. 2016), using tree-bisection-reconnection (TBR) as the branch-swapping algorithm. The robustness of the tree was evaluated using 1,000 bootstrap replication indices and the consistency index, retention index and composite index were calculated.

## Results

We discovered *S. bogedaensis* from Baitag Bogd Mt in the DzG region of Mongolia. This species is newly documented in the Mongolian flora. Detailed data on morphological and genetic identification, geographical distribution and conservation status of the *S. bogedaensis* are provided below.

### New record

***Saussurea bogedaensis* Yu J.Wang & J.Chen, PloS ONE 13(7): e0199416 (12) (2018)**
Figs 1, 3

**Morphological identification.** *Saussurea bogedaensis* (Fig. 1) was recently discovered on Bogeda Mt in Xinjiang, China by Chen and Wang (2018) (Fig. 3). This species is very similar to *S. involucrata* and *S. orgaadayi* (Fig. 2), but several morphological characteristics of the bracts, involucres and phyllaries differentiate them (Chen and Wang 2018). In particular, *S. bogedaensis* differs by having elliptic, apically obtuse stem leaves (Fig. 1C) vs. lanceolate, long-acuminate stem leaves in *S. orgaadayi* (Fig. 2A); dirty white pappus colour (Fig. 1D) vs. straw-coloured pappi in *S. orgaadayi* (Fig. 2D); densely pubescent phyllaries (Fig. 1E) vs. glabrous phyllaries in *S. involucrata*; and campanulate involucres in *S. bogedaensis* vs. hemispherical involucres in *S. involucrata*.

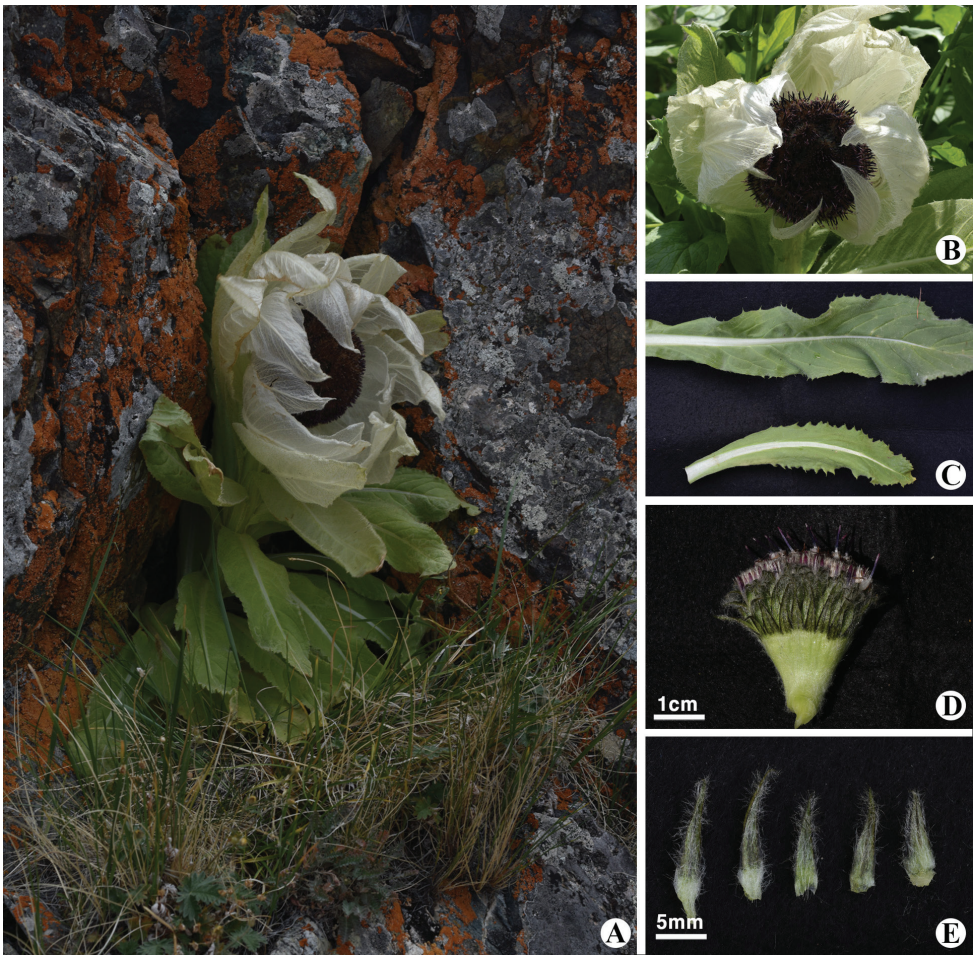


**Figure 1.** *Saussurea bogedaensis* in Buduun Khargait river, Baitag Bogd Mt, Uyench sum, Khovd Province, Mongolia. **A** general habit in Baitag Bogd Mt, DzG region **B** fruiting **C** leaves **D** pappus **E** phyllaries. Photos: 28 July 2019, Sh. Baasanmunkh.

**Genetic identification.** The combined sequence dataset consisted of 15 samples, including the outgroup, *Jurinea multiflora*. The sequence dataset comprised 2,315 characteristics, of which 20 were parsimony-informative, 108 were variable and 2,169 were constant. The gene boundaries on the ITS – *trnK* – *trnH-psbA* – *rbcL* multi-locus alignment were as follows: ITS: 1–656, *trnK*: 657–1,284, *trnH-psbA*: 1,285–1,680 and *rbcL*: 1,681–2,315. The final ML optimisation likelihood of ML analysis was: Inl = -3650.7353. A single most parsimonious tree was generated by MP analysis with a tree length of 105 steps, consistency index: 1.0, retention index: 1.0 and composite index: 1.0. The BI phylogeny, including BI posterior probability values, as well as ML and MP bootstrap support values, are provided in Fig. 4.

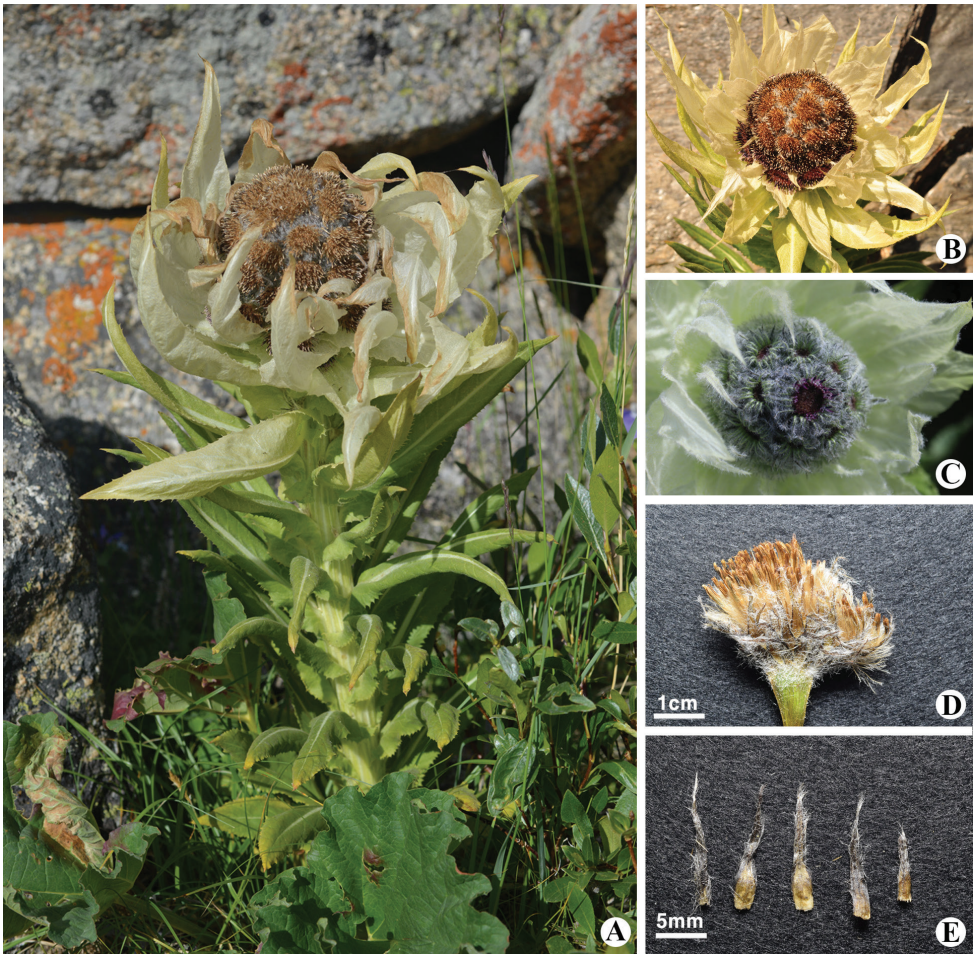


**Figure 2.** *Saussurea orgaadayi* in Khukh Nuur, Munkhkhairkhan sum, Khovd Province, Mongolia **A** general habit in Munkhkhairkhan Mt, MA region **B** fruiting **C** flowering **D** pappus **E** phyllaries. Photos: 29 July 2016, B. Oyuntsetseg (**A, C**) Sh. Baasanmunkh (**B, D, E**).

Our genetic identification revealed a similar topology to that of Chen and Wang (2018) and confirms each distinct clade of *S. bogedaensis*, *S. involucrata* and *S. orgaadayi*, respectively (Fig. 4). Three individuals of newly-revealed *Saussurea* specimens from Baitag Bogd Mt formed one cluster with the Chinese *S. bogedaensis* with high support: BI/ML/MP = 1/100/99. Additionally, sequence divergence amongst the three species was 0–0.002% in our *S. bogedaensis* specimens, whereas there was 3.02% sequence divergence in *S. involucrata* and 2.04% sequence divergence in *S. orgaadayi.* Sequence alignment revealed that the Mongolian and Chinese *S. bogedaensis* share several specific nucleotide residues that are different from those of other *Saussurea* species (Fig. 5). The other three samples (Fig. 2) from Munkhkhairkhan Mt in the MA region

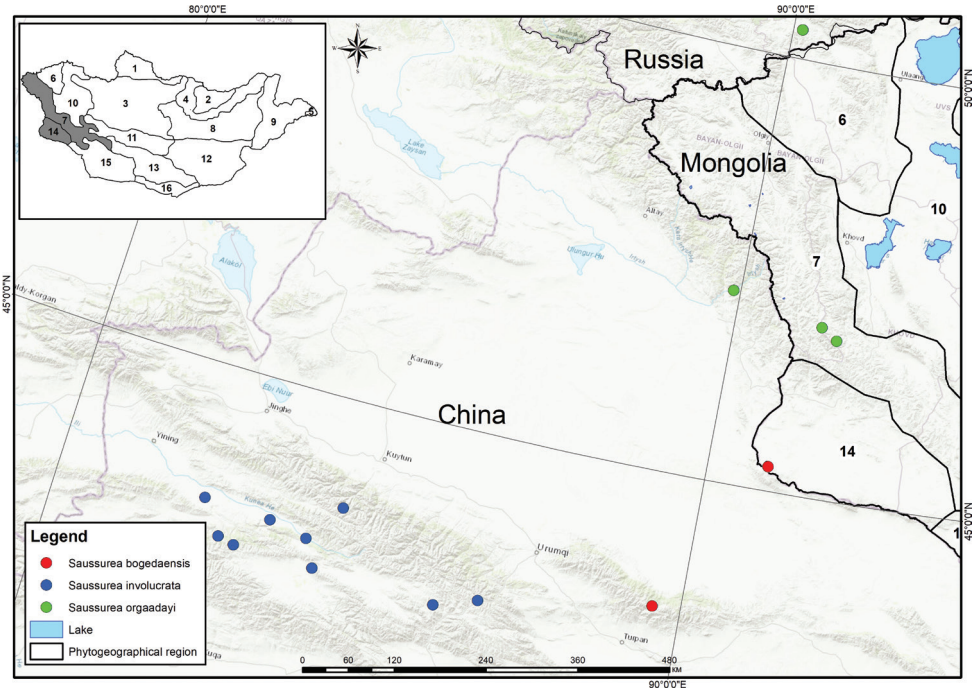


**Figure 3.** Distribution of *S. bogedaensis* (red dots), *S. involucrata* (blue dots) and *S. orgaadayi* (green dots) in Mongolia, Russia and Chinese Tien-Shan Mts based on field surveys and herbarium materials as well as specimens from China based on the publications of Chen and Wang (2018) and Chen et al. (2019). Region numbers on the Mongolian map are phytogeographical regions according to Grubov (1982): 6 – Khovd, 7 – Mongolian Altai, 10 – Depression of Great Lakes and 14 – Dzungarian Gobi.

clustered with *S. orgaadayi* from China (BI/ML/MP = 1/100/99). Therefore, our study proves that the *Saussurea* samples from the DzG and MA regions are *S. bogedaensis* (Fig. 1) and *S. orgaadayi* (Fig. 2), respectively. Our genetic results provide only the genetic differences between the three related species in the subg. *Amphilaena* and not a true phylogeny of all related *Saussurea* species.

**General distribution and habitat.** Mongolia (Dzungarian Gobi, Baitag Bogd Mt) and China (Xinjiang, Bogeda Mt). In Mongolia, *S. bogedaensis* grows on high mountain rocky slopes, screes, boulders and river banks in the alpine belt at altitudes of 2400–3300 m a.s.l. This species is closely related to *S. involucrata* and *S. orgaadayi*. However, the three species are geographically isolated: *S. bogedaensis* occurs in the Dzungarian basin and the eastern Chinese Tien-Shan Mts and *S. involucrata* occurs in the Tien-Shan Mts (which cover parts of China and Central Asian states), whereas *S. orgaadayi* is present in the Altai Mts (which cover parts of China, Mongolia and Russia) (Fig. 3), according to Raab-Straube (2017) and Chen and Wang (2018).

**Conservation status.** *Saussurea bogedaensis* is new to the Mongolian flora and occurs in the Baitag Bogd Mt in the DzG region. Individuals of the species were found in a few

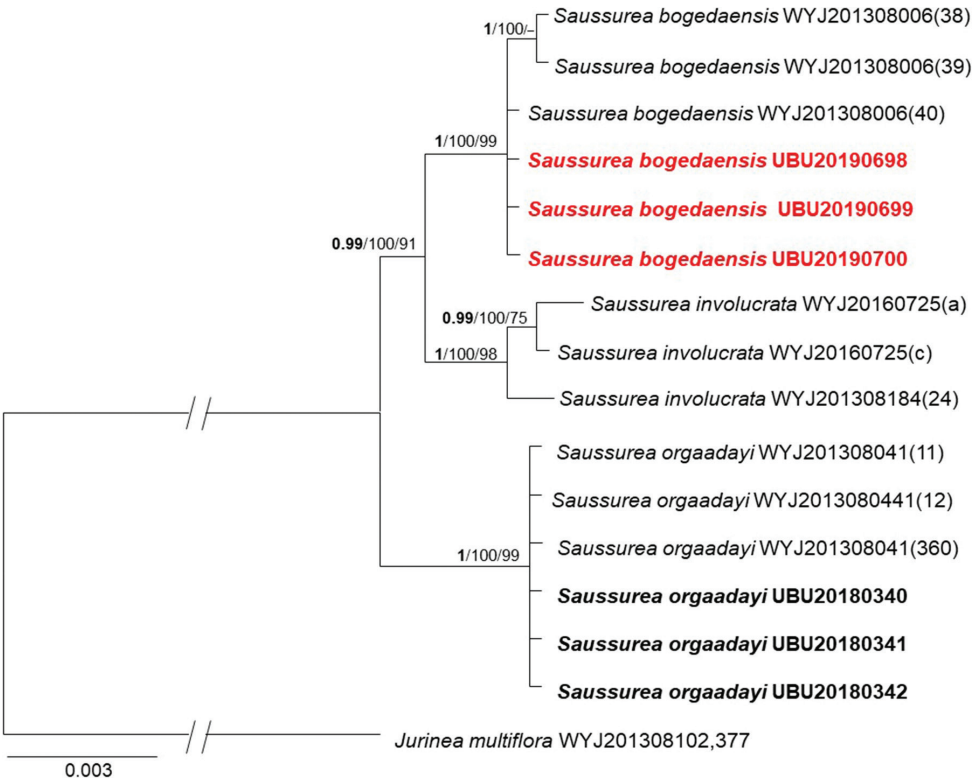


**Figure 4.** Phylogenetic tree based on concatenated sequence alignments of nrDNA (ITS) and cpDNA (*trnK*, *trnH-psbA*, and *rbcL*) regions. Bayesian Inference (BI) posterior probability support values above 90% (bold), Maximum Likelihood (ML) and Maximum Parsimony (MP) bootstrap support values above 70% are shown in the branches in the following order **BI**/ML/MP. The new samples of *S. bogedaensis* and *S. orgaadayi* originated from Mongolia are in red and black bolds, respectively.

locations, namely in Baitag Bogd Mt and Altan Ovoo in the DzG region (Fig. 3). During our field surveys, we detected two different populations, which in total, accounted for fewer than 600 individuals in this region. This species is under threat, particularly owing to human interference and random cutting. Thus, *S. bogedaensis* has been assessed as Critically Endangered [CR C2a(i)] in Mongolia according to the IUCN Red List categories and criteria (IUCN 2019). This species was also evaluated as critically endangered in China (Chen and Wang 2018). *In situ* studies on the reproductive biology of *S. bogedaensis* are needed to more accurately assess the conservation status of this species in Mongolia.

**Specimens examined (new record).** Mongolia. Dzungarian Gobi region: Khovd Province, Uyench sum, Baitag Bogd Mt, Buduun Khargait river, 45°13'14.52"N, 90°55'12.97"E, 2742 m a.s.l., 28 Jul 2019, *Sh. Baasanmunkh et al.*, *20190698*, *20190699*, *20190700* (UBU). The samples from this site were used for the molecular analysis confirming the identity of the Mongolian plants as *S. bogedaensis*.

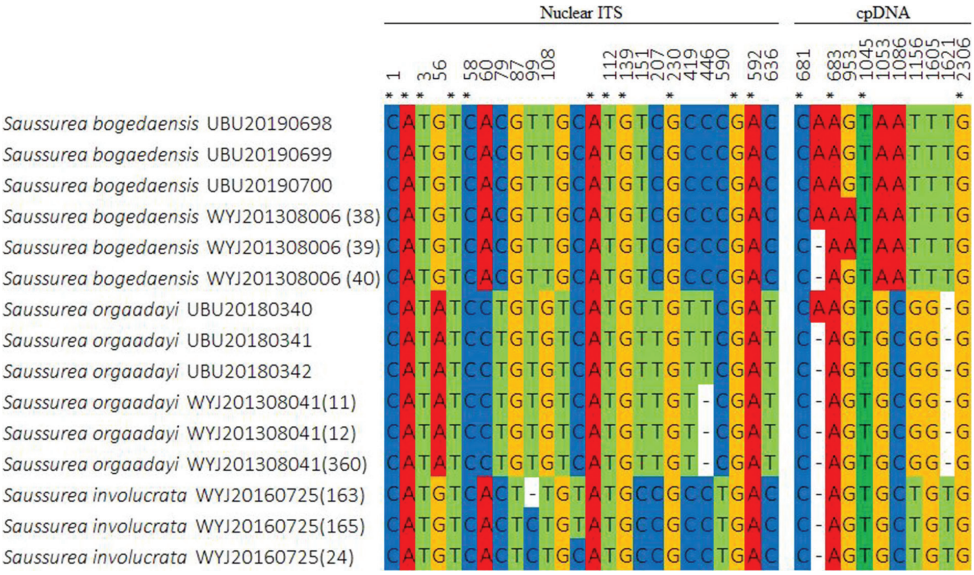


**Figure 5.** Multiple sequence alignment of combined nr DNA (ITS) and cpDNA (*trnK*, *trnH-psbA* and *rbcL*) sequences. ITS region shows more differences than cpDNA regions amongst those closely related species. (*) – no differences found between species.

## Discussion

*Saussurea bogedaensis*, *S. orgaadayi* and *S. involucrata* belong to the taxonomically complicated *Saussurea* subg. *Amphilaena* (Raab-Straube 2017). Despite their similar morphological characteristics and habitats, there are clear morphological differences, geographically isolated distributions and genetic identities that make these species recognisable with an in-depth investigation (Figs 1–5; Chen and Wang 2018; Chen et al. 2019). There are some distribution records of *S. involucrata* from the regions of Khovd and the Depression of Great Lake in Mongolia (Urgamal et al. 2014). Due to limited numbers of samples and surveyed areas of the MA and DzG regions in this study, data on Mongolian *S. involucrata* are still unclear. Hence, correct identification based on this study will provide an important basis for future studies on the taxonomic identity of Mongolian *S. involucrata*.

## Acknowledgements

Our study is supported by a research project (A survey on the vascular flora of Mongolia; Grant Number KNA 1-2-38, 20-5) of the Korean National Arboretum, South Korea and partly supported by the National University of Mongolia's "Seed Grant". We are grateful to Dr. Steffen Bien (Senckenberg Museum of National History Görlitz, Germany) for his help with phylogenetic analysis. We also thank to Ms. Joscie Norris (University of Vermont, Burlington, United States) for her help with

improving the English writing of manuscript. Finally, the authors thank Dr. Yu-Jin Wang (Lanzhou University, China) for his careful review with valuable suggestions and personal discussion on the first draft.

## References

Ahmad S (2005) Genus *Saussurea* DC. (Compositae) of Pakistan. PhD Thesis, Quaid-i-Azam University, Pakistan.

Butola JS, Samant SS (2010) *Saussurea* species in Indian Himalayan region: Diversity, distribution and indigenous uses. International Journal of Plant Biology 1(1): 43–51. https://doi.org/10.4081/pb.2010.e9

Chase MW, Soltis DE, Olmstead RG, Morgan D, Les DH, Mishler BD, Duvall MR, Price RA, Hills HG, Qiu YL, Kron KA, Rettig JH, Conti E, Palmer JD, Manhart JR, Sytsma KJ, Michaels HJ, Kress WJ, Karol KG, Clark WD, Hedren M, Gaut BS, Jansen RK, Kim K-J, Wimpee CF, Smith JF, Furnier GR, Strauss SH, Xiang Q-Y, Plunkett GM, Soltis PS, Swensen SM, Williams SE, Gadek PA, Quinn CJ, Eguiarte LE, Golenberg E, Learn GH, Graham SW, Barrett SCH, Dayanandan S, Albert VA (1993) Phylogenetics of seed plants: An analysis of nucleotide sequences from the plastid gene rbcL. Annals of the Missouri Botanical Garden 80(3): 528–580. https://doi.org/10.2307/2399846

Chen J, Wang Y-J (2018) New *Saussurea* (Asteraceae) species from Bogeda Mountain, eastern Tianshan, China, and inference of its evolutionary history and medical usage. PLoS One 13(7): e0199416. https://doi.org/10.1371/journal.pone.0199416

Chen YS, Yuan Q (2015) Twenty-six new species of *Saussurea* (Asteraceae, Cardueae) from the Qinghai-Tibetan Plateau and adjacent regions. Phytotaxa 213(3): 159–211. https://doi.org/10.11646/phytotaxa.213.3.1

Chen J, Zhao Y, Wang Y, Li X (2019) Identification of species and materia medica within *Saussurea* subg. *Amphilaena* based on DNA barcodes. PeerJ 7: e6357. https://doi.org/10.7717/peerj.6357

Dariimaa S (2017) Flora of Mongolia. (Asteraceae–Asteroideae). Udam Soyol Publishing, Ulaanbaatar, 1–277. [in Mongolian]

Doyle JJ, Doyle JL (1987) A rapid DNA isolation procedure for small amounts of fresh leaf tissue. Phytochemical Bulletin 19(1): 11–15.

Grierson AJC, Springate LS (2001) Compositae (Asteraceae). In: Grierson AJC, Long DG, Springate LS (Eds) Flora of Bhutan, Vol. 2(3). Royal Botanic Garden, Edinburgh, 1397–1632.

Grubov VI (1982) Key to the vascular plants of Mongolia. Nauka Publishing, Leningrad, 1–443. [in Russian]

Gubanov IA (1996) Conspectus of the flora of Outer Mongolia. Valang Press, Moscow, 1–136. [in Russian]

Hajra PK (2000) *Saussurea costus* (Falc.) Lipschitz. In: Nayar MP, Sastry ARK (Eds) Red Data Book of Indian Plants, Vol. 2. Botanical Survey of India, New Delhi, 1–279.

Huelsenbeck JP, Ronquist F (2001) MRBAYES: Bayesian inference of phylogenetic trees. Bioinformatics (Oxford, England) 17(8): 754–755. https://doi.org/10.1093/bioinformatics/17.8.754

IUCN (2019) Guidelines for using the IUCN Red List Categories and Criteria. Version 12. Prepared by the Standards and Petitions Subcommittee. http://jr.iucnredlist.org/documents/RedListGuidelines.pdf [accessed 10.01.2020]

Julio R, Albert FM, Juan CSD, Sara GR, Pablo L, Sebastián ER, Alejandro SG (2017) DnaSP v6: DNA sequence polymorphism analysis of large datasets. Molecular Biology and Evolution 34(12): 3299–3302. https://doi.org/10.1093/molbev/msx248

Kamalpreet LK, Singh A, Kaur J, Kaur N (2019) A brief review of remedial uses of *Saussurea lappa*. Journal of Pharmacognosy and Phytochemistry 8(3): 4423–4430.

Kearse M, Moir R, Wilson A, Stones-Havas S, Cheung M, Sturrock S, Buxton S, Cooper A, Markowitz S, Duran C, Thierer T, Ashton B, Meintjes P, Drummond A (2012) Geneious Basic: An integrated and extendable desktop software platform for the organization and analysis of sequence data. Bioinformatics (Oxford, England) 28(12): 1647–1649. https://doi.org/10.1093/bioinformatics/bts199

Kumar S, Strecher G, Li M, Knyaz C, Tamura K (2016) MEGA 7: Molecular evolutionary genetics analysis version 7.0 for bigger datasets. Molecular Biology and Evolution 33(7): 1870–1874. https://doi.org/10.1093/molbev/msw054

Lipschitz S (1979) The genus *Saussurea* DC. (Asteraceae). Nauka Publishing, Leningrad, 1–281. [In Russian]

Mishra AP, Saklani S, Sharifi-Rad M, Iriti M, Salehi B, Maurya VK, Rauf A, Milella L, Rajabi S, Baghalpor N, Sharifi-Rad J (2018) Antibacterial potential of *Saussurea obvallata* petroleum ether extract: A spiritually revered medicinal plant. Cellular and Molecular Biology 64(8): 65–70. https://doi.org/10.14715/cmb/2018.64.8.10

Olmstead RG, Michaels HJ, Scott KM, Palmer JD (1992) Monophyly of the Asteridae and identification of their major lineages inferred from DNA sequences of rbcL. Annals of the Missouri Botanical Garden 79(2): 249–265. https://doi.org/10.2307/2399768

Oyuntsetseg B, Baasanmunkh S, Oyundelger K, Munkhzul O, Kim JY, Cho HJ, Batkhuu N, Chung GY, Choi HJ (2017) Contribution to the knowledge on the flora of Munkhkhairkhan mountain area, Mongolia. Journal of Asia-Pacific Biodiversity 10(4): 573–582. https://doi.org/10.1016/j.japb.2017.05.005

Oyuntsetseg B, Baasanmunkh S, Nyambayar D, Batkhuu N-O, Lee Ch, Chang KS, Chung GY, Choi HJ (2018) The conservation status of 100 rare plants in Mongolia. Korea National Arboretum, Pocheon.

Qureshi NA, Khalil AA, Alsanad SM (2018) Spiritual and religious healing practices: Some reflections from Saudi National Center for complementary and alternative medicine, Riyadh. Journal of Religion and Health 59(2): 845–869. https://doi.org/10.1007/s10943-018-0677-0

Raab-Straube EV (2017) Taxonomic revision of *Saussurea* subgenus *Amphilaena* (Compositae, Cardueae). Berlin: BGBM, Freie Universität Berlin.

Ronquist F, Huelsenbeck JP (2003) MrBayes 3: Bayesian phylogenetic inference under mixed models. Bioinformatics (Oxford, England) 19(12): 1572–1574. https://doi.org/10.1093/bioinformatics/btg180

Sang T, Crawford D, Stuessy T (1997) Chloroplast DNA phylogeny, reticulate evolution, and biogeography of *Paeonia* (Paeoniaceae). American Journal of Botany 84(8): 1120–1136. https://doi.org/10.2307/2446155

Semwal P, Painuli S (2019) Antioxidant, antimicrobial, and GC-MS profiling of *Saussurea obvallata* (Brahma Kamal) from Uttarakhand Himalaya. Clinical Phytoscience 5(1): 12. https://doi.org/10.1186/s40816-019-0105-3

Shi Z, Raab-Straube EV (2011) *Saussurea* Candolle. In: Wu ZY, Raven PH (Eds) Flora of China, Vol. 20. Beijing: Science Press, Beijing & Missouri Botanical Garden Press, St Louis, 56–149.

Shurupova MN, Zverev AA (2017) Conservation categories and rarity types of Siberian *Saussurea* species. The International Journal of Environmental Studies 74(5): 724–731. https://doi.org/10.1080/00207233.2017.1283937

Stamatakis A (2006) RAcML-VL-HPC: Maximum likelihood-based phylogenetic analysis with thousands of taxa and mixed models. Bioinformatics (Oxford, England) 22(21): 2688–2690. https://doi.org/10.1093/bioinformatics/btl446

Stamatakis A (2014) RAxML version 8: A tool for phylogenetic analysis and post-analysis of large phylogenies. Bioinformatics (Oxford, England) 30(9): 1312–1313. https://doi.org/10.1093/bioinformatics/btu033

Thiers B (2019+) [continuously updated] Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. http://sweetgum.nybg.org/ih/ [accessed 15.10.2019]

Thompson JD, Gibson TJ, Plewniak F, Jeanmougin F, Higgins DG (1994) The CLUSTAL_X windows interface: Flexible strategies for multiple sequence alignment aided by quality analysis tools. Nucleic Acids Research 25(24): 4876–4882. https://doi.org/10.1093/nar/25.24.4876

Urgamal M, Oyuntsetseg B (2017) Atlas of the endemic vascular plants of Mongolia. Bembi San Press, Ulaanbaatar, 1–107.

Urgamal M, Oyuntsetseg B, Nyambayar D, Dulamsuren C (2014) Conspectus of the Vascular Plants of Mongolia. In: Sanchir C, Jamsran T (Eds) Admon Press, Ulaanbaatar, 1–334.

Wang WJ, Susanna A, Raab-Straube EV, Milne R, Liu JQ (2009) Island-like radiation of *Saussurea* (Asteraceae: Cardueae) triggered by uplifts of the Qinghai-Tibetan Plateau. Biological Journal of the Linnean Society. Linnean Society of London 97(4): 893–903. https://doi.org/10.1111/j.1095-8312.2009.01225.x

White TJ, Bruns T, Lee S, Taylor JL (1990) Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. PCR Protocols: A Guide to Methods and Applications 18(1): 315–322. https://doi.org/10.1016/B978-0-12-372180-8.50042-1

PhytoKeys 160: 123–129 (2020)
doi: 10.3897/phytokeys.160.53937
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RESEARCH ARTICLE

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# A new taxon within *Biscutella laevigata* L. (Brassicaceae) endemic to calamine areas in southern Poland

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Academic editor: Peter de Lange | Received 5 May 2020 | Accepted 7 August 2020 | Published 8 September 2020

**Citation:** Wierzbicka M, Pielichowska M, Bemowska-Kałabun O, Rostański A, Wąsowicz P (2020) A new taxon within *Biscutella laevigata* L. (Brassicaceae) endemic to calamine areas in southern Poland. PhytoKeys 160: 123–129. https://doi.org/10.3897/phytokeys.160.53937

## Abstract

A new taxon *Biscutella laevigata* subsp. *woycickii* (Brassicaceae) is described from southern Poland. The taxon is similar to *B. laevigata* subsp. *gracilis*, but differs in having thin, light-green rosette leaves very densely covered by simple non-glandular trichomes, smaller seeds and the ability to tolerate and accumulate high amounts of heavy metals. This new taxon is supported by results of cultivation experiments, as well as genetic and paleobotanical evidence.

## Keywords

Biscutella, Biscutella laevigata subsp. woycickii, Brassicaceae, new subspecies, southern Poland, taxonomy

## Introduction

Heavy-metal-rich calamine soils have been attracting human attention for several thousand years. Initially, the total area occupied by these environments was limited to small, isolated outcrops of ore-bearing rocks. Usually these areas were easy to spot due to unique vegetation covering soils that naturally developed on a metal-rich rocky

substrate. Mining activities carried out in Europe since the Bronze Age (ca. 3 kyr BP) (Coulson 2012) contributed to a significant increase in the areas covered by calamine soils (nowadays represented mainly by mining waste heaps, riparian areas along rivers polluted by wastewater and sediments from ore-processing factories, mines etc.) and to the almost total destruction of the primary habitats of calamine vegetation (Baker et al. 2010). However, this huge, anthropogenic environmental change did not lead to the total extinction of all the plant taxa connected with calamine areas (Baker et al. 2010). On the contrary, while primary habitats of the calamine flora were destroyed, new and often more spacious environments have developed around the mining sites. Heaps of waste materials from early metal mines, which could not be easily colonised by other plants due to the very high content of zinc and lead, became ideal refugia for calamine-adapted plants.

Heavy-metal-polluted calamine soils and natural processes that resulted in the development of metal-tolerant vegetation covering such places have been at the focus of attention for many scholars since the beginning of the 20th century (Baker et al. 2010). Soon this research demonstrated that calamine areas host unique plant taxa that are often endemic. In Europe, a number of such taxa have already been formally recognised. Examples of these taxa include: *Viola calaminaria* (DC. ex Ging.) Lej., *Noccaea caerulescens* (J.Presl & C.Presl) F.K.Mey. subsp. *calaminaris* (Lej.) Holub and *Armeria alpina* Willd. subsp. *halleri* (Wallr.) Nyman.

In the vicinity of Olkusz (southern Poland), there is an old mining area with lead and zinc mining activities dating back to the 12th century (Molenda 1984). Until the end of the 20th century, open, shallow pits were used to excavate Zn-Pb ores that were located close to the ground level (Szarek-Łukaszewska et al. 2015). During the 900 years of ore exploitation, natural sites of calamine vegetation have been completely erased, but the rich and diverse calamine flora can be found in secondary habitats in the vicinity of Olkusz. Calamine grasslands occurring there on old mining waste heaps have been studied by biologists since the beginning of the 20th century (Wóycicki 1913).

In this paper, we argue that a new taxon endemic to calamine areas close to Olkusz in southern Poland deserves formal recognition at a subspecies level within *Biscutella laevigata* L.

## Materials and methods

The study is based on field surveys, laboratory studies including experiments under controlled growing conditions, as well as on genetic analyses. Results of these studies have already been published in several papers dealing with ecology and physiology of *B. laevigata* from calamine areas. Detailed descriptions of experiments carried out by us can be found especially in papers by Wierzbicka and Pielichowska (2004) and Wasowicz et al. (2014). We also undertook an extensive review of literature and all relevant data from already published studies are also cited in our paper.

## Taxonomy

***Biscutella laevigata* L. subsp. *woycickii* M.Wierzb., Pielich. & Wasowicz, subsp. nov.**
urn:lsid:ipni.org:names:77211421-1
Figure 1

**Type.** Poland. Olkusz, 1922, R. Kobendza, s.n. (holotype, WA0000071422 !).

**Diagnosis.** *Biscutella laevigata* subsp. *woycickii* is similar to subsp. *gracilis*, but differs from the latter in having thin, light-green rosette leaves very densely covered by simple non-glandular trichomes. Plants belonging to subsp. *woycickii* have smaller seeds and are characterised by the ability to tolerate and accumulate high quantities of heavy metals.

**Etymology.** This subspecies is dedicated to a renowned Polish botanist Zygmunt Wóycicki (1871–1941), a pioneer of biological research on calamine areas.

**Distribution and ecology.** Calamine areas in the vicinity of Olkusz, Powiat Olkuski (Olkusz County), Województwo Małopolskie (Lesser Poland Voivodeship/ Province), southern Poland.

**Phenology.** Flowering in April–May, fruiting in July–August.

**Chromosome number.** A study carried out by Skalińska (1950) on plants from the calamine population in the vicinity of Olkusz resulted in the diploid chromosome number, $2n = 18$.

**Preliminary conservation status.** Currently, the taxon is known only from calamine areas in the vicinity of Olkusz, where it is quite abundant on calamine soils. The extent of occurrence (EOO) of the taxon is 7 km$^2$ and the area of occupancy (AOO) is 14 km$^2$. A steady decline in population size has been observed during the last 20 years. It seems that the new taxon could be classified as Vulnerable according to the IUCN criteria (Standards IUCN 2019), but more research is needed to estimate the number of mature individuals and population dynamics.

## Discussion

The morphological and geographic distinctiveness of *B. levigata* populations from the Olkusz Ore Bearing Region have been recognised by botanists already in the 19$^{th}$ century (Zalewski 1886, Wóycicki 1913, Zając 1996), but the detailed morphological, anatomical and physiological studies on the problem were initiated only at the beginning of 21$^{st}$ century. The research, carried out by us previously and already published, demonstrated that a significant amount of morphologic, physiologic and genetic differentiation exists between the isolated population of *B. laevigata* from the calamine areas near Olkusz (S Poland) and the nearest mountainous populations located in the Tatra Mountains and belonging to subsp. *gracilis*. We determined that the calamine population differs from subsp. *gracilis* in having light-green, thin rosette leaves densely covered by simple epidermal hair (Wierzbicka and Pielichowska 2004) (Fig. 2A–C). Our research has also demonstrated that the calamine morphotype has smaller seeds


**Figure 1.** A holotype of *Biscutella laevigata* subsp. *woycickii* Wierzbicka, Pielichowska & Wasowicz (WA0000071422).

(as compared to subsp. *gracilis*) and shows an intense formation of daughter rosettes through vegetative reproduction (Fig. 2D). Furthermore, we identified the presence of pronounced physiological differences, including increased tolerance to Zn, Pb and Cd

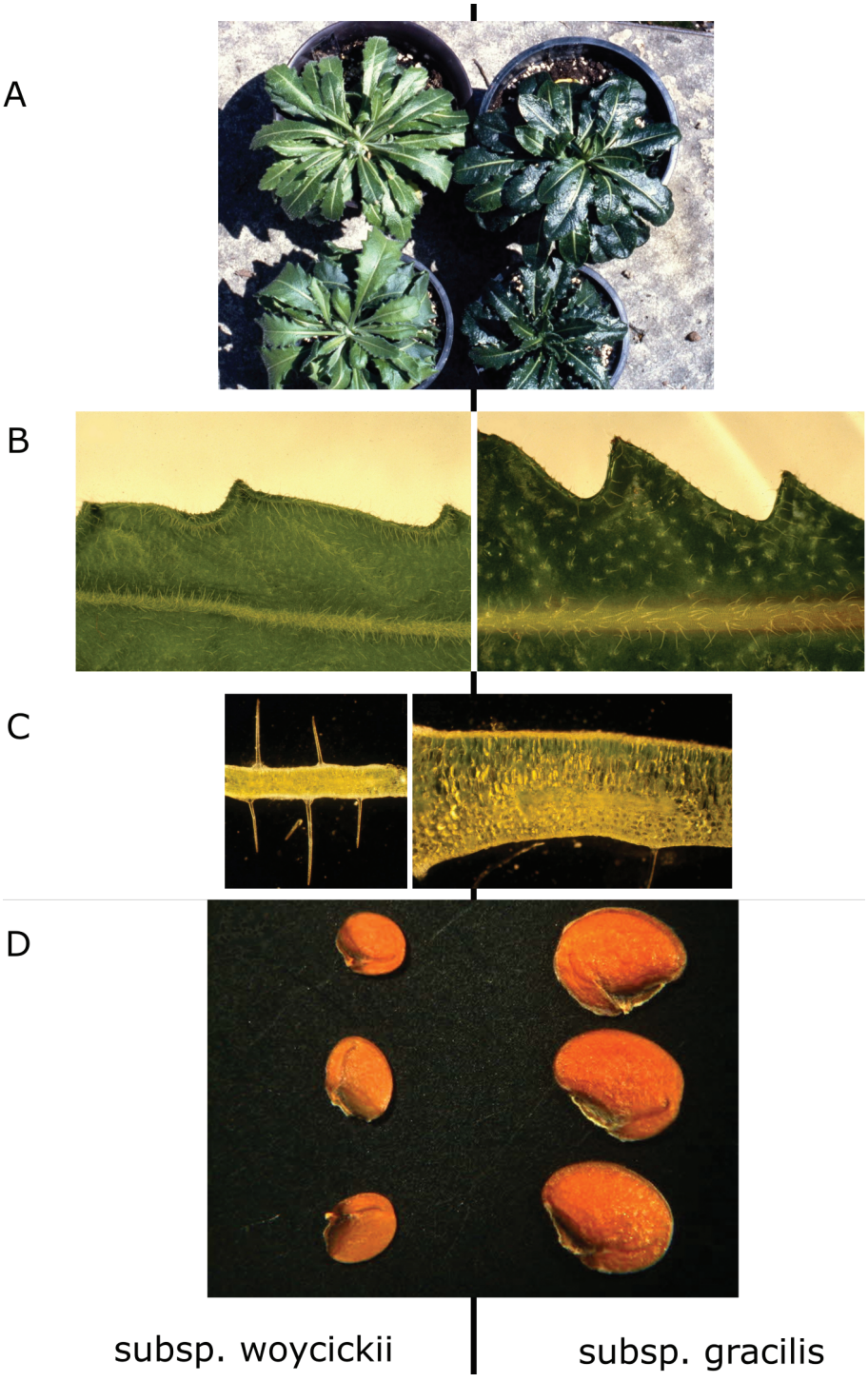


**Figure 2.** Comparison of morphological characters in *Biscutella laevigata* subsp. *woycickii* subsp. nov. and *B. laevigata* subsp. *gracilis*: **A** rosette leaves **B** leaf trichomes (both images at the same scale) **C** cross-section of the leaf blade (both images at the same scale) **D** seeds.

present in the calamine population (Wierzbicka and Pielichowska 2004). Our previous research showed that this differentiation is not merely a result of phenotypic plasticity. The phenotypic differentiation was stable and preserved when plants were grown in the greenhouse under standard conditions (Wierzbicka and Pielichowska 2004) (Fig. 2). Genetic analyses, carried out using Amplified Fragment Length Polymorphisms (AFLPs), showed that a strong genetic differentiation exists between calamine populations and the nearest natural populations located in the Western Carpathians (Wasowicz et al. 2014) and there are no signs of gene flow between these two areas. No evident signs of a bottleneck effect were evidenced by AFLP (Wasowicz et al. 2014). The DW Index (Schönswetter and Tribsch 2005), measuring the genetic divergence, was high in the calamine population, suggesting their long-term isolation (Wasowicz et al. 2014).

The paleobotanical study carried out in the near vicinity clearly suggests that calamine populations in the area of Olkusz could have originated before the Last Glacial Maximum (LGM) from local, interglacial populations. The presence of the species in the region has been determined by Szafer (1930), who, during his research in Ludwinow (about 40 km SE from Olkusz), found fossil siliques of *Biscutella laevigata* dating back to the Weichselian glaciation in Northern Europe (115–11.7 kyr BP, mainly corresponding to the Würm glaciation in the Alps and the Valdai glaciation in Eastern Europe).

A recently published study, carried out on local populations in southern Poland and focused on population genetic structure using nine nuclear micro-satellite loci (Babst-Kostecka et al. 2014), fully agrees with the paleobotanical data and our AFLP results (Wasowicz et al. 2014). Babst-Kostecka et al. (2014) concluded that the local calamine population in the vicinity of Olkusz originated as a result of an old vicariance predating the Last Glacial Maximum.

All these findings have led us to propose a hypothesis that the calamine population of *B. laevigata* from Olkusz Ore Bearing Region is a descendant of an ancient relict population that, through development of a series of adaptations to heavy metal stress, colonised natural calamine areas in the vicinity of Olkusz and, subsequently (when natural calamine sites were destroyed due to mining activities), also secondary sites (Wasowicz et al. 2014). Taking the above-mentioned differences into account, we argue that the morphotype from calamine areas in the vicinity of Olkusz should be formally recognised at subspecies level.

## References

Babst-Kostecka AA, Parisod C, Godé C, Vollenweider P, Pauwels M (2014) Patterns of genetic divergence among populations of the pseudometallophyte *Biscutella laevigata* from southern Poland. Plant and Soil 383(1–2): 245–256. https://doi.org/10.1007/s11104-014-2171-0

Baker AJM, Ernst WHO, van der Ent A, Malaisse F, Ginocchio R (2010) Metallophytes: the unique biological resource, its ecology and conservational status in Europe, central Africa and Latin America. In: Batty LC, Hallberg KB (Eds) Ecology of Industrial Pollution. Cambridge University Press, Cambridge, 7–40. https://doi.org/10.1017/CBO9780511805561.003

Coulson M (2012) The history of mining: The events, technology and people involved in the industry that forged the modern world. Harriman House Limited, 600 pp.

Molenda D (1984) Der polnische Bleibergbau und seine Bedeutung für den europäischen Bleimarkt vom 12. bis 17. Jahrhundert. In: Kroker W, Westermann E (Eds) Montanwirtschaft Mitteleuropas vom 12. bis 17. Jahrhundert: Stand, Wege und Aufgaben der Forschung. Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum, Bochum, 187–198.

Schönswetter P, Tribsch A (2005) Vicariance and dispersal in the alpine perennial *Bupleurum stellatum* L. (Apiaceae). Taxon 54(3): 725–732. https://doi.org/10.2307/25065429

Skalińska M (1950) Studies in chromosome numbers of Polish Angiosperms. Acta Societatis Botanicorum Poloniae 20(1): 45–68. https://doi.org/10.5586/asbp.1950.003

Standards IUCN (2019) Guidelines for Using the IUCN Red List Categories and Criteria. Version 14. Prepared by the Standards and Petitions Committee. http://www.iucnredlist.org/documents/RedListGuidelines.pdf

Szafer W (1930) Element górski we florze niżu polskiego (The mountain element in the flora of the Polish Plain) Rozprawy Wydziału Matematyczno-Przyrodniczego, Polska Akademia Umiejętności 69, Seria III 29. Dział B 3: 1–112.

Szarek-Łukaszewska G, Nowak T, Grodzińska K, Kapusta P, Godzik B (2015) Przyroda Olkuskiego Okręgu Rudnego. In: Wierzbicka M (Ed.) Ekotoksykologia: rośliny, gleby, metale. Wydawnictwo Uniwersytetu Warszawskiego, Warszawa, 163–174.

Wasowicz P, Pielichowska M, Przedpelska-Wasowicz EM, Bednarek P, Szarek-Łukaszewska G, Abratowska A, Wierzbicka M (2014) Physiological and genetic differentiation between metallicolous and non-metallicolous diploid populations of alpine *Biscutella laevigata* (Brassicaceae) in the Tatra Mountains and the northern Carpathian foreland. Annales Botanici Fennici 51: 227–239. http://www.sekj.org/PDF/anbf51/anbf51-227.pdf

Wierzbicka M, Pielichowska M (2004) Adaptation of *Biscutella laevigata* L., a metal hyperaccumulator, to grow on a zinc-lead waste heap in southern Poland. I: Differences between waste-heap and mountain populations. Chemosphere 54: 1663–1647. https://doi.org/10.1016/j.chemosphere.2003.08.031

Wóycicki Z (1913) Roślinność terenów galmanowych Bolesławia i Olkusza. Obrazy roślinności Królestwa Polskiego. Kasa Mianowskiego, Warszawa, 1–56.

Zając M (1996) Mountain vascular plants in the Polish lowlands. Polish Botanical Studies 11: 1–92.

Zalewski A (1886) Zapiski roślinnicze z Królestwa Polskiego i z Karpat. Sprawozdania Komisji Fizjograficznej Akademii Umiejętności, vol. 20. Polska Akademia Umiejętności, Kraków, 1–20.

PhytoKeys 160: 131–139 (2020)
doi: 10.3897/phytokeys.160.54993
http://phytokeys.pensoft.net

RESEARCH ARTICLE

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# A new rare and endemic species of *Sloanea* (Elaeocarpaceae) from the Chocó region of Ecuador

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Academic editor: Hugo De Boer | Received 3 June 2020 | Accepted 10 August 2020 | Published 8 September 2020

**Citation:** Guevara Andino JE, Fernandez-Fernandez D (2020) A new rare and endemic species of *Sloanea* (Elaeocarpaceae) from the Chocó region of Ecuador. PhytoKeys 160: 131–139. https://doi.org/10.3897/phytokeys.160.54993

**Abstract**

A new species collected in the lowland forests of the Chocó region of Ecuador, *Sloanea cayapensis*, is described and illustrated and its morphological similarities with other species of *Sloanea* are discussed.

**Keywords**

Chocó, Ecuador, endemic, lowland humid forest, *Sloanea*

## Introduction

The genus *Sloanea* L. is the second largest within the family Elaeocarpaceae and comprises approximately 200 species in the tropics and more than 120 species in the Neotropics (Smith 1954; Smith 2001; Sampaio 2009). Smith (1954) proposed that the centre of diversity for this group is the northern portion of the Amazon basin, including the Guiana Shield, but the genus is as diverse in Central and Western Amazonia as in the previously mentioned region (Castañeda 1981; Boeira 2010).

The most recent taxonomic study of *Sloanea* in Ecuador revealed that 25–30 species of the genus occur in the country (Jaramillo 2003, Pennington and Wise 2017) and this number has increased with recent new descriptions (Guevara Andino et al. 2016; Guevara Andino et al. 2017). The genus is very diverse in Amazon lowland

forests and in the Chocó forests on Ecuador's Pacific coast. As the southernmost extension of Colombia's Chocó forests, Ecuador's coastal Chocó is strikingly diverse (Gentry 1982) but remains poorly studied, despite several new species of the genus having been recently described (Palacios-Duque 2004a, b, 2005).

## Materials and methods

We describe a new species of *Sloanea* from the Ecuadorian Chocó region, based on an analysis of morphological characters from material deposited in four Ecuadorian herbaria: the Herbario de la Pontificia Universidad Católica del Ecuador (**QCA**), Herbario Nacional del Ecuador (**QCNE**), Herbario Alfredo Paredes (**QAP**) and Herbario Amazónico del Ecuador (**ECUAMZ**). We also compared the new species with images of type specimens deposited in JStor and reviewed voucher specimens in the virtual herbaria of the Field Museum (F), the New York Botanical Garden (**NY**), the Herbario Nacional de Colombia (**COL**) and the Herbário do Instituto Nacional de Pesquisas da Amazônia (**INPA**); herbaria abbreviations follow Thiers 2016. In this work, we used the sub-generic classification developed by Smith (1954) for the circumscription of the new taxa. Earlier works have demonstrated that a single diagnostic character, the position of the calyx in relation to the bud, is the only consistent character in the group and may be considered diagnostic for the circumscription of taxa to the subgenus level (Sampaio 2009; Guevara Andino et al. 2016).

## Taxonomic treatment

***Sloanea cayapensis*** **J.Jaram. & J.E. Guevara, sp. nov.**
urn:lsid:ipni.org:names:77211422-1
Figs 1–4

**Diagnosis.** *Sloanea cayapensis* resembles *S. grandiflora* Smith and *S. fragrans* Rusby, the most morphologically similar taxa, but can be differentiated from them by having short petioles (2–7.5 cm), obovate-spatulate leaves, 6–8 free sepals, shorter thick and acute-obtuse anthers (1.5–2 mm), densely hirsute filaments and styles and by having capsules with large, flexible, curled bristles (2.8–6 cm).

**Type.** Ecuador. Esmeraldas: Borbón-Río Cayapas, 78°50'W, 1°5'S, 10 m elev., 3 May 2003, *Jaime Jaramillo, A. Sola, S. Yandun 24200* (holotype [2 sheets]: QCA7007914! (fl, fr); QCA7007917!; isotypes QCA7007915!,QCA7007916! (fl), QCA204513!).

Medium-sized trees up to 15–18 m tall. Trunk striated, bark rough, brownish. Branchlets glabrous, quadrangular and covered by ovoid, cream-coloured lenticels. Leaves alternate; petioles 2–7.5 cm long, semi-terete, striated, shortly pubescent, thickened at the insertion with the blade; blades (18.8–)42–52(–61.8) cm long, (9.5–)17–26(–32) wide, coriaceous obovate-spatulate, attenuate-subcordate or rounded at base,

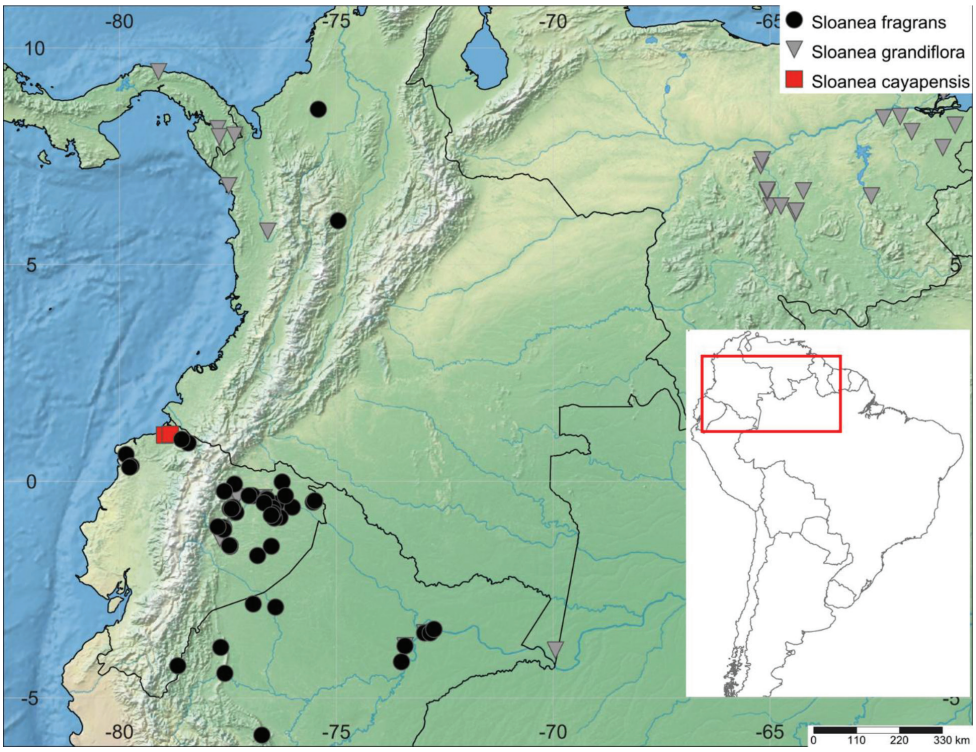


**Figure 1.** Map of the geographic distribution of *Sloanea cayapensis* J. Jaramillo ex J.E. Guevara, sp. nov. (red squares), *Sloanea fragrans* Rusby (black circles) and *Sloanea grandiflora* Sm. (grey inverted triangles).

obtuse-retuse at apex, the margins entire, slightly revolute; foliaceous stipules persistent at the top of the individual branchlets, 3.9–13 cm long, 2.1–3.9 cm wide, elliptical with acuminate apex, the margin entire or shallowly sinuate; primary vein prominent on the adaxial surface, very prominent and angular on the abaxial surface, secondary venation eucamptodromous, 11–20 secondary veins, prominent on the abaxial surface and ascendant (angle > 45°), flat on the adaxial surface, tertiary veins prominent on the abaxial surface, slightly flat on the adaxial surface. Inflorescence axillary, racemose; peduncles 2–6 cm long; rachis 5–18.5 cm long, slightly pubescent, deeply striated and quadrangular; pedicels 1–7 cm, stout, shortly pubescent, finely striate and quadrangular, pedicels, 1–1.5 cm long, navicular bracts at the base of individual pedicels, 4–4.5 mm long, dense appressed pubescence on both abaxial and adaxial surfaces, apex acute, commonly deciduous. Flowers with the receptacle large, expanded; sepals 6–8, free, 3–5 mm long, 2.5–3 mm wide, greenish coloured, ovate, apex acute-acuminate, margins entire, slightly involute, yellow on the outer surface, not covering the reproductive organs before anthesis. Stamens 5–6 mm long, yellow with orange anthers; filaments 3–3.5 mm long, densely hirsute, striated and angulate; anthers 1.5–2 mm long, densely hirsute, thick, the connective thin on the abaxial surface of the anther


**Figure 2.** *Sloanea cayapensis*. Image from the holotype at QCA (*J. Jaramillo 24200*).

sacs, extended as an acute or obtuse awn, very short, up to 0.5 mm long; anther sacs not opening widely along entire length. Ovary 2–4 mm long, 1.5–2.7 wide, with four locules, 4-angled, ovoid, densely hirsute; placentation axillary; style to 8 mm long, densely hirsute at the base, becoming sparsely hirsute towards the apex. Fruits globose capsules


**Figure 3.** *Sloanea cayapensis*. Image from the holotype at QCA (*J. Jaramillo 24200*).

1.2–2.5 cm long, 1–2 cm wide, rounded, opening by 4 rigid valves; bristles 2.8–6 cm long, curled, contorted and flexible, laterally flattened, densely hirsute at the base, more sparse and appressed pubescence towards the apex, easily detached. Seeds not studied.

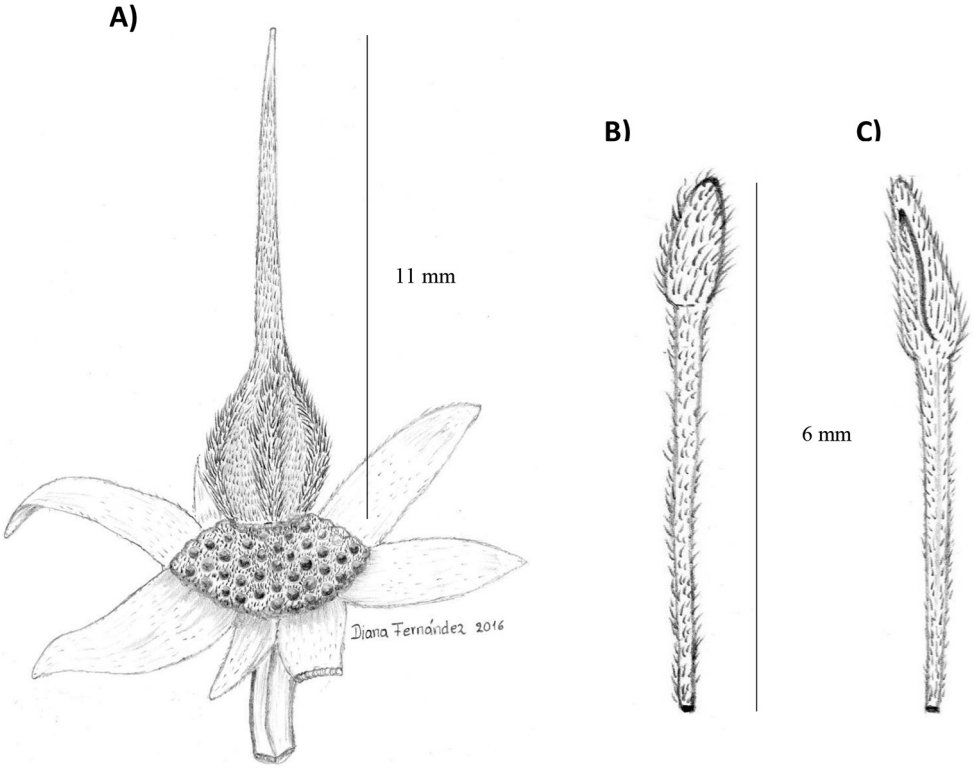


**Figure 4.** *Sloanea cayapensis* **A** detail of ovary and sepals **B** dorsal view of stamen **C** ventral view of stamen (**A–C** from *J. Jaramillo 24200* QCA).

**Specimens examined.** ***Paratypes.*** Ecuador: Esmeraldas: La Chiquita, bosque secundario, 45 m elev., *Jaime Jaramillo* 24422 (QCA-236170!); Esmeraldas: Localidad Borbón, entre Punta Piedra y Maldonado, 78°58'W, 1°4'S, 60 m elev., febrero 13 de 1993, *Jaime Jaramillo 15016* (QCA-204514!).

**Distribution and habitat.** *Sloanea cayapensis* is a medium-sized tree only known from two localities on high alluvial terraces along the Cayapas River in the Lowland Evergreen Forests of Equatorial Chocó (Ministerio del Ambiente del Ecuador 2013). This area lies in the Chocó floristic province, where forest structure is characterised by a canopy 25–30 m high, with occasional emergent trees reaching 40 m. High levels of endemism and dominance of families, such as Moraceae, Fabaceae, Meliaceae, Myristicaceae and Lecythidaceae, have been reported for this area (Gentry 1982; Ministerio del Ambiente del Ecuador 2013) and the label of the type specimen indicates that *S. cayapensis* co-occurs with the following tree species: *Terminalia amazonia* (Combretaceae), *Swartzia littlei* (Fabaceae), *Matisia cordata* (Malvaceae) and *Cordia alliodora* (Boraginaceae). The climate of this area is rainy near the Ecuador-Colombia border and becomes more seasonal to the south, where it transitions into the Lowland Seasonal Evergreen Forests of the Equatorial Chocó (Ministerio del Ambiente del Ecuador 2013).

**Etymology.** From the Spanish word Cayapa, with reference to the Chachi indigenous group that inhabits a great portion of the evergreen lowland forests of the Equatorial Chocó in Ecuador. The word Chachi means 'pure' in the Cha'palaachi language. The species name was first proposed by the late Ecuadorian botanist J. Jaramillo as a written annotation on herbarium specimens, but was never validly published.

**Conservation status.** *Sloanea cayapensis* may be catalogued as Endangered (EN) following IUCN (2012) criterion A2c, which indicates: "An observed, estimated, inferred or suspected population size reduction of ≥ 50% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased or may not be understood or may not be reversible" and criterion B1ab(iii), which indicates: "Extent of occurrence (EOO) estimated to be less than 5,000 km$^2$ and estimates indicating continuing decline, observed, inferred or projected, in area, extent and/or quality of habitat". The analysis using the GeoCat tool for geospatial conservation assessment determined an EOO of 2000 km$^2$ (Bachman et al. 2011). *Sloanea cayapensis* is only known from two localities on the banks of the Cayapas River, in the lowland evergreen forest of the Equatorial Chocó. The area has suffered extensive clear-cutting in the last 30 years, leading to a drastic reduction of native forests and expansion of oil palm plantations and illegal logging, these being the major threats faced by the species. Since collection of the types in 2003, no other specimens of this species have been recorded despite the fact that subsequent field trips have sampled the same habitat occupied by this species. Over the last 26 years, the annual rate of deforestation in the lowland evergreen forest of the Equatorial Chocó in Ecuador has been 1.7–2.9% and the remnant forests in this area cover just 24% of their original extent (Sierra 2013). Consequently, the habitat occupied by this species in Ecuador has been drastically reduced. However, the species is likely to occur in similar habitats in the Colombian Chocó where the dynamic of deforestation is less drastic but a cause for concern.

## Discussion

Based on our description, *Sloanea cayapensis* is morphologically similar to *S. grandiflora* and *S. fragrans*, both members of the subgenus *Sloanea*. The new species can be readily distinguished from *S. fragrans* by having longer (3–3.5 mm vs. 1.5–2 mm long) and densely hirsute angle-striated filaments (vs. cylindrical puberulent filaments). It also differs from *S. fragrans* by having shorter anthers (1.5–2 mm vs. 2–3 mm long), acute or obtuse awn-shaped (vs. lanceolate) anthers densely hirsute (vs. glabrous to sub-glabrous), lanceolate stipules with entire margins (vs. navicular with remarkable irregular serrate margins) and shorter petioles (2–7.5 cm vs. 5.5–20(–25) cm long) (see Table 1).

*Sloanea cayapensis* is distinguished from *S. grandiflora* in having a densely hirsute style (vs. glabrous style at the apex and slightly pubescent at the base), thin connective (vs. very wide connective between the anthers sacs on the abaxial surface), thick and obtuse anthers (vs. linear-lanceolate) and an ovoid and densely hirsute ovary with 4 locules (vs. pubescent ovary with 4–6 locules). It also differs from *S. grandiflora* in

**Table 1.** Diagnostic characters for *Sloanea cayapensis* and its closest relatives, as well as their geographical distribution in the Neotropics: Western Amazon (WA), Central Amazon (CA), Chocó region (Chocó), Central America (CAm) and the Guiana Shield (GS).

| Characters | *Sloanea cayapensis* | *Sloanea grandiflora* | *Sloanea fragrans* |
|---|---|---|---|
| Leaf size | (18.8–)42–52(–61.8) long, (9.5–)17–26(–32) cm wide | 21–43.5 cm long, 15–25.5 cm wide | 45–65 cm long, 21–29.5 cm wide |
| Leaf shape | Obovate-spatulate | Elliptic to elliptic-bovate | Obovate |
| Leaf margins | Entire to shallowly sinuate | Irregularly dentate | Irregularly undulate |
| Stipules | Lanceolate with entire margins | navicular with irregular serrate margins | navicular with finely dentate margins |
| Stamens | 5–6 mm long | 7–9 mm long | 4–8 mm long |
| Filaments | 3–3.5 mm long densely hirsute angle-striated | 2–4 mm long angled or laterally flattened | 1.5–2 mm long cylindrical puberulent |
| Anthers | 1.5–2 mm long, thick and obtuse | 3–4 mm long, linear-lanceolate | 2–3 mm long, lanceolate |
| Ovary | Ovoid, 2–4 mm long, 1.5–2.7 mm wide | Ovoid, 4 mm long, 2.5 mm wide | Globose, 3 mm long, 3 mm wide |
| Style | Densely hirsute in its entire length up to 8 mm long | Pubescent at the base glabrous above, 7–9 mm long | Pubsecent in its entire length, 5–10 mm long |
| Capsule | Globose densely covered by curled flexible spines | Ellipsoidal covered by stramineous flexible curled spines | Globose densely covered by short spines |
| Elevation | 0–500 m | 0–1500 m | 0–1100 m |
| Geographic distribution | Chocó | WA, CA, GS and CAm | WA and CAm |

having lanceolate stipules (vs. navicular stipules with finely dentate margins), shorter pedicels (4–11 mm vs. 7–25 mm) and strongly ascendant numerous secondary veins (11–20 vs. 13–15 slightly ascendant secondary veins).

## Acknowledgements

We thank the staff at the herbaria ECUAMZ, QCA, QAP and QCNE for their support and permission to access material deposited in these institutions. This work honours Jaime Jaramillo Asanza, a professor in the Biology Department at the Catholic University of Ecuador who made a great contribution to our knowledge of the Ecuadorian flora and who started a taxonomic revision of the genus *Sloanea* for Ecuador. Katya Romoleroux provided insightful comments to earlier versions of the manuscript.

## References

Bachman S, Moat J, Hill AW, de Torre J, Scott B (2011) Supporting Red List threat assessments with GeoCAT: Geospatial conservation assessment tool. ZooKeys 150: 117–126. https://doi.org/10.3897/zookeys.150.2109

Boeira ASP (2010) O gênero *Sloanea* L. (Elaeocarpaceae) na Reserva Florestal Adolpho Ducke. Dissertação de mestrado, Instituto Nacional de Pesquisas da Amazonia, Manaus.

Castañeda MDA (1981) Revisão taxonômica do gênero *Sloanea* Linnaeus (Elaeocarpaceae) na Amazônia Brasileira. Dissertação de mestrado, Fundação Universidade do Amazonas/ Instituto Nacional de Pesquisas da Amazonia, Manaus.

Gentry AH (1982) Phytogeographic patterns as evidence for a Chocó refuge. In: Biological Diversification in the Tropics. In: Prance GT (Ed.) Columbia University Press, New York, 112–136.

Guevara J, Pitman NCA, Mogollón H, García-Villacorta R, Cerón C, Palacios W (2009) Floristic variation in Ecuadorian Amazonia terra firme tree communities. Cinchonia 9(1): 75–93.

Guevara Andino JE, Fernandez-Fernandez D, Palacios WA (2016) A new species of Sloanea (Elaeocarpaceae) subgenus Quadrisepala from Ecuadorian Amazonia. Phytotaxa 263(2): 147–153. https://doi.org/10.11646/phytotaxa.263.2.7

Guevara Andino JE, Fernandez-Fernandez D, Pitman NCA (2017) An undescribed and overlooked species of Sloanea (Elaeocarpaceae) from the Ecuadorian Amazon. Brittonia 70(2): 221–226. https://doi.org/10.1007/s12228-017-9511-3

IUCN (2012) IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, [iv +] 32 pp.

Jaramillo J (2003) La taxonomía del género *Sloanea* L. (Elaeocarpaceae) en Ecuador. Ph.D. thesis. Pontíficia Universidad Católica del Ecuador, Quito.

Ministerio del Ambiente del Ecuador (2013) Sistema de Clasificación de los Ecosistemas del Ecuador Continental. Subsecretaría de Patrimonio Natural. Quito.

Palacios-Duque L (2004a) Dos nuevas especies de *Sloanea* (Elaeocarpaceae) del Chocó (Colombia). Caldasia 26(2): 429–432.

Palacios-Duque L (2004b) Una nueva especies de *Sloanea* (Elaeocarpaceae) del Chocó (Colombia). Hickenia 3(49): 201–204.

Palacios-Duque L (2005) *Sloanea pacuritana* Pal.-Duque, sp. nov. (Elaeocarpaceae) del Chocó (Colombia). Anales del Jardin Botanico de Madrid 62(2): 191–193. https://doi.org/10.3989/ajbm.2005.v62.i2.23

Pennington TD, Wise R (2017) The genus Sloanea (Elaeocarpaceae) in America. dh Books, England, 432 pp.

Sampaio D (2009) Revisão taxonômica das espécies neotropicais extra-amazônicas de *Sloanea* L. (Elaeocarpaceae) na América do Sul. PhD thesis, Universidade Estadual de Campinas, Instituto de Biologia, Campinas/SP, Brazil.

Sierra R (2013) Patrones y factores de deforestación en el Ecuador continental, 1990–2010. Y un acercamiento a los próximos 10 años. Conservación Internacional Ecuador y Forest Trends. Quito.

Smith CE (1954) The new world species of *Sloanea* (Elaeocarpaceae). Contr. Gray Herb. 175: 1–144.

Smith DA (2001) Elaeocarpaceae. In: Stevens WD, Ulloa-Ulloa C, Pool A, Montiel OM (Eds) Flora de Nicaragua (Vol. 1). Acanthaceae-Euphorbiaceae. Monographs in systematic botany from the Missouri Botanical Garden 85: 816–820.

Thiers B (2016 onwards) Index Herbariorum. A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. http://sweetgum.nybg.org/science/ih