

The Cuito catchment of the Okavango system: a vascular plant checklist for the Angolan headwaters

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Abstract

This paper aims to provide a baseline for conservation planning by documenting patterns of plant diversity and vegetation in the upper catchment of the Cuito River. 417 species are recorded from this region. Nine of these are species potentially new to science. Ten species are newly recorded from Angola, with an additional species only recorded previously within Angola from the northern enclave of Cabinda. The 108 new provincial records for Moxico clearly indicate the lack of collections from Angola's largest province. We note the existence of extensive peat deposits in the Cuito river system for the first time and suggest that one of Barbosa's vegetation types in the area needs to be reassessed.

Keywords

Angola, Botswana, Cuando Cubango, Moxico, peat deposits, Namibia

Introduction

Internationally famous for its wildlife, the Okavango Delta wetland in northern Botswana was the 1000th World Heritage Site to be designated by UNESCO and is surrounded by desert. The hydrology and ecology of the Delta are dependent entirely on rainfall in the highlands of central Angola, and the flow of water south and east through the Okavango's two principal tributaries, the Cuito and Cubango rivers. The Cubango system has been studied extensively in recent years (Oldeman et al. 2013), but little attention has been paid to biodiversity or conservation of the Cuito drainage.

Central and eastern Angola is overlain by deep Kalahari sands formed from uplifted and reworked deposits of an ancient palaeo-lake. The upper catchment of the Cuito and Cuanavale rivers falls mostly within Moxico Province where the plateau lies at an altitude of around 1500m, and the rivers have cut down to an elevation of around 1350 m. The landscape receives rainfall of approximately 1250 mm a year in the headwater lakes region, dropping to around 750 mm at the southern limits of the core study area which is marked by the Menongue – Longa – Cuito Cuanavale road in Cuando Cubango Province. The rainy season lasts from November to April and soils are highly leached. In consequence, they support very little agriculture (Diniz 1973).

Barbosa (1970) assigned the vegetation of the region stretching from just east of Camacupa [General Machado] to Luena [Luso] and south to Longa to vegetation type 17A. This he described as dense, high, mixed (Zambesian and Congolian) miombo woodland with “chanas” or geoxylic-rich grasslands. According to Barbosa, these woodlands comprise *Brachystegia* species (*B. spiciformis* Benth. and *B. longifolia* Benth.) and *Julbernardia paniculata* (Benth.) Troupin, with some *Guibourtia* species, *Cryptosepalum* species and *Marquesia* species. Around Longa, the vegetation transitions into Barbosa's vegetation type 24, which he describes as a mosaic of savanna, woodland and dry forest with characteristic woody vegetation containing *Brachystegia bakeriana* Hutch. & Burt Davy and *Burkea africana* Hook.

White (1977) drew attention to the high rainfall highly leached Kalahari sand system and its peculiar flora in a seminal paper on the underground forests of Africa, extrapolating from his knowledge of similar habitats in north-west Zambia. But detailed surveys of the flora of this region are lacking.

Angola is the least intensively inventoried country in southern Africa for plants (Goyder and Gonçalves in press) – this can be seen graphically in the paucity of plant distribution records for the country (Fig. 1) at the start of the National Geographic Okavango Wilderness Project series of expeditions in 2015. Not only is the whole country under-recorded in terms of plants, but the eastern half of the country has very little geo-referenced specimen data (Marshall et al. 2016, Stropp et al. 2016, Sosef et al. 2017). Early collectors such as the Austrian botanist Friedrich Welwitsch collected along the coast, and along routes into the interior as far as Malange Province in the north and the Huíla Plateau in the south, but no further east (Albuquerque 2008, Goyder and Gonçalves in press). Swiss botanist John Gossweiler collected in all of Angola's provinces over the course of fifty years but spent very little time in central and

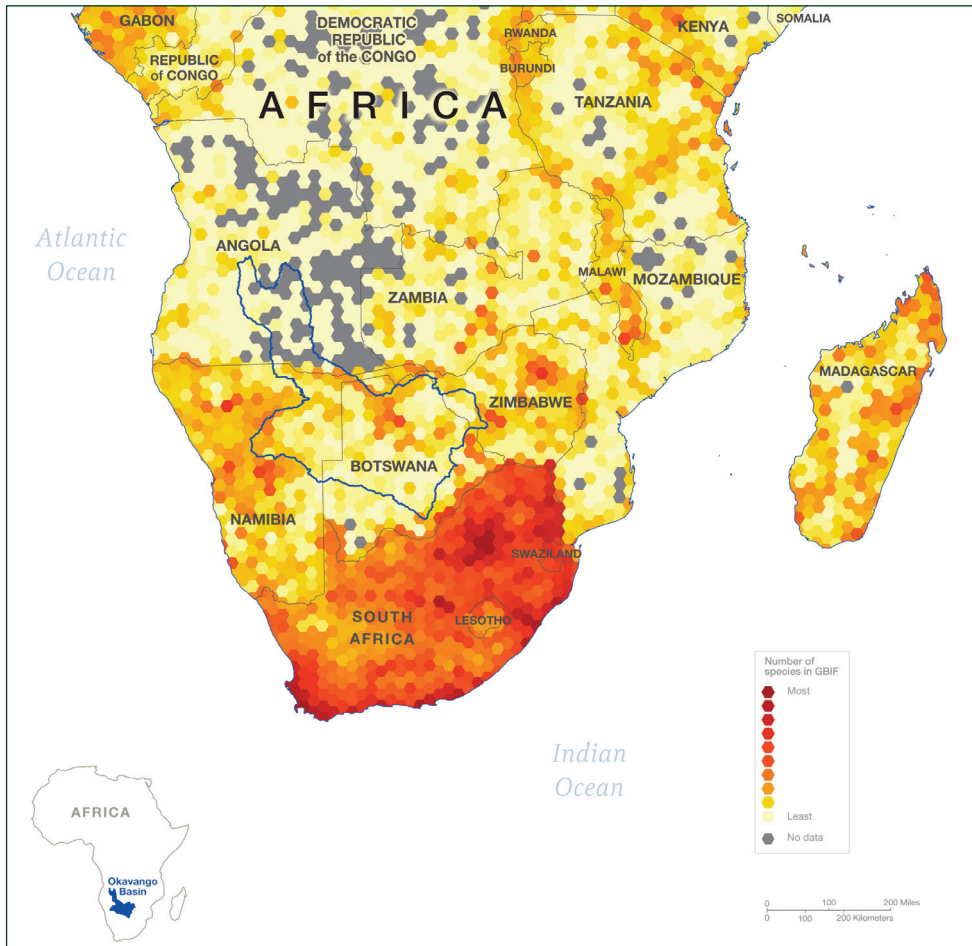


Figure 1. Plant distribution records for southern Africa. Raw data from GBIF (<https://www.gbif.org>). Note the absence of records for the Upper Cuito River.

eastern parts of the country apart from surveys of the Dundo area, Lunda Norte, in 1946 and 1948 funded by the diamond concession DIAMANG (Cavaco 1959, Figueiredo and Smith 2008). In addition, many of Gossweiler's collections are difficult to localise with outdated place names, and duplicates in herbaria accessible to the authors frequently omit locality data altogether. Slowly, as Angola has become more accessible following the end of the civil conflict in 2002, botanical surveys have resumed in areas of high endemism or conservation concern along the western escarpment (Hind and Goyder 2014, Gonçalves and Goyder 2016, Gonçalves et al. 2016), but the large eastern provinces of Moxico and Cuando Cubango remain poorly documented.

The only major expedition to study parts of the Cuito catchment botanically was the Kunene-Sambesi Expedition led by Pieter van der Kellen, and that covered only the area either side of the present-day Menongue – Longa – Cuito Cuanavale road. The expedition was in the Cuito system from 17th December 1899 to around 4th March 1900,

and again between 4–18th April 1900. The botany of the expedition was written up by Warburg (1903) and summarised by Figueiredo et al. (2009) who included notes on the botanist Hugo Baum and on the itinerary. Collections which form the basis of the many species described by predominantly Berlin-based botanists in Warburg (1903) and by subsequent authors were made from the Longa, Cuiriri and Cuito rivers. The area was revisited by Mendes whose 1959–1960 expedition covered the area between Kuvango [Artur de Paiva], Menongue [Serpa Pinto] and Cuito Cuanavale. Prior to the start of the Okavango Wilderness Project many species were known only from this area, and the surveys offered the chance to see if they occurred more widely.

Material and methods

The core study area is located to the south of Munhango (Figs 2, 3), and fieldwork was centred initially around the source lakes of the Cuito and Cuanavale rivers (Fig. 4), with excursions radiating from these points to the area south of Tempue and to nearby headwater lakes of other river catchments. In addition, more southerly tributaries such as the Longa (Fig. 5), Luassingua and Cuiriri river valleys were accessed from the Menongue – Cuito Cuanavale road. The darker green area towards the top left of Fig. 2 corresponds with the elevated and dissected plateau covered with moist miombo woodland which formed our core study area.

Botanical surveys were conducted at four different seasons to maximise recording of plant diversity – May–June 2015 (dry season), February–March 2016 (height of the rainy season), October–November 2016 (early rainy season) and April 2018 (late rains/early dry season). DG took part in all four surveys and focussed principally on the higher rainfall zones of the catchment between the headwaters and the Menongue – Cuito Cuanavale road (Barbosa vegetation type 17A and its transition to vegetation type 24). FG participated in the third of these surveys, and AF focussed on the Longa and Cuiriri river valleys (transition zone between Barbosa 17A and 24 vegetation types), which were the core of Baum's study in 1899 and 1900, and which had proved to be of particular botanical interest in earlier surveys. NB, SB and MJ surveyed the Longa area and the catchment south of the Menongue – Cuito Cuanavale road in June 2015.

Plant diversity was mostly assessed through walk-over surveys of each habitat in turn. But for grasses specifically, plots were set up in February–March 2016 following the methodology of Vorontsova et al. (2016) in order to feed into wider continental assessments of natural and anthropogenic grassland diversity. One plot was set up in undisturbed valley grassland near Tempué, a second in grassland possibly cleared from plateau woodland, but apparently long established, above the Cuito source lake, and the third plot was placed in open miombo woodland on the slope immediately adjacent to the Cuito source lake.

The major vegetation types generally form discrete, readily observable units in different parts of the landscape and were categorised informally.

Herbarium collections were made in sets of four where possible and deposited in two Angolan institutions (the National Biodiversity Institute of the Ministério do Am-

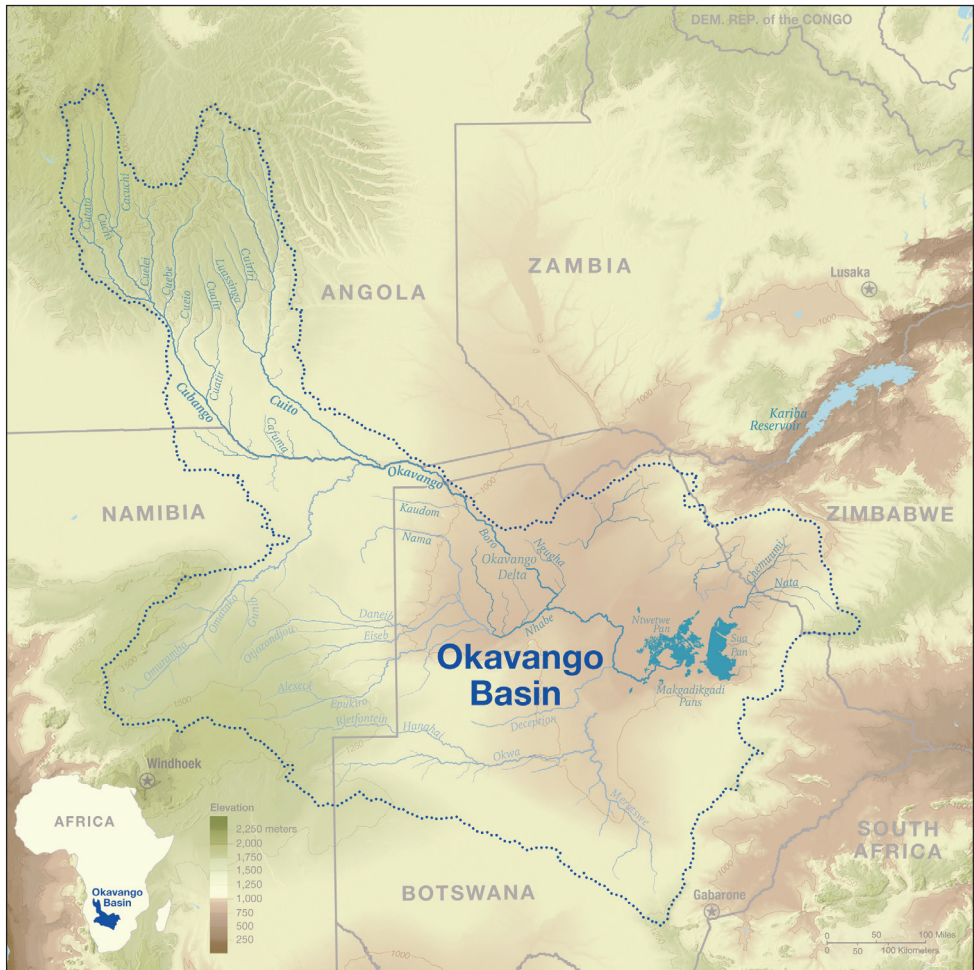


Figure 2. The Okavango Basin and its two principal tributaries the Cuito and Cubango rivers. The core study area is in the more elevated darker green zone of the upper Cuito river.

biente in Luanda and the Lubango Herbarium (LUBA) at ISCED-Huíla), one in the UK (Royal Botanic Gardens, Kew (K)) and one in South Africa (the SANBI Herbarium in Pretoria (PRE)). Plants covered by CITES regulations (*Aloe*, succulent *Euphorbia*, Orchidaceae) were deposited only in Angolan institutions, and identified from photographs. Plants were dried on a frame over a gas burner, using aluminium corrugates to transmit heat and dry air through the press. Collections were identified principally by DG at Kew by reference to the unrivalled tropical African collections and literature held there. Expert opinion was sought from specialists in particular plant groups: Gill Challen – Euphorbiaceae, Phyllanthaceae; Phillip Cribb – Orchidaceae; Iain Darbyshire – Acanthaceae, Linderniaceae, Orobanchaceae; Sebsebe Demissew – *Asparagus*; Peter Goldblatt – *Gladiolus*; Nicholas Hind – Compositae; Isabel Larridon – Cyperaceae; Gwylim Lewis – Leguminosae; Mike Lock – Xyridaceae, Zingiberaceae; Inger Nordal – *Crinum*; Jorge Paiva – *Polygala*; Alan Paton – Lamiaceae; Sylvia Phillips – Eriocaul-



Figure 4. Cuito River source lake, Moxico Province. Extensive moist miombo woodland on the plateau with a few partially cleared areas on the slopes, peaty marsh surrounding the source lake and a narrow strip of fire-maintained grassland between the marsh and the miombo. Photograph D. Goyder.

and beehives. Several cultural artefacts were purchased and deposited in the Economic Botany collections at Kew, where some have since been put on public display. Vouchers of the relevant plants were taken for verification at Kew.

Results

Approximately 1100 plant collections were made over the course of the four expeditions, with a further 40+ site-based observations recorded.

The principal vegetation types of the core study area are outlined below.

Vegetation

Moist miombo woodlands

Vast swathes of central and eastern Angola are covered in this vegetation. The most common trees we observed were *Brachystegia bakeriana*, *B. longifolia*, *Cryptosepalum exfoliatum*



Figure 5. Upper Longa River valley at the southern end of the study area, Cuando Cubango Province. Moist miombo woodland on the plateau with a much broader valley containing more extensive peaty wetlands and fire-maintained grassland zones. The river is fast-flowing in deep sinuous channels with bare sandy bottoms. Photograph D. Goyder.

De Wild. subsp. *pseudotaxus* (Baker f.) P.A.Duvign. & Brenan, *Julbernardia paniculata*, with frequent *Pterocarpus angolensis* DC., *Erythrophleum africanum* (Welw. ex Benth.) Harms, *Baphia massaiensis* Taub. subsp. *obovata* (Schinz) Brummitt var. *obovata*, *Bobgunnia madagascariensis* (Desv.) J.H. Kirkbr. & Wiersema, *Guibourtia coleosperma* (Benth.) J.Léonard, *Monotes dasyanthus* Gilg., *M. glaber* Sprague, and *Englerophytum magalismontanum* (Sond.) T.D.Penn. Shrubs include *Bauhinia mendoncae* Torre & Hillc., *Bauhinia urbaniana* Schinz and *Copaifera baumiana* Harms. Rainfall is generally between 750–1250 mm a year in the upper Cuito catchment. Where the rainfall drops below this, to the south (lower Longa valley and Cuito Cuanavale southwards), other elements such as *Baikiaea plurijuga* Harms come in, and by M’Pupo Falls, all elements of miombo are replaced by dry thorn-scrub.

Isoberlinia angolensis (Benth.) Hoyle & Brenan var. *lasiocalyx* Hoyle & Brenan and *B. spiciformis* are essentially absent from the Cuito catchment, occurring instead on richer substrate to the west. We only noted a single occurrence of *B. spiciformis* in plateau woodland in the Cuito system.

Brachystegia bakeriana is most common near the outer margins of Cuito miombo woodland, and where the miombo patches are very small, as in the “fairly forests” near

the Cuanavale source, these are dominated by this species. More extensive miombo is on the slopes is usually dominated by *Julbernardia paniculata*, and some plateau miombo (presumably with different soil composition) by *Cryptosepalum exfoliatum* subsp. *pseudotaxus*, which can form dense, closed canopy stands of miombo forest rather than woodland. Forest lacks the flammable grass layer that is present in woodland and under *Cryptosepalum* we frequently observed the presence of a hummock-forming moss not generally found elsewhere. *Julbernardia paniculata* was seen as the principle nectar source for honey bees during our 2016 surveys.

Swamp forest

We spent a short time in a small patch of swamp forest at the source of the Rio Cuiva (Kwanza drainage). Swamp forest appears to be rare and highly localised in Moxico, unlike in Lunda Norte where extensive formations occur along tributaries of the Kasai River (Congo drainage). The Cuiva swamp forest contained species of Guineo-Congolian affinity such as *Zanthoxylum gillettii* (De Wild.) P.G. Waterman and *Syzygium owariense* (P.Beauv.) Benth.

Seasonally burned savannas

These high rainfall grasslands receive 750–1250 mm of rain a year in the upper Cuito catchment, and are on highly leached Kalahari sand. Eastern Angola contains probably 80% of this habitat, which also extends into parts of NW Zambia and western parts of the DR Congo. This habitat is fire-adapted, and is dominated by grasses or by geoxyllic suffrutices, plants with large underground woody biomass and seasonal above-ground shoots. Factors governing whether grasses dominated, or geoxyllic suffrutices dominated these areas were not clear. Maurin et al. (2014) argue that across Africa, fire is the evolutionary driver of such lifeforms, whereas Finckh et al. (2016) provide convincing evidence that in upland central and eastern Angola, frost also plays a principal role, with cold air pooling in valley bottoms in the winter dry season and “burning” new shoots. Proximity to the water table limits growth of trees also.

The 2016 surveys took us to several sites with significant expanses of natural or little disturbed grasslands. They were particularly extensive near the confluence of the Cuito and Calua rivers downstream of the Cuito source lake, and the equivalent confluence downstream of the Cuanavale source lake. The third notable site was the Tempué valley grasslands. Grassland diversity plots were placed at three sites – one on the plateau above the Cuito source lake, one in the nearby miombo, and one in the Tempué valley grassland. *Loudetia* species dominated – *L. simplex* (Nees) C.E. Hubb. in open areas and *L. lanata* (Stent & J.M. Rattray) C.E. Hubb. in the woodland. Five to seven grass species were found in each plot. Total grass diversity in the upper Cuito-Cuanavale system was 27 species, the majority (18) occurring in open grassland. Grassland diversity appears significantly higher than in the lower altitude plateau grasslands of Lunda Norte, also dominated by *Loudetia simplex* (Darbyshire et al. 2011, 2014). *Polygala*

robusta Gürke seems to be associated with diverse natural grassland and could perhaps be considered an indicator of good quality habitat. Another rare species encountered in this environment was the Angolan endemic *Blepharis flava* Vollesen, known from just eight earlier collections. Both of these species are newly recorded from Moxico. A spectacular blue-flowered *Barleria* is new to science and was collected at the Cuito-Calua confluence. Also new to science is a geoxylic species of *Baphia* (Leguminosae), a genus of around 50 species of tree and shrub – the “underground forest” life form had not been recorded in *Baphia* before. This taxon was only seen in one area of the upper Lungué-Bungo catchment, in plains with a rich flora of geoxylic legume species.

Burkea africana was a common tree in savanna vegetation at the Cuanavale source lake. This was encountered much less frequently in the Cuito source region.

Further south, the upper Longa valley, despite large-scale conversion to rice cultivation, has extensive areas of burned savanna, with some extremely rare species. *Orthanthera gossweileri* C.Norman was known only from the type, but we recollected it in the Longa valley in March 2016, and at the Cuanavale source in October 2016 extending its range some 200 km to the north.

Wetland

Wetlands tend not to be very diverse botanically, nor to have local endemics. They are however, poorly sampled in Angola.

The extensive peaty wetlands of the Cuito have a much more diverse flora than the rather limited equivalent on the Cubango, which is a much faster flowing river running through a rocky valley. Clump- or tussock-forming plants such as Eriocaulaceae and Xyridaceae are common, while plants such as Droseraceae and Lentibulariaceae are able to supplement the limited nutrients available to other plants by trapping and digesting insects or aquatic invertebrates. Sedges (Cyperaceae) are present but are not as common as preliminary palynological records might suggest (unpublished preliminary results).

The headwater lakes of the Cuito system support a wider range of open water aquatics (true water lilies (Nymphaeaceae) and other aquatics such as *Nymphoides* and *Brasenia*) than is present on the Cubango. One unusual aquatic plant encountered in the fast-flowing upper Longa river was *Mayaca baumii* Gürke (Mayacaceae), a near-endemic and the only old-world representative of this otherwise entirely neotropical family.

Conversely, rocky rapid specialists such as *Hydrostachys triaxialis* Engl. & Gilg (Hydrostachyaceae) and *Inversodicraea warmingiana* (Gilg) Engl. (Podostemaceae) which are present on suitable portions of the Cubango (Cheek et al. 2017) are completely absent from the Cuito.

Robust river-margin plants include *Gardenia imperialis* K.Schum. (Rubiaceae) are present throughout both river catchments, while plants such as *Tacazzea rosmarinifolia* Oliv. (Apocynaceae) with rheophytic adaptations and requiring a rocky footing are found only on the Cubango.

Many wetland species have their known distributions extended dramatically. *Genlisea angolensis* R.D.Good, for example, was formerly known in Angola from just Cuando Cubango and from one collection in the DR Congo – collections in both 2015 and 2016 demonstrate this species occurs throughout the catchment of the Cuito and Cuanavale rivers (Goyder 2016). Wetland species of *Polygala* and Eriocaulaceae show similar distributions. The photographic record of *Crinum binghamii* Nordal & Kwembeya from just N of Cuito Cuanavale demonstrates this also, as it was formerly known only from western Zambia (Nordal and Kwembeya 2004, Zimudzi et al. 2008). While extending the known distributions, the new limits reflect the high rainfall, low nutrient Kalahari sand ecology.

The source lakes generally have deep accumulations of unconsolidated peat at their margins. We measured these to a depth of at least five metres at the Cuito source lake. The valleys also have more consolidated peat deposits. Such deposits are rare in tropical Africa. Reiley and Page (2016), in a recent volume on tropical peatland, state that the only significant peat deposits in Angola are on the lower Cuanza River 50 km from Luanda. The upper Cuito and Cuanavale lakes and wetlands seem to have been overlooked, despite reference in the same volume to peaty deposits in the Okavango Delta in Botswana. Analysis of peat cores from these deposits in ongoing at the University of the Witwatersrand in South Africa – pollen trapped in different strata has the potential to shed light on changes in vegetation in the region over thousands of years.

Plant diversity

417 species of vascular plant were recorded from the core study area of the high-rainfall upper Cuito and Cuanavale drainage system. The Checklist was compiled principally from our own collections from the high-rainfall zone, but with some additional collection made by Hugo Baum in the transition zone to the south. The majority of Baum's collections from the Cuito drainage system were, however, made in Barbosa's drier vegetation type 24 even further to the south and are not included in this checklist. Note that Baum's specimens citing Longa as the locality refer to the river, not to the village currently known as Longa, which is at the southern limit of our core study area, nor to Baixo Longa 100 km to the S, and outside the core study area. A further point of confusion is Warburg's (1903) map showing the route of the Kunene-Sambesi Expedition places "Hadjon Longa" close to the confluence of the Longa and Cuito rivers even further south in the region of the present-day village of Nankova.

We report nine species from the core study area which are potentially new to science (Table 1). Ten species are newly recorded for Angola with an additional species which had only been recorded within Angola from the northerly enclave of Cabinda. *Orthochilus* is a new generic record for the country (Table 2). But it is the new provincial records that give the clearest indication of how poorly studied the core project area has been to date – we recorded ten new records for Bié Province, ten for Cuando Cubango, and 108 for Moxico – the largest province in Angola.

Table 1. Species potentially new to science.

Family	Species	Notes
Acanthaceae	<i>Barleria</i> sp. nov.	Grassland at the Cuito-Calua confluence. Also in grasslands of upper Lungué-Bungo tributary
Compositae	<i>Vernonia</i> sp. nov.	Growing in the floating peaty mat at Cuanavale source lake
Euphorbiaceae	<i>Acalypha</i> sp. not matched	Similar to <i>A. angustissima</i> but dioecious. Pyrophytic grassland at head of Rio Cuanavale valley and N of Tempué
Gramineae	<i>Loudetia</i> sp. nov.	Closest to <i>L. densispica</i> . Grassland in Longa river valley
Lamiaceae	<i>Endostemon</i> sp. nov.	Grassland at the Cuito-Calua confluence, Moxico province
Leguminosae	<i>Baphia</i> sp. nov.	Found at a single locality in upper Lungué-Bungo catchment
Linderniaceae	<i>Crepidorrhodon</i> sp. nov.	Open sand in upper Lungué-Bungo catchment
Orchidaceae	possibly sp. nov.	Same site as the <i>Barleria</i> sp. nov. A eulophioid orchid, but generic affinities uncertain
Orobanchaceae	<i>Buchnera</i> sp. not matched at Kew	May be undescribed, or a species from DR Congo. Awaiting comment from expert

Table 2. Species newly recorded from Angola.

Family	Species	Notes
Acanthaceae	<i>Justicia subsessilis</i> Oliv.	Westerly range extension
Amaryllidaceae	<i>Crinum binghamii</i> Nordal & Kwembeya	Cuanavale River N of Cuito-Cuanavale. Known also from similar habitats in western Zambia
Apocynaceae	<i>Landolphia cuneifolia</i> Pichon	Known from NW Zambia and DR Congo
Apocynaceae	<i>Secamone dewevrei</i> De Wild. subsp. <i>elliptica</i> Goyder	Only known previously from western Zambia.
Cyperaceae	<i>Cyperus unioloides</i> R.Br.	Widely distributed across tropical and subtropical Africa
Gramineae	<i>Schizachyrium claudopus</i> (Chiov.) Chiov.	Known from Tanzania, DR Congo and Zambia
Loranthaceae	<i>Englerina gabonensis</i> (Engl.) Balle	Congolian element, near Cuanavale source. New record for Angola excluding Cabinda
Orchidaceae	<i>Brachycorythis congoensis</i> Kraenzl.	Marsh in the Longa and Cuiriri valleys
Orchidaceae	<i>Bulbophyllum josephi</i> (Kuntze) Summerh.	Moist miombo woodland in Moxico
Orchidaceae	<i>Orthochilus aurantiacus</i> (Rolfe) Bytebier	New generic record for Angola
Rubiaceae	<i>Gardenia resiniflua</i> Hiern subsp. <i>resiniflua</i>	Suffrutescent form – Longa valley

Botanically, the pyrophytic grassland zone between the marsh and the miombo woodland contains most of the new and interesting species. Over 40 underground forest species (whose nearest relatives are forest trees or shrubs) were recorded from this zone and as part of the ground flora of neighbouring miombo woodlands. They include *Napoleonaea gossweileri* Baker f. (Lecythidaceae), *Trichilia quadrivalvis* C.DC (Meliaceae), and an undescribed species of *Baphia* (Leguminosae). The *Baphia* was flowering profusely at ground level in the upper Lungué-Bungo catchment, where it occurred in an assemblage of other underground forest species. *Baphia* is a genus of 50 species of trees and shrubs in Africa and Madagascar – this is the first record of a pyrophytic underground forest species in the genus, and it appears to be a species new to science. The diversity of rubber-producing Apocynaceae species in the grassland zone was not-

ed – *Landolphia lanceolata* (K.Schum.) Pichon, *L. thollonii* Dewèvre, *Chamaecлитandra henriquesiana* (Hallier f.) Pichon, and *Raphionacme michelii* De Wild. were common elements and have been used as sources of natural rubber in earlier times. Other much rarer species of Apocynaceae were also recorded from this zone, including *Orthanthera gossweileri* C.Norman, which we found at the source of the Cuanavale river, 200 km north of its earlier known distribution. The new species of *Baphia* will be described separately, along with a more detailed discussion of the geoxylic suffrutex flora of the region.

Thirty-nine legume species were recorded from the upper catchment of the Cuito Cuanavale system and were found in both open and woodland habitats. Most of the miombo trees belong to this family, but there were many herbs also. Other significant elements of the flora include Rubiaceae (26 spp.), Apocynaceae (19 spp.), Lamiaceae (20 spp.) and the genus *Polygala* (Polygalaceae) with 14 species recorded – each habitat had its own suite of *Polygala* species. Monocot diversity was also substantial, with 31 grass species recorded, 17 orchids – mostly in the marsh and grassland zones – and seven species of *Gladiolus* (Iridaceae).

A flame lily species, *Gloriosa sessiliflora* Nordal & M.G.Bingham, was recorded from Angola for the second and third times ever, by the headwater team and the Longa/Cuiriri team respectively. It was described from similar marshland habitats in western Zambia in 1998.

Discussion

Miombo woodland is generally regarded as Zambesian floristically. Nevertheless, we encountered a small but significant element of moist-miombo species with Guineo-Congolian affinities. These include several species of Apocynaceae, *Uvaria angolensis* Welw. ex Oliv. in the Annonaceae, *Paropsia brazzaeana* Baill. in the Passifloraceae and *Englerina gabonensis* (Engl.) Balle in the Loranthaceae. The small patch of swamp forest at the head of the Río Cuiva is also Guineo-Congolian in affinity with *Syzygium owariense* (Myrtaceae) and *Zanthoxylum gillettii* (Rutaceae) widely distributed in the Congo Basin and West Africa. Phylogenetically, *Crinum binghamii* (Amaryllidaceae), a wetland species, is closer to Congolian members of the genus than to Zambesian species (Nordal and Kwembeya 2004).

Cape elements in the flora were restricted to savanna or grassland habitats, sometimes where rocky substrate was encountered locally. *Protea*, *Cliffortia* and *Erica* are three genera with predominantly Cape affinities and species radiations.

Floristic links outside of Africa are demonstrated by a couple of wetland taxa. *Mayaca baumii* (Mayacaceae) is the only African species of an otherwise entirely neotropical genus and family. *Mesanthemum glabrum* Kimpouni (Eriocaulaceae) is allied phylogenetically to a species from Ecuador (Larridon pers. comm., unpublished work in progress). These distributions probably reflect historic transatlantic dispersal events involving birds.

Human population in the region is low, and the few villages we passed are far apart. The low-nutrient landscape does not support much agriculture. Nevertheless, one or two

villages grew a diverse range of crops, and neighbouring miombo woodland was cleared for shifting maize and cassava cultivation. Habitat conversion is local but increasing in what is otherwise a remarkably intact ecosystem. Major human impact on the vegetation of the Cuito-Cuanavale system was only really apparent around the town of Cuito Cuanavale, and the section of the Longa valley affected by the large-scale rice project, although many of the grasslands are burned more frequently than they would be without human presence. Also, timber in the upper Lungué-Bungo valley is increasingly targeted as this area is closer to the provincial capital Luena than the rest of the core project area.

Many native plant species are used as medicines or for construction. It is mostly the most common species that are used.

The most frequent miombo tree, *Julbernardia paniculata*, is not only the principle source of nectar for honey bees but is also the preferred tree for the construction of beehives (Fig. 6). A cylinder of bark is removed from the tree (killing the individual), stapled together with stakes made from another legume timber (*Bobgunnia madagascariensis*), and tied together with stringy underbark from a third (*Julbernardia paniculata*, *Brachystegia bakeriana* or *Cryptosepalum exfoliatum* subsp. *pseudotaxus*). Internal bracing hoops come from flexible young shoots of either *Diplorhynchus condylocarpon* (Müll.Arg.) Pichon or *Baphia massaiensis* subsp. *obovata*, the permanent wooden cap at one end is made from *Parinari curatellifolia* Planch. ex Benth., while the removable cap at the other end is of woodland grasses, mostly *Loudetia* spp. Such traditional methods of construction are destructive but sustainable when population levels are low. However, harvesting of honey and production of beehives is becoming an industry, with some villages boasting of 300+ hives in active use.

Large fish traps were constructed from saplings of *Englerophytum magalismontanum*, tied together with fine bark string as above. The small fishtrap was constructed from the grass *Loudetia densispica* (Rendle) C.E.Hubb.

Locally made bark canoes were present in most lakes and major watercourses we visited (Fig. 7). These were generally made from bark of the legume tree *Erythrophloeum africanum* and stitched together as above with strips of stringy underbark from *Brachystegia* or *Cryptosepalum* spp.

It was noted that local people have a detailed understanding of plants with active biological properties in their immediate environment and know how to use these to treat a variety of conditions in the absence of accessible western medicine.

Conclusions

Over 1100 plant collections were made during the course of the National Geographic Okavango Wilderness Project, the majority from the core project area of the upper Cuito and Cuanavale river catchments. These form the basis of what is undoubtedly the most detailed specimen-based assessment of the vegetation and plant diversity of this region.

The flora of the upper Cuito and Cuanavale system is diverse and endemism is high, although the latter has not been analysed in detail for this study. New records extend the known geographic range of many species 200 km to the north, to the



Figure 6. Beehive made in Samenunga village, Moxico Province, now displayed in the Economic Botany collection of the Royal Botanic Gardens, Kew, UK. The body of the beehive is a cylinder of bark from the locally dominant legume tree *Julbernardia paniculata*. Other species are used to provide stakes, bracing hoops and endcaps. Photograph D. Goyder.

headwaters of the Cuito and Cuanavale rivers. They also underline the need for further surveys in Moxico Province where 108 new provincial records were reported, and provide evidence that the absence of plant records for eastern Angola revealed on the GBIF data map of southern Africa is real, and not a data artefact. All four *Protea* species collected in Moxico had never been recorded there before.

Barbosa (1970)'s vegetation type 17A needs to be critically reconsidered in the light of our findings in this area – we observed a fundamental change in composition of the miombo woodlands east of Cuemba once we moved onto the deep white sands, where several woody species drop out – no *Isoberlinia angolensis* (Benth.) Hoyle & Brenan was seen east of this point, and *Brachystegia spiciformis* occurred exceptionally rarely. Both *Burkea africana* and *Brachystegia bakeriana* are significant elements of the landscape in the headwater lakes region, not just in the transition zone around Longa. We saw no *Marquesia* species in the headwaters zone, but *Monotes* is common. *Baphia massaiensis* subsp. *obovata*, more commonly associated with dry *Baikiaea*-dominated woodland, was a common element of the miombo right up into the headwater region.

We also highlight the existence of extensive peat deposits in the Cuito river system. These are not as extensive as those recently reported from the Congo Basin (Dargie et al. 2017), but must be significant in terms of carbon storage nevertheless.



Figure 7. Bark canoe (foreground) made from *Erythrophleum africanum* (Leguminosae) alongside a fibre-glass “dugout” brought in by the National Geographic Okavango Wilderness Project from the Okavango Delta. Cuito source lake. Photograph D. Goyder.

Checklist

An annotated checklist of the upper Cuito & Cuanavale drainage system – the flora of high rainfall (annual precipitation more than c. 750 mm), highly leached Kalahari sand deposits from the headwaters to c. 15°S, based principally on 2015, 2016 and 2018 field surveys (Barbosa vegetation type 17A and transition to vegetation type 24).

Table Checklist

Family	Species	Habitat	Vouchers	New Records
LYCOPODIOPHYTA				
Lycopodiaceae	<i>Lycopodiella affinis</i> (Bory) Pic.Serm.	Wetland	Frisby 3027; Goyder 8261	
	<i>Lycopodiella cernua</i> (L.) Pic.Serm.	Wetland	sight record 38	
	<i>Lycopodiella sarcocaulon</i> (A.Braun & Welw. ex Kuhn) Pic.Serm.	Wetland	Goyder 8298	
PTERIDOPHYTA				
Aspleniaceae	<i>Asplenium aethiopicum</i> (Burm.f.) Bech.	Humid Forest	Goyder 8329	
Gleicheniaceae	<i>Dicranopteris linearis</i> (Burm.f.) Underw.	Wetland	Goyder 8396	
Thelypteridaceae	<i>Cyclosorus interruptus</i> (Willd.) H.Itô	Wetland	Goyder 8317	Mexico
	<i>Thelypteris confluens</i> (Thunb.) Morton	Wetland	Barker et al. 139	

Family	Species	Habitat	Vouchers	New Records
ANGIOSPERMAE: MAGNOLIIDS				
Annonaceae	<i>Annona stenophylla</i> Engl. & Diels subsp. <i>nana</i> (Exell) N.Robson	Grassland	Goyder & Maiato 8759; Goyder & Maiato 8843	
	<i>Artabotrys antunesii</i> Engl. & Diels	Woodland	Goyder 8436	Moxico
	<i>Uvaria angolensis</i> Welw. ex Oliv.	Woodland	Goyder 8034; Goyder 8414; Goyder 8438	
	<i>Xylopia odoratissima</i> Welw. ex Oliv.	Woodland	Frisby 3067; Goyder & Maiato 8806	
	<i>Xylopia tomentosa</i> Exell	Woodland	Barker et al. 50; Frisby 3057; Goyder 8027; Goyder 8048; Goyder 8096; Goyder 8288; Goyder 8918	Bié
Cabombaceae	<i>Brasenia schreberi</i> J.F.Gmel.	Wetland	Goyder 8295	Moxico
Lauraceae	<i>Cassytha pondoensis</i> Engl. var. <i>pondoensis</i>	Woodland	Goyder 8104	
Nymphaeaceae	<i>Nymphaea heudelotii</i> Planch.	Wetland	Barker et al. 44; Goyder 8259	
	<i>Nymphaea nouchali</i> Burm.f. var. <i>caerulea</i> (Savigny) Verdc.	Wetland	Frisby 4013; Goyder 8296; Goyder 8376	
	<i>Nymphaea sulphurea</i> Gilg.	Wetland	Baum 657; Frisby 3050; Frisby 3064; Frisby 3072; Goyder 8097; Goyder 8297; Goyder 8393	
ANGIOSPERMAE: MONOCOTS				
Alismataceae	<i>Limnophyton angolense</i> Buchenau	Wetland	Frisby 3093; Goyder 8375; sight record 15	Moxico
Amaryllidaceae	<i>Boophone disticha</i> (L.f.) Herb.	Grassland	Goyder & Maiato 8829	
	<i>Crinum binghamii</i> Nordal & Kwembeya	Wetland	sight record 42	
	<i>Cryptostephanus densiflorus</i> Welw. ex Baker	Woodland	Goyder 8258	Moxico
	<i>Cyrtanthus welwitschii</i> Hiern ex Baker	Wetland	Frisby 4023	Cuando Cubango
Asparagaceae	<i>Asparagus africanus</i> Lam. var. <i>puberulus</i> (Baker) Sebsebe	Grassland	Goyder 8439	
	<i>Chlorophytum colubrinum</i> (Baker) Engl.	Grassland	Baum 611	
	<i>Chlorophytum fasciculatum</i> (Baker) Kativu	Grassland	Baum 683; Goyder 9495	
	<i>Chlorophytum sphaecelatum</i> (Baker) Kativu	Grassland	Goyder 9495a	
	<i>Chlorophytum</i> sp.	Grassland	Goyder 8263	
	<i>Dipcadi viride</i> (L.) Moench	Wetland	Goyder & Maiato 8801	
	<i>Sansevieria aubrytiana</i> Carrière	Woodland	Goyder & Maiato 8838	Moxico
	<i>Schizocarpus nervosus</i> (Burch.) Van der Merwe	Grassland	Goyder & Maiato 8779	Moxico
Asphodelaceae	<i>Aloe nuttii</i> Baker	Grassland	Baum 698	
	<i>Aloe zebrina</i> Baker	Woodland	Goyder 8255	
	<i>Trachyandra arvensis</i> (Schinz) Oberm.	Grassland	Frisby 3062; Goyder 8494; Goyder & Maiato 8816; Goyder & Maiato 8820	
Colchicaceae	<i>Gloriosa sessiliflora</i> Nordal & M.G.Bingham	Wetland	Frisby 4035; Goyder & Maiato 8822	Cuando Cubango; Moxico
	<i>Gloriosa simplex</i> L.	Woodland	Goyder 8425	Moxico
Commelinaceae	<i>Aneilema plagiocapsa</i> K. Schum.	Woodland	Barker et al. 82; Baum 716; Goyder 8244	Moxico
	<i>Commelina africana</i> L. var. <i>lancispatha</i> C.B.Clarke	Woodland	Goyder 8245	
	<i>Commelina sphaerorrhizoma</i> Faden & Layton	Woodland	Goyder 8243	Moxico

Family	Species	Habitat	Vouchers	New Records
Commelinaceae	<i>Commelina welwitschii</i> C.B. Clarke	Grassland	Baum 814	
	<i>Cyanotis longifolia</i> Benth.	Grassland	Goyder & Maiato 8832	Mexico
Costaceae	<i>Costus spectabilis</i> (Fenzl) K. Schum.	Grassland	Goyder 8947	
Cyperaceae	<i>Abildgaardia ovata</i> (Burm.f.) Kral	Wetland	Frisby 3041	
	<i>Bulbostylis laniceps</i> C.B. Clarke ex T. Durand & Schinz	Grassland	Goyder 8290	Mexico
	<i>Cyperus chrysocephalus</i> (K. Schum.) Kük.	Wetland	Frisby 3071	
	<i>Cyperus denudatus</i> L.f.	Wetland	Goyder 8931	
	<i>Cyperus erinaceus</i> (Ridl.) Kük.	Grassland	Goyder 8334	
	<i>Cyperus hensii</i> T. Durand & Schinz	Wetland	Frisby 3081	
	<i>Cyperus kipasensis</i> Cherm.	Wetland	Goyder 8939	
	<i>Cyperus margaritaceus</i> Vahl	Grassland	Goyder 8335; Goyder & Maiato 8831; Goyder 8925	
	<i>Cyperus pectinatus</i> Vahl	Wetland	Goyder 8294	
	<i>Cyperus proteus</i> (Welw.) Bauters	Wetland	Barker et al. 63; Baum 627; Baum 628; Frisby 3009; Goyder 8005; Goyder 8365	
	<i>Cyperus proteus</i> (Welw.) Bauters var. <i>bellidiflora</i> Welw.	Wetland	Goyder 8936	
	<i>Cyperus rhynchosporoides</i> Kük.	Grassland	Goyder & Maiato 8830	
	<i>Cyperus subtrigonus</i> (C.B. Clarke) Kük.	Wetland	Goyder 8940	
	<i>Cyperus unioides</i> R.Br.	Wetland	Goyder 8941	Angola
	<i>Cyperus</i> sp. not matched	Grassland	Barker et al. 71; Barker et al. 111	
	<i>Eleocharis acutangula</i> (Roxb.) Schult. subsp. <i>acutangula</i>	Wetland	Goyder 8945	
	<i>Fimbristylis dichotoma</i> (L.) Vahl var. <i>dichotoma</i>	Wetland	Goyder 8942	
	<i>Fuirena umbellata</i> Rottb.	Grassland	Barker et al. 136; Goyder 8924	
	<i>Lipocarpa chinensis</i> (Osbeck) J. Kern.	Wetland	Goyder 8938	
	<i>Rhynchospora candida</i> (Nees) Boeck.	Wetland	Barker et al. 62; Goyder 8302; Goyder 8368	
	<i>Rhynchospora rugosa</i> (Vahl) Gale subsp. <i>brownii</i> (Roem. & Schult.) T. Koyama	Grassland	Barker et al. 65	
	<i>Scleria erythrorrhiza</i> Ridl.	Wetland	Barker et al. 57; Goyder 8933	
	<i>Scleria griegiifolia</i> (Ridl.) C.B. Clarke	Wetland	Goyder 8239; Goyder 8360; sight record 41	
Eriocaulaceae	<i>Eriocaulon lanatum</i> H.E. Hess	Wetland	Goyder 8202; Goyder 8369	Mexico
	<i>Eriocaulon teuszii</i> Engl. & Ruhland	Wetland	Goyder 8099; Goyder 8364	Mexico
	<i>Mesanthemum glabrum</i> Kimpouni	Wetland	Baum 645; Frisby 3065; Goyder 8004; Goyder 8201; Goyder 8238; Goyder 8358	Mexico
	<i>Mesanthemum reductum</i> H.E. Hess	Wetland	Barker et al. 115	
	<i>Syngonanthus angolensis</i> H.E. Hess	Wetland	Goyder 8237; Goyder 8359	Mexico
	<i>Syngonanthus wahlbergii</i> (Wikstr. ex Körn.) Ruhland	Wetland	Goyder 8100	
Gramineae	<i>Aristida nemorivaga</i> Henrard	Woodland	Barker et al. 108	
	<i>Brachiaria dura</i> Stapf	Grassland	Barker et al. 59; Goyder 8289	Cuando Cubango
	<i>Ctenium newtonii</i> Hack.	Grassland	Barker et al. 54	Cuando Cubango
	<i>Digitaria milanjana</i> (Rendle) Stapf	Woodland	Goyder 8306	

Family	Species	Habitat	Vouchers	New Records
Gramineae	<i>Diheteropogon amplexens</i> (Nees) Clayton var. <i>amplexens</i>	Grassland; Woodland	Goyder 8274; Goyder 8285	Moxico
	<i>Diheteropogon filifolius</i> (Nees) Clayton	Grassland	Barker et al. 60; Goyder 8407	Cuando Cubango
	<i>Eleusine coracana</i> (L.) Gaertn.	Wetland	Baum 693	
	<i>Elymandra grallata</i> (Stapf) Clayton	Grassland	Barker et al. 98; Barker et al. 105	Cuando Cubango
	<i>Eragrostis brainii</i> (Stent) Launert	Woodland	Goyder 8268; Goyder 8282	
	<i>Eragrostis thollonii</i> Franch.	Woodland	Goyder 8284	Moxico
	<i>Heteropogon contortus</i> (L.) P.Beauv.	Grassland	Goyder 8272; Goyder 8404	
	<i>Hyparrhenia newtonii</i> (Hack.) Stapf	Grassland	Goyder 8042; Goyder 8923	Bié
	<i>Leersia hexandra</i> Sw.	Wetland	Goyder 8930	
	<i>Loudetia angolensis</i> C.E.Hubb.	Wetland	Goyder 8264	Moxico
	<i>Loudetia densispica</i> (Rendle) C.E.Hubb.	Grassland	Barker et al. 109; Goyder 8273; Goyder 8442	Moxico
	<i>Loudetia lanata</i> (Stent & J.M.Rattray) C.E.Hubb.	Woodland	Goyder 8281	Moxico
	<i>Loudetia simplex</i> (Nees) C.E.Hubb.	Grassland	Goyder 8228; Goyder 8269; Goyder 8403	Bié; Moxico
	<i>Loudetia</i> sp. nov. aff. <i>L. densispica</i>	Grassland	Barker et al. 55	
	<i>Miscanthus junceus</i> (Stapf) Pilg.	Wetland	Goyder 8299	Moxico
	<i>Monocymbium cerasiiforme</i> (Nees) Stapf	Grassland	Goyder 8275; Goyder 8405	Moxico
	<i>Panicum natalense</i> Hochst.	Grassland	Goyder 8271; Goyder 8409	Moxico
	<i>Pennisetum polystachion</i> (L.) Schult.	Ruderal	Goyder 8043	Bié
	<i>Phragmites mauritianus</i> Kunth	Wetland	Goyder 8935	
	<i>Pogonarthria squarrosa</i> (Roem. & Schult.) Pilg.	Grassland	Barker et al. 97	
	<i>Rhytache robusta</i> Stapf	Woodland	Goyder 8283	
	<i>Schizachyrium claudopus</i> (Chiov.) Chiov.	Grassland	Barker et al. 58	
	<i>Sporobolus welwitschii</i> Rendle	Grassland	Goyder 8291	
	<i>Trachypogon spicatus</i> (L.f.) Kuntze	Grassland	Goyder 8913	
	<i>Tristachya hubbardiana</i> Conert	Grassland	Goyder 8408	Moxico
	<i>Tristachya nodiglumis</i> K.Schum.	Grassland	Barker et al. 72	
	<i>Tristachya rehmannii</i> Hack.	Grassland	Goyder 8270; Goyder 8406	
Hydrocharitaceae	<i>Blyxa radicans</i> Ridl.	Wetland	Baum 827	
	<i>Ottelia muricata</i> (C.H.Wright) Dandy	Wetland	Barker et al. 118	
	<i>Ottelia ulvifolia</i> (Planch.) Walp.	Wetland	Goyder 8929	
Hypoxidaceae	<i>Hypoxis canaliculata</i> Baker	Grassland	Goyder & Maiato 8790	
Iridaceae	<i>Ferraria welwitschii</i> Baker	Grassland	Frisby 4012; Goyder 8496; Goyder & Maiato 8768	Moxico
	<i>Gladiolus atropurpureus</i> Baker	Grassland	Goyder 8498	Cuando Cubango
	<i>Gladiolus benguellensis</i> Baker	Grassland	Baum 632	
	<i>Gladiolus dalenii</i> Van Geel subsp. <i>dalenii</i>	Wetland	Frisby 3029; Goyder 8461	Moxico
	<i>Gladiolus gregarius</i> Welw. ex Baker	Woodland	Goyder 8401	
	<i>Gladiolus gregarius</i> Welw. ex Baker – anomalous form with filiform leaves and green flowers	Grassland	Goyder 8499	
	<i>Gladiolus laxiflorus</i> Baker	Wetland	Frisby 3010; Frisby 3066; Goyder & Maiato 8793	
	<i>Gladiolus magnificus</i> (Harms) Goldblatt	Grassland	Baum 651; Goyder 8497	

Family	Species	Habitat	Vouchers	New Records
Iridaceae	<i>Gladiolus unguiculatus</i> Baker	Grassland	Frisby 3025; Frisby 3038; Goyder & Maiato 8777; Goyder & Maiato 8778	
Mayacaceae	<i>Mayaca baumii</i> Gürke	Wetland	Barker et al. 117; Baum 811	
Orchidaceae	<i>Brachycorythis congoensis</i> Kraenzl.	Wetland	Frisby 3068	
	<i>Bulbophyllum josephi</i> (Kuntze) Summerhayes	Woodland	Goyder 8419	
	<i>Disa caffra</i> Bolus	Wetland	Goyder & Maiato 8791	
	<i>Disa ochrostachya</i> Rchb. f.	Wetland	Frisby 4005; Goyder & Maiato 8763; Goyder & Maiato 8796	
	<i>Disa hircicornis</i> Rchb.f.	Wetland	Frisby 3075	
	<i>Disa welwitschii</i> Rchb.f.	Wetland	Frisby 3063	
	<i>Eulophia angolensis</i> (Rchb.f.) Summerh.	Wetland	Frisby 3032	
	<i>Eulophia horsfallii</i> (Bateman) Summerh.	Wetland	Goyder & Maiato 8792	Moxico
	<i>Eulophia longisepala</i> Rendle	Grassland	Goyder & Maiato 8753	Moxico
	<i>Eulophia rolfeana</i> Kraenzl.	Grassland	Frisby 3095; Goyder & Maiato 8755	Moxico
	<i>Eulophia speciosa</i> (R. Br. ex Lindl.) Bolus	Grassland	Goyder & Maiato 8774	Moxico
	<i>Habenaria retinervis</i> Summerh.	Woodland	Goyder 8220	
	<i>Orthochilus aurantiacus</i> (Rolfe) Bytebier	Grassland	Frisby 4002; Goyder & Maiato 8752; Goyder & Maiato 8796	Cuando Cubango
	<i>Phaius occidentalis</i> Schltr.	Wetland	Goyder & Maiato 8761	Moxico
	<i>Polystachya concreta</i> (Jacq.) Garay & H.R.Sweet	Woodland	Goyder 8225	
	<i>Satyrrium trinerve</i> Lindl.	Wetland	Frisby 3080; Frisby 4001	
	possibly sp. nov.	Grassland	Goyder 8351	
Smilacaceae	<i>Smilax anceps</i> Willd.	Ruderal	sight record 16	
Xyridaceae	<i>Xyris capensis</i> Thunb.	Wetland	Goyder 8373	
	<i>Xyris congensis</i> Büttner	Wetland	Barker et al. 64; Goyder 8322	
	<i>Xyris foliolata</i> L.A.Nilsson	Wetland	Barker et al. 128	
	<i>Xyris friesii</i> Malme	Wetland	Goyder & Maiato 8800	Moxico
	<i>Xyris imitatrix</i> Malme	Wetland	Goyder 8332	
Zingiberaceae	<i>Aframomum alboviolaceum</i> (Ridl.) K.Schum.	Ruderal	sight record 17	
	<i>Siphonochilus aethiopicus</i> (Schweinf.) B.L.Burt	Grassland Woodland	Frisby 3089; Goyder & Maiato 8769	
	<i>Siphonochilus puncticulatus</i> (Gagnep.) Lock	Grassland Woodland	Frisby 3076; Goyder & Maiato 8770	
ANGIOSPERMAE: EUDICOTS				
Acanthaceae	<i>Barleria crassa</i> C.B.Clarke subsp. <i>crassa</i>	Woodland	Goyder 8028	
	<i>Barleria</i> sp. nov.	Grassland	Goyder 8343; Goyder 8952	
	<i>Blepharis flava</i> Vollesen	Grassland	Goyder 8277	Moxico
	<i>Blepharis glumacea</i> S.Moore	Grassland	Goyder 8909	
	<i>Justicia subsessilis</i> Oliv.	Grassland	Barker et al. 89	
	<i>Lepidagathis macrochila</i> Lindau	Woodland	Baum 779; Goyder 8040; Goyder 8415	Moxico
	<i>Strobilanthopsis linifolia</i> (T.Anderson ex C.B.Clarke) Milne-Redh.	Woodland	Barker et al. 107; Goyder 8026	Moxico
	<i>Thunbergia gosseileri</i> S.Moore	Woodland	Goyder 8241	Moxico
Amaranthaceae	<i>Mecrowia grandiflora</i> Schinz	Grassland Woodland	Frisby 4010; Goyder 8112; Goyder 8385	Moxico

Family	Species	Habitat	Vouchers	New Records
Anacardiaceae	<i>Lannea gossweileri</i> Exell & Mendonça subsp. <i>gossweileri</i>	Grassland	Goyder & Maiato 8834	
	<i>Ozoroa stenophylla</i> (Engl. & Gilg) R.Fern. & A.Fern.	Grassland	Baum 662; Frisby 3012; Goyder 8310	Moxico
	<i>Ozoroa verticillata</i> (Engl.) R.Fern. & A.Fern.	Grassland	Goyder 8287	Moxico
	<i>Rhus gracilipes</i> Exell	Woodland	Goyder 8254	Moxico
	<i>Rhus kirkii</i> Oliv.	Grassland	Goyder 8344; Goyder 8911	
Anisophylleaceae	<i>Anisophyllea boehmii</i> Engl.	Woodland	Goyder 8232	
	<i>Anisophyllea fruticulosa</i> Engl. & Gilg	Grassland	Barker et al. 46; Baum 808†; Gossweiler 2856; Goyder 8106; Goyder & Maiato 8765	
Apocynaceae	<i>Chamaecitandra henriquesiana</i> (Hallier f.) Pichon	Grassland	Barker et al. 81; Goyder & Maiato 8766; Goyder & Maiato 8807	Moxico
	<i>Ceropegia racemosa</i> N.E.Br.	Woodland	Goyder 8402	Moxico
	<i>Cryptolepis oblongifolius</i> (Meisn.) Schltr.	Woodland	Barker et al. 78; Barker et al. 112; Frisby 3037; Goyder 8118; Goyder 8124; Goyder 8300	
	<i>Diplorhynchus condylocarpon</i> (Müll.Arg.) Pichon	Grassland Woodland	Barker et al. 52A; Frisby 3058; Frisby 3061; Goyder 8213; Goyder 8381; Goyder 8445; sight record 1; sight record 8; sight record 36	
	<i>Glossostelma ceciliae</i> (N.E.Br.) Goyder	Grassland	Frisby 4033; Goyder & Maiato 8789	
	<i>Gomphocarpus semiamplectens</i> K.Schum.	Woodland	Barker et al. 121	
	<i>Landolphia camptoloba</i> (K.Schum.) Pichon	Woodland	Barker et al. 49; Barker et al. 122; Baum 669; Frisby 4004; Goyder 8025; Goyder 8400	
	<i>Landolphia cuneifolia</i> Pichon	Woodland	Goyder 8331	
	<i>Landolphia lanceolata</i> (K.Schum.) Pichon	Grassland	Barker et al. 79; Goyder 8019; Goyder 8266; Goyder & Maiato 8803	
	<i>Landolphia thollonii</i> Dewèvre	Grassland	Goyder 8431; Goyder & Maiato 8825 [photographic record]	
	<i>Orthanthera gossweileri</i> C.Norman	Grassland	Frisby 3051; Goyder 8500; Goyder & Maiato 8827	Moxico
	<i>Raphionacme globosa</i> K.Schum.	Grassland	Goyder & Maiato 8797	Moxico
	<i>Raphionacme linearis</i> K.Schum.	Wetland	Frisby 3020; Frisby 3035; Frisby 3039; Frisby 3078; Goyder & Maiato 8776; Goyder & Maiato 8856	
	<i>Raphionacme michelii</i> De Wild.	Grassland	Frisby 3026; Goyder & Maiato 8788; Goyder & Maiato 8809; Goyder & Maiato 8771	Moxico
	<i>Secamone brevipes</i> (Benth.) Pichon	Woodland	Goyder 8330	Moxico
	<i>Secamone dewevrei</i> De Wild. subsp. <i>elliptica</i> Goyder	Woodland	Goyder 8041; Goyder 8223	
	<i>Strophanthus welwitschii</i> (Baill.) K.Schum.	Woodland	Goyder & Maiato 8837	
	<i>Tabernanthe iboga</i> Baill.	Woodland	Goyder 8226; sight record 18	
	<i>Xysmalobium holubii</i> Scott Elliot	Wetland	Baum 715; Frisby 3034; Goyder & Maiato 8785; Goyder & Maiato 8853	Moxico
Campanulaceae	<i>Lobelia</i> sp.	Grassland	Barker et al. 116	
	<i>Wahlenbergia collomoides</i> (A.DC.) Thulin	Grassland	Goyder 8906	
	<i>Wahlenbergia</i> possibly sp. B of Thulin (1975)	Grassland	Barker et al. 94	

Family	Species	Habitat	Vouchers	New Records
Caryophyllaceae	<i>Polycarpha corymbosa</i> (L.) Lam.	Grassland	Barker et al. 132; Baum 818; Goyder 8457	
Celastraceae	<i>Gymnosporia senegalensis</i> (Lam.) Loes.	Wetland	Goyder 8934	
	<i>Salacia bussei</i> Loes.	Grassland	Goyder 8292; Goyder & Maiato 8810	Mexico
Chrysobalanaceae	<i>Parinari capensis</i> Harv.	Grassland	Barker et al. 130; Goyder 8256	
	<i>Parinari curatellifolia</i> Planch. ex Benth.	Woodland	Goyder 8444	
Combretaceae	<i>Combretum dumetorum</i> Exell	Woodland	Goyder 8426	Mexico
	<i>Combretum gossweileri</i> Exell	Woodland	Goyder 8023	
	<i>Combretum platypetalum</i> Welw. ex M.A.Lawson	Grassland	Frisby 3036; Goyder 8121	
	<i>Combretum psidioides</i> Welw. subsp. <i>psidioides</i>	Grassland	Frisby 3053; Goyder 8345	
	<i>Combretum</i> sp. not matched 1	Woodland	Goyder 8307	
	<i>Combretum</i> sp. not matched 2	Grassland	Goyder 8346	
	<i>Preleopsis anisoptera</i> (Welw. ex M.A.Lawson) Engl. & Diels	Woodland	Goyder 8418	
	<i>Terminalia brachystemma</i> Welw. ex Hiern	Woodland	Frisby 3011; Goyder 8378	
Compositae	<i>Anisopappus chinensis</i> Hook. & Arn.	Grassland	Goyder 8908	
	<i>Bidens crocea</i> Welw. ex O.Hoffm.	Woodland	Goyder 8253	
	<i>Blumea axillaris</i> (Lam.) DC.	Grassland	Barker et al. 134	
	<i>Crassocephalum</i> sp. not matched	Woodland	Goyder 8305	
	<i>Dicoma schinzii</i> O.Hoffm.	Grassland	Barker et al. 85	
	<i>Emilia baumii</i> (O.Hoffm.) S.Moore	Woodland	Baum 707; Goyder 8252; Goyder 8910	Mexico
	<i>Erlangia misera</i> (Oliv. & Hiern) S.Moore	Woodland	Barker et al. 125	
	<i>Hypericophyllum gossweileri</i> S.Moore	Grassland	Goyder 8948	Angola
	<i>Mikania sagittifera</i> B.L.Robb.	Grassland	Barker et al. 104; Baum 679	
	<i>Nidorella resedifolia</i> DC.	Grassland	Barker et al. 126	
	<i>Pasaccardoa baumii</i> O.Hoffm.	Grassland	Frisby 3013; Goyder 8111	
	<i>Pleiotaxis linearifolia</i> O. Hoffm.	Grassland Woodland	Barker et al. 69; Barker et al. 120	
	<i>Pleiotaxis rugosa</i> O.Hoffm.	Woodland	Barker et al. 75	
	<i>Pleiotaxis subscaposa</i> C.Jeffrey	Grassland	Goyder 8279; Goyder 8456	Mexico
	<i>Pseudognaphalium luteoalbum</i> (L.) Hilliard & B.L.Burt	Grassland	Barker et al. 70; Frisby 3019	
	<i>Senecio strictifolius</i> Hiern	Wetland	Barker et al. 110; Barker et al. 127; Goyder 8915	
	<i>Vernonia</i> sp. nov.	Wetland	Goyder 8357	
	<i>Vernonia</i> sp.	Grassland	Goyder 8459	
	<i>Vernonia gerberiformis</i> Oliv. & Hiern subsp. <i>gerberiformis</i> var. <i>gerberiformis</i>	Grassland	Goyder 8109	
	<i>Vernonia ornata</i> S.Moore	Wetland	Frisby 3091	
	<i>Vernonia poskeana</i> Vatke & Hildebr. subsp. <i>poskeana</i>	Woodland	Barker et al. 84	
	<i>Vernonia subplumosa</i> O.Hoffm.	Woodland	Baum 703; Goyder 8286	Mexico
	<i>Vernonia turbinella</i> S.Moore	Woodland	Goyder 8017	
Convolvulaceae	<i>Ipomoea welwitschii</i> Vatke ex Hallier f.	Grassland	Goyder & Maiato 8828	Mexico
Cucurbitaceae	<i>Acanthosicyos naudinianus</i> (Sond.) C. Jeffrey	Ruderal; Grassland	Barker et al. 119; Goyder 8086	
Dilleniaceae	<i>Tetracera poggei</i> Gilg	Woodland	Goyder 8021; Goyder 8214	Bié; Mexico
Dipterocarpaceae	<i>Monotes dasyanthus</i> Gilg	Woodland	Goyder 8039; sight record 34	

Family	Species	Habitat	Vouchers	New Records
Dipterocarpaceae	<i>Monotes glaber</i> Sprague	Woodland	Goyder 8014; Goyder 8122; sight record 20; sight record 33	
	<i>Monotes gossweileri</i> De Wild.	Grassland	Goyder 8338; Goyder 8951	
Droseraceae	<i>Drosera affinis</i> Welw. ex Oliv.	Wetland	Baum 687; Goyder 8260; Goyder 8356	Mexico
	<i>Drosera burkeana</i> Planch.	Wetland	Goyder & Maiato 8794	
	<i>Drosera madagascariensis</i> DC.	Wetland	Frisby 4011; Goyder 8003; Goyder 8006; Goyder 8372; sight record 40; Goyder & Maiato 8786	
Ebenaceae	<i>Diospyros batocana</i> Hiern	Woodland	Barker et al. 142; Goyder 8029	
	<i>Diospyros chamaethamnus</i> Dinter ex Mildbr.	Grassland	Goyder 8901	
	<i>Diospyros pseudomespilus</i> Mildbr. subsp. <i>brevicalyx</i> F.White	Woodland	Goyder 8032; sight record 32	
	<i>Diospyros virgata</i> (Gürke) Brenan	Woodland	Goyder 8015	
Ericaceae	<i>Erica benguelensis</i> (Welw. ex Engl.) E.G.H.Oliv. var. <i>benguelensis</i>	Grassland	Goyder 8352	
Euphorbiaceae	<i>Acalypha</i> sp. not matched	Grassland	Goyder & Maiato 8802; Goyder & Maiato 8814	
	<i>Maprounea africana</i> Müll.Arg. pyrophytic form	Grassland	Goyder 8312	
	<i>Sclerocroton oblongifolius</i> (Müll.Arg.) Kruit & Roebers	Grassland	Goyder 8314; Goyder & Maiato 8844	
Gentianaceae	<i>Farea salutaris</i> Welw.	Wetland; Grassland	Barker et al. 53; Frisby 4000; Goyder 8216	
	<i>Neurotheca congolana</i> De Wild. & T.Durand	Wetland	Goyder 8234; Goyder 8354	Mexico
	<i>Pycnosphaera buchananii</i> (Baker) N.E.Br.	Wetland	Goyder 8462	
	<i>Schinziella tetragona</i> (Schinz) Gilg	Wetland	Goyder 8333; Goyder 8355	
Gisekiaceae	<i>Gisekia africana</i> (Lour.) Kuntze	Grassland	Barker et al. 124; Goyder 8233; Goyder 8949	Mexico
Hypericaceae	<i>Hypericum oligandrum</i> Milne-Redh.	Wetland	Frisby 4026	
	<i>Psorospermum baumii</i> Engl.	Woodland	Frisby 4003; Goyder 8221	Bié
Ixonanthaceae	<i>Ochthocosmus lemaireanus</i> T.Durand & H.Durand	Woodland	Barker et al. 48; Barker et al. 74; Baum 712; Goyder 8095; Goyder 8311; Goyder 8313; sight record 27	Mexico
Lamiaceae	<i>Alvesia rosmarinifolia</i> Welw.	Woodland	Barker et al. 45; Baum 676; Goyder 8036	
	<i>Clerodendrum baumii</i> Gürke	Grassland	Baum 661; Goyder 8125; Goyder 8367	
	<i>Clerodendrum buchneri</i> Gürke	Grassland	Goyder 8262	
	<i>Clerodendrum formicarum</i> Gürke	Grassland	Goyder & Maiato 8798	
	<i>Endostemon</i> sp. nov.	Grassland	Goyder & Maiato 8762	
	<i>Haumaniastrum katangense</i> (S.Moore) J.Duvign. & Plancke	Grassland	Goyder 8903	
	<i>Haumaniastrum prealtum</i> (Briq.) J.Duvign. & Plancke var. <i>succisifolium</i> (Baker) A.J.Paton	Grassland	Goyder 8341; Goyder 8454	Mexico
	<i>Haumaniastrum sericeum</i> (Briq.) A.J.Paton	Grassland	Barker et al. 87; Goyder 8440	
	<i>Kalaharia uncinata</i> (Schinz) Moldenke	Grassland	Goyder & Maiato 8782	
	<i>Leonotis nepetifolia</i> (L.) R.Br. var. <i>nepetifolia</i>	Ruderal	Baum 822	

Family	Species	Habitat	Vouchers	New Records
Lamiaceae	<i>Ocimum obovatum</i> E.Mey. ex Benth. var. <i>obovatum</i>	Grassland	Goyder & Maiato 8787	
	<i>Plectranthus betonicifolius</i> Baker	Wetland	Goyder 8463	Mexico
	<i>Plectranthus gracillimus</i> (T.C.E.Fr.) Hutch. & Dandy	Grassland	Goyder 8902	
	<i>Plectranthus guerkei</i> Briq.	Grassland	Barker et al. 86	
	<i>Plectranthus mirabilis</i> (Briq.) Launert	Wetland	Barker et al. 140; Baum 794; Goyder 8007; Goyder 8928	
	<i>Pycnostachys gracilis</i> R.D.Good	Woodland	Goyder 8441	
	<i>Tinnea eriocalyx</i> Welw.	Grassland	Goyder 8250	
	<i>Tinnea fusco-luteola</i> Gürke	Grassland	Baum 695	
	<i>Tinnea benguelensis</i> Gürke	Grassland	Baum 697; Goyder 8458	Mexico
	<i>Vitex madiensis</i> Oliv. subsp. <i>milanjiensis</i> (Britten) F.White	Woodland	Frisby 3023; Frisby 3046; Goyder 8044; Goyder 8416; Goyder 8428	
Lecythidaceae	<i>Napoleonaea gossweileri</i> Baker f.	Grassland	Goyder 8107; Goyder & Maiato 8812	Mexico
Leguminosae	<i>Aeschynomene dimidiata</i> Welw. ex Baker	Woodland	Goyder 8392	Mexico
	<i>Aeschynomene glabrescens</i> Welw. ex Baker	Wetland	Goyder & Maiato 8784	
	<i>Albizia adianthifolia</i> (Schumach.) W.Wight	Woodland	Goyder 8212	
	<i>Baphia massaiensis</i> Taub. subsp. <i>obovata</i> (Schinz) Brummitt var. <i>obovata</i>	Woodland	Frisby 3024; Goyder 8092; Goyder 8449; sight record 7; sight record 31; Goyder & Maiato 8780	
	<i>Baphia</i> sp. nov.	Grassland	Goyder & Maiato 8772	
	<i>Bauhinia mendoncae</i> Torre & Hillc.	Woodland	Barker et al. 76; Goyder 8030; Goyder 8391	
	<i>Bauhinia petersiana</i> Bolle subsp. <i>macrantha</i> (Oliv.) Brummitt & J.H. Ross	Woodland	Frisby 4017	
	<i>Bobgunnia madagascariensis</i> (Desv.) J.H. Kirkbr. & Wiersema	Woodland	Goyder 8031; Goyder 8384; Goyder 8429; Goyder 8450	
	<i>Brachystegia bakeriana</i> Hutch. & Burt Davy	Woodland	Barker et al. 100; Frisby 3014; Goyder 8020; Goyder 8090; Goyder 8116; Goyder 8386; Goyder 8430; Goyder 8432; Goyder 8448; sight record 10	
	<i>Brachystegia longifolia</i> Benth.	Grassland; Woodland	Goyder 8011; Goyder 8328; Goyder 8921	
	<i>Brachystegia spiciformis</i> Benth.	Woodland	Goyder 8038	
	<i>Burkea africana</i> Hook.	Grassland	Goyder 8379; sight record 37; sight record 43	
	<i>Chamaecrista mimosoides</i> (L.) Greene sens. lat.	Woodland	Barker et al. 83	
	<i>Clitoria kaessneri</i> Harms – depauperate form	Grassland	Goyder & Maiato 8758	
	<i>Copaifera baumiana</i> Harms	Grassland; Woodland	Goyder 8018; Goyder 8113; Goyder 8224; Goyder 8388; sight record 3; Goyder & Maiato 8847; Goyder 8919	
	<i>Crotalaria abscondita</i> Welw. ex Baker	Grassland	Goyder 8465	Mexico
	<i>Crotalaria angulicaulis</i> Harms	Grassland	Goyder 8452	Mexico
	<i>Crotalaria annua</i> Milne-Redh.	Grassland	Goyder 8900	
	<i>Crotalaria kambolensis</i> Baker f.	Woodland	Goyder 8424	
	<i>Crotalaria leptoclada</i> Harms	Grassland	Baum 829	
	<i>Crotalaria mendoncae</i> Torre	Woodland	Goyder 8016; Goyder 8103; sight record 26	Cuando Cubango

Family	Species	Habitat	Vouchers	New Records
Leguminosae	<i>Crotalaria stenoptera</i> Welw. ex Baker	Grassland; Wetland; Woodland	Barker et al. 146; Baum 677; Goyder 8093; Goyder 8257	
	<i>Crotalaria youngii</i> Baker f.	Grassland; Woodland	Goyder 8218	Bié
	<i>Crotalaria</i> cf. <i>youngii</i> Baker f.	Grassland; Woodland	Barker et al. 144; Goyder 8944	
	<i>Cryptosepalum exfoliatum</i> De Wild. subsp. <i>pseudotaxus</i> (Baker f.) P.A.Duvign. & Brenan	Woodland	Goyder 8022; Goyder 8323; Goyder 8446; sight record 4; sight record 12; sight record 24	
	<i>Cryptosepalum mimosoides</i> Welw. ex Oliv.	Grassland	Goyder 8337; Goyder & Maiato 8751	Moxico
	<i>Desmodium barbatum</i> (L.) Benth. var. <i>dimorphum</i> (Welw. ex Baker) B.G.Schub.	Grassland	Baum 685; Goyder 8502	
	<i>Dialium englerianum</i> Henriq.	Woodland	Goyder & Maiato 8805	
	<i>Entada arenaria</i> Schinz subsp. <i>arenaria</i>	Grassland; Woodland	Goyder 8390; Goyder & Maiato 8836	Moxico
	<i>Erythrophleum africanum</i> (Welw. ex Benth.) Harms	Woodland	Goyder 8010; Goyder 8380; Goyder 8389; sight record 29; Goyder 8922	
	<i>Erythrina baumii</i> Harms	Grassland	Frisby 4034; Goyder & Maiato 8767	
	<i>Guibourtia coleosperma</i> (Benth.) J.Léonard	Woodland	Goyder 8035; Goyder 8377; sight record 2; sight record 13; sight record 23; sight record 30; sight record 35	
	<i>Indigofera baumiana</i> Harms	Grassland	Baum 819; Goyder & Maiato 8818	
	<i>Indigofera sutherlandioides</i> Baker	Woodland	Goyder 8046; Goyder 8955	
	<i>Kotschyia strobilantha</i> (Welw. ex Baker) Dewit & P.A.Duvign.	Grassland	Barker et al. 56; Goyder 8091; Goyder 8943	
	<i>Julbernardia paniculata</i> (Benth.) Troupin	Woodland	Goyder 8012; Goyder 8089; Goyder 8123; Goyder 8308; Goyder 8443; sight record 11; sight record 19	
	<i>Macrotyloma rupestre</i> (Welw. ex Baker) Verdc.	Woodland	Goyder 8247	Moxico
	<i>Pterocarpus angolensis</i> DC.	Woodland	Barker et al. 52B; Goyder 8009; Goyder 8382; sight record 6; sight record 22; sight record 28	
	<i>Rhynchosia procurrens</i> (Hiern) K.Schum.	Woodland	Barker et al. 77	
	<i>Sphenostylis erecta</i> (Baker f.) Hutch. ex Baker f. subsp. <i>obtusifolia</i> (Harms) Potter & Doyle	Woodland	Goyder 8248; Goyder 8950	Moxico
Lentibulariaceae	<i>Genlisea angolensis</i> R.D.Good	Wetland	Frisby 3073; Goyder 8120; Goyder 8315; Goyder 8371	Moxico
	<i>Utricularia gibba</i> L.	Wetland	Barker et al. 44a; Goyder 8098	
	<i>Utricularia spiralis</i> Sm.	Wetland	Frisby 3094; Goyder 8114	
	<i>Utricularia subulata</i> L.	Wetland	Baum 691; Goyder 8370	
	<i>Utricularia stellaris</i> L.f.	Wetland	Frisby 3088	
Limeaceae	<i>Limeum fenestratum</i> (Fenzl) Heimerl	Grassland	Barker et al. 80; Baum 688	
Linderniaceae	<i>Crepidorrhodon</i> ?sp. nov.	Grassland	Goyder 8917	
Loranthaceae	<i>Englerina gabonensis</i> (Engl.) Balle	Woodland	Goyder 8413	
	<i>Tapinanthus dependens</i> (Engl.) Danser	Woodland	Barker et al. 137	
Lythraceae	<i>Rotala myriophylloides</i> Welw. ex Hiern	Wetland	Barker et al. 68	
Malvaceae	<i>Grewia falcistipula</i> K.Schum.	Woodland	Frisby 3022	
	<i>Grewia</i> sp.	Ruderal	Goyder & Maiato 8819	
	<i>Triumfetta dekindtiana</i> Engl.	Woodland	Barker et al. 133	

Family	Species	Habitat	Vouchers	New Records
Melastomataceae	<i>Antherotoma debilis</i> (Sond.) Jacq.-Fél.	Wetland	Barker et al. 47; Frisby 4031; Goyder 8094	
	<i>Dissotis brazzae</i> Cogn.	Grassland	Goyder 8927	
	<i>Dissotis rhinanthifolia</i> (Brenan) A.Fern. & R.Fern. var. <i>rhinanthifolia</i>	Wetland	Goyder & Maiato 8823	
	<i>Dissotis welwitschii</i> Cogn.	Wetland	Goyder 8240	Mexico
	<i>Memecylon huillense</i> A.Fern. & R.Fern.	Woodland	Goyder 8399	Mexico
Meliaceae	<i>Trichilia quadrivalvis</i> C.DC.	Woodland	Frisby 3070; Goyder & Maiato 8839	Mexico
Menyanthaceae	<i>Nymphoides forbesiana</i> (Griseb.) Kuntze	Wetland	Goyder & Maiato 8824	Mexico
	<i>Nymphoides indica</i> (L.) Kuntze subsp. <i>occidentalis</i> A.Raynal	Wetland	Barker et al. 113	
Moraceae	<i>Ficus pygmaea</i> Welw. ex Hiern	Wetland	Barker et al. 141	
	<i>Ficus verruculosa</i> Warb.	Wetland	Goyder 8320	
Myricaceae	<i>Morella serrata</i> (Lam.) Killick	Wetland	Goyder 8914	
Myrtaceae	<i>Syzygium cordatum</i> Hochst. ex Krauss subsp. <i>cordatum</i>	Wetland	Barker et al. 145; Goyder 8319	
	<i>Syzygium guineense</i> (Willd.) DC. subsp. <i>huillense</i> (Hiern) F.White	Grassland	Barker et al. 67; Frisby 3045; Goyder 8339; Goyder & Maiato 8835	
	<i>Syzygium owariense</i> (P.Beauv.) Benth.	Humid Forest	Goyder 8326	Mexico
Ochnaceae	<i>Brackenridgea arenaria</i> (De Wild. & T.Durand) N.Robson	Grassland	Frisby 3015; Frisby 3016; Frisby 3060; Goyder & Maiato 8781; Goyder & Maiato 8804	
	<i>Ochna katangensis</i> De Wild.	Grassland	Goyder & Maiato 8754A	
	<i>Ochna manikensis</i> De Wild.	Grassland	Frisby 3031; Goyder 8108; Goyder 8309	Mexico
	<i>Ochna pulchra</i> Hook.	Woodland	Goyder 8013; Goyder 8383; sight record 21	Mexico
	<i>Ochna pygmaea</i> Hiern	Grassland	Frisby 3059; Goyder & Maiato 8754B	Mexico
Olacaceae	<i>Olax gossweileri</i> Exell & Mendonça	Woodland	Goyder & Maiato 8846	Mexico
Oleaceae	<i>Olea capensis</i> L. subsp. <i>macrocarpa</i> (C.H.Wright) I.Verd.	Woodland	Goyder 8437	Mexico
Onagraceae	<i>Ludwigia octovalvis</i> (Jacq.) P.H.Raven	Wetland	Barker et al. 138	
Orobanchaceae	<i>Buchnera prorepens</i> Engl. & Gilg	Grassland	Goyder 8349; Goyder 8451	Mexico
	<i>Buchnera attenuata</i> Skan	Wetland	Frisby 3086; Frisby 4021	
	<i>Buchnera</i> sp. not matched at K	Grassland	Goyder 8276	
	<i>Buchnera welwitschii</i> Engl.	Grassland	Barker et al. 93	
	<i>Cynium tubulosum</i> (L.f.) Engl. subsp. <i>tubulosum</i>	Grassland	Frisby 4019	
	<i>Gerardiina angolensis</i> Engl.	Wetland	Goyder 8101	
	<i>Gerardiina angolensis</i> Engl. – unusual form with branched inflorescence	Wetland	Goyder 8293	
	<i>Melasma calycinum</i> (Hiern) Hemsl.	Wetland	Frisby 4018; Goyder & Maiato 8760	
	<i>Micrargeriella aphylla</i> R.E.Fr.	Wetland	Goyder & Maiato 8783	Mexico
	<i>Sopubia simplex</i> (Hochst.) Hochst.	Wetland	Frisby 3083; Frisby 4024; Goyder & Maiato 8821	Mexico
	<i>Striga angolensis</i> K.I.Mohamed & Musselman	Wetland	Goyder 8336	
	<i>Striga bilabiata</i> (Thunb.) Kuntze	Wetland	Frisby 4028; Goyder & Maiato 8795	Mexico
	<i>Basananthe baumii</i> (Harms) W.J. de Wilde var. <i>caerulescens</i> (A.Fern. & R.Fern.) W.J. de Wilde	Grassland	Goyder & Maiato 8826	
Passifloraceae	<i>Paropsia brazzaeana</i> Baill.	Woodland	Barker et al. 101; Goyder 8024; sight record 25; Goyder 8920	
Pedaliaceae	<i>Sesamum calycinum</i> Welw.	Grassland	Frisby 4022	

Family	Species	Habitat	Vouchers	New Records
Peraceae	<i>Clutia benguelensis</i> Müll.Arg.	Grassland	Goyder 8455	Moxico
Phrymaceae	<i>Mimulus gracilis</i> R.Br.	Wetland	Barker et al. 135	
Phyllanthaceae	<i>Bridelia duvigneaudii</i> J.Léonard	Woodland	Goyder 8423	Moxico
	<i>Hymenocardia acida</i> Tul.	Woodland	Goyder 8231	
	<i>Uapaca nitida</i> Müll.Arg.	Woodland	Goyder 8047; Goyder 8427	
	<i>Uapaca nitida</i> Müll.Arg. – pyrophytic form	Grassland Woodland	Goyder 8217	
Picodendraceae	<i>Oldfieldia dactylophylla</i> (Welw. ex Oliv.) J.Léonard	Grassland	Goyder 8267; Goyder 8421	
Plantaginaceae	<i>Linnophylla ceratophylloides</i> (Hiern) Skan	Wetland	Goyder 8318	Moxico
Polygalaceae	<i>Polygala africana</i> Chodat	Wetland	Frisby 4027	
	<i>Polygala arenicola</i> Gürke	Woodland	Barker et al. 123; Goyder 8229	
	<i>Polygala dewevrei</i> Exell	Wetland	Goyder 8361 (blue fls); Goyder 8362 (white fls); Goyder & Maiato 8849; Goyder 8926	Bié
	<i>Polygala gomesiana</i> Welw. ex Oliv.	Wetland	Goyder 8374	Cuando Cubango
	<i>Polygala kalaxariensis</i> Schinz	Grassland	Barker et al. 96	
	<i>Polygala mendoncae</i> E.M.A.Petit	Woodland	Goyder 8037; Goyder 8417	
	<i>Polygala nambalensis</i> Gürke	Grassland	Goyder 8453	Moxico
	<i>Polygala nematophylla</i> Exell	Grassland	Goyder 8366	Moxico
	<i>Polygala paludicola</i> Gürke	Wetland	Barker et al. 92; Frisby 3040; Frisby 3085; Goyder 8119; Goyder 8236	
	<i>Polygala poggei</i> Gürke	Grassland	Goyder 8278	Moxico
	<i>Polygala rivularis</i> Gürke	Grassland	Barker et al. 90	
	<i>Polygala robusta</i> Gürke	Grassland	Baum 704; Frisby 3047; Goyder 8085; Goyder 8280; Goyder 8303; Goyder 8411	Moxico
	<i>Polygala spicata</i> Chodat	Wetland	Frisby 3084; Goyder 8235; Goyder 8363	
	<i>Polygala welwitschii</i> Chodat subsp. <i>pygmaea</i> (Gürke) Paiva	Grassland	Goyder 8350; Goyder 8916	Moxico
	<i>Securidaca longipedunculata</i> Fresen.	Woodland	sight record 44	
Polygonaceae	<i>Oxygonum annuum</i> S.Ortiz & Paiva	Grassland	Goyder 8348	Moxico
	<i>Oxygonum fruticosum</i> Dammer ex Milne-Redh.	Woodland	Goyder 8008; Goyder 8105; Goyder 8954	
	<i>Oxygonum pachybasis</i> Milne-Redh.	Grassland	Frisby 3090; Goyder & Maiato 8799	Moxico
Proteaceae	<i>Faurea deleuyi</i> De Wild.	Wetland; Woodland	Goyder 8398	
	<i>Faurea saligna</i> Harv.	Woodland	Barker et al. 102	
	<i>Protea angolensis</i> Welw. var. <i>angolensis</i>	Grassland	Goyder 8410	Moxico
	<i>Protea baumii</i> Engl. & Gilg subsp. <i>baumii</i>	Grassland	Barker et al. 106	
	<i>Protea petiolaris</i> (Hiern) Baker & C.H.Wright subsp. <i>petiolaris</i>	Grassland	Goyder 8412	Moxico
	<i>Protea poggei</i> Engl. subsp. <i>haemantha</i> Chisumpa & Brummitt	Woodland	Baum 709; Goyder 8215; sight record 14; Goyder 8956	Bié; Moxico
	<i>Protea welwitschii</i> Engl.	Grassland	Goyder 8117; Goyder 8353; Goyder 8397; Goyder 8460	Moxico
Ranunculaceae	<i>Clematis villosa</i> DC.	Grassland	Goyder 8912	
Rosaceae	<i>Cliffortia nitidula</i> R.E.Fr. & T.C.E.Fr. var. <i>angolensis</i> (Weim.) Brenan	Grassland	Barker et al. 103; Baum 650; Goyder 8395; Goyder & Maiato 8855; Goyder 8932	
Rubiaceae	<i>Ancylanthos rubiginosus</i> Desf.	Grassland Woodland	Frisby 3056; Goyder 8115; Goyder & Maiato 8775; Goyder & Maiato 8848	

Family	Species	Habitat	Vouchers	New Records
Rubiaceae	<i>Bertiera</i> sp.	Humid Forest	Goyder 8325	
	<i>Diodia flavescens</i> Hiern	Grassland	Barker et al. 99	
	<i>Fadogia cienkowski</i> Schweinf.	Grassland	Frisby 3018; Goyder 8501	
	<i>Fadogia fuchsioides</i> Oliv.	Grassland	Goyder 8340	
	<i>Fadogia gossweileri</i> Robyns	Woodland	Frisby 4032	
	<i>Fadogia tomentosa</i> De Wild. var. <i>flaviflora</i> (Robyns) Verdc.	Woodland	Goyder 8246	
	<i>Ganguelia gossweileri</i> (S.Moore) Robbr.	Grassland	Goyder & Maiato 8815	
	<i>Gardenia imperialis</i> K.Schum.	Wetland	Goyder 8321; Goyder 8394; sight record 39	
	<i>Gardenia resiniflua</i> Hiern subsp. <i>resiniflua</i>	Woodland	Barker et al. 143	
	<i>Gardenia resiniflua</i> Hiern subsp. <i>resiniflua</i> – suffrutescent form	Woodland	Barker et al. 51; Frisby 4007	
	<i>Leptactina benguelensis</i> (Benth. & Hook.f.) R.D.Good	Woodland	Frisby 4029; Goyder & Maiato 8842	
	<i>Morinda angolensis</i> (R.D.Good) F.White	Grassland	Goyder & Maiato 8756; Goyder & Maiato 8851	Mexico
	<i>Pavetta nitidula</i> Hiern	Woodland	Goyder & Maiato 8840	
	<i>Pavetta</i> sp. 1	Woodland	Goyder 8242	
	<i>Pavetta</i> sp. 2	Woodland	Goyder 8249	
	<i>Pavetta</i> sp. 3	Grassland	Goyder 8301	
	<i>Psychotria</i> sp.	Humid Forest	Goyder 8324	
	<i>Psydrax gillettii</i> (De Wild.) Bridson	Woodland	Goyder 8434	
	<i>Psydrax</i> sp.	Woodland	Goyder 8433	
	<i>Pygmaeothamnus zeyheri</i> (Sond.) Robyns	Grassland	Goyder & Maiato 8808; Goyder & Maiato 8811	
	<i>Rothmannia engleriana</i> (K.Schum.) Keay var. <i>engleriana</i>	Woodland	Goyder 8420	
	<i>Rytigynia orbicularis</i> (K.Schum.) Robyns	Woodland	Goyder 8227	
	<i>Tricalysia angolensis</i> A.Rich. ex DC.	Woodland	Barker et al. 73	
	<i>Tricalysia</i> sp.	Woodland	Goyder 8435	
	<i>Vangueria</i> sp. not matched at K	Woodland	Goyder 8265	
	<i>Vangueriopsis</i> cf. <i>lanciflora</i> (Hiern) Robyns	Woodland	Goyder 8422	
Rutaceae	<i>Zanthoxylum gillettii</i> (De Wild.) P.G. Waterman	Humid Forest	Goyder 8327	Mexico
Santalaceae	<i>Thesium atrum</i> A.W.Hill	Grassland	Goyder 8342; Goyder & Maiato 8813	Mexico
	<i>Thesium subaphyllum</i> Engl.	Grassland	Barker et al. 91; Goyder 8347; Goyder 8937	
Sapotaceae	<i>Chrysophyllum bangweolense</i> R.E.Fr.	Woodland	Goyder & Maiato 8841	
	<i>Englerophytum magalismontanum</i> (Sond.) T.D.Penn.	Woodland	Goyder 8033; Goyder 8387; Goyder 8447; sight record 5	
	<i>Englerophytum magalismontanum</i> (Sond.) T.D.Penn. – pyrophytic form	Grassland Woodland	Goyder & Maiato 8854	
Simaroubaceae	<i>Hannoa chlorantha</i> Engl. & Gilg	Woodland	Barker et al. 66; Barker et al. 129; Baum 674; Goyder 8946	Mexico
Thymelaeaceae	<i>Craterosiphon quarrei</i> Staner	Woodland	Goyder 8219; Goyder & Maiato 8845	Mexico
	<i>Gnidia gossweileri</i> (S.Moore) B.Peterson subsp. <i>gossweileri</i>	Wetland; Grassland	Barker et al. 88	
	<i>Gnidia kraussiana</i> Meisn.	Grassland	Goyder 8110; Goyder & Maiato 8817	
Umbelliferae	<i>Afrocarum imbricatum</i> (Schinz) Rauschert	Wetland	Goyder 8957	
	<i>Pseudoselinum angolense</i> (C.Norman) C.Norman	Grassland; Woodland	Goyder 8045; Goyder 8251; Goyder 8953	Bié; Mexico

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Diatoms from Wrangell-St. Elias National Park, Alaska, USA

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Abstract

As a contribution to our knowledge of diatom biodiversity and biogeography in the United States, high resolution light microscope images are provided for 139 diatom taxa recorded from lake, stream, spring and glacier habitats in Wrangell-St. Elias National Park, Alaska. The spring had the highest taxa richness of the four habitats that were sampled, likely owing to the relative stability of this habitat compared to the others. Most of the taxa were described from northern and alpine locations in Europe and North America and are typical of habitats in the northern Rocky Mountains, with two notable exceptions. *Surirella arctica* had been reported previously only from locations in the High Arctic of North America, north of 68°N latitude. *Gomphonema caperatum* has a disjunct distribution in montane regions of the eastern and far western contiguous United States. This may be the first record of this taxon from Alaska.

Keywords

diatoms, Alaska, diatom biodiversity, diatom biogeography, glacier diatoms

Introduction

For a land area as large as Alaska (1,717,856 km²), there are relatively few published articles on freshwater diatom taxonomy and biodiversity (Patrick and Freese 1961, Foged 1971, 1981, McLaughlin and Stone 1986, Hein 1990). All of these studies pre-date the general availability of scanning electron microscopy and relied on taxonomic references that today are widely considered to be incomplete and out-of-date. One recent study (Pite et al. 2009) addressed the historical morphology and abundance of two *Didymosphenia* species in an Alaskan Lake.

Wrangell-St. Elias National Park and Preserve (WRST) is located in the southeast corner of Alaska (Fig. 1). At 53,320 km², it is the largest national park in the United States, six times larger than Yellowstone and about the same size as the country of Croatia. It is also one of the least visited of the national parks and much of it is untracked wilderness. Elevations in the park range from sea level to 5,489 m Mt. St. Elias. The mountainous terrain and ample winter snowfall from north Pacific weather systems produce some of the largest glaciers and ice fields in the world (US National Park Service 2018).

Although diatoms have been used to assess water quality and climate change within and near WRST (Simmons 2007, Brabets et al. 2011, Griffiths 2015), these studies did not include images of voucher specimens to verify identifications. Published studies on diatom taxonomy and biodiversity in the park appear to be wanting. Here we present high-resolution LM images of 139 diatom taxa collected in early summer 2018 from a lake, a stream, a spring and a glacier in WRST. This paper is intended only as a preliminary checklist of park diatoms with images of voucher specimens (illustrated checklist). Results are discussed briefly with respect to diatom biodiversity and biogeography.

Methods

Samples of benthic diatoms were collected from four sites in WRST (Table 1, Fig. 1). Donoho Lake (Fig. 2) is a shallow lake surrounded by white and black spruce forest, located between the Kennicott and Root Glaciers south of Donoho Peak. Jumbo Creek is a high-gradient perennial stream that originates in the mountains east of Root Glacier and north of Kennecott Mine and Townsite. McCarthy Spring is located east of Kennicott River and serves as the water source for the town of McCarthy. Four samples were collected from Root Glacier (Figs 3, 4), one each from three open pools (moulins) on the Root Glacier Ice Field and one from melt water discharging from a smaller rock glacier on the ice field.

Substrata that were sampled at WRST collection sites were cobbles (Jumbo Creek), sediment (all sites) and peat (moulins). As there were very few diatom cells in the samples from Root Glacier pools, they were combined for the purpose of sample processing and reporting. The pools appeared to extend to the bottom of the glacier, so diatoms in the pool samples may have originated from greater depth. The Root Glacier Ice Field is up to 213 m thick at this location, which is near its confluence with the Kennicott Glacier. Collection sites on the glacier were 6 km below the massive 2,133 m Staircase Ice Fall, at the head the valley, which is the largest icefall outside the Himalayas.

Sediment samples were collected with a large-bore pipette (5 mm diameter) with a suction bulb. The pipette was rinsed with ambient water twice between collection sites. Approximately 7.5 cm³ of water and sediment was pulled from the upper 1 cm of sediment at each sample site and stored in collection bottles. At Jumbo Creek, the surface film on several cobbles was scraped into the sample bottle and some peat material was included in the moulin samples. Iodine was added to each sample within 12 hours of collection. In the laboratory, samples were treated with 30% hydrogen peroxide (H₂O₂) and heated gently for several days to remove organic matter. After

Table 1. Samples collected on 29 June 2018 from WRST, Alaska. Sample numbers are for the Montana Diatom Collection and database. Slide numbers are for slides in the diatom collection at the University of Montana Herbarium, Missoula (MONTU). The numbers in the column headed “WRST” are National Park Service catalogue numbers for accession WRST-00483.

Sample number	Site name	Latitude (°N)	Longitude (°W)	Slide number	WRST
6955	Donoho Lake	61.5275	-142.9580	50–31	22949
6956	Jumbo Creek	61.5030	-142.8972	50–32	22950
6957	McCarthy Spring	61.4344	-142.9278	50–33	22951
6958	Root Glacier (pools)	61.5098	-142.9265	50–34	22952
6959	Root Glacier (rock glacier)	61.5122	-142.9211	50–35	22953

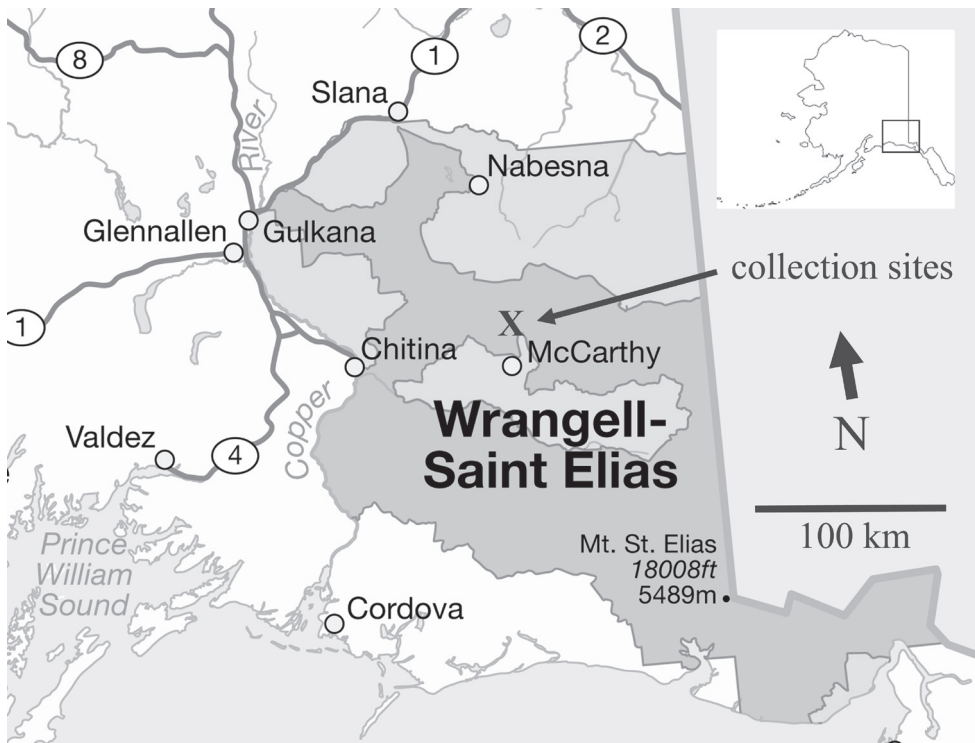


Figure 1. Map of Wrangell-St. Elias National Park showing approximate location of collection sites. Base map: U. S. National Park Service.

several rinses in distilled water, cleaned diatom material was dried on cover slips and mounted permanently on glass slides using Naphrax.

One slide per sample was examined under light microscopy (LM) with differential interference contrast optics and images were captured using a Leica DM LB2 research microscope and a Spot Insight monochrome digital camera (Model 14.0). Slides examined for this study will be deposited in the University of Montana Herbarium, Missoula (MONTU) on completion of the study. Imaged diatoms were identified to the lowest practical taxonomic unit using available identification resources, mainly Patrick and

2



3



4



Figures 2–4. Collection sites. **2** Donoho Lake **3** Root Glacier **4** Pool of standing water (moulin) on Root Glacier. Photos: Tara Luna.

Reimer 1966, 1975, Krammer and Lange-Bertalot 1986, 1988, 1991a, 1991b, Krammer 1997a, 1997b, 2000, 2002, 2003, Lange-Bertalot 2001, Levkov 2009, Lange-Bertalot et al. 2011 and Levkov et al. 2013, 2016. The Diatoms of North America website (INSTAAR 2018) and other sources were also consulted as needed. The INA card file at the University of California Herbarium (2018) was consulted for type localities of taxa.

Each slide was systematically scanned at 100 magnifications to locate very large taxa that might otherwise be missed while scanning at higher magnifications. After these large taxa were identified, listed and photographed, slides were examined under oil immersion at 630 and 1,000 magnifications in order to find, identify and photograph smaller taxa. A “random walk” was taken around each slide and additional taxa were listed and photographed until no additional taxa were found after 20 minutes of scanning. The number of images that were captured of each taxon is roughly proportional to the relative abundance of that taxon in a sample.

Results

A total of 139 taxa were identified at the genus or subgenus level (Table 2, Plates 1–14). None of the species is described as new to science, but some are designated as unknowns (e.g. *Hantzschia* sp.) or as comparable to another taxon (cf.). Alternate identifications are provided for some taxa in the plate legends.

Most taxa were described from type material collected in Europe (117 taxa), mostly northern Europe (Table 2). Other type localities include North America (18 taxa) [including 2 taxa from Alaska], Africa (1), Asia (1), Japan (1), Tristan da Cunha (1) and unknown (1). The total number of taxa in each habitat ranged from 29 on Root Glacier to 61 in McCarthy Spring.

Except for McCarthy Spring, diatom cells were scarce in all of the samples, as may be expected for such austere habitats. Glacial sediment (rock flour) dominated all but the McCarthy Spring sample and often obscured specimens for photography. Capturing quality images of voucher specimens was further hindered by diatom frustules that were often broken, eroded or encrusted with lime.

Table 2. List of taxa and key to plates.

Taxa	Plate	Donoho Lake	Jumbo Creek	McCarthy Spring	Root Glacier	Type Locality
<i>Achnanthis gracillimum</i> (Meister) Lange-Bertalot	4		x			Japan
<i>Achnanthis minutissimum</i> (Kützing) Czarnecki	4	x	x	x		Germany
<i>Amphora</i> Ehrenberg in Kützing	10	x				Europe
<i>Amphora copulata</i> (Kützing) Schoeman & Archibald	10		x			Germany
<i>Amphora inariensis</i> Krammer	10		x	x		Finnish Lapland
<i>Amphora pediculus</i> (Kützing) Grunow	10			x		Germany
<i>Brachysira microcephala</i> (Grunow) Compère	6		x			Austria
<i>Caloneis alpestris</i> (Grunow) Cleve	7	x		x		Austria
<i>Caloneis falcifera</i> Lange-Bertalot, Genkal & Vekhov	7	x				Russia
<i>Caloneis silicula</i> (Ehrenberg) Cleve	7			x		New England, USA
<i>Caloneis tenuis</i> (Gregory) Krammer	7			x		Scotland
<i>Caloneis thermalis</i> (Grunow) Krammer	7	x				Germany
<i>Cocconeis placentula</i> Ehrenberg	4		x	x	x	Germany
<i>Cymatopleura solea</i> (Brébisson) W. Smith	13			x		France
<i>Cymbella alpestris</i> Krammer	9	x		x		Switzerland
<i>Cymbella cleve-eulerae</i> Krammer	9		x			Sweden
<i>Cymbella cosleyi</i> Bahls	9		x			Montana, USA
<i>Cymbella excisiformis</i> Krammer	9				x	Germany
<i>Cymbella neocistula</i> var. <i>neocistula</i> Krammer	9		x	x		Germany
<i>Cymbella neocistula</i> var. <i>islandica</i> Krammer	9		x			Iceland
<i>Cymbopleura angustata</i> (W. Smith) Krammer	9	x			x	Scotland
<i>Cymbopleura austriaca</i> (Grunow) Krammer	9			x		Austria
<i>Cymbopleura incerta</i> (Grunow) Krammer	9		x	x		Norway

Taxa	Plate	Donoho Lake	Jumbo Creek	McCarthy Spring	Root Glacier	Type Locality
<i>Cymboppleura lapponica</i> (Grunow) Krammer	9		x		x	Swedish Lapland
<i>Cymboppleura naviculiformis</i> (Auerswald) Krammer	9				x	Germany
<i>Cymboppleura oblongata</i> Krammer	9		x		x	Spitsbergen
<i>Cymboppleura subaequalis</i> (Grunow) Krammer	9				x	Belgium
<i>Delicata</i> Krammer	10		x			France
<i>Delicata alpestris</i> (Krammer) Bahls	10		x			Austria
<i>Delicata delicatula</i> (Kützing) Krammer	10		x			France
<i>Denticula kuetzingii</i> Grunow	11	x		x	x	Austria
<i>Denticula tenuis</i> Kützing	11			x		Germany
<i>Diatoma tenuis</i> Agardh	1				x	Scandinavia
<i>Diatoma vulgaris</i> Bory de Saint-Vincent	1	x				France
<i>Diploneis krammeri</i> Lange-Bertalot & Reichardt	6			x		Austria
<i>Encyonema neogracile</i> Krammer	10				x	Finnish Lapland
<i>Encyonema perminutum</i> Krammer	10		x			Spitsbergen
<i>Encyonema silesiacum</i> (Bleisch) Mann	10			x	x	Germany
<i>Encyonopsis alpina</i> Krammer & Lange-Bertalot	10		x			Germany
<i>Encyonopsis cesatii</i> (Rabenhorst) Krammer	10			x		Italy
<i>Encyonopsis czarneckii</i> Bahls	10		x			Montana, USA
<i>Encyonopsis montana</i> Bahls	10		x			Montana, USA
<i>Encyonopsis stafsholtsii</i> Bahls	10		x			Montana, USA
<i>Encyonopsis subminuta</i> Krammer & Reichardt	10		x			Switzerland
<i>Eucocconeis alpestris</i> (Brun) Lange-Bertalot	4		x	x		Switzerland
<i>Eucocconeis flexella</i> (Kützing) Meister	4		x	x		Switzerland
<i>Eucocconeis laevis</i> (Østrup) Lange-Bertalot	4		x	x		Denmark
<i>Eunotia arcus</i> Ehrenberg	4			x		Sweden
<i>Eunotia valida</i> Hustedt	4		x			Switzerland
<i>Fragilaria Lyngbye</i>	2		x	x		Russia?
<i>Fragilaria amphicephala</i> Ehrenberg	2			x		Oregon, USA
<i>Fragilaria sepes</i> Ehrenberg	2	x				Russia
<i>Fragilaria tenera</i> (W. Smith) Lange-Bertalot	2		x			Ireland
<i>Fragilaria vaucheriae</i> (Kützing) Petersen	2			x		Germany
<i>Frustulia amosseana</i> Lange-Bertalot in Rumrich et al.	2	x				Scotland
<i>Gomphonema</i> Agardh	8			x	x	Germany
<i>Gomphonema bozenae</i> Lange-Bertalot & Reichardt	8			x		Finland
<i>Gomphonema caperatum</i> Ponader & Potapova	8				x	Virginia, USA
<i>Gomphonema lateripunctatum</i> Reichardt & Lange-Bertalot	8		x			Germany
<i>Gomphonema minusculum</i> Krasske	8				x	Tristan da Cunha
<i>Gomphonema olivaceoides</i> Hustedt	8				x	Germany
<i>Gomphonema pseudobohemicum</i> Lange-Bertalot & Reichardt	8				x	Germany
<i>Gomphonema pumilum</i> (Grunow) Reichardt & Lange-Bertalot	8		x			Belgium
<i>Gyrosigma</i> Hassall	6	x				Germany

Taxa	Plate	Donoho Lake	Jumbo Creek	McCarthy Spring	Root Glacier	Type Locality
<i>Hannaea arcus</i> (Ehrenberg) Patrick	2		x			Germany
<i>Hantzschia</i> Grunow	12	x		x		USA
<i>Hantzschia abundans</i> Lange-Bertalot	12				x	Germany
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow	12			x	x	USA
<i>Hantzschia elongata</i> (Hantzsch) Grunow	12	x				Germany
<i>Hantzschia hyperborea</i> (Grunow) Lange-Bertalot	12	x				Russia
<i>Hygropetra balfouriana</i> (Grunow) Krammer	7			x		Scotland
<i>Kurtkrammeria aequalis</i> (W. Smith) Bahls	10				x	Scotland
<i>Lindavia antiqua</i> (W. Smith) Nakov et al.	1			x		Ireland
<i>Luticola mutica</i> (Kützing) Mann	6			x		Germany
<i>Luticola ventricosa</i> (Kützing) Mann	6			x		Germany
<i>Meridion circulare</i> (Greville) Agardh	1		x			Scotland
<i>Muelleria gibbula</i> (Cleve) Spaulding & Stoermer	5	x				Norway
<i>Navicula angusta</i> Grunow	7			x	x	Austria
<i>Navicula cryptocephala</i> Kützing	7	x				Germany
<i>Navicula cryptotenella</i> Lange-Bertalot	7	x				Belgium
<i>Navicula lanceolata</i> (Agardh) Ehrenberg	7				x	Germany
<i>Navicula libonensis</i> Schoeman	7	x				Lesotho
<i>Navicula radiosa</i> Kützing	7			x		Germany
<i>Navicula seibigiana</i> Lange-Bertalot	7		x			Switzerland
<i>Navicula subconcentrica</i> Lange-Bertalot	7	x	x			Germany
<i>Navicula vulpina</i> Kützing	7		x	x		Germany
<i>Neidiomorpha binodiformis</i> (Krammer) Cantonati et al.	5			x		Germany
<i>Neidium</i> Pfitzer	5	x				Germany
<i>Neidium bergii</i> (Cleve-Euler) Krammer	5	x				Scandinavia
<i>Neidium bisulcatum</i> (Lagerstedt) Cleve	5	x				Spitsbergen
<i>Neidium bobmarshallensis</i> Bahls	5	x				Montana, USA
<i>Neidium distinctepunctatum</i> Hustedt	5	x				Austria
<i>Neidium fagedii</i> Bahls	5	x		x		Alaska, USA
<i>Neidium kozlowii</i> var. <i>ellipticum</i> Mereschkowsky	5	x			x	Tibet
<i>Nitzschia alpina</i> Hustedt	11			x		Switzerland
<i>Nitzschia amphibia</i> Grunow	11	x				Austria
<i>Nitzschia angustata</i> (W. Smith) Grunow	11			x		Sussex, UK
<i>Nitzschia dissipata</i> (Kützing) Rabenhorst	11			x		Germany
<i>Nitzschia dissipata</i> var. <i>oligotraphenta</i> Lange-Bertalot	11				x	Austria
<i>Nitzschia exilis</i> Sovereign	11	x				Oregon, USA
<i>Nitzschia fonticola</i> (Grunow) Grunow	11			x		Belgium
<i>Nitzschia homburgiensis</i> Lange-Bertalot	11			x		Germany
<i>Nitzschia inconspicua</i> Grunow	11			x		Austria
<i>Nitzschia lacuum</i> Lange-Bertalot	11		x			Germany
<i>Nitzschia linearis</i> W. Smith	11			x		UK
<i>Nitzschia palea</i> (Kützing) W. Smith	11	x				Germany
<i>Nitzschia perminuta</i> Grunow	11			x		unknown

Taxa	Plate	Donoho Lake	Jumbo Creek	McCarthy Spring	Root Glacier	Type Locality
<i>Nitzschia pura</i> Hustedt	11		×			Germany
<i>Nitzschia pusilla</i> (Kützing) Grunow	11		×			Germany
<i>Nitzschia sublinearis</i> Hustedt	11		×	×		Austria
<i>Odontidium hyemale</i> Kützing	1		×	×	×	Germany
<i>Odontidium mesodon</i> (Ehrenberg) Kützing	1			×		Germany
<i>Pinnularia</i> Ehrenberg	8			×		Germany
<i>Pinnularia krammeri</i> Metzeltin	8	×				Finland
<i>Pinnularia permicrostauron</i> Krammer & Metzeltin	8	×				Finland
<i>Pinnularia sinistra</i> Krammer	8		×			Germany
<i>Pinnularia subanglica</i> Krammer	8				×	Sweden
<i>Pinnularia subcommutata</i> Krammer	8			×		Belgium
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg	8	×				Germany
<i>Placoneis abiskoensis</i> Hustedt	6			×		Sweden
<i>Planothidium lanceolatum</i> (Brébisson) Lange-Bertalot	4				×	France
<i>Psammothidium helveticum</i> (Hustedt) Bukhtiyarova & Round	4				×	Switzerland
<i>Pseudostaurosira robusta</i> (Fusey) Williams & Round	3			×		France
<i>Rhopalodia gibba</i> (Ehrenberg) O. Müller	14	×				Siberia
<i>Sellaphora laevisima</i> (Kützing) Mann	6			×		Italy
<i>Sellaphora pupula</i> (Kützing) Mereschkowsky	6			×		Germany
<i>Stauroneis amphicephala</i> Kützing	6	×				Germany
<i>Stauroneis gracilis</i> Ehrenberg	6	×				French Guiana
<i>Stauroneis reichardtii</i> Lange-Bertalot et al.	6	×				Italy
<i>Stauroneis vandevijveri</i> Bahls	6	×				Montana, USA
<i>Staurosira</i> Ehrenberg	3			×		Connecticut, USA
<i>Staurosira construens</i> Ehrenberg	3			×		Connecticut, USA
<i>Staurosira construens</i> var. <i>venter</i> (Ehrenberg) Hamilton	3			×		Germany
<i>Staurosirella lapponica</i> (Grunow) Williams & Round	3			×		Sweden
<i>Staurosirella leptostauron</i> (Ehrenberg) Williams & Round	3			×		Germany
<i>Staurosirella pinnata</i> (Ehrenberg) Williams & Round	3			×		USA
<i>Surirella arctica</i> (Patrick & Freese) Veselá & Potapova	14	×				Alaska, USA
<i>Surirella minuta</i> Brébisson	14				×	France
<i>Ulnaria ulna</i> (Nitzsch) Compère	2				×	Germany
Total taxa		39	41	61	29	

Plates

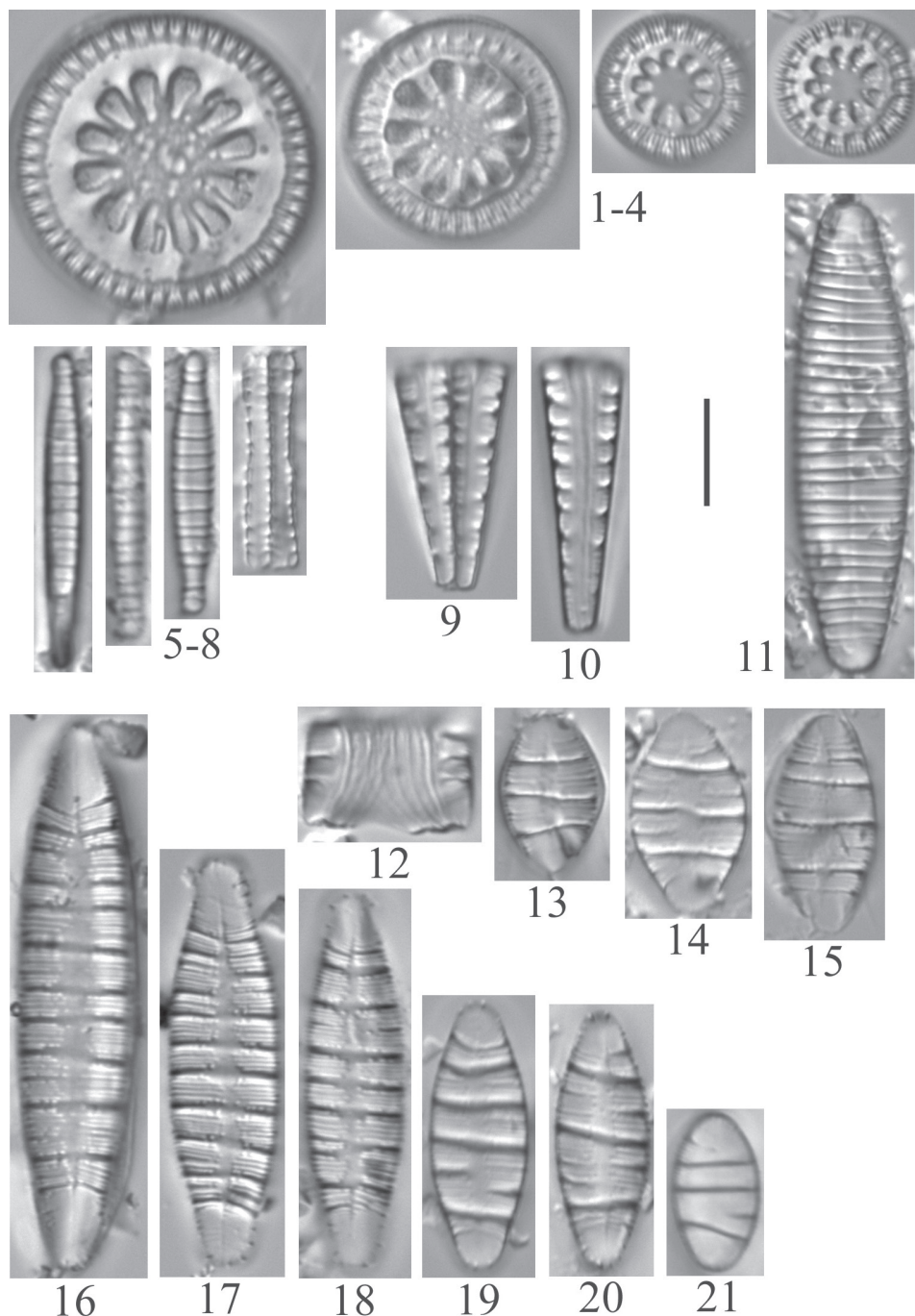


Plate I. 1–4 *Lindavia antiqua* (6957) 5–8 *Diatoma tenuis?* [*D. moniliformis?*] (6958) 9, 10 *Meridion circulare* (6956) 11 *Diatoma vulgaris* (6955) 12–15 *Odontidium mesodon* (6957) 16–21 *Odontidium hyemale* (6957). Scale bar: 10 μ m.

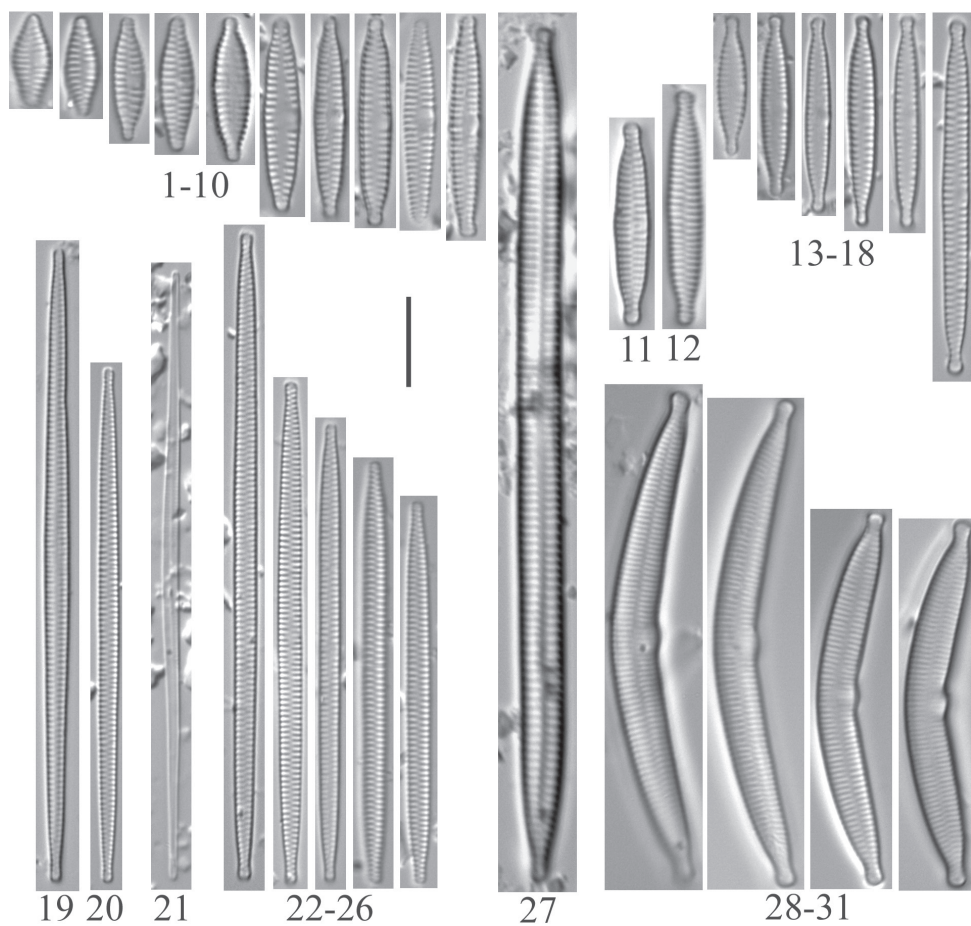


Plate 2. **1–10** *Fragilaria vaucheriae*? [*F. perminuta*?] (6957) **11, 12** *Fragilaria* sp. (6956) **13–18** *Fragilaria* sp. (6957) **19, 20** *Fragilaria tenera* (6956) **21** *Fragilaria sepes* (6955) **22–26** *Fragilaria amphicephala* (6957) **27** *Ulnaria ulna*? (6958) **28–31** *Hannaea arcus* (6956). Scale bar: 10 μ m.

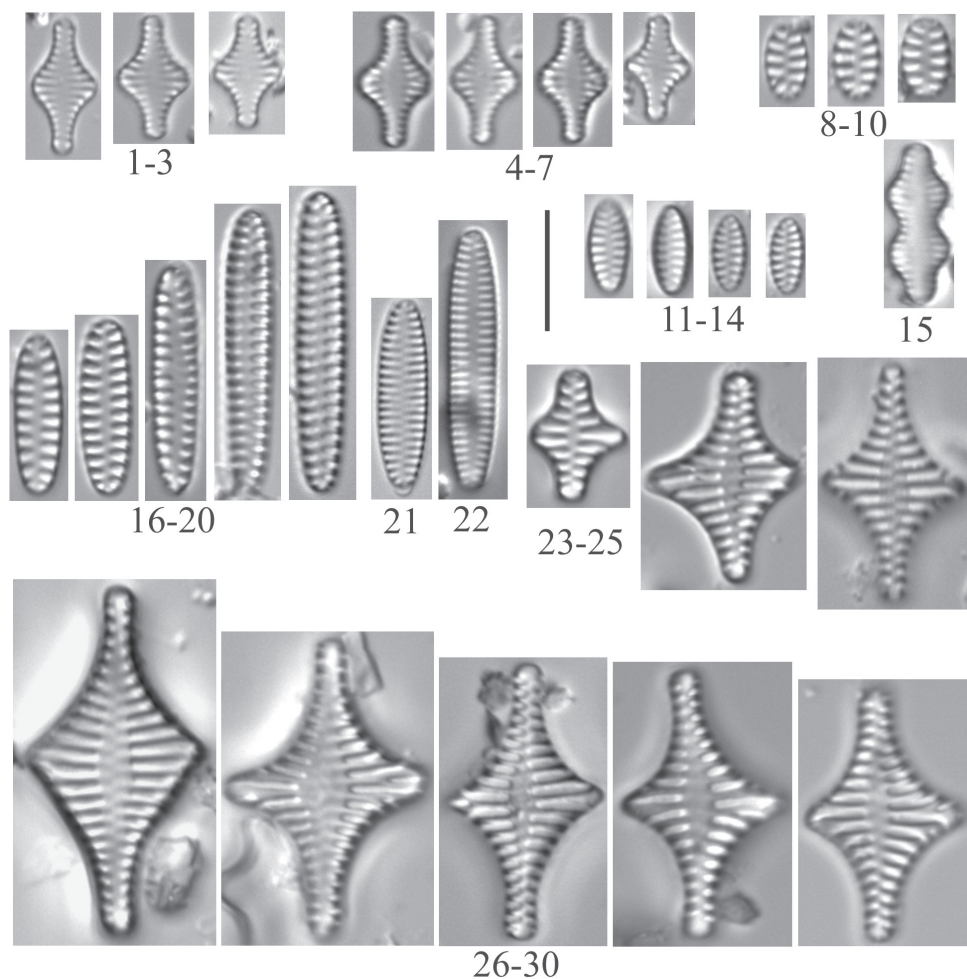


Plate 3. 1-7 *Staurosira construens* (6957) 8-10 *Staurosirella pinnata* (6957) 11-14 *Staurosira* sp. cf. *construens* var. *venter* (6957) 15 *Pseudostaurosira robusta* (6957) 16-20 *Staurosirella lapponica* (6957) 21, 22 *Staurosira* sp. (6957) 23-30 *Staurosirella leptostauron* (6957). Scale bar: 10 μ m.

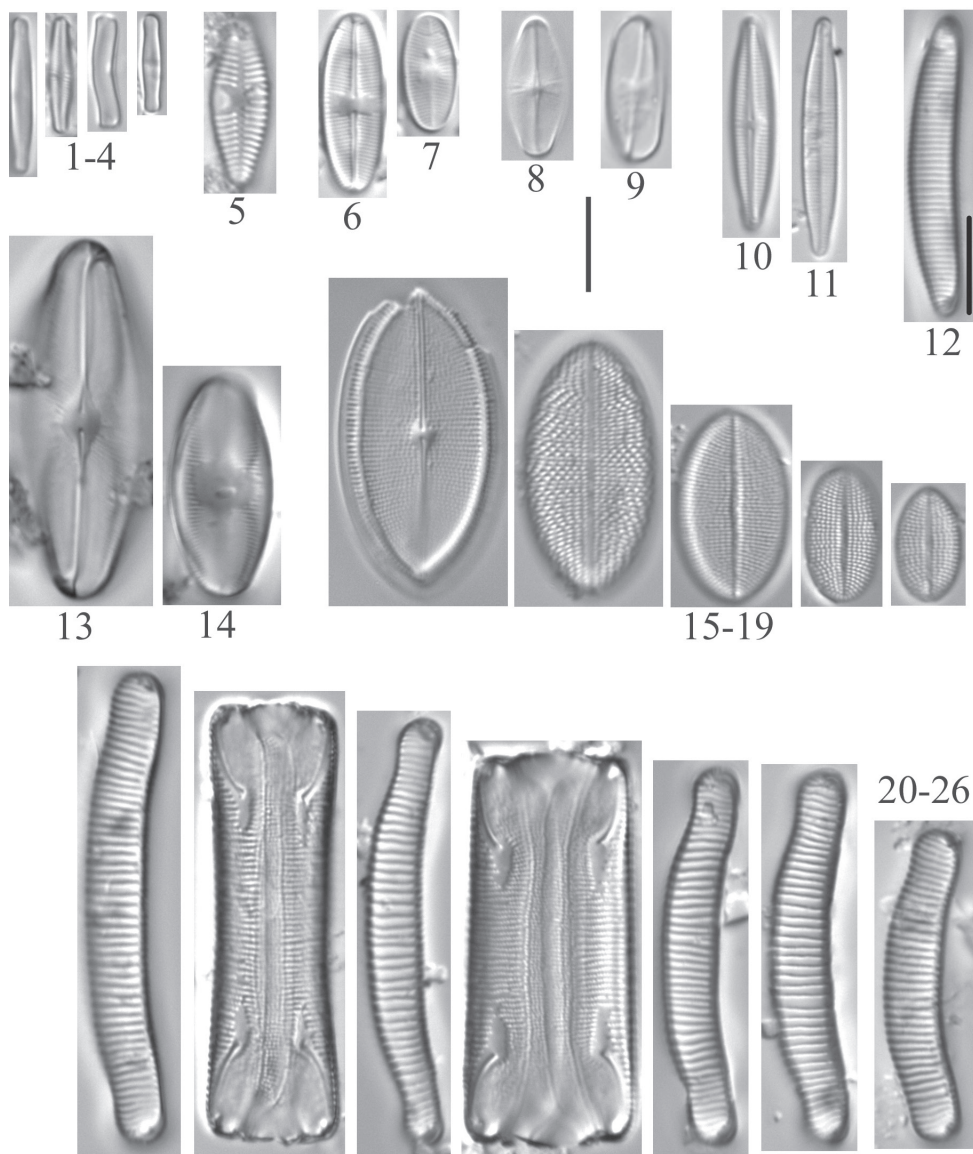


Plate 4. 1–4 *Achnantheidium minutissimum* (6955, 6956, 6957) 5 *Planothidium lanceolatum* (6958) 6, 7 *Psammothidium helveticum* (6959) 8 *Eucocconeis laevis* (6956) 9 *Eucocconeis alpestris* (6956) 10, 11 *Achnantheidium gracillimum* (6956) 12 *Eunotia valida* (6956) 13, 14 *Eucocconeis flexella* (6957) 15–19 *Cocconeis placentula* var.? (6956, 6957, 6958) 20–26 *Eunotia arcus* or *Eunotia arcubus* Nörpel-Schempp & Lange-Bertalot (6957). Scale bar: 10 μm .

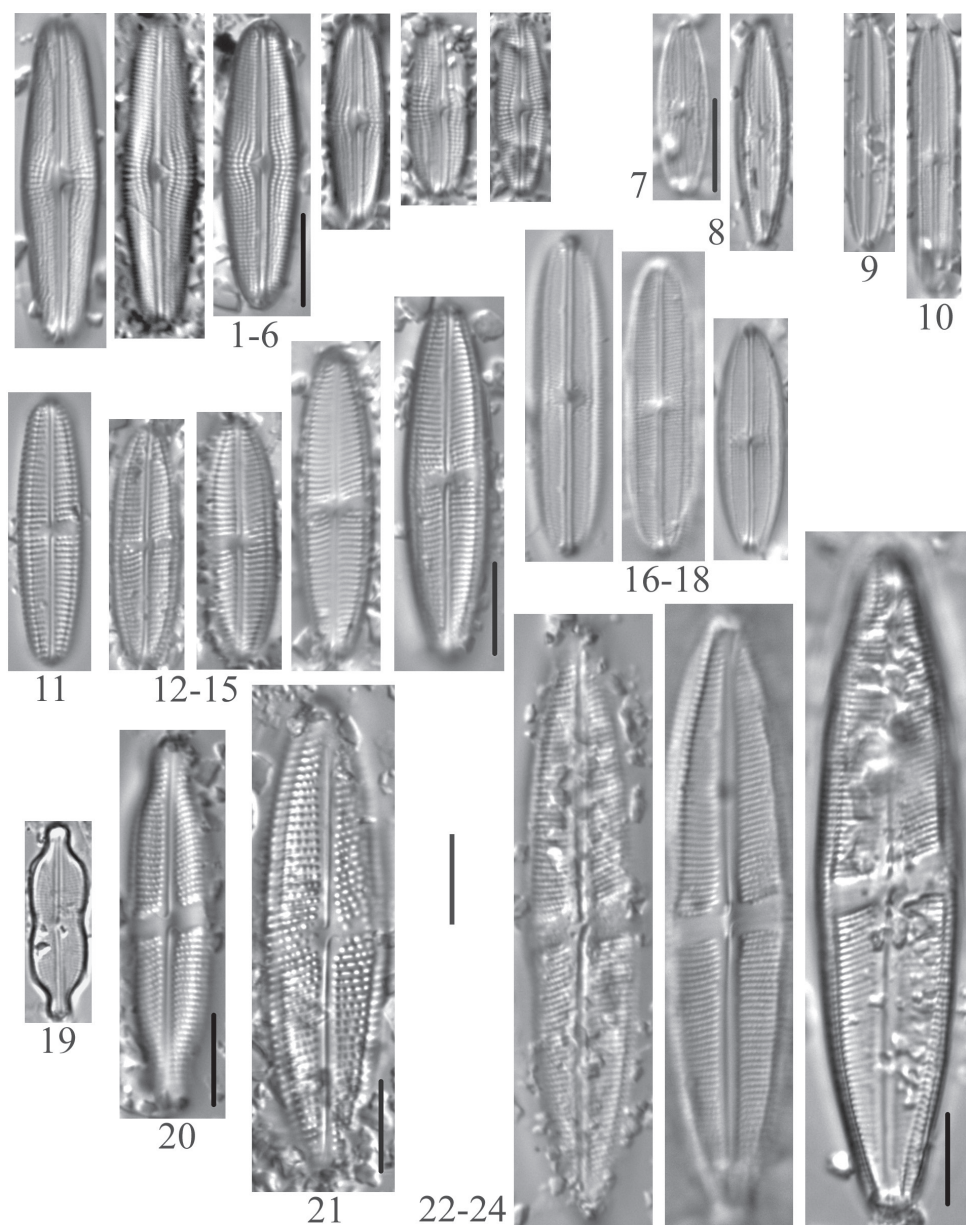


Plate 5. 1–6 *Muelleria gibbula* (6955) 7, 8 *Neidium bergii* (6955) 9, 10 *Neidium* sp. cf. *N. bisulcatum* (6955) 11 *Neidium* sp. cf. *Neidium boreale* Foged (6955) 12–15 *Neidium kozlowii* var. *ellipticum* (6955) 16–18 *Neidium* sp. (6955, 6957) 19 *Neidiopsis binodiformis* (6957) 20 *Neidium fogedii* (6955) 21 *Neidium distinctepunctatum* (6955) 22–24 *Neidium bobmarshallensis* (6955). Scale bar: 10 μ m.

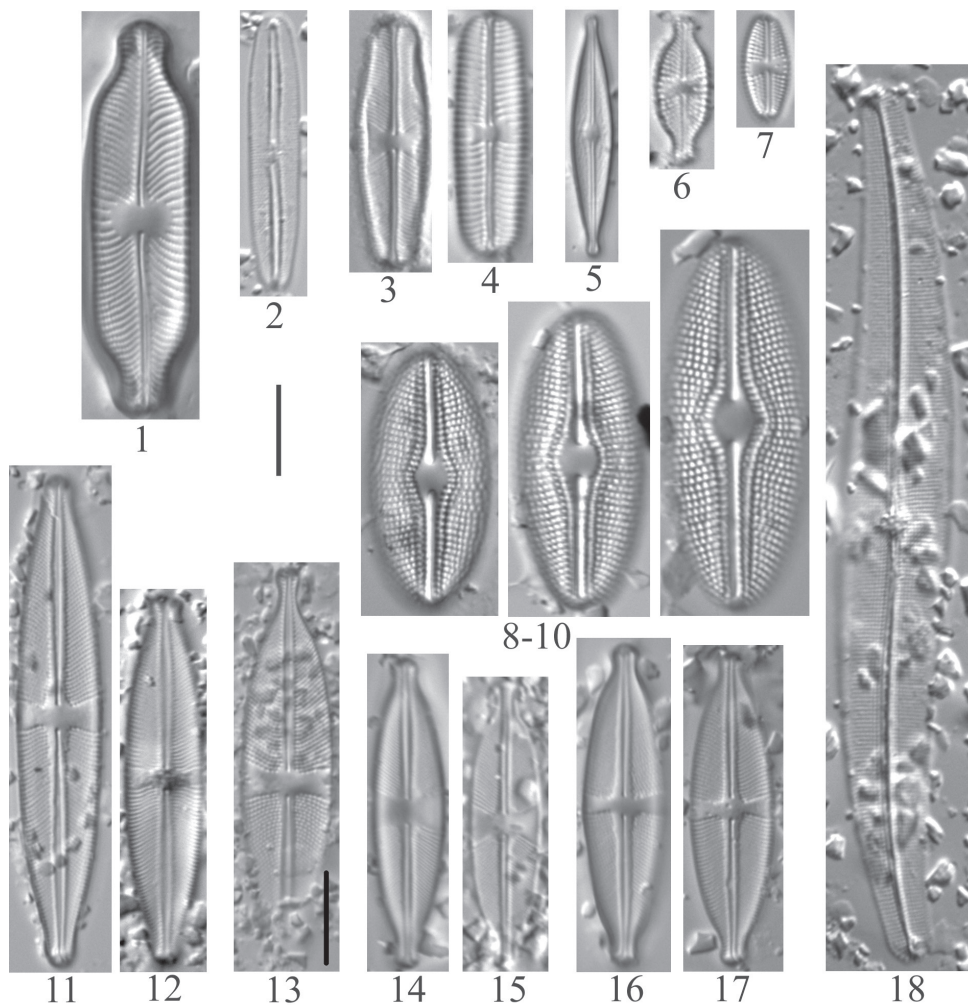


Plate 6. **1** *Placoneis abiskoensis* Hustedt (6957) **2** *Frustulia amosseana* (6955) **3** *Sellaphora pupula* (6957) **4** *Sellaphora laevissima* (6957) **5** *Brachysira microcephala* (6956) **6** *Luticola ventricosa* (6957) **7** *Luticola mutica* (6957) **8–10** *Diploneis krammeri* (6957) **11, 12** *Stauroneis gracilis* (6955) **13** *Stauroneis amphicephala* or *Stauroneis ancepsfallax* Bahls) (6955) **14, 15** *Stauroneis vandeijveri* (*S. "arctic-anceps"* Van de Vijver et al.) (6955) **16, 17** *Stauroneis reichardtii* (?) (6955) **18** *Gyrosigma* sp. (6955). Scale bar: 10 μ m.

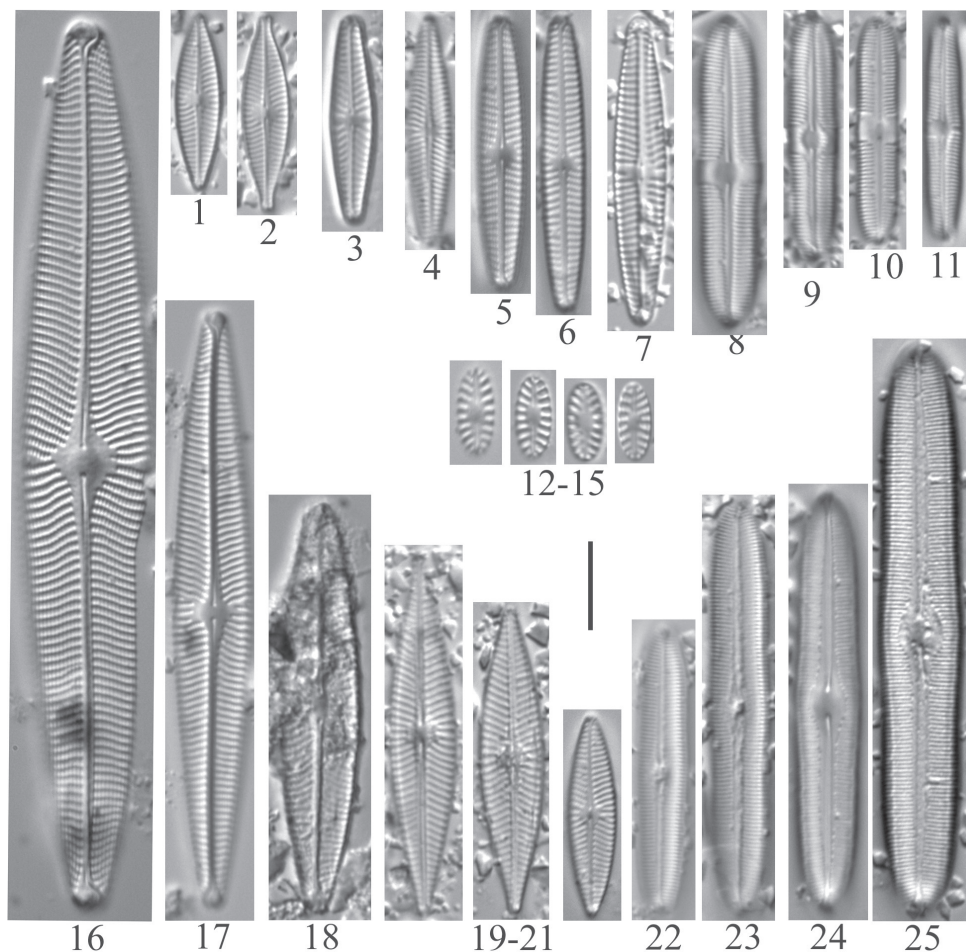


Plate 7. **1, 2** *Navicula cryptocephala* (6955) **3** *Navicula seibigiana* (6956) **4** *Navicula cryptotenella* (6955) **5, 6** *Navicula angusta* (6957, 6958) **7** *Navicula libonensis* (6955) **8** *Caloneis silicula* (6957) **9, 10** *Caloneis falcifera* (6955) **11** *Caloneis tenuis* (6957) **12–15** *Hygropetra balfouriana* (6957) **16** *Navicula vulpina* (6957) **17** *Navicula radiosa* (6957) **18** *Navicula lanceolata* (6958) **19–21** *Navicula subconcentrica* (6955, 6956) **22, 23** *Caloneis thermalis* (6955) **24, 25** *Caloneis alpestris* (6955, 6957). Scale bar: 10 μm .

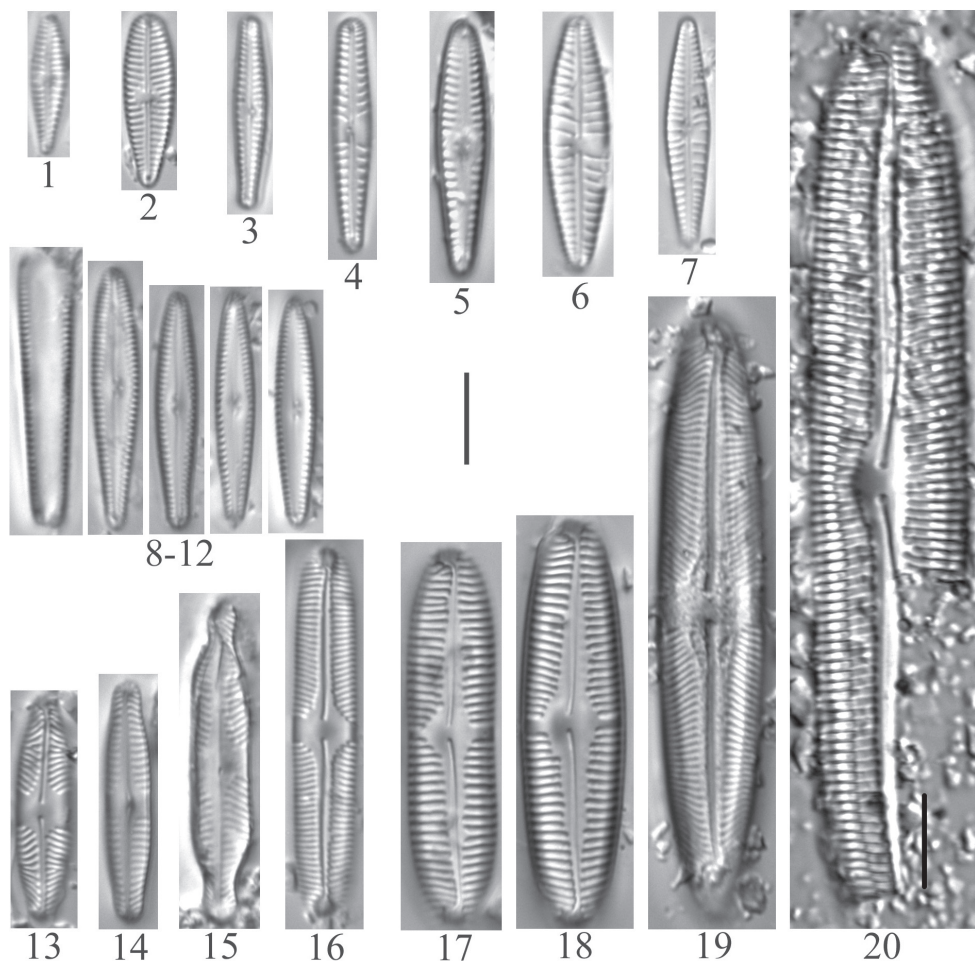


Plate 8. 1 *Gomphonema* sp. (6957, 6959) **2** *Gomphonema olivaceoides* (6958) **3** *Gomphonema minusculum* Krasske (6958) **4** *Gomphonema lateripunctatum* (6956) **5** *Gomphonema pumilum?* (6956) **6** *Gomphonema bozenae* (6957) **7** *Gomphonema pseudobohemicum* (6958) **8–12** *Gomphonema caperatum* (6958) **13** *Pinnularia krammeri* (6955) **14** *Pinnularia sinistra* (6956) **15** *Pinnularia subanglica* (6958) **16** *Pinnularia* sp. (6957) **17, 18** *Pinnularia subcommutata* (6957) **19** *Pinnularia permicrostauron* (6955) **20** *Pinnularia viridis* (6955). Scale bar: 10 μm.

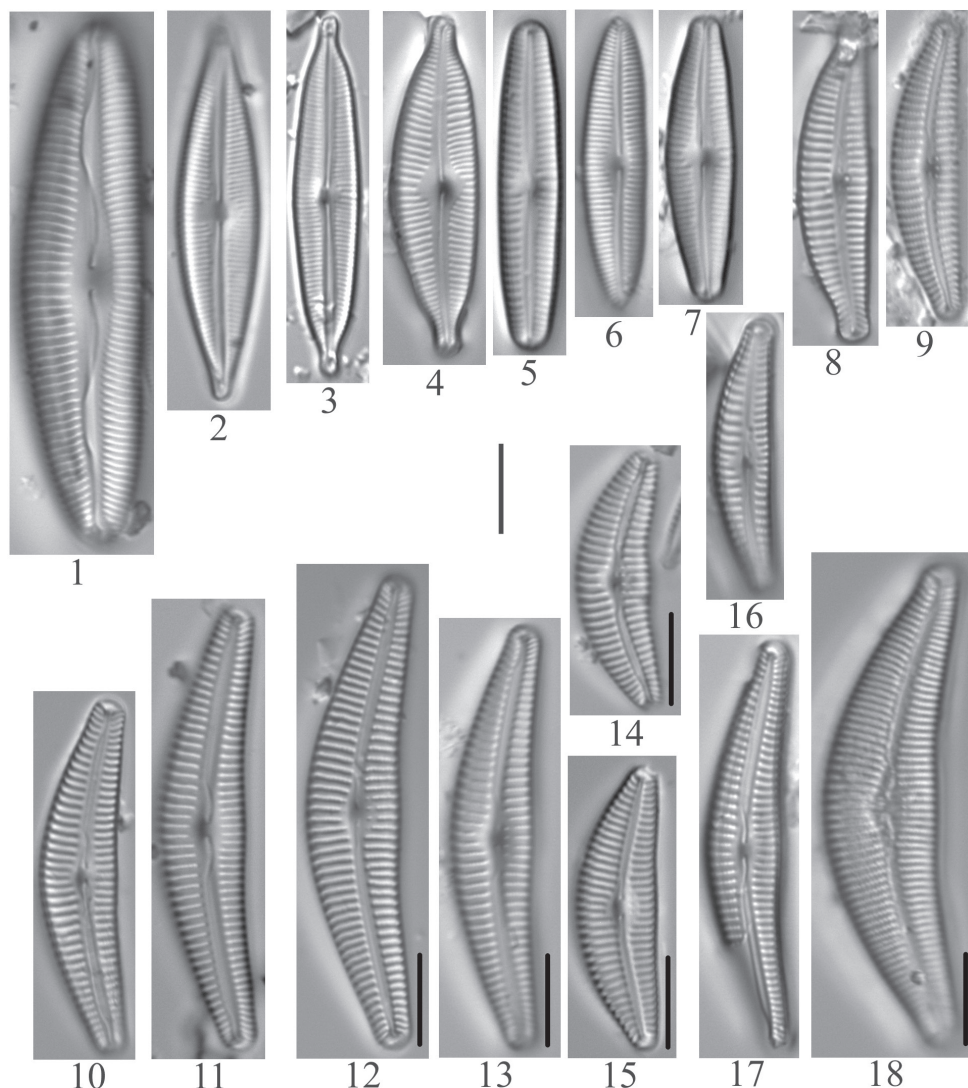


Plate 9. 1 *Cymbopleura austriaca* (6957) 2 *Cymbopleura lapponica* (6956) 3 *Cymbopleura angustata* (6958) 4 *Cymbopleura naviculiformis* (6959) 5 *Cymbopleura oblongata* (6956) 6 *Cymbopleura incerta* (6956) 7 *Cymbopleura subaequalis* (6958) 8, 9 *Cymbella excisiformis* (6958) 10, 11 *Cymbella alpestris* (6957) 12–15 *Cymbella neocistula* (6956, 6957) 16 *Cymbella cosleyi* (6956) 17 *Cymbella cleve-eulerae* (6956) 18 *Cymbella neocistula* var. *islandica* (6956). Scale bar: 10 μ m.

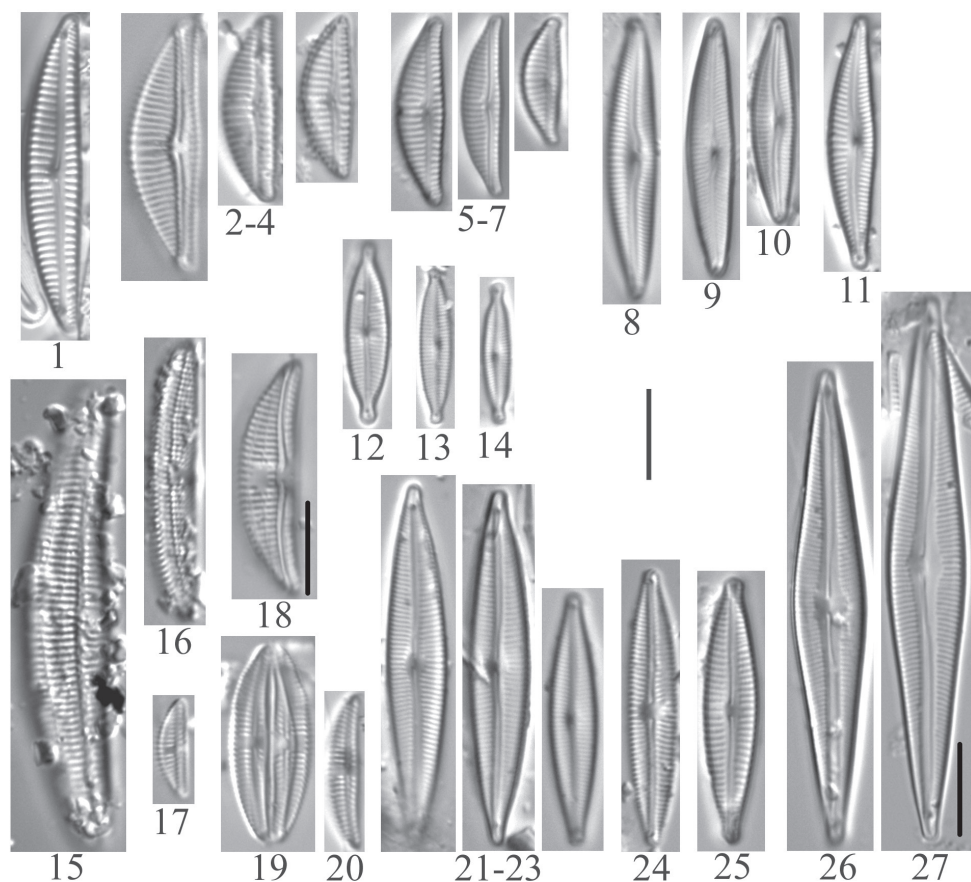


Plate 10. **1** *Encyonema neogracile* (6958) **2–4** *Encyonema silesiacum* (6957) **5–7** *Encyonema perminutum* (6956) **8** *Delicata delicatula* (6956) **9, 10** *Delicata alpestris* (6956) **11** *Delicata* sp. (6956) **12** *Encyonopsis czarneckii* (6956) **13** *Encyonopsis subminuta* (6956) **14** *Encyonopsis alpina* (6956) **15, 16** *Amphora* sp. (6955) **17** *Amphora pediculus* (6957) **18** *Amphora copulata* (6956) **19, 20** *Amphora inariensis* (6957) **21–23** *Encyonopsis stafsholtii* (6956) **24** *Encyonopsis cesatii* (6957) **25** *Kurtkrammeria aequalis* (6958) **26, 27** *Encyonopsis montana* (6956). Scale bar: 10 µm.

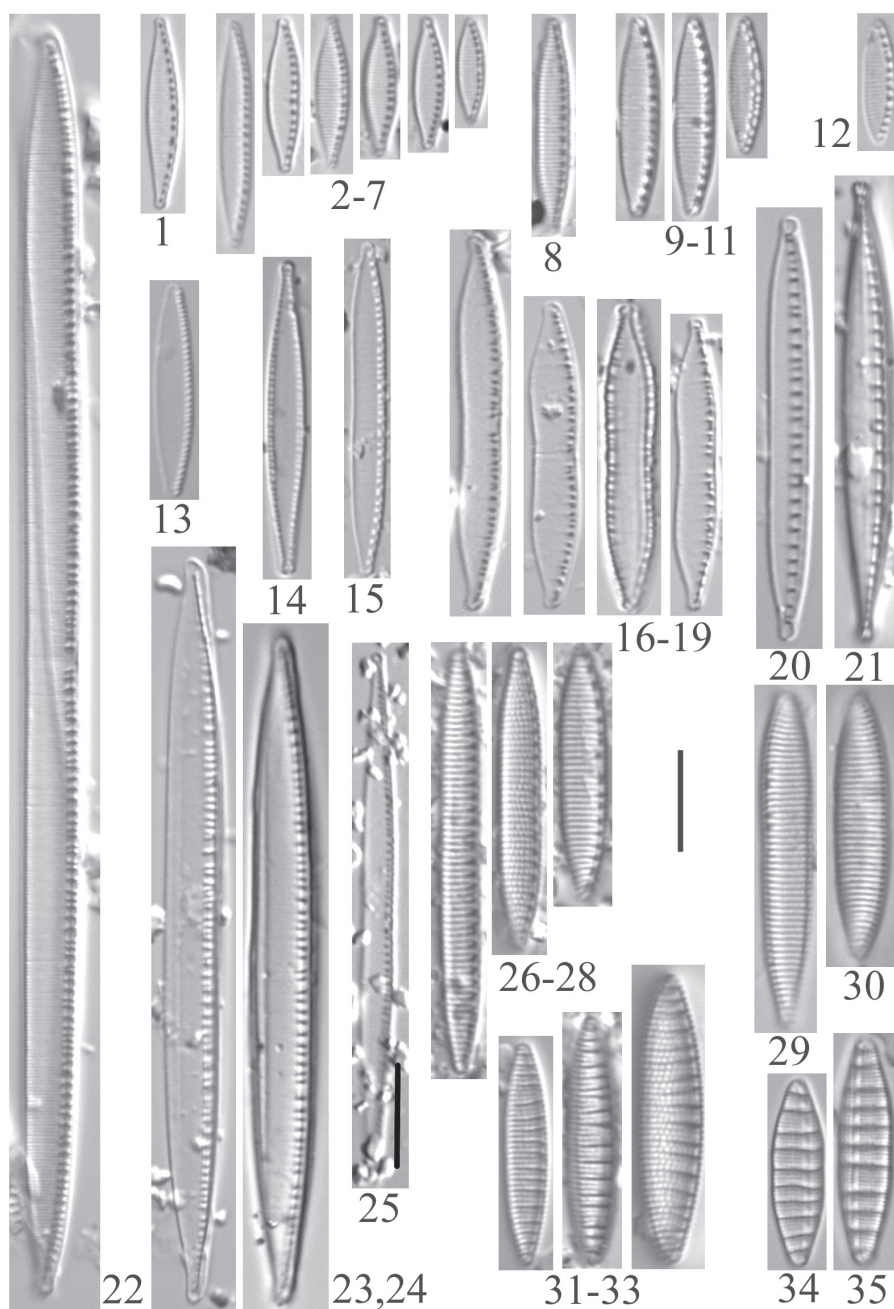


Plate 11. 1 *Nitzschia lacuum* (6956) 2-7 *Nitzschia fonticola* (6957) 8 *Nitzschia perminuta* (6957) 9-11 *Nitzschia alpina* (6957) 12 *Nitzschia inconspicua* (6957) 13 *Nitzschia pusilla* (6956) 14 *Nitzschia pura* (6956) 15 *Nitzschia palea* (6955) 16-19 *Nitzschia hamburugiensis* (6957) 20 *Nitzschia dissipata* (6957) 21 *Nitzschia dissipata* var. *oligotraphenta* (6958) 22 *Nitzschia linearis* (6957) 23, 24 *Nitzschia sublinearis* (6956, 6957) 25 *Nitzschia exilis* (6955) 26-28 *Nitzschia amphibia* (6955) 29, 30 *Nitzschia angustata* (6957) 31-33 *Denticula kuetingii* (6955, 6957) 34, 35 *Denticula tenuis* (6957). Scale bar: 10 μ m.

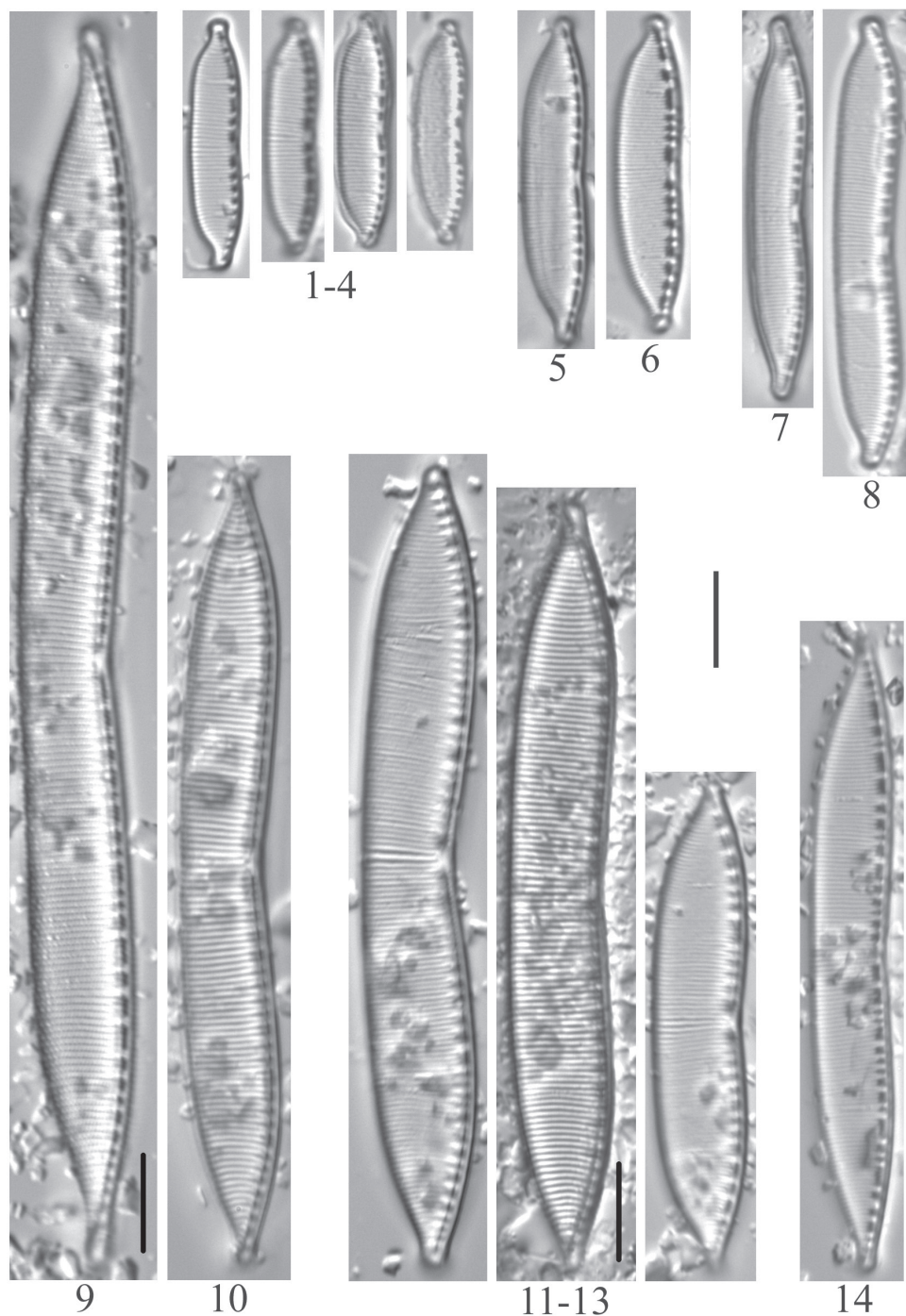


Plate 12. 1–4 *Hantzschia amphioxys* (6957, 6959) 5, 6 *Hantzschia* sp. (6957) 7, 8 *Hantzschia abundans* [*Hantzschia amphioxys*?] (6958) 9, 10 *Hantzschia elongata* (6955) 11–13 *Hantzschia hyperborea* (6955) 14 *Hantzschia* sp. (6955). Scale bar: 10 μ m.

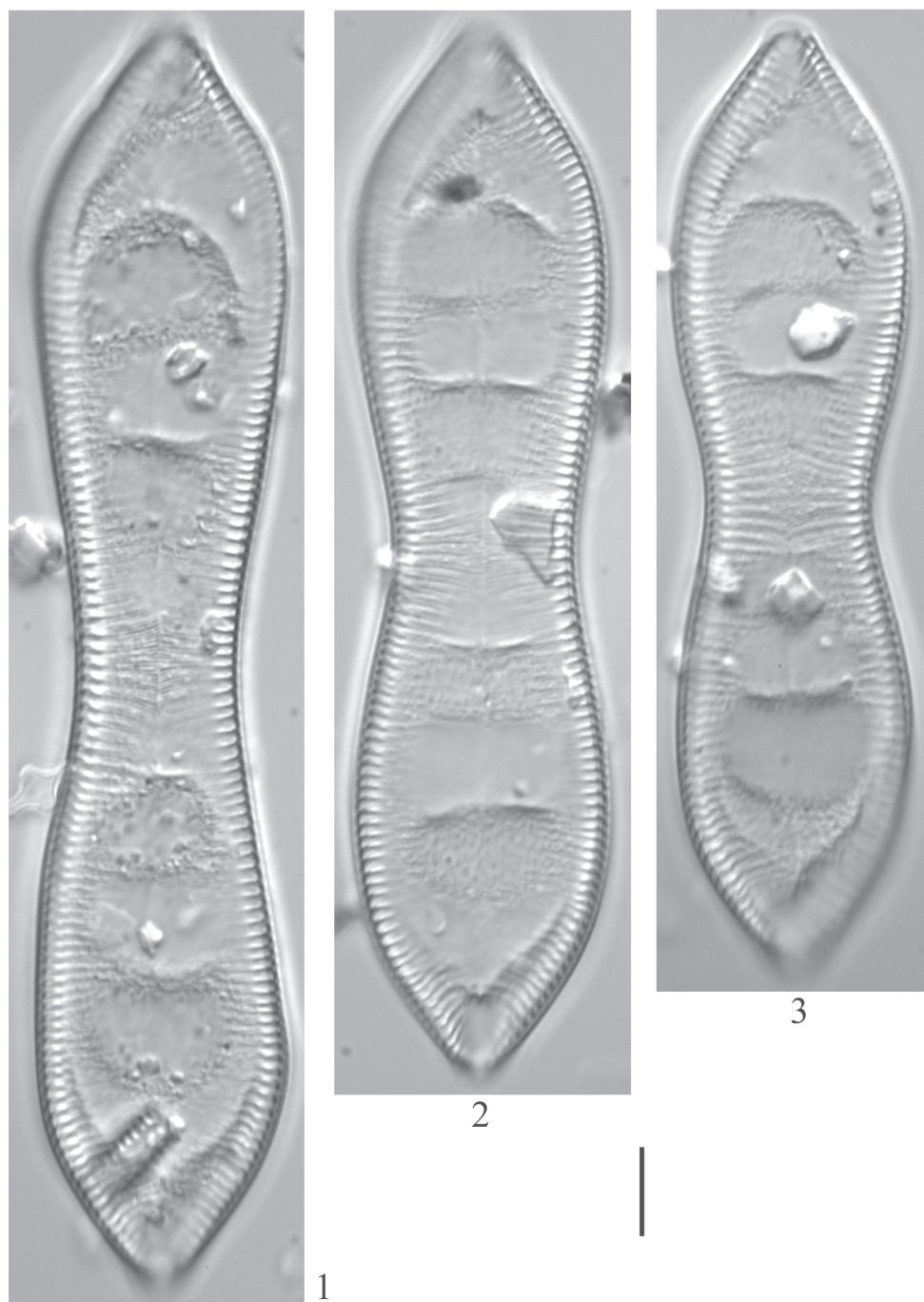


Plate 13. 1–3 *Cymatopleura solea* (6957). Scale bar: 10 μm .

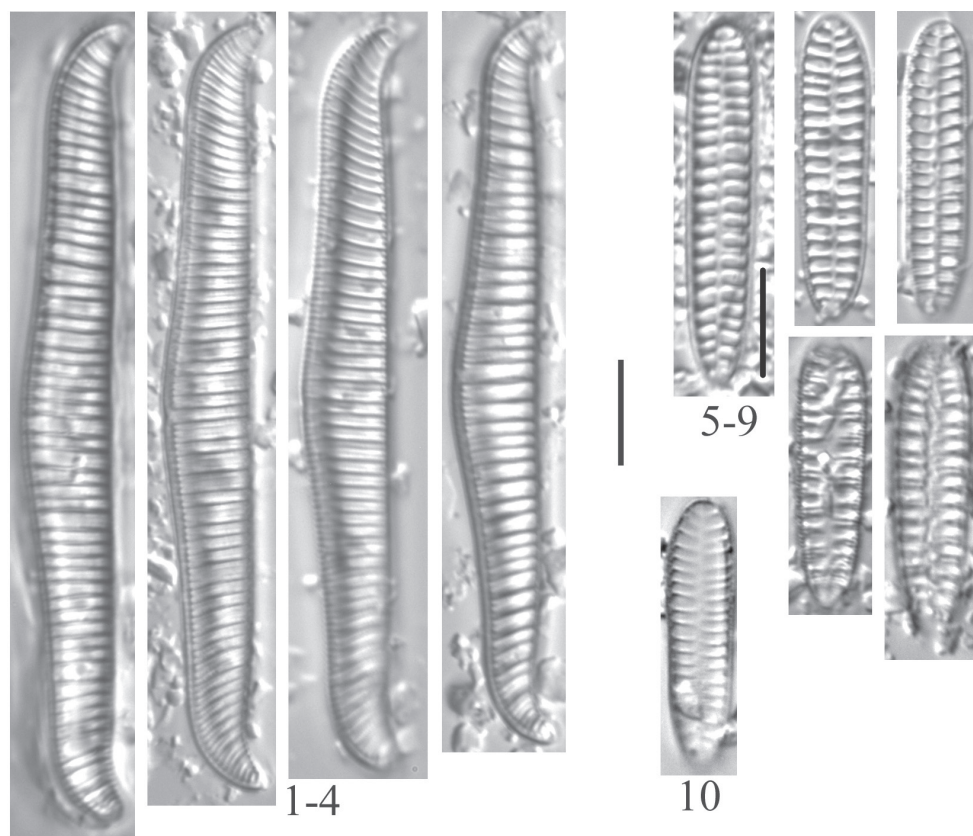


Plate 14. 1–4 *Rhopalodia gibba* (6955) 5–9 *Surirella arctica* (6955) 10 *Surirella minuta* (6959). Scale bar: 10 μ m.

Discussion

McCarthy Spring had the highest species richness of the four habitats that were sampled, likely owing to the relative stability of this habitat compared to the lake, stream and glacier habitats. That most of the type localities for these taxa are in Europe is not surprising for two reasons: 1) Most of the early work in diatom taxonomy was conducted in Europe and 2) The existence of a Holarctic or circumboreal kingdom of diatoms has been well established (Bahls 2018). Only two of the species have their type localities in Alaska: *Neidium fogedii* and *Surirella arctica*.

Most of the 139 taxa documented from WRST are typical elements of diatom associations in the Northern Rocky Mountains of Alberta, Canada and Montana, USA (Bahls, unpublished data). Two notable exceptions from the Rocky Mountain flora are *Surirella arctica* and *Gomphonema caperatum*.

Surirella arctica is a rare Arctic species that had been recorded previously only from localities in the high Arctic (Patrick and Freese 1961, Antoniadès et al. 2008, Veselá and Potapova 2014, Veselá 2017). This is the first record of this species south of 68°N

latitude. Its presence in WRST at 61°N latitude is likely made possible because of the extreme Arctic-like conditions that prevail in the park.

Gomphonema caperatum, collected from a moulin on the Root Glacier, has a disjunct distribution in montane regions of the eastern and far western United States (Bishop 2017, Ponader et al. 2017). In the eastern U. S., it ranges from the southern Appalachians to Quebec (Ponader et al. 2017); in the West, it ranges from the Sierra Nevada Mountains in California up through the Willamette and Puget Sound basins of Oregon and Washington, respectively (Bishop 2017). Notably, it was the most common diatom on the Root Glacier and one of the few taxa from the glacier represented by more than one or two frustules, perhaps indicating a viable population in this habitat. This may be the first confirmed record of this taxon from Alaska.

The four samples reported here provide just a hint of the diatom biodiversity in this wild and immense national park. Samples from other lakes, springs, streams and glaciers and samples from other habitats (e.g. seeps and wetlands) will likely produce hundreds more taxa and provide more clues to the origins and geographic and ecological affinities of the WRST diatom flora. Elsewhere in Alaska, there are vast areas and countless diverse habitats that remain to be explored for diatoms.

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Thismia sumatrana* (Thismiaceae), a new species from West Sumatra, Indonesia, with discussions on the taxonomic identity of *Thismia clavigera

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Abstract

A new species of the mycoheterotrophic genus *Thismia* Griff. (Thismiaceae), *Thismia sumatrana* Suetsugu & Tsukaya, from West Sumatra, Indonesia, is described, based on a rehydrated herbarium specimen from National Museum of Nature and Science, Japan. *Thismia sumatrana* is closely related to *T. clavigera* (Becc.) F.Muell. but is distinguished by a much larger flower.

Keywords

Thismia, taxonomy, new species, mycoheterotrophy, Sumatra

Introduction

Thismia Griff. is a genus of rare mycoheterotrophic plants that are mainly distributed in tropical Asia. Although only about 30 *Thismia* species were recognised until the 1990s, the diversity of *Thismia* is likely far underestimated, owing to the plants' inconspicuous nature (i.e. highly reduced aboveground parts and small size that allows them to be easily covered by fallen leaves). Indeed, as more comprehensive field expeditions have been undertaken, a number of *Thismia* taxa have been discovered and described from various countries in Asia (Chantanaorrapint et al. 2016, Kumar et al. 2017, Sochor et al. 2017, 2018a,b, Suetsugu et al. 2017, 2018a,b, Sujanapal et al. 2017, Tsukaya et al. 2017, Chantanaorrapint and Suddee 2018, Hroneš et al. 2018, Nishioka et al. 2018, Yunoh 2018). Accordingly, the genus has been updated to include ca. 80 accepted species, making it one of the most species-rich mycoheterotrophic genera amongst vascular plants.

Based on these findings, it is likely that botanical surveys in tropical Asia will continue to uncover other previously undescribed taxa and present new distribution records. In addition, it is possible that the re-examination of herbarium specimens in natural history museums could reveal additional diversity (e.g. Suetsugu et al. 2018b). Here, *Thismia sumatrana* Suetsugu & Tsukaya, from West Sumatra, Indonesia, is described, based on the specimen from National Museum of Nature and Science, Japan (TNS), with the habitat information obtained by Nurainas Nurainas and Hiroshi Okada.

Materials and methods

The examined specimen included two individuals (one in flower and one with immature fruit) that were mounted on a single sheet. As previous studies have suggested that the precise identification of *Thismia* specimens requires the observation of floral characteristics that are hidden in the perianth tube (e.g. Sochor et al. 2018a,b), the flowering individual of the specimen was removed from the herbarium sheet and rehydrated, by boiling in water for ca. 2 min, in order to investigate the specimen's inner floral morphology. However, since the rehydration by boiling process was inadequate for dissection, the plant was kept in room temperature water for ca. 1 d. After that, the plant was carefully dissected and preserved in 70% ethanol. The fruiting plant remained dry and on the herbarium sheet. The structure of both individuals was observed using a stereomicroscope (MZ16a; Leica Microsystems, Cambridge, UK). It should be noted that our measurements, except for that of the inner floral parts, are based on the dry herbarium specimen and that the measurements may be smaller than those found in nature, owing to desiccation and shrinkage. In fact, during rehydration, the size of the inner floral parts increased by ca. 10% compared with that of the dry condition.

The morphological characters of both the unknown specimen and its putative closest relative, *T. clavigera*, were compared with detailed images of the holotype deposited in FI from JSTOR Global Plants (<http://plants.jstor.org/>) and previously published

descriptions, illustrations and photographs of *T. clavigera* [i.e. Beccari (1878), Jonker (1938), Stone (1980), Chantanaorrapint and Chantanaorrapint (2009)]. The morphological characters of *T. clavigera* were evaluated based on the following criteria: (i) when the previous descriptions contained information on the lengths of the targeted parts, the values were used and (ii) when the descriptions did not contain information on the lengths of the targeted parts, the lengths were inferred from illustrations, photographs or images and the lengths of the parts that were included in the descriptions of Table 1 for comparison with the unknown specimen. Herbarium abbreviations follow Index Herbariorum (Thiers 2018, <http://sweetgum.nybg.org/science/ih/>).

Taxonomy

Thismia sumatrana Suetsugu & Tsukaya, sp. nov.

urn:lsid:ipni.org:names:77192417-1

Figs 1, 2

Diagnosis. *Thismia sumatrana* differs from its close relative *T. clavigera*, in having a much larger flower (ca. 8 cm vs. ca. 2.8 cm long).

Type. INDONESIA. West Sumatra: Padang Pariaman, Sipisang, ca. 300 m alt., 0°33'S, 100°21'E, 27 Feb 1994, *Okada et al.* 112 (holotype TNS!, dried plant on a herbarium sheet (TNS-01051838) and liquid-preserved material in a bottle, labelled as the same specimen).

Terrestrial, mycoheterotrophic herb. Roots not seen. Stems erect, unbranched, 5–7.5 cm long. Leaves ca. 10, scale-like, appressed, triangular-ovate to lanceolate, 3–9 mm long, apex acute or slightly acuminate. Flowers solitary, sessile, terminal. Floral bracts ovate-lanceolate, 10–13 mm long, apex acute to acuminate, slightly curved. Flowers bisexual, ca. 8 cm long (including appendages); perianth tube, campanulate, ca. 2.7 by 1.3 cm, narrowest just above the ovary, widest at the top, with 12 longitudinal ribs, transverse bars inside present; outer perianth lobes 3, broadly triangular, ca. 2.5 mm long; inner perianth lobes 3, incurved, apically adnate to form a dome-shaped mitre with three lateral holes, dome-shaped mitre ca. 9 mm in diam., bearing three eaves-like to hood-like accessory lobes at the tip and three slender claviform appendages at the top, appendages ca. 3.8 cm long; stamens 6, borne on the thickened margin of the perianth tube; filaments short, ribbon-shaped, free; connective broad, connate to form a tube with a quadrangular lateral appendage, apex acute, hairy; individual connective bearing four thecae; theca oblong, 1.2–1.4 mm long on the uppermost part of connective; interstaminal gland rectangular, 1.2–1.4 mm long on the line of fusion between each connective; style short, ca. 0.8 mm long; stigmas elliptic-oblong, ca. 2.5 mm long, 3-lobed; apex of lobes truncate; ovary ca. 5 mm long, cup-shaped. Mature fruit and seeds not seen.

Distribution. It is known from only a single collection comprising of one flowering and one fruiting individual.

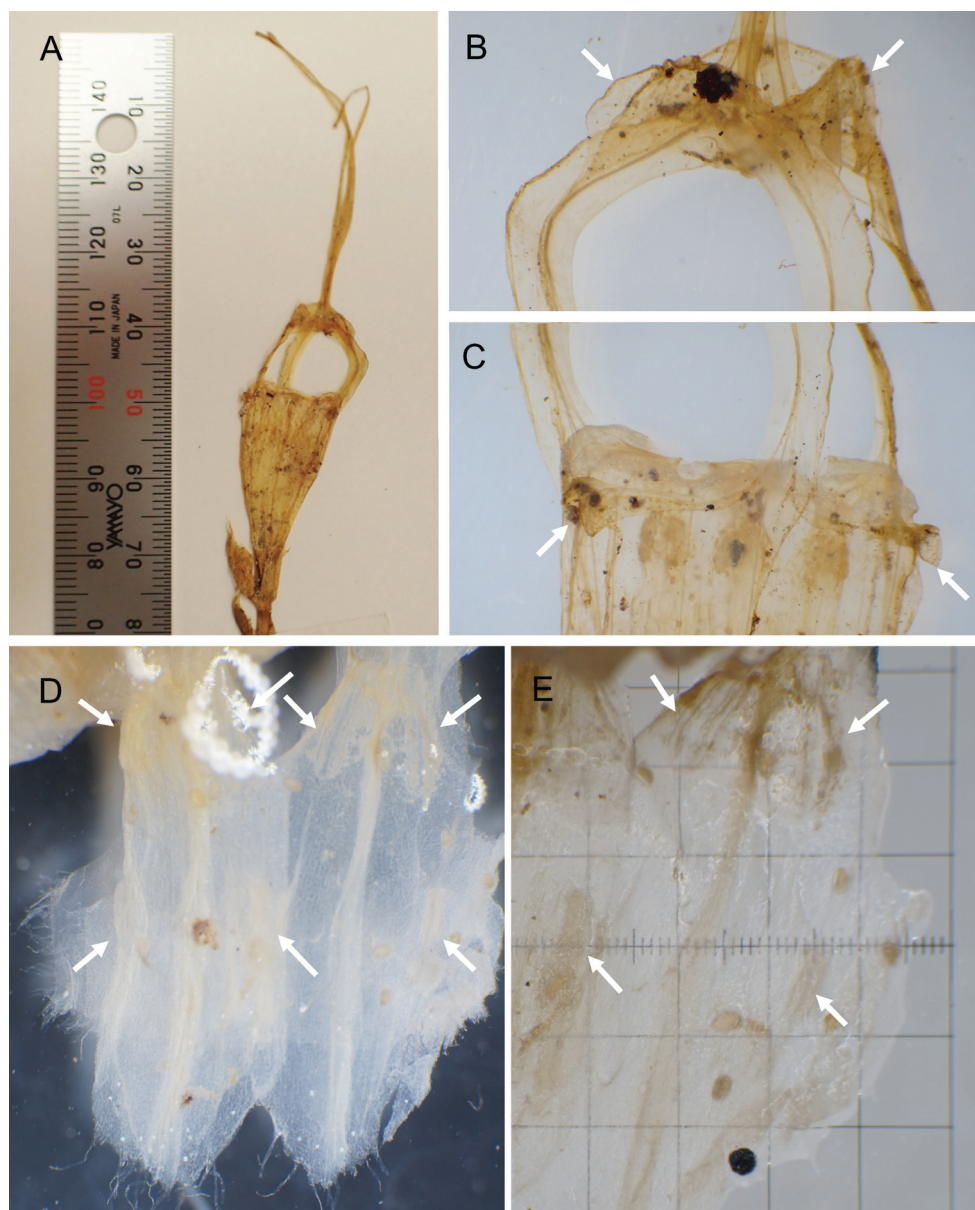


Figure 1. *Thismia sumatrana* from West Sumatra, Indonesia (from the holotype). **A** Flower **B** Dome-shaped mitre bearing the eaves-like to hood-like accessory lobes. The accessory lobes are indicated using the arrows **C** Upper part of perianth tube. Outer perianth lobes are indicated by arrows **D** Inner view of two pendulous stamens. Thecae and glands are indicated by upper and lower arrows, respectively **E** Outer view of a pendulous stamen. Thecae and glands are indicated by upper and lower arrows, respectively. One grid is equal to 1 mm².

Thismia sumatrana was collected from a forest floor beside a rheophytic zone along Anak Air Ganggu (Ganggu Stream), 0°33'S, 100°21'E, at Sipisang Village, Padang Pariaman, West Sumatra, Indonesia. The area was covered by mixed primary

Table 1. Morphological comparison between *Thismia sumatrana* and the plants reported as *Thismia clavigera*.

Characters	<i>T. sumatrana</i>	<i>T. clavigera</i> (type locality) ¹	<i>T. clavigera</i> (Langkawi) ²	<i>T. clavigera</i> (Aceh) ²	<i>T. clavigera</i> (Tarutao) ³
Stem height	5–7.5 cm	6–9 cm	up to 12 cm	similar to Langkawi	up to 9 cm
Floral bract	10–13 mm long	6–7 mm long	up to 12 mm long	similar to Langkawi	ca. 12 mm long
Number of flowers	1	3	1–6	similar to Langkawi	1–2(–3)
Appendices on the tip of mitre	eaves-like to hood-shaped	eaves-like	poorly developed	similar to Langkawi	poorly developed
Length of perianth tube	ca. 27 mm	ca. 9 mm	ca. 13 mm	similar to Langkawi	15–19 mm
Length of claviform appendages	ca. 38 mm	8–12 mm	12–14 mm	ca. 5 mm long	19–32 mm
Size of outer perianth lobe	ca. 2.5 mm	ca. 1 mm	0.3–0.4 mm	similar to Langkawi	ca. 1 mm
Status of nectariferous gland on the top of mitre	rectangular, 1.2–1.4 mm long	unknown	rectangular, ca. 0.9 mm long	similar to Langkawi	orbicular, ca. 0.8 mm diameter
Status of thecae	oblong, 1.2–1.4 mm long, located in the uppermost part of connective	unknown	oblong, ca. 1 mm long, located in the uppermost part connective	similar to Langkawi	oblong, ca. 2 mm long, located little above the middle of connective

¹from Beccari (1878), Jonker (1938) and our own examination of holotype image. ²from Stone (1980). ³from Chantanaorrapint and Chantanaorrapint (2009).

and secondary forest along a stream, where relatively natural conditions remained. For example, there were many individuals of a rare and large herbaceous plant, *Amorphophallus titanum* (Becc.) Becc. (Araceae). In addition, many individuals of a rheophytic plant, *Furtadoa sumatrensis* M.Hotta (Araceae), grew on small rocks both in the stream and on the stream bank (Mori and Okada 2001).

Taxonomic notes. The distinctive characteristics of *Thismia sumatrana* include 1) minute outer tepals, 2) stamens with acute distal parts and 3) large flower. The combination of the first two characteristics, which have also been reported for *Thismia clavigera* and *T. kelantanensis*, but not for the other *Thismia* species (Stone 1980, Chantanaorrapint and Chantanaorrapint 2009, Tsukaya and Okada 2012, Yunoh 2018), suggests that *T. kelantanensis*, *T. sumatrana*, and *T. clavigera* are closely related. However, *T. kelantanensis* can be easily distinguished from the other two species by the six-partite hood on its mitre (Yunoh 2018).

Thismia clavigera was originally described as a member of the genus *Geomitra* Becc., based on collections from Sarawak in the early 1860s (Beccari 1878). Unfortunately, Beccari (1878) did not describe the inner floral characteristics, such as the structure of the connectives that are crucial in the identification of *Thismia* species and, instead, provided detailed drawings of the taxon's external appearance. Nonetheless, comparing our material to Beccari's original description, illustration and holotype specimen of *T. clavigera* revealed that *T. sumatrana* can be easily distinguished from *T. clavigera* by its much larger flowers (ca. 8 cm vs. ca. 2.8 cm long), whereas stems of *T. sumatrana* and *T. clavigera* are similar in length (ca. 5–7.5 cm long vs. 6–9 cm long; Table 1). As noted above, the flower of the *T. sumatrana* specimen may be shorter than those in nature, owing to desiccation and shrinkage. Nevertheless, the flowers are much larger than those of *T. clavigera*.

It should be noted that *T. clavigera* has been reported not only in type collections but also from different localities. Stone (1980) reported the rediscovery of *T. clavigera*

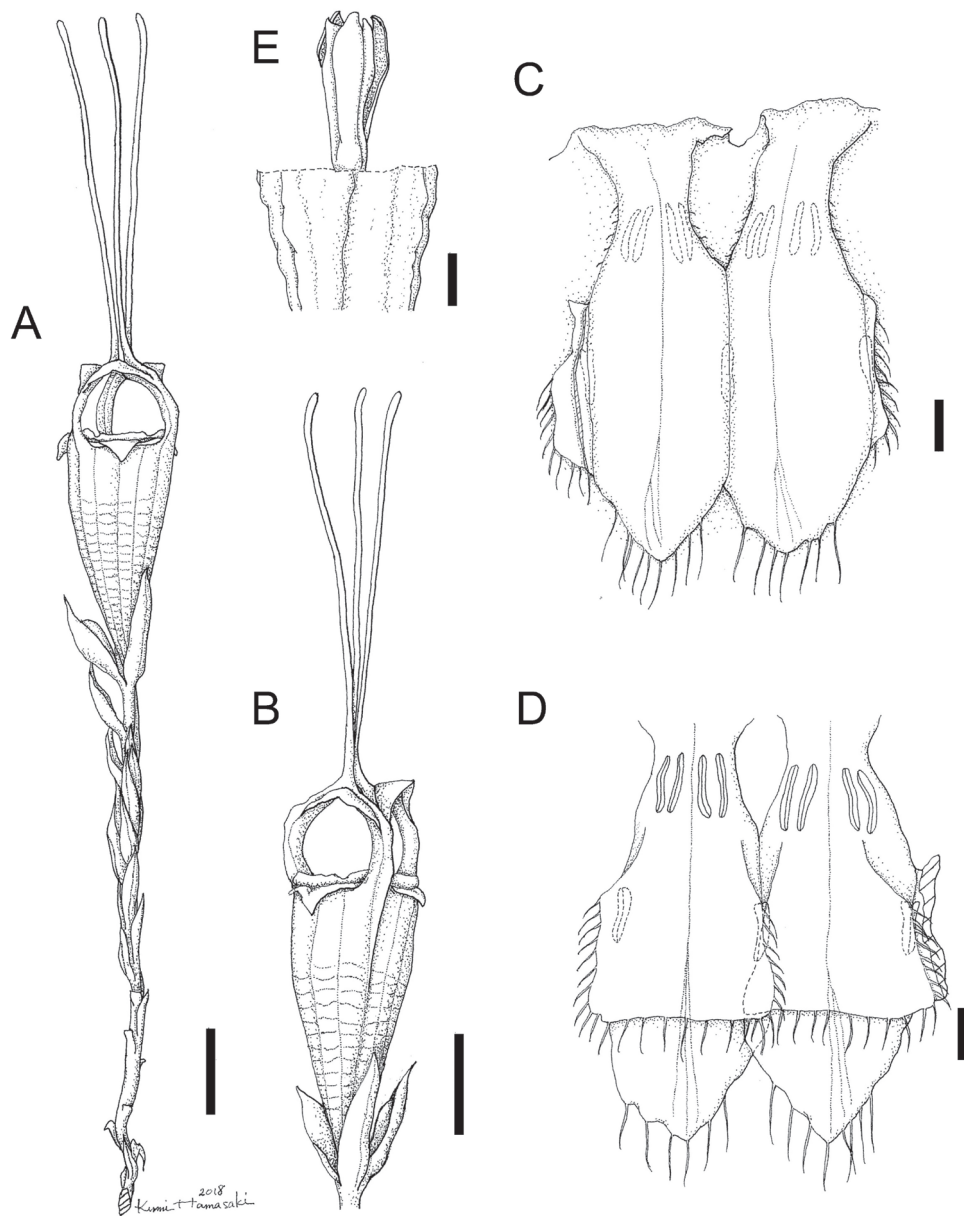


Figure 2. *Thismia sumatrana* from West Sumatra, Indonesia (Drawn from the holotype). **A** Flowering plant **B** Flower **C** Inner view of two pendulous stamens **D** Outer view of two pendulous stamens **E** Ovary with style and stigmas. Drawn by Kumi Hamasaki. Scale bars: 1 cm (**A–B**), 1 mm (**C–E**).

from Pulau Langkawi, in the western part of the Malay Peninsula and Aceh, in northern Sumatra in 1979. Chantanaorrapint and Chantanaorrapint (2009) also reported that *T. clavigera* occurs on Tarutao Island, southern Thailand, which is close to Lang-

kawi. In addition, one specimen seems to have been collected in Sarawak by Caddick (Caddick et al. 1998) and subjected to DNA sequencing by other authors (e.g. Merckx et al. 2006), although neither the precise locality nor the description is known, and no such specimen was found in K from where Caddick et al. (1998) reported on the deposited voucher specimen (Alison Moore, Curator of K, personal communication). However, we found that there are notable morphological variations amongst specimens recorded as *T. clavigera*.

The shape of the mitre, for example, varies amongst the specimens recorded as *T. clavigera* from different localities (Table 1). While Beccari (1877) depicted *T. clavigera* with small eave-like projections, such projections being very poorly developed in *T. clavigera* specimens from Langkawi and Tarutao (Stone 1980, Chantanaorrapint and Chantanaorrapint 2009) and the slender claviform appendages of the mitri-form inner tepals are much shorter in *T. clavigera* from Aceh (ca. 5 mm) than in *T. clavigera* from other localities. Moreover, Stone (1980) also noted that *T. clavigera* from Aceh exhibits unique purple claviform appendages. However, these differences may only represent intraspecific variation, especially considering that Sochor et al. (2018b) noted that variation amongst mitre morphology is not necessarily taxonomically informative, at least for some *Thismia* species.

Yet, variations amongst *T. clavigera* from different localities have also been reported for other morphological characters. For example, *T. clavigera* specimens from Thailand exhibit orbicular interstaminal glands (Chantanaorrapint and Chantanaorrapint 2009), whereas the Langkawi specimens exhibit long, rectangular glands (Stone 1980) and the thecae of *T. clavigera* specimens from Thailand are situated slightly above the middle of the connective (Chantanaorrapint and Chantanaorrapint 2009), whereas those of Langkawi specimens are located in the uppermost part of the connective (Stone 1980). Therefore, considering that inner floral morphology is considered important for *Thismia* classification, differences in *T. clavigera* plants from Langkawi and Tarutao strongly suggest that at least two interspecific groups exist. Here, taxonomic treatments of specimens recorded as *T. clavigera* from other localities were not conducted because the inner floral characteristics of *T. clavigera* from the type locality are unavailable. Further investigation, based on specimens from the type locality of *T. clavigera*, is critical for elucidating the true taxonomic identities of specimens recorded as *T. clavigera* from other localities.

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A new genus of Compositae (Eupatorieae, Piqueriinae) from Peru, named *Centenaria* to honour the 100th anniversary of the Natural History Museum of the National University Mayor of San Marcos

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Abstract

A little herb from central Peru is recognised as a new species of a new genus. *Centenaria rupacquiiana* belongs to the tribe Eupatorieae, subtribe Piqueriinae. It has asymmetrical corollas with two inner lobes smaller, a flat and epaleaceous receptacle and the presence of pappus. In Peru, *Centenaria* is related to the genera *Ferreyrella* and *Ellenbergia*, but *Ferreyrella* is different by having no pappus and a paleate receptacle; and on the other hand, *Ellenbergia* is different by having symmetrical corollas.

Resumen

Una pequeña hierba del centro del Perú es reconocida como una especie nueva en un nuevo género. *Centenaria rupacquiiana* es miembro de la tribu Eupatorieae subtribu Piqueriinae. Tiene corolas asimétricas con dos lóbulos internos más pequeños, receptáculo plano y sin palea, y presencia de papus. En Perú, *Centenaria* está relacionada a los géneros *Ferreyrella* y *Ellenbergia*, Pero *Ferreyrella* se diferencia por carecer de papus y presentar un receptáculo con paleas; por otro lado, *Ellenbergia* se diferencia por sus corolas simétricas.

Keywords

Asteraceae, *Ellenbergia*, Eupatorieae, *Ferreyrella*, Rupac

Introduction

The Compositae has more than 30000 accepted species in more than 1900 genera (Nordenstam et al. 2009). Currently, twelve subfamilies are recognised, of which Asteroideae (Cass.) Lindl. comprises over 60% of the species in the family, placed in ca. 1229 genera and 20 tribes and is the largest subfamily of Compositae (Pelser and Watson 2009). One of these tribes is Eupatorieae Cass., the fourth largest tribe in the subfamily and the sixth largest in the family (Funk et al. 2009, Pelser and Watson 2009). The tribe Eupatorieae contains 19 subtribes, 185 genera and 2200 species (as of Hind and Robinson 2007, Rivera et al. 2016); and one of these subtribes is Ageratinae Less. with 26 genera and between 300 and 350 species (Hind and Robinson 2007, Robinson et al. 2009), although these numbers of genera and species will certainly change since, recently, it has been shown that the earlier concept of Ageratinae was polyphyletic (Rivera et al. 2016). For this reason, the subtribe Piqueriinae is treated here as separate (following Robinson et al. 2009).

In Peru, the tribe Eupatorieae is one of the largest with 46 genera and 325 species (Dillon and Sagástegui 2002). The subtribe Ageratinae contains seven genera in Peru (Brako and Zarucchi 1993, Ulloa Ulloa et al. 2004, Hind and Robinson 2007), of which four belong to the narrower concept of Piqueriinae and three (*Ascidioogyne* Cuatrec., *Ellenbergia* Cuatrec. and *Ferreya* S.F. Blake) are endemic to this country (Beltrán et al. 2006).

On 15 April 2018 during a field trip, as part of a botanic course of the “Universidad Nacional Mayor de San Marcos”, to an area east to the city of Lima, we found a little plant of Compositae growing along the trail between Pampas and Rupac (Lima, Peru). It was here that serendipity brought us and the new species face to face. After two weeks, we concluded that it was a member of what is here treated as Piqueriinae that had not been previously reported for the Peruvian flora (Brako and Zarucchi 1993, Ulloa Ulloa et al. 2004, 2017, Beltrán et al. 2006, Dillon and Sagástegui 2002, Vásquez et al. 2002, Linares et al. 2010, Gonzáles et al. 2016). For this reason, on 7 May, we decided to make a new trip to look for more populations and to make more collections for the study of this plant.

This previously unknown dwarf member of the tribe Eupatorieae from the higher elevations of the Department of Lima in Peru shows a combination of characteristics unmatched in other previously known genera of the tribe. The entity is described here as the new genus *Centenaria* in honour of the centennial of the establishment of the Natural History Museum of National University Mayor of San Marcos (28 Feb 1918).

As shown in the study of the tribe Eupatorieae of the Asteraceae by King and Robinson (1987), the tribe contains many genera with a dwarf habit and a reduced or absent apical appendage on the anther. These genera are scattered geographically from Mexico southwards to the Andes of South America and eastwards to Brazil. Most genera show ex-imbricate involucre with broad and blunt-tipped phyllaries and corollas with narrow bases and broadly campanulate limbs. Such genera seem mostly to be related to the *Piqueria* group in the subtribe Piqueriinae of the Eupatorieae (Robinson

et al. 2009, Rivera et al. 2016). The new genus differs from all of these genera by the presence of a pappus of lanceolate scales on only the inner florets of the capitulum. Zygomorphic corollas of the plant are an unusual characteristic in the tribe, but are also seen in the genus *Microspermum* Lagasca of Mexico, in one of the species of *Iltisia* S.F.Blake of Costa Rica, in one of the species of *Ferreyrella* of Peru and in the following members of the monophyletic subtribe Praxelinae (Rivera et al. 2016), the Brazilian and Bolivian turf-forming genus *Piqueriopsis* G.M.Barroso, the Brazilian *Eitenia* R.M.King & H.Rob. and a few members of the mostly Brazilian polyphyletic *Praxelis* Cass. (Rivera et al. 2016). The latter genera can be distinguished by having no pappus or a pappus of many capillary setae. Two genera, *Piqueriopsis* R.M.King of Mexico and *Iltisia* of Costa Rica are distinct in having 4-lobed corollas. Of the above genera, the more northern *Microspermum* and *Iltisia* also seem to have a more remote relationship because of their narrower and more pointed phyllaries.

Of most interest for purposes of comparison are the presumably related dwarf genera that occur in Peru, *Ascidiogyne*, *Ellenbergia*, *Ferreyrella* and *Guevaria* R.M.King and H.Rob. Of these, *Ferreyrella* differs by its paleate receptacle, *Ellenbergia* differs by its pappus of many narrow segments, *Guevaria* differs by its total lack of pappus, its conical receptacle and prostrate to procumbent habit and *Ascidiogyne* differs by its car-nose nature and prostrate habit with clusters of short peduncles arising from short leafy lateral branches. These genera are distinguished more completely in the key below.

Material and methods

All morphological characters were studied under a Leica-EZ4 1×–4.5× stereo microscope and an Olympus SP5-70UZ Digital Camera. Specimens of Piqueriinae housed at herbaria GOET, MO, MOL, P, GH, U, UC, US and USM, (Thiers 2018) have been examined. Digitised specimens were viewed via online herbarium catalogues (Herbarium virtual austral Americano 2018) or via JSTOR (2018).

Taxonomic Treatment

Centenaria P.González, A.Cano & H.Rob., gen. nov.

urn:lsid:ipni.org:names:77192419-1

Description. Small, erect, annual herbs, to 30 cm tall. Leaves opposite, blade ovate to broadly elliptical, coarsely to finely serrate. Inflorescence a diffuse corymbose cyme. Phyllaries 5, distant, biseriate, subequal to equal, persistent, oblong-elliptical to obovate-elliptical, with shortly apiculate apices; receptacle flat, foveolate, glabrous, epaleaceous. Florets 7–14; corollas asymmetrical with the two inner lobes smaller, white, with distinct short constricted basal tube bearing glandular or eglandular hairs; throat short and broad-campanulate; lobes as long as wide or outer lobes of peripheral florets

longer, short-papillose on inner surface and margins; lower part of filament glabrous; anther collars rather short; style base not enlarged, glabrous; arms rather short-clavate, densely short-papillose; papillae larger and less dense below clavate tip. Achenes prismatic, 5-ribbed, ribs setuliferous, narrowed and setuliferous above carpopodium; carpopodium inconspicuously, short-cylindrical; pappus 5 long, lanceolate squamellae, densely scabrid on margins, nearly smooth on outer surface, smooth on inner surface.

***Centenaria rupacquiana* P.González, A.Cano & H.Rob., sp. nov.**

urn:lsid:ipni.org:names:77192421-1

Figure 1

Diagnosis. A little herb characterised by its asymmetrical corollas with two small inner lobes, flat and epaleaceous receptacle and presence of pappus.

Type. Peru. Dept. Lima: prov. Huaral, Dist. Atavillos Bajo, NE of Pampas, road to Rupac, archaeological monument pre Inca, slopes with loamy clay soil, scrubland, -11.313333, -76.613333, 3033–3509 m a.s.l., 15 Apr 2018, (fl, fr), *A. Cano, P. González, E. Huamán, S. Riva & S. Rivera* 22682 (holotype: USM-3070016!, isotypes: MO!, MOL!, US-3730645!, USM!).

Description. Slender and small herb 9–20(30) cm high, bearing 2–10 heads. Roots thin and delicate, 2–4 cm long. Stem unique, terete, 0.3–1(1.7) mm thick, often purplish tinged, rather densely pilose with several celled acuminate mostly spreading whitish or purplish hair up to 0.3–0.7(1) mm long, internodes 1–3, mostly (1)3–5(6) cm long. Leaves opposite, membranous, petioles short, ca. 1–1.5 mm long, pubescent like the stem, larger leaf blades 10–20 mm long, 7–12 mm wide, obtuse to acutish, at base cuneate, obtusely about 3-toothed on each side, triplinerved from near base and lightly reticulate veiny beneath, pilose on surface above and chiefly along veins beneath with hair like those of stem, thin herbaceous; upper leaves (subtending branches of inflorescence) mostly sessile, smaller, the uppermost bracteiform. Capitula homogama, discoid, mostly in groups of 2 or 10 at tips of stem and branches, 4–5 mm high, 2.5–4 mm thick, on densely pubescent pedicels 2–8(12) mm long, pedicel pilose and pilose-glandulose (globose-stippled glands); involucre 3–3.5(4) mm high, 2–2.3 mm wide, phyllaries 5, biseriate, imbricate, outermost phyllaries 3, membranous, elliptical to obovate-elliptical, obtuse, 3–3.5 mm long, 1–1.7 mm wide, 5-nerved, the phyllaries rather glabrate, apex tinted purple, slightly erose-ciliate, innermost phyllaries 2, elliptical to obovate, obtuse, 3.5–3.8 (4) long, 2–2.2 wide, 5-nerved, the phyllaries rather glabrate, apex erose-ciliate; receptacle flat foveolate; pales none. Flowers hermaphroditic, (7)9–12(14), corollas asymmetrical, the two inner lobes are smaller, white, funnelform, 2 (inner) to 3 (outer) mm long, outermost corollas 3–4 very asymmetrical, the tube 0.9–1.2 mm long, tube base expanded, the throat about 0.3–0.5 mm long, the longer teeth 1–1.5 mm long, triangular-lanceolate, the shorter about 0.2–0.3 mm long, triangular, apex acute, margin stout minute papillose, innermost corollas 7–8(10), the tube 0.7–1 mm long, tube base dilated, the throat about 0.2–0.5

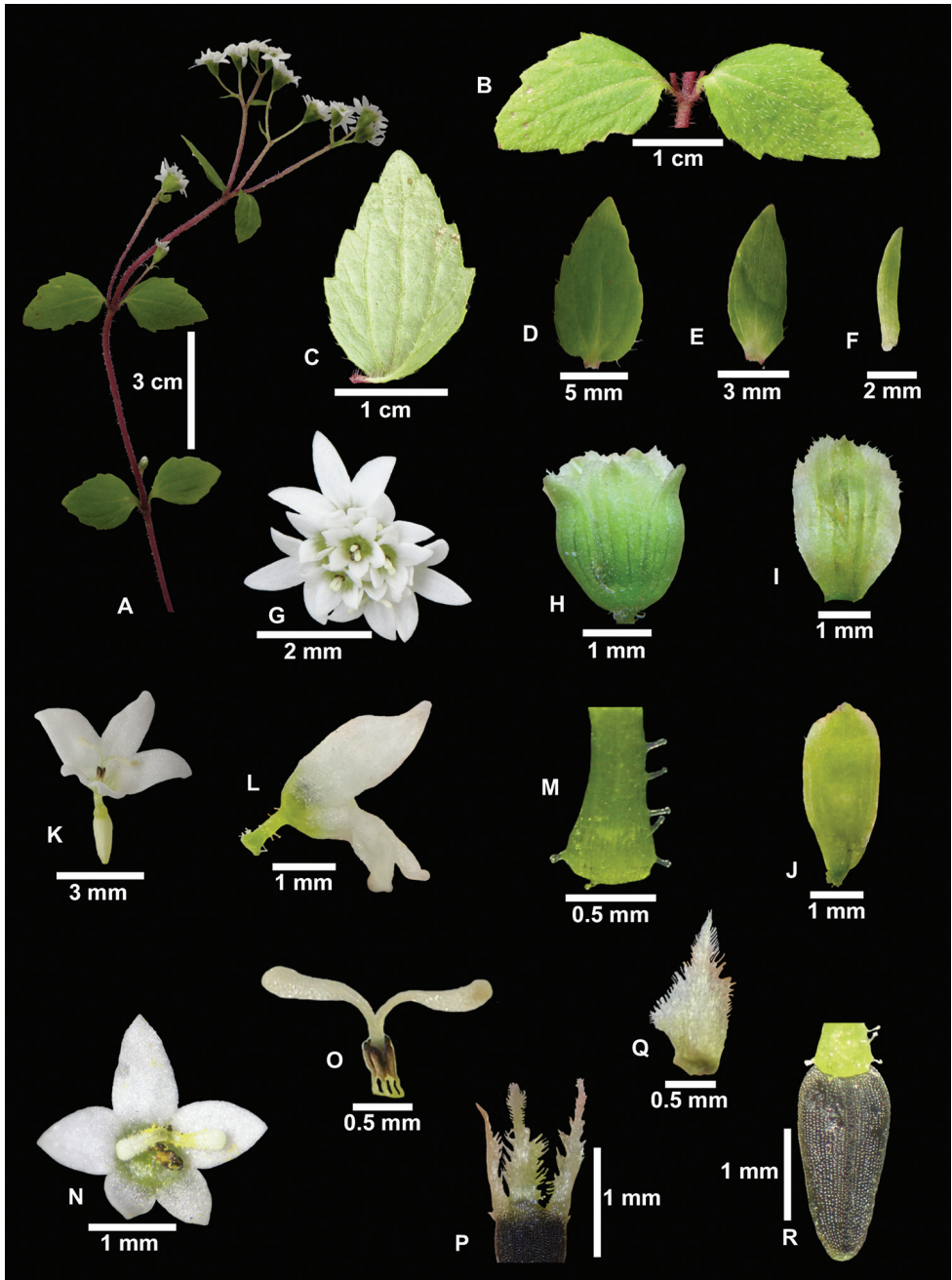


Figure 1. *Centenaria rupacquiiana*. **A** Plant **B** leaf (adaxial surface) **C** mature leaf (abaxial surface) **D** mature leaf (adaxial surface) **E** upper leaf **F** uppermost leaf bracteiform **G** capitula (upper view) **H** involucre **I** inner phyllaries **J** outer phyllaries **K** flower (frontal view) **L** flower (lateral view) **M** flower tube with glandular trichomes **N** flower (upper view) **O** style and stamens **P, Q** scale of pappus **R** achene without pappus. Photos by P. Gonzáles.

mm long, the longer teeth 0.2–0.3 mm long, triangular-lanceolate, the shorter about 0.1–0.2 mm long, triangular, apex acute, margin stout, minute papillose, anthers oblong, apex obtuse, emarginate, subtruncate, exappendiculate, base obtuse, 0.2–0.3 mm long and 0.1–0.2 mm wide, filaments inconspicuous, ca. 0.1–0.2 mm, stylus crassiusculus, 1–1.3 mm, with 2 stigmatic arms 0.5–0.7 mm long, arms recurvate, clavate, densely papillose in the stigmatic region. Fruit an achene mature black, 1.5–2 mm long, 0.5–0.7 mm wide (above), prismatic, base attenuate, 5-ribbed, ribs setuliferous, narrowed and setuliferous above carpopodium; carpopodium inconspicuous, shortly cylindrical, less than 0.1 mm; pappus (only in the innermost flowers of the capitula, outermost flowers without pappus) of 5 lanceolate squamellae, densely scabrid on margins, nearly smooth on outer surface, smooth on inner surface, scales 1–1.2 mm long, 0.2–0.3 mm wide (lowermost), to 0.7 mm wide (middle part), united in the base, easily separable from the achene.

Distribution. Known only from the type locality in Rupac, northeast from Lima Department.

Ecology. Terrestrial plant growing on open area amongst shrubs, in the western Cordillera shrubland, between 3000–3500 m a.s.l. Co-occurring species include *Paracalia jungioides* (Hook. & Arn.) Cuatrec., *Heliopsis buphthalmoides* (Jacq.) Dunal, *Dasyphyllum ferox* (Wedd.) Cabrera and *Vulpia megalura* (Nutt.) Rydb. Flowering and fruiting between April and May.

Etymology. The genus is dedicated to the centennial of the institutional foundation of the Natural History Museum of National University Mayor of San Marcos (1918–2018), for their hard work on the research, conservation, preservation and diffusion of the biodiversity of the country. All these actions are steadily increasing our knowledge of the flora and fauna of our native land. The specific epithet refers to Rupac, a small village with archaeological remains from the Atavillos culture, where the only two populations of this species are known from this place.

Conservation status. *Centenaria rupacquiiana* is only known from the type collection and is therefore assessed as Data Deficient (DD) according to the IUCN (2012, 2017) criteria. However, we recommend it should be considered critically endangered (CR), as it is only known from a single locality (Criterion B1a) with a continuing decline of its quality of habitat inferred from the intensive livestock in the area (Criterion B1b). Furthermore, is only known from two populations with an estimated number fewer than 250 mature individuals (Criterion C1a(ii)).

Specimens Examined. **PERU. Lima:** Huaral, Atavillos Bajo, near to village Pampas, road to archaeological monument Rupac, slopes with loamy clay soil, scrubland, –11.323055, –76.78138, 3033–3099 m a.s.l., 7 May 2018, (fl, fr), A. Cano, P. Gonzáles, E. Huamán & S. Riva 22721 (HUT!, HSP!, MO!, MOL!, SI!, US!, USM-307017!).

Discussion. *Centenaria* belongs to the subtribe Piqueriinae of the Eupatorieae, being considered related to the genera *Microspermum* and *Iltisia* from Mexico and Central America and *Ferreyrella* of Peru, all having asymmetrical corollas with the two inner lobes smaller than the rest; however, *Microspermum*, *Iltisia* and *Ferreyrella* have no pappus or only a few capillary setae (Hind and Robinson 2007). Furthermore,

Centenaria is evidently related to the genus *Ellenbergia* of Peru, which has a pappus of many segments but has symmetrical corollas.

The species described here is very similar to *Ferreyrella*; both have strikingly asymmetrical corollas, from which it differs primarily in having a flat epaleaceous receptacle (vs. slenderly conic paleaceous receptacle) and the presence of pappus (vs. lack of pappus). Although this distinction is usually important in the *Eupatorieae*, as it is in Compositae generally, it becomes merely a specific or even, in one case, a varietal character in *Ageratum* (Blake 1957). The flat receptacle and the pappus of lanceolate squamellae with densely scabrid margins in *Centenaria* are very suggestive of those of *Ellenbergia*, although the pappus is not so extremely united at the base into a cup-shaped piece, an additional significant feature not found in *Ellenbergia*.

Robinson et al. (2009) commented about a group formed by small, mostly rather ephemeral Eupatorieae, which usually have many-flowered heads. At this time, *Guevaria*, *Ferreyrella*, *Ellenbergia* and *Centenaria* would also fit in this group despite having fewer flowers.

Key to the dwarf genera of the Eupatorieae in Peru

- 1 Rather carnose creeping plants with fascicles of short pedunculate heads on short lateral branches; anthers exappendiculate *Ascidiogyne*
- Thinly herbaceous-leaved erect or decumbent plants, with heads not in fascicles; anthers with vestigial apical appendages except in *Centenaria* **2**
- 2 Receptacles paleate *Ferreyrella*
- Receptacles without paleae **3**
- 3 Achenes without a pappus; receptacles conical **Guevaria**
- Achenes with a pappus; receptacles flat or slightly convex **4**
- 4 Pappus of many subulate persistent segments; corollas radially symmetrical ..
..... *Ellenbergia*
- Pappus of few easily deciduous lanceolate scales restricted to innermost florets of heads; corollas zygomorphic with inner lobes shorter than outer lobes
..... *Centenaria*

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Similarity analysis between species of the genus *Quercus* L. (Fagaceae) in southern Italy based on the fractal dimension

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Abstract

The fractal dimension (FD) is calculated for seven species of the genus *Quercus* L. in Calabria region (southern Italy), five of which have a marcescent-deciduous and two a sclerophyllous character. The fractal analysis applied to the leaves reveals different FD values for the two groups. The difference between the means and medians is very small in the case of the marcescent-deciduous group and very large when these differences are established between both groups: all this highlights the distance between the two groups in terms of similarity. Specifically, *Q. crenata*, which is hybridogenic in origin and whose parental species are *Q. cerris* and *Q. suber*, is more closely related to *Q. cerris* than to *Q. suber*, as also expressed in the molecular analysis. We consider that, in combination with other morphological, physiological and genetic parameters, the fractal dimension is a useful tool for studying similarities amongst species.

Keywords

deciduous, dimension, fractal analysis, phenotype, sclerophyllous, species, Calabria

Introduction

Quercus L. is an important genus containing several species of trees dominating different forest communities. The ecological and economic role of *Quercus* spp. is well known (Quinto-Canas et al. 2010, 2018, Vila-Viçosa et al. 2015, Piñar Fuentes et al. 2017, Spampinato et al. 2016, 2017, Vessella et al. 2017). Some species (such as cork oak) are specifically very useful for carbon sequestration and as raw materials for a post carbon city (Del Giudice et al. 2019, De Paola et al. 2019, Malerba et al. 2019, Massimo et al. 2019, Spampinato et al. 2019).

In the genus *Quercus* have been counted between 300 (Lawrence 1951, Elias 1971) and 600 species (Soepadmo 1972). However, several inventories (Schwarz 1964, Nixon 1993, Valencia 2004, Menitsky 2005) amount between 396 and 430 species for this critical genus. According to Musarella and Spampinato (2012a,b) in Calabria region (Southern Italy), there are 11 taxa: *Quercus ilex* L. subsp. *ilex*, *Q. suber* L., *Q. congesta* C.Presl., *Q. cerris* L., *Q. frainetto* Ten., *Q. robur* L. subsp. *brutia* (Ten.) O.Schwarz., *Q. virgiliana* (Ten.) Ten., *Q. amplifolia* Guss., *Q. dalechampii* Ten., *Q. crenata* Lam. and *Q. petraea* (Matt.) Liebl. subsp. *austrotyrrhenica* Brullo, Guarino & Siracusa. Bartolucci et al. (2018) record 17 taxa for Italy (9 of these sure for Calabria). Unfortunately, these authors do not consider in their checklist some species, such as *Q. virgiliana* and *Q. crenata*. However, we consider that *Q. virgiliana* is present in Calabria and it is clearly distinct from *Q. pubescens* Willd. subsp. *pubescens* according to Brullo et al. (1999), Viscosi et al. (2011) and Brullo and Guarino (2017). This species plays a very important role in the forest vegetation of the region (Brullo et al. 2001) and characterises the habitat 91AA*: Eastern white oak woods (AA.VV 2013, Biondi et al. 2009) distributed in Italy and in the Balkan Peninsula. Moreover, we consider *Q. crenata* as a species of hybrid origin from *Q. cerris* and *Q. suber*, according to Conte et al. (2007) and Brullo and Guarino (2017).

Leaf morphology has been studied throughout the history of botany, using leaf shape, edge, vein arrangement, hairiness and other features as important characters in systematics (Coutinho 1939, Amaral Franco 1990). Species have been described by means of the analysis of the size and shape of several leaf characters and using biometric studies. Morphometry and the leaf vascular system have traditionally been key aspects for establishing the description and biometrics of the species; in morphometry, the leaf shape and edge and the arrangement of the veins are all common systematic characters used to characterise different species. For a correct determination of each species and their hybrids, their taxonomic characters must be observed with specific instruments, e.g. powerful microscopes capable of highlighting micromorphometric characters (Vila-Viçosa et al. 2014).

Numerous authors have noted the comparative inaccuracy of early descriptive and biometric studies (Mouton 1970, 1976, Hickey and Wolfe 1975, Hickey 1979). Classic descriptive methods do not establish clear differences between pure individuals and their hybrids, so molecular studies are proposed for pure and hybrid strains (Conte et al. 2007, Curtu et al. 2007, Coutinho et al. 2014, 2015). More precise biometric studies subsequently emerged that allowed a more meticulous representation of the leaf

detail or the other parts of the plants (e.g. Cano et al. 2017). Biometrics thus came into its own for pinpointing the differences between species and taxonomic groups.

In their study of several *Quercus* species, Camarero et al. (2003) and Fortini et al. (2015) analysed the leaf morphology for pure and hybridogenic populations and observed the variability of their morphological characters. These phenotypical characters must be precisely quantified to establish the differences between pure species and their hybrids, which can be recognised through fractal analysis.

We calculated the fractal dimension by the box-counting method integrated in the ImageJ software (Abramoff et al. 2004), as it allows the possibility of assessing the fractal dimension of structures that are not totally self-similar. To resolve the controversy regarding certain species/subspecies in the genus *Quercus*, a discriminant analysis is required that can clearly differentiate the species/subspecies and the degree of relationship between them. The fractal dimension, which has not so far been widely applied in botany, although somewhat more so in medicine, was used for this purpose (Esteban et al. 2007, 2009, Lopes and Beltrouni 2009).

The main aim of this work is to establish an analysis of similarity of leaf shape amongst seven species in the genus *Quercus* from Italy and corroborate our previous studies (Musarella et al. 2013), in which we proposed a $FD < 1.6$ for sclerophyllous *Quercus* and $FD > 1.6$ for deciduous and marcescent *Quercus*.

Methods

Data collection

In this work, we analysed 7 species living in Calabria using 275 tree samples belonging to *Quercus robur* subsp. *brutia*, *Q. cerris*, *Q. congesta*, *Q. crenata*, *Q. ilex* subsp. *ilex*, *Q. suber* and *Q. virgiliana*. Orientation largely determines the amount of light the leaves receive for photosynthesis and their size can thus be affected by this greater or lesser exposure to light. For this reason, samples were taken from the four cardinal points on each tree to examine the possible influence of orientation on leaf development. A total of 1,099 leaves were analysed from 120 samples of *Q. robur* subsp. *brutia*, 120 from *Q. cerris*, 154 from *Q. congesta*, 147 from *Q. crenata*, 240 from *Q. ilex* subsp. *ilex*, 139 from *Q. suber* and 179 from *Q. virgiliana*. All the leaves were colour-scanned in a scanner with a resolution of 1200 dpi and 24-bit colour. After scanning, the leaf was transformed to image 8-bit greyscales and the image was segmented by selecting the greyscale between 111 and 126. We opened this image with the ImageJ programme in order to determine its fractal dimension (FD).

The fractal dimension (FD)

Fractal geometry is the most suitable method for characterising the complexity of the vascular system or other mathematically similar structures such as stream drainage net-

works in chicken embryos or the distribution of the vascular system of a leaf (Horton 1945, Vigo et al. 1998). De Araujo Mariath et al. (2010) developed a method using digital images of leaves to determine the fractal dimensions of the leaf vascular system in three species of *Relbunium* (Endl.) Hook. F. (Rubiaceae), with the aim of quantifying and determining its complexity so it could be used as a taxonomic character. Recently, Cuzzocrea et al. (2017) described an algorithm to estimate the parameters of Iterated Function System (IFS) fractal models, using IFS to model speech and electroencephalographic signals and to compare the results.

All man-made objects can be described in simple shapes using Euclidean geometry. However, natural objects have irregular forms that cannot always be represented using this method (Glenny et al. 1985).

Due to the recentness of the discovery and its wide range of applications, there is still no universal definition of what actually constitutes a fractal. They are thus described according to their common properties: specifically, they must have the same appearance at any scale of observation, meaning that a fractal object can be broken down into parts, each of which is identical to the whole object (self-affinity or self-similarity); they must have a fractional and not a whole dimension (fractal dimension); and finally the relationship between two of their variables must be a power law (where the exponent is its fractal dimension, Mandelbrot 1983). Topological and Euclidean dimensions cannot be applied to highly irregular objects such as coastlines. Mandelbrot (1967) published a widely-referenced work where he proved that it was impossible to give an exact value of the length of the coast, as this measurement depended on the unit of scale used. Thus in the case of irregular curves, a small FD of close to 1 signifies a low level of complexity, whereas values close to 2 indicate a very high level of irregularity.

When an object is totally self-similar, such as the mathematical fractal known by the name of the Koch curve (Figure 1), the dimension used is known as the self-similarity dimension.

A unit segment can be divided – for example – into three pieces similar to the original, each with a length of $1/3$. In general, where $N(h)$ is the number of pieces with a length h , it follows that $N(h) \cdot h^1 = 1$. If we now look at a square with a unit side, we can break it down into $9 = 3^2$ smaller squares with a side of $1/3$; that is to say $N(h) \cdot h^2 = 1$. Finally, in the case of a cube, it is easy to see that the following is true: $N(h) \cdot h^3 = 1$. That is, the exponent of h coincides with the topological and Euclidean dimension of the straight line (1), the square (2) and the cube (3) (Martinez Bruno and de Oliveira Plotze 2008).



Figure 1. The Koch curve.

By extrapolation from this concept, if the object is completely self-similar, there is a relationship between the scale factor h and the number of pieces $N(h)$ into which the object can be divided, which is given by $N(h) = (1/h)^D$; that is to say

$$D = \frac{\log(N(h))}{\log(\frac{1}{h})}.$$

Thus the fractal dimension of the Koch curve is:

$$D = \frac{\log(4)}{\log(3)} = 1.2619,$$

a number that is very similar to the FD of the English coastline.

However, natural objects like leaves are not perfect fractals, as they are not totally self-similar but are said to be statistically similar. In this case, the value of their fractal dimension is known by the name of Hausdorff-Besicovitch and is:

$$D = \lim_{h \rightarrow 0} \frac{\log(N(h))}{\log(\frac{1}{h})}.$$

The calculation of this limit is somewhat complicated and requires the use of different algorithms such as dilation methods, the perimeter method, Grassberger and Procaccia's correlation dimension and box-counting method. This last is the most widely used as it is very simple to implement with computer technology and highly accurate (Glenny et al. 1985, Jian Li et al. 2009).

To find the fractal dimension of a digital image using the box-counting method (Mandelbrot 1983), the image must be transformed into black (the leaf) and white (the background). A grid is then superimposed on the image and the number of times the leaf intersects a grid square is counted. The image is covered with a grid of squares initially with side 2 and subsequently with squares with side 3, 4, 6, 8, 12, 16 and 32 (in Table 1; C2, C3, C4, C6, C8, C12, C16 and C32). The side of square h is then reduced and the logarithm of the number of intersections $N(h)$ is represented based on the logarithm of the inverse function of the side. The dimension of the object coincides with the slope of the regression line defined by the point cluster $(\log(1/h), \log(N(h)))$ produced when the value of the side of the grid square is changed.

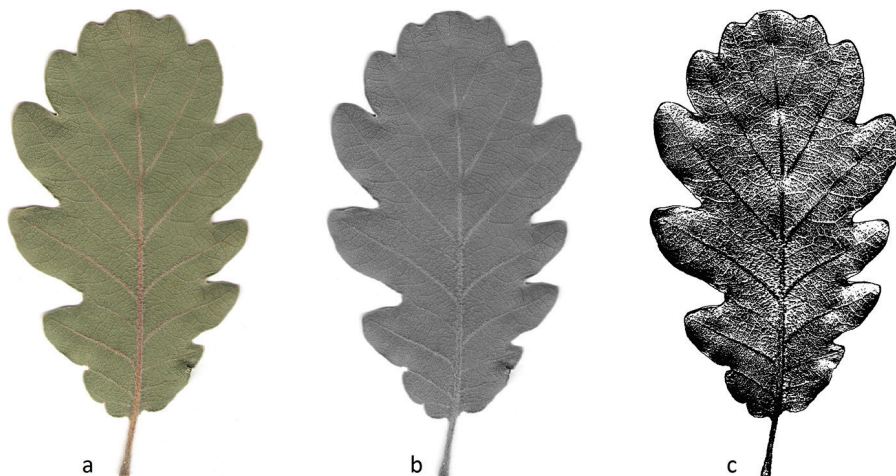
The graphic representation of the regression line and the point cluster shows two very clearly differentiated parts. The minimum and maximum box size is therefore very important when applying this method. In fact, the approximation error must be reduced by selecting points with a "more linear" form as a box size.

Calculating the fractal dimension (FD)

The FD was calculated by the box-counting method (Esteban et al. 2007) using the free software ImageJ version 1.47 (<http://imagej.com>). The digital image of the leaf in RGB col-

Table 1. Number of boxes occupied for each box size.

Label	C2	C3	C4	C6	C8	C12	C16	C32	D
QCONGESTA1_E_01	358874	166858	97125	44308	25268	11452	6553	1727	1.93

**Figure 2.** **a** RGB colour image **b** 8-bit greyscale image and **c** binary selection of an image of a *Quercus crenata* leaf.

our (Figure 2a) was first converted into an 8-bit image (Figure 2b) where each pixel was represented with a greyscale from 1 to 256. In order to select the most important information, the image was subsequently segmented to produce a greyscale between 111 and 126 and then converted into binary so the leaf takes the value 1 and the rest the value 0 (Figure 2c).

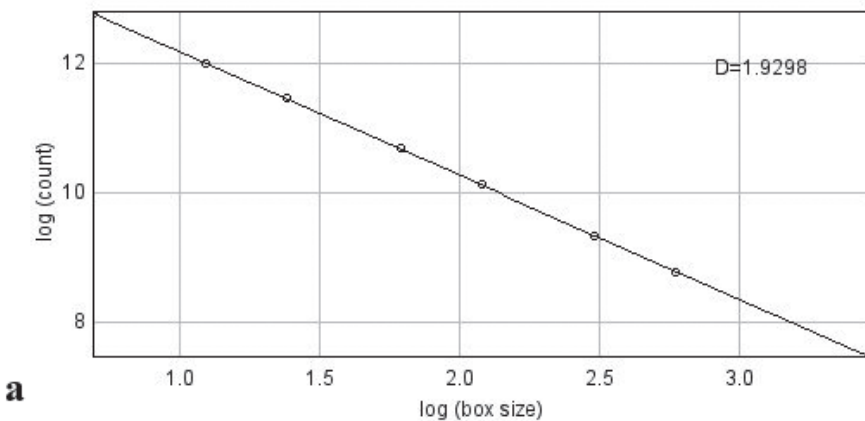
The box-counting algorithm was then applied to this black-and-white image of the venation network of the leaf to calculate the FD with box sizes (h) ranging from 2 to 32. Specifically, the image is covered with a grid of squares initially with side 2 and subsequently with squares with sides 3, 4, 6, 8, 12, 16 and 32 (in the image C2, C3, C4, C6, C8, C12, C16 and C32). Table 1 shows the number of boxes occupied ($N(h)$) for each box size.

Once the points were represented ($\log(1/h)$, $\log(N(h))$), we calculated the regression line (Figure 3) whose slope corresponds to the value of the fractal dimension; in our case, the $FD=1.9298$, Standard Error= 0.0044, p-Value= 1.01384×10^{-14}). As can be seen in the graph, the fit is fairly good as the points are very close to the resulting regression line.

For the statistical treatment, the mean FDs were obtained for each species and an analysis of variance was undertaken to test for significant differences amongst the means. First, the Shapiro-Wilk normality test and the difference between the mean, median and kurtosis indicate that our data do not follow a normal distribution (Table 2), meaning non-parametric methods must be used. To determine whether orientation affects the leaf morphological character, we applied a non-parametric Kruskal-Wallis test which, based on the medians, compares the leaves from the same population

Table 2. Descriptive statistics of FD values for each species and orientation.

	Taxa	Median	Mean	Variance (n-1)	Kurtosis (Pearson)	St. root of the variance	St. root [kurtosis (Fisher)]
North	<i>Q. robur</i> subsp. <i>brutia</i>	1.5440	1.5290	0.0730	-1.3300	0.0192	0.8327
	<i>Q. cerris</i>	1.6760	1.6676	0.0375	-0.5768	0.0098	0.8327
	<i>Q. congesta</i>	1.8780	1.8310	0.0138	1.8836	0.0032	0.7587
	<i>Q. crenata</i>	1.9195	1.8669	0.0172	6.2735	0.0040	0.7497
	<i>Q. ilex</i> subsp. <i>ilex</i>	1.3530	1.3804	0.0297	0.9245	0.0055	0.6133
	<i>Q. suber</i>	0.8620	0.9001	0.0703	0.3360	0.0173	0.7879
	<i>Q. virgiliana</i>	1.9310	1.9192	0.0016	7.4011	0.0003	0.6876
South	<i>Q. robur</i> subsp. <i>brutia</i>	1.7675	1.6220	0.0895	-1.6597	0.0235	0.8327
	<i>Q. cerris</i>	1.6600	1.6190	0.0337	0.3597	0.0089	0.8327
	<i>Q. congesta</i>	1.9000	1.8749	0.0058	2.8406	0.0014	0.7587
	<i>Q. crenata</i>	1.9200	1.8803	0.0106	2.8957	0.0025	0.7497
	<i>Q. ilex</i> subsp. <i>ilex</i>	1.3610	1.3442	0.0149	-0.2129	0.0028	0.6133
	<i>Q. suber</i>	0.9395	0.9487	0.0408	0.0321	0.0100	0.7879
	<i>Q. virgiliana</i>	1.9120	1.8780	0.0060	1.1207	0.0013	0.6876
East	<i>Q. robur</i> subsp. <i>brutia</i>	1.8405	1.7336	0.0428	-0.2321	0.0112	0.8327
	<i>Q. cerris</i>	1.8360	1.8110	0.0143	-0.0039	0.0037	0.8327
	<i>Q. congesta</i>	1.9230	1.9215	0.0008	2.2392	0.0002	0.7587
	<i>Q. crenata</i>	1.9270	1.8476	0.0257	1.2883	0.0060	0.7497
	<i>Q. ilex</i> subsp. <i>ilex</i>	1.3170	1.2954	0.0196	1.7224	0.0036	0.6133
	<i>Q. suber</i>	0.8850	0.9059	0.0475	-0.3256	0.0117	0.7879
	<i>Q. virgiliana</i>	1.9445	1.9287	0.0032	11.3639	0.0007	0.6876
West	<i>Q. robur</i> subsp. <i>brutia</i>	1.5715	1.5676	0.0800	-1.2799	0.0210	0.8327
	<i>Q. cerris</i>	1.6050	1.6116	0.0643	2.0300	0.0169	0.8327
	<i>Q. congesta</i>	1.9180	1.8985	0.0030	0.4157	0.0007	0.7587
	<i>Q. crenata</i>	1.9030	1.8754	0.0085	2.8668	0.0020	0.7497
	<i>Q. ilex</i> subsp. <i>ilex</i>	1.4170	1.4302	0.0429	0.1534	0.0080	0.6133
	<i>Q. suber</i>	0.9535	0.9746	0.0615	0.2308	0.0151	0.7879
	<i>Q. virgiliana</i>	1.9440	1.9317	0.0015	6.6553	0.0003	0.6876
Mean	<i>Q. robur</i> subsp. <i>brutia</i>	1.5500	1.6130	0.0493	-1.6202	0.0129	138.47.00
	<i>Q. cerris</i>	1.7029	1.6773	0.0253	1.8675	0.0066	0.8327
	<i>Q. congesta</i>	1.8960	1.8815	0.0026	-0.6569	0.0006	0.7587
	<i>Q. crenata</i>	1.8866	1.8675	0.0052	0.9650	0.0012	0.7497
	<i>Q. ilex</i> subsp. <i>ilex</i>	1.3625	1.3625	0.0053	-0.4868	0.0010	0.6133
	<i>Q. suber</i>	0.9164	0.9323	0.0267	-0.1453	0.0066	0.7879
	<i>Q. virgiliana</i>	1.9184	1.9144	0.0007	-0.9555	0.0001	0.6876

**Figure 3.** Regression line for the points ($\log(1/h)$, $\log(N(h))$).

and from the four orientations. We also applied the standardised kurtosis coefficient to determine whether there is significant normality in the data. In the case of significant differences in the analysis of variance, we applied the LSD (Least Significant Difference) multiple comparison test.

In the hypothetical case that the difference between the fractal values (means and medians) for two species is zero or has a quotient of one, the degree of relationship between the two species is 100%; $DfA - DfB = 0$; $DfA / DfB = 1$, species A and B are equal; thus the lower the fractal difference or the nearer the fractal quotient is to 1, the greater the similarity between the species.

Results

The analysis of the FD values for each orientation and for each species shows that for *Q. robur* subsp. *brutia*, *Q. cerris*, *Q. congesta* and *Q. virgiliana*, the orientation influences the values of FD, as there are significant differences for these species (Table 3).

These species correspond to deciduous or marcescent species, whereas the perennial species *Q. ilex* subsp. *ilex*, *Q. suber* and *Q. crenata* do not show significant differences in the values of FD for the different levels of orientation.

Table 3. Kruskal-Wallis analysis for the values of FD in each orientation for each of the species. In bold: the significant values for which orientation influences the FD at 95% confidence.

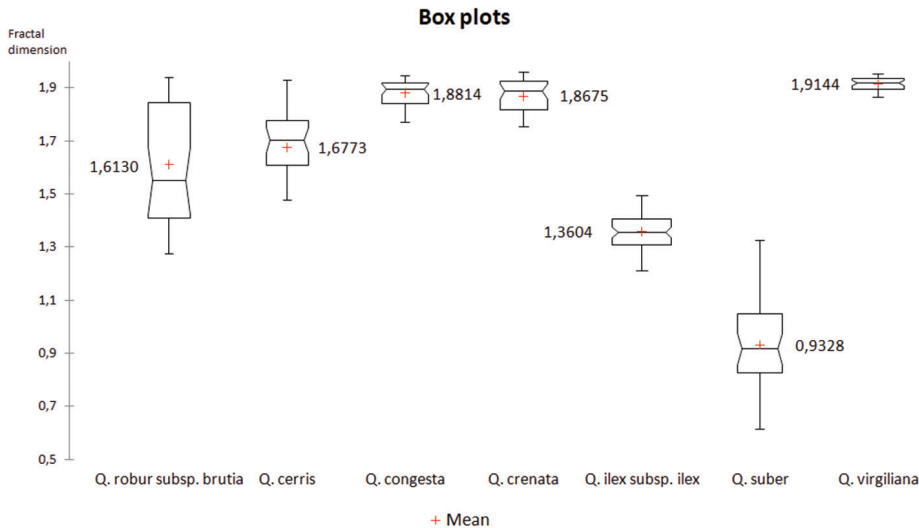
Kruskal-Wallis:	<i>Q. robur</i> subsp. <i>brutia</i>	<i>Q. cerris</i>	<i>Q. congesta</i>	<i>Q. crenata</i>	<i>Q. ilex</i> subsp. <i>ilex</i>	<i>Q. suber</i>	<i>Q. virgiliana</i>
Mean North	1.5290	1.6676	1.8310	1.8669	1.3804	0.9001	1.9192
Mean South	1.6220	1.6190	1.8749	1.8803	1.3442	0.9487	1.8780
Mean East	1.7336	1.8110	1.9215	1.8476	1.3276	0.9059	1.9287
Mean West	1.5676	1.6116	1.8985	1.8754	1.3895	0.9746	1.9317
St. Deviation North	0.2702	0.1936	0.1174	0.1313	0.1723	0.2651	0.0406
St. Deviation South	0.2992	0.1836	0.0763	0.1030	0.1220	0.2020	0.0777
St. Deviation East	0.2069	0.1194	0.0288	0.1602	0.1074	0.2180	0.0563
St. Deviation West	0.2829	0.2535	0.0546	0.0921	0.1564	0.2479	0.0392
K (Observed value)	9.9875	20.5115	23.0332	1.6844	8.0795	3.0683	38.4400
K (Critical value)	9.4877	7.8147	7.8147	7.8147	9.4877	7.8147	7.8147
p-value	0.0406	0.0001	< 0.0001	0.6404	0.0887	0.3812	< 0.0001

Table 4. Kruskal-Wallis test.

K (Observed value)	220.2702
K (Critical value)	12.5916
GDL	6
p-value (bilateral)	< 0.0001
alpha	0.05

Table 5. Differences in FD by pairs between each species (in parentheses, p-value). In bold: significant differences at 95% confidence.

	<i>Q. robur</i> subsp. <i>brutia</i>	<i>Q. cerris</i>	<i>Q. congesta</i>	<i>Q. crenata</i>	<i>Q. ilex</i> subsp. <i>ilex</i>	<i>Q. suber</i>	<i>Q. virgiliana</i>
<i>Q. robur</i> subsp. <i>brutia</i>	–						
<i>Q. cerris</i>	4.26 (0.6392)	–					
<i>Q. congesta</i>	71.21 (<0.0001)	66.95 (<0.0001)	–				
<i>Q. crenata</i>	68.55 (<0.0001)	64.29 (<0.0001)	-2.65 (0.7439)	–			
<i>Q. ilex</i> subsp. <i>ilex</i>	-58.63 (<0.0001)	-62.9 (<0.0001)	-129.85 (<0.0001)	-127.19 (<0.0001)	–		
<i>Q. suber</i>	-109.43 (<0.0001)	-113.7 (<0.0001)	-180.65 (<0.0001)	-177.99 (<0.0001)	-50.8 (<0.0001)	–	
<i>Q. virgiliana</i>	96.87 (<0.0001)	92.61 (<0.0001)	25.66 (0.001)	28.32 (0.0002)	155.51 (<0.0001)	206.31 (<0.0001)	–

**Figure 4.** Value of the medians for each homogeneous group. Fractal dimensions (mean values) of the studied species where *Quercus ilex* subsp. *ilex* and *Quercus suber* have an FD < 1.6 and the marcescent *Quercus* has a FD > 1.6.

An analysis of the average FD values for each species indicates that there are significant differences between the different levels of species under study (Table 4). Subsequently, the Conover-Iman test of multiple comparisons between all pairs shows the pairs of species between which there are significant differences (Table 5).

As can be seen in Table 5, there are pairs of species for which there are significant differences in the values of FD. These differences are not only significant between the species *Q. robur* subsp. *brutia* - *Q. cerris* and between *Q. crenata* - *Q. congesta*. The fractal dimension is therefore sufficient alone to characterise and separate the species *Q.*

ilex subsp. *ilex*, *Q. suber* and *Q. virgiliana*, while the fractal dimension of the vascular network of the leaves calculated by the methodology described does not distinguish *Q. robur* subsp. *brutia* from *Q. cerris* and *Q. congesta* from *Q. crenata* on its own.

The analysis of the medians of the seven groups (Figure 4) shows that the lowest values of FD correspond to the sclerophyllous *Quercus* species *Q. ilex* subsp. *ilex* and *Q. suber*, whose values are below 1.6, as occurs in the case of the medians. However the marcescent *Quercus* have a median FD of > 1.6; the mean FD values of *Q. suber* and *Q. ilex* subsp. *ilex* are 0.932 and 1.363, respectively, whereas it is 1.613 for the marcescent *Q. robur* subsp. *brutia*; 1.677 for *Q. cerris*; 1.881 for *Q. congesta*; 1.868 for *Q. crenata*; and 1.914 for *Q. virgiliana*.

In the multiple comparison analysis (Figure 5) of means and medians, the most significant differences in the two cases are between the sclerophyllous and marcescent *Quercus*, where these differences (means) are 0.982 for *Q. virgiliana*-*Q. suber* and *0.984 in the case of the medians; however the differences between the marcescent *Quercus* are minimal with *0.015 for *Q. congesta*-*Q. crenata* and *0.188 between *Q. cerris*-*Q. crenata*. As the value for *Q. crenata*-*Q. suber* is *0.939, it is evident that *Q. crenata* is more closely related to *Q. cerris* than to *Q. suber* (Figure 5).

In the case of both mean and median values, it is confirmed that the value of the fractal dimension (FD) is less than 1.6 in the case of sclerophyllous *Quercus* and greater for marcescent and deciduous *Quercus* (Figure 4).

The differences between average FD values for marcescent and deciduous *Quercus* species are very low (Table 6). These low differences between average FD values are due to the close similarity between these species. However, there are significant differences in the FD between marcescent and sclerophyllous *Quercus* as they are very distant from each other in evolutionary terms: *Q. virgiliana*-*Q. ilex* subsp. *ilex* 0.551; *Q. virgiliana*-

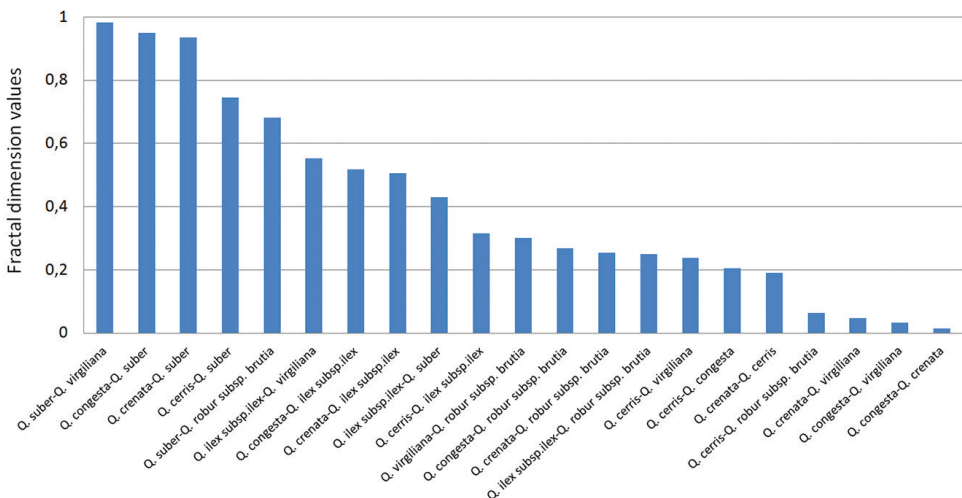


Figure 5. Multiple comparison analysis.

Table 6. Homogeneous character of the groups.

Species	Count	Sum of the ranges	Mean of the ranges	Homogeneous groups				
<i>Q. suber</i>	34	626.0000	18.4118	A				
<i>Q. ilex</i> subsp. <i>ilex</i>	59	4083.5000	69.2119		B			
<i>Q. robur</i> subsp. <i>brutia</i>	30	3835.5000	127.8500			C		
<i>Q. cerris</i>	30	3963.5000	132.1167			C		
<i>Q. crenata</i>	38	7463.5000	196.4079				D	
<i>Q. congesta</i>	37	7365.5000	199.0676				D	
<i>Q. virgiliana</i>	46	10337.5000	224.7283					E

Q. suber 0.982; *Q. congesta*-*Q. ilex* subsp. *ilex* 0.518; *Q. congesta*-*Q. suber* 0.949; *Q. crenata*-*Q. ilex* subsp. *ilex*; 0.505; *Q. crenata*-*Q. suber* 0.936; *Q. cerris*-*Q. ilex* subsp. *ilex* 0.314; *Q. cerris*-*Q. suber* 0.745; and *Q. ilex* subsp. *ilex*-*Q. suber* 0.431.

Based on the differences obtained from $FDA - FDB = 0$, the most closely related species are: *Q. congesta*-*Q. crenata* 0.023; *Q. cerris*-*Q. robur* subsp. *brutia* 0.064; *Q. virgiliana*-*Q. congesta* 0.033; *Q. virgiliana*-*Q. crenata* 0.046; and *Q. crenata*-*Q. cerris* 0.191. The most distant relationship is between *Q. virgiliana*-*Q. suber* 0.982 and *Q. congesta*-*Q. suber* 0.949 (Figure 5).

Discussion

There is a widespread consensus that complex objects with the same features can be included in the category of fractals. Self-similarity is one of the characteristics of fractal objects, meaning that when these images are broken down into smaller pieces, each one is identical to the whole. The fractional dimension is another of its features.

In the hypothetical case that the difference between the fractal values of two species is zero, or their quotient is one, the degree of relationship between the two species is 100%: $Df_A - Df_B = 0$; $Df_A / Df_B = 1$, species A and B are equal. Thus the smaller the fractal difference or the closer the fractal quotient is to 1, the greater the similarity between the species; if the value of this quotient is far from 1, as occurs between $Df_{vi} / Df_{su} > 2$, the species *Q. virgiliana* and *Q. suber* are very distant from each other. This occurs when the fractal values are the same and means that the same or similar characters have been measured

Conte et al. (2007) point out the hybridogenic origin of *Q. crenata* and the molecular analysis reveals a closer genetic similarity between *Q. crenata* and *Q. cerris* than between *Q. crenata* and *Q. suber*. The FD of *Q. crenata* is 1.868; for *Q. cerris* it is 1.677; and for *Q. suber* it is 0.932; where $Df_{Qce} - Df_{Qsu} = 0.745$ and $Df_{Qce} / Df_{Qsu} = 1.8$, pointing to a large phenotypical (genetic) difference between the parental species. More similarity can be seen between *Q. crenata* and *Q. cerris* than between *Q. crenata* and *Q. suber*, as the difference $Df_{Qcr} - Df_{Qce} = 0.191$ and $Df_{Qcr} / Df_{Qce} = 1.1$; they therefore have a high degree of similarity; whereas $Df_{Qcr} - Df_{Qsu} = 0.936$ and $Df_{Qcr} / Df_{Qsu} > 2$, indicating substantial phenotypical differences between the hybrid and parental species.

Coutinho et al. (2014, 2015) report a high degree of polymorphism in the genus *Quercus* and establish the molecular analysis of ribosomal DNA through the restriction enzymes to confirm the taxonomic classifications and establish the phylogeny between *Quercus* species. Their results show that the group known as *cerris* contains *Q. crenata* and its parental species *Q. cerris*, whereas it excludes the parental species *Q. suber*; *Q. crenata* is closer to *Q. cerris* with a similarity of 96% compared to a 66% similarity between *Q. suber* and the previous species. Our fractal analysis corroborates the results of Conte et al. (2007) and Coutinho et al. (2015). Curtu et al. (2007) studied four oak species, including *Q. robur* and *Q. cerris* and the intermediate or hybridogenic forms using morphological leaf and genetic markers to classify the hybridisation. In our case, the intermediate or hybrid form corresponds to *Q. crenata* which has its origins in the parental species *Q. cerris* and *Q. suber*. Here the intermediate form *Q. crenata* has a fractal value close to *Q. cerris* and very far from *Q. suber*.

Finally, the orientation has no influence on the fractal dimension between either the same species or between the different species. This means that the shape of the distribution of the leaf vascular network is not affected by possible changes in orientation, thus discounting the effects of environmental variables such as amount of light, temperature, humidity etc., associated with orientation. This evidence is important in *Quercus* species, as in other cases, these environmental variables can influence seed germination and the capacity of some plant species to adapt to extreme environments (Signorino et al. 2011, Musarella et al. 2018, Panuccio et al. 2018, Spampinato et al. 2018): in some cases, the survival or disappearance of a species in an environment may depend on it.

Conclusions

We confirm that the application of fractal analysis identifies the phenotypical differences between species and can be used as a method to establish their degree of relationship; this is supported by molecular analysis by various authors. In this work we can affirm that sclerophyllous *Quercus* species have a fractal dimension of < 1.6 and marcescent and deciduous *Quercus* species have $FD > 1.6$; and that *Q. crenata*, a hybrid of *Q. suber* and *Q. cerris*, has a greater similarity to *Q. cerris* than to *Q. suber*. The low values of the mean and median FD revealed by the differences between the FD for marcescent-deciduous *Quercus* species suggest a high degree of similarity amongst the five marcescent-deciduous species. Based on their FD, marcescent *Quercus* species (semideciduous) are more closely related to deciduous than to sclerophyllous *Quercus* species, whereas the sclerophyllous *Q. ilex* subsp. *ilex* and *Q. suber* show substantial morphological differences with the marcescent and deciduous *Quercus* species, as evidenced by fractal analysis. These two species have followed different evolutionary paths from the others, as is to be expected, as the centre of origin of sclerophyllous *Quercus* species is Mediterranean, whereas deciduous *Quercus* species have a temperate origin and marcescent *Quercus* species come from the boundary between the Temperate and Mediterranean bioclimates (Amaral Franco 1990, Sánchez de Dios et al. 2009).

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The indigenous vascular flora of the forest domain of Anela (Sardinia, Italy)

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Abstract

The importance of mountains for plant diversity and richness is underestimated, particularly when transition zones between different bioclimates are present along altitudinal gradients. Here we present the first floristic data for a mountain area in the island of Sardinia (Italy), which exhibits Mediterranean bioclimates at the bottom and temperate bioclimate at the top. We discovered a very high floristic richness, despite the fact that the number of endemic taxa is not high and the number of exclusive taxa is very low. Many of the detected taxa are at their range periphery and/or ecological margin. We conclude that climate transition zones in Mediterranean mountains and especially on islands are key areas regarding plant biodiversity and should be better investigated and protected.

Keywords

bioclimate, biodiversity, Mediterranean mountains, submediterranean, temperate

Introduction

Mountains are a critical landscape and ecosystem; they not only provide water for the lowlands but are a source of well-being and inspiration for numerous people (Korner 2004). The green ‘coat’ of the world’s mountains is composed of specialised biota, all

nested in a great variety of microhabitats. Mountains biota are determined by a series of climatically different life zones over short elevational distances (Rahbek 1995, Korner 2000, Hemp 2002, Korner and Paulsen 2004), which often result in areas of high biodiversity of high conservation interest (Korner 2004). However, those areas are also under high threat regarding climate change, as it is expected that they experience drastic changes (Inouye 2008).

Mountain biodiversity can be studied at a multitude of scales in space, time and function (Molau 2004). Even though species richness is usually the focal component in nature conservation, genetic diversity within species is equally important. The small-scale distribution of species in the tropical Andes, as exemplified by the plant genera *Calceolaria* (Calceolariaceae) and *Bartsia* (Orobanchaceae), contrasts against the situation in high-latitude mountains, e.g. the Scandes, where species have wide ranges and many are circumpolar (Molau 2004). Several studies on alpine plants, based on molecular data, show that the intraspecific genetic diversity tends to increase with latitude, a situation brought about by glaciation cycles permitting repeated contraction-expansion episodes of species' distributions (Abbott et al. 2000, Abbott and Brochmann 2003, Gamache et al. 2003, Holderegger and Abbott 2003, Lian et al. 2003, Abbott and Comes 2004). In tropical mountains, species distributions are geographically much narrower, often as a result of relatively recent, local speciation (Deshpande et al. 2001, Friar et al. 2001, Tremetsberger et al. 2003a, 2003b, Zhou et al. 2003). Thus, the classical decrease of genetic diversity observed from the equator toward the pole can eventually be blurred for mountain species. Actually, repeated contraction-expansion of species ranges has led rear edge populations to maintain some genetic diversity, therefore counterbalancing the effect of peripheral isolation (Hampe and Petit 2005). Conjointly, the high genetic differentiation between populations underlines the conservation relevance of those populations.

Mediterranean mountains represent an interesting case, because they often have a relic temperate-like bioclimate at their top (with no or little summer drought) in a context characterised by severe water deficit for at least two consecutive months at lower altitudes. Mediterranean mountains can therefore be considered as climatic islands, where plant diversity patterns are influenced by different factors (or in different ways) with respect to temperate and boreal mountains (Winkler et al. 2016). Furthermore, climatic and land-use changes have different effects on Mediterranean vs Boreal-Temperate mountains of Europe, being detrimental for the floral richness of the first and increasing the species richness of the second (Pauli et al. 2012). Considering that expected climatic trend is an increasing of temperature and a decrease of precipitation (mainly during spring) in Mediterranean mountains, whereas non-Mediterranean European mountains will not experience a reduction of annual and spring precipitation (Bravo et al. 2008), the urgency rises to monitor those mountains at the transition between Temperate and Mediterranean bioclimates. Moreover, before the middle of the century, the expected climatic changes will provoke the disappearance or strong reduction of a suitable habitat in the summit area, where most of the endemic and/or rare species are located (Benito et al. 2011). The most endangered habitats and species

are those linked to water availability like streams, wet meadows and temporary ponds (Ghosn et al. 2010, Pérez-Luque et al. 2015). On islands, threats to mountain floras are even more acute compared to mainlands, because narrower spatial scales of habitats and the usually lower mountain altitudes (Vogiatzakis et al. 2016), led some species to have a relic distribution (Petit et al. 2005, Mayol et al. 2015, Fazan et al. 2017). Historical climatic fluctuations and associated ecological constraints are the basis of the fragmented distribution of Boreal-Temperate species on Mediterranean mountains (Mayol et al. 2015, Iszkulo et al. 2016) and determine the presence of plant refugia, climatically stable areas that constitute key areas for the long-term persistence of species and genetic diversity, especially at present and future decades given the threat posed by the extensive environmental change processes operating in the Mediterranean region. These refugia, including large Mediterranean islands, represent ‘phylogeographical hotspots’; that is, significant reservoirs of unique genetic diversity favourable to the evolutionary processes of Mediterranean plants (Médail and Diadema 2009).

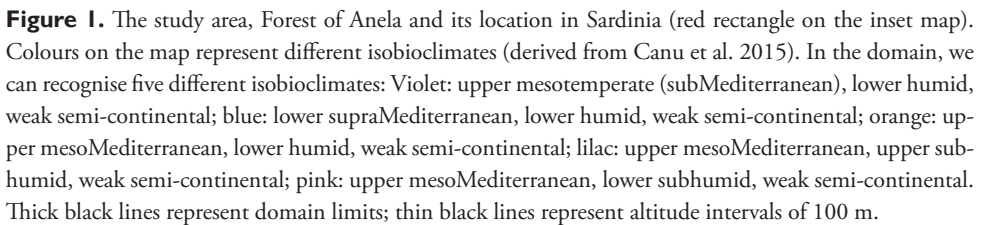
The island of Sardinia, the second largest in the whole Mediterranean basin, was already known to have a prevalent Mediterranean bioclimate, with a temperate bioclimate in the two main massifs of the island, the Gennargentu (centre-eastern Sardinian, maximum elevation 1834 m a.s.l.) and the Limbara (north-eastern Sardinia, maximum elevation 1359 m a.s.l.) (Arrigoni 1968). Recent detailed bioclimate analysis (Canu et al. 2015) also showed that the only mountain chain of the island named Marghine-Goceano (located between the Limbara and the Gennargentu massifs, maximum elevation at Mt. Rasu 1259 m a.s.l.) is characterised by a temperate bioclimate (in the sub-Mediterranean variant) along the ranges summit. Although the mountain floras of the Gennargentu and Limbara are well documented (Veri and Bruno 1974, Arrigoni and Camarda 2015), floristic information about the Marghine-Goceano range is lacking (Valsecchi and Corrias 1966).

This paper goes some way to fill this knowledge gap by reporting on the indigenous flora of a forest domain located in the middle of the Marghine-Goceano range. Our aim was to provide a checklist of the flora located in this area to enable future characterisation of the biotic environment of this mountain area of Sardinia. This data will also allow the identification of target species to monitor and understand climate changes in the particular context of Mediterranean islands.

Methods

Study area

The forest domain of Anela is a public property since 1886, at present managed by the Sardinian regional agency Forestas (Fig. 1). The domain covers 1280 hectares of which 1200 ha fall in the municipality of Anela, 55 ha in that of Bultei (to the east) and 25 ha in that of Bono (to the west). The lowest altitude is about 600 m a.s.l. in locality *Badu Edras* whereas the summit point is at *Punta Masiedda* 1158 m a.s.l. The



geographic coordinates of the forestry station headquarter are 40°27'14"N; 9°01'36"E. At present, the vegetation cover is mainly characterised by coppices and mature shrubs linked to sub-Mediterranean woods *Glechomo sardoae-Quercetum congestae* and *Saniculo europaeae-Quercetum ilicis* above 800 m a.s.l. and meso-Mediterranean *Loncomelo pyrenaici-Quercetum ichnusae* and *Galio scabri-Quercetum ilicis* below 800 m a.s.l., as described by Bacchetta et al. (2009). The 2004 forest census determined that 46% of this area was occupied by holm oak (*Quercus ilex* L.) woods, 2.7% by deciduous oak (*Q. pubescens* Willd.) woods, 23.4% by mixed woods of holm oak and deciduous oak, 0.8% by cork oak (*Q. suber* L.) woods, 2.8% by plantations with alien trees (*Abies*,

Cedrus, *Acer*, *Fagus*, *Pinus*), 14.7% by shrub communities (with *Erica arborea*, *Crataegus monogyna*, *Rubus ulmifolius*), 6.2% by dwarf communities (with *Helichrysum microphyllum* subsp. *tyrrhenicum*, *Thymus herba-barona*, *Genista desoleana*), 0.3% by rocky places and the rest by human activities (including buildings, an artificial lake and firebreaks) (Sechi and Falchi 2013). It should be noted that a large fire destroyed 800 hectares of the domain on 31 July 1945, so the wooded area decreased from 72.4% in 1910 to less than 20% in the 50s (Sechi and Falchi 2013).

In the ambit of the Sardinian-Corsican biogeographic province (as defined by Bacchetta et al. 2012), the study area falls in the Goceano-Logudorese sector (Fenu et al. 2014).

The geology of the study area comprises Palaeozoic granites and schists (Madrau 2013). The impermeable nature of these substrates has created a substantial aquifer evident by the presence of 39 springs (half perennial and half seasonal) in the study area (Farris 2013b).

Bioclimate analysis of 1971–2000 data (Canu et al. 2015) showed that 96.9% of the area falls in the Mediterranean Pluviseasonal Oceanic bioclimate, whereas 3.1% in the Temperate Oceanic bioclimate (submediterranean variant). A total of 64.6% of the area is included in the meso-Mediterranean thermotype, 32.3% in the supra-Mediterranean and 3.1% in the meso-Temperate.

Thermo-pluviometric data of the period 1951–1985 showed annual mean temperature of 11.2 °C and annual mean rainfall of 1040 mm; after the year 2000 temperatures did not vary significantly, whereas a reduction of ca. 30% in the annual rainfall was recorded. Late spring and summer rainfall (May–August) decreased even more (more than 50%, see Farris 2013a).

The study area is entirely included in the Natura 2000 site of community importance ITB 011102 “Catena del Marghine e Goceano”, extended on 14,984 ha and is also nominated as a Protection Oasis for wildlife “Foresta Anela”, managed by the Province of Sassari.

Floristic research

Floristic research started in the year 2000 and was intensified in the years 2012–17 with regular monthly sampling. Each month, we made one day excursions, which covered three altitudinal ranges (< 800 m a.s.l.; 800–1000 m a.s.l.; > 1000 m a.s.l. on the third). For each excursion, we tried to visit as many habitats as possible in order to capture the highest environmental heterogeneity. Collected plants were stored at the Herbarium SS, where we also searched for specimens collected in previous decades (if present, they are reported in the floristic list).

Plant names were derived from the Euro+Med PlantBase (Euro+Med 2006–2018), except for: a) families not already included in this database for which we referred to the Checklists of Italian Flora (Conti et al. 2005; Bartolucci et al. 2018), APG IV (APG 2016); b) the family Orchidaceae (for which we follow GIROS (2016)); c) the genus *Orobanche*, for which we follow Domina and Arrigoni (2007); d) the genus *Dianthus*,

for which Bacchetta et al. (2010) is followed; e) and the species *Struthiopteris spicant* which we use in preference to *Blechnum spicant* (Gasper et al. 2016); f) for endemics, we also consulted Arrigoni et al. (1976–1991) and Peruzzi et al. (2014). The Italian floras (Pignatti 1982, 2017–2018) and the Sardinian flora (Arrigoni 2006–2015) were also consulted. When other relevant literature was followed, it is specified in the text.

Plant authorities and names were further verified using ‘The Plant List’, ‘The World Checklist of Selected Plant Families’ and ‘The International Plant Names Index’ (IPNI). Herbarium acronyms follow Thiers (2018).

The taxonomic circumscription of orders and families, as well as their sequence in the list was derived from Smith et al. (2006) for Pteridophytes; and APG III (APG 2009), APG IV (APG 2016) and Haston et al. (2009) for Angiosperms. Within each family, genera, species and subspecies are listed in alphabetical order. Species and subspecies are numbered progressively.

For each taxon we report:

Progressive number Scientific name (with authority) Biological type, Chorologic type
Abundance (locality(ies) of collection is(are) specified only for uncommon or range restricted taxa): Habitat
Notes (eventual)

Biological types are in accordance to Raunkiær (1934) and were verified on the collected samples and also in Pignatti (1982, 2017–2018); chorologic types were determined following maps reported in the Euro+Med PlantBase (Euro+Med 2006–2018) and again verified in Pignatti (1982, 2017–2018) and the other bibliographic sources reported in the text.

Geographical abbreviations are:

Atl.	Atlantic;	Medit.	Mediterranean;
Cauc.	Caucasian;	Medit. Mont.	Mediterranean montane;
Circumbor.	circum-boreal;	S. Europ. Orof.	Southern European Oro-
Cosmop.	cosmopolitan;		phylous;
Endem.	endemic;	Paleotemp.	paleo-temperate;
Euras.	Eurasian;	Paleotrop.	paleo-Tropical;
Eurimedit.	uri-Mediterranean;	Sib.	Siberian;
Europ.	European;	Stenomedit.	Steno-Mediterranean;
Eurosib.	Euro-Siberian;	Subatl.	sub-Atlantic;
It	Italy;	Subcosmop.	sub-cosmopolitan;
Itc	central Italy;	Submedit.	sub-Mediterranean;
Its	northern Italy;	Subtrop.	sub-Tropical;
Macaron.	Macaronesian;	Turan.	Turanian.

Here we consider as endemics *sensu stricto* all taxa limited to the Corsican-Sardinian biogeographic province (*sensu* Bacchetta et al. 2012), therefore including the Tuscan Archipelago. Other taxa are considered endemic *sensu lato*, which includes those present in western Mediterranean islands and continental areas – Calabria in Europe, Kabylies in Africa – as far as the Miocene part of the Hercynian chain (Hercynian endemics *sensu* Mansion et al. 2008). Finally, other endemics *sensu lato* are ‘administrative endemics’, i.e. taxa confined within Italian national borders (Peruzzi et al. 2014). For endemics, geographic abbreviations are as follows:

Ag	Algeria;	Hy	Hyères islands;
AT	Tuscan Archipelago;	Sa	Sardinia;
Bl	Balearic Islands;	Si	Sicily.
Co	Corsica;		

Abundance is expressed on the basis of the following criteria:

- RR range restricted: taxa present in only one locality within the study area or covering a surface not exceeding 1 hectare, i.e. *Mentha requienii* subsp. *requienii*;
 U uncommon: taxa found in 2–5 localities within the study area, or covering a surface not exceeding 1 km², i.e. *Arisarum vulgare*;
 L localised: taxa present in 6 or more localities within the study area, but covering less than 2.5 km², i.e. *Agrostis capillaris*;
 C common: taxa covering more than 2.5 km², i.e. *Quercus ilex*.

Results

Floristic list

Lycopodiopsida

Isoetales

Isoetaceae

- 1 *Isoetes histrix* Bory G bulb, Stenomedit.-Atl.
 U (Zuanne Cane Malu, near Mt. Masiennera): Temporary ponds

Selaginellales

Selaginellaceae

- 2 *Selaginella denticulata* (L.) Spring Ch rept, Stenomedit.
 C: Woods, wet cliffs

Polypodiopsida

Osmundales

Osmundaceae

- 3 *Osmunda regalis* L. G rhiz, Subcosmop.
L: *Alnus glutinosa* woods, streams

Polypodiales

Dennstaedtiaceae

- 4 *Pteridium aquilinum* (L.) Kuhn subsp. *aquilinum* G rhiz, Cosmop.
C: Woods, meadows, fringes, garrigues, shrublands

Pteridaceae

- 5 *Anogramma leptophylla* (L.) Link T caesp, Cosmop.
L: Shady rocks and cliffs

Aspleniaceae

- 6 *Asplenium adiantum-nigrum* L. H ros, Paleotemp.
C: Shady rocks and cliffs, sometimes woods
Notes: since the taxon has been excluded from the Sardinian flora by Marchetti (2004), Arrigoni (2006–2015) and Bartolucci et al. (2018), here we consider it as new for the Sardinian flora.
- 7 *Asplenium onopteris* L. H ros, Subtrop.
C: Woods, sometimes cliffs
- 8 *Asplenium ceterach* L. subsp. *ceterach* H ros, Euras.
L: Walls
- 9 *Asplenium foreziense* Magnier H ros, NW-Medit.-Mont.
U (Badu Edras): Shady rocks and cliffs
Notes: the taxon has been excluded from the Sardinian flora by Marchetti (2004) and Bartolucci et al. (2018), but confirmed by Arrigoni (2006–2015).
- 10 *Asplenium obovatum* Viv. subsp. *obovatum* H ros, Stenomedit.
U (Mt. Masiennera): Crevices at the top of the mountain
- 11 *Asplenium trichomanes* subsp. *quadrivalens* D.E. Mey. H ros, Cosmop.
C: Shady rocks and cliffs

Woodsiaceae

- 12 *Athyrium filix-femina* (L.) Roth H Ros, Subcosmop.
L: Wet places, mainly *Alnus glutinosa* woods

Blechnaceae

- 13 *Struthiopteris spicant* (L.) F.W.Weiss H ros, Circumbor.
RR (Few individuals in a wet wood near Sos Sauceddodds spring): *Alnus glutinosa* wood

Dryopteridaceae

- 14 *Polystichum setiferum* (Forssk.) Woynt. G rhiz, Circumbor.
C: Woods

Polypodiaceae

- 15 *Polypodium cambricum* L. subsp. *cambricum* H ros, Eurimedit.
C: Rocks, big trees
- 16 *Polypodium interjectum* Shivas H ros, Paleotrop.
U (Bidighinzos): Shady rocks

Magnoliopsida**Alismatales****Araceae**

- 17 *Arisarum vulgare* O. Targ. Tozz. G rhiz, Stenomedit.
U (Bonu Trau, Badde Cherchi, Badu Edras): Woods and shrubland (lower altitudes)
- 18 *Arum italicum* Mill. subsp. *italicum* G rhiz, Stenomedit.
L: Fringes
- 19 *Arum pictum* L. f. G rhiz, Endem. Sa-Co-AT-BI
RR (Su Pizzu Sa Pedra): at the base of a cliff
Notes: this taxon is not considered as an Italian endemic by Peruzzi et al. (2014)
- 20 *Lemna gibba* L. I nat, Subcosmop.
L: Wet places, standing water
- 21 *Lemna minor* L. I nat, Subcosmop.
RR (Su Francallossu spring): standing water

Dioscoreales**Dioscoreaceae**

- 22 *Dioscorea communis* (L.) Caddick & Wilkin G rad, Eurimedit.
C: Woods

Liliales**Colchicaceae**

- 23 *Colchicum nanum* K. Perss. G bulb, Endem. Sa-Co
L: Wet pastures and meadows

Smilacaceae

- 24 *Smilax aspera* L. NP, Subtrop.
C: Woods

Liliaceae

- 25 *Gagea bohemica* (Zauschn.) Schult. & Schult.f. G bulb, Eurimedit.
C: Pastures

Asparagales

Orchidaceae

- 26 *Anacamptis laxiflora* (Lam.) R. M. Bateman, Pridgeon & M. W. Chase
G bulb, Eurimedit.
L: Wet meadows
Specimen examined (syn. *Orchis laxiflora* Lam.): Funtana Arile, Anela, 08 June 1980, B. Corrias, S. Diana (SS)
- 27 *Anacamptis longicornu* (Poir.) R. M. Bateman, Pridgeon & M. W. Chase
G bulb, W-Stenomedit.
Not found in the field during this research
Specimen examined (syn. *Orchis longicornu* Poir.): S'Isfundadu, Anela, 13 May 1965, B. Corrias (SS)
- 28 *Anacamptis papilionacea* (L.) R. M. Bateman, Pridgeon & M. W. Chase
G bulb, Eurimedit.
C: Dry grasslands
Specimen examined (syn. *Orchis papilionacea* L.): Funtana Arile, Anela, 08 June 1980, B. Corrias, S. Diana (SS)
- 29 *Dactylorhiza insularis* (Sommier) Landwehr G bulb, W-Stenomedit.
Not found in the field during this research
Specimen examined (syn. *D. sambucina* (L.) Soó): S'Isfundadu, Anela, 13 May 1965, B. Corrias (SS)
- 30 *Limodorum abortivum* (L.) Sw. G rhiz, Eurimedit.
U (Littu Majore and Minda 'e Bassu - Minda 'e Supra): *Quercus ilex* woods
- 31 *Orchis provincialis* Balb. ex Lam. & DC. G bulb, Stenomedit.
L: Clearings, fringes
Specimens examined: S'Isfundadu, Anela, 13 May 1965, B. Corrias (2 specimens, SS)
- 32 *Serapias lingua* L. G bulb, Stenomedit.
L: Wet meadows
Specimen examined: Funtana Arile, Anela, 08 June 1980, B. Corrias, S. Diana (SS)
- 33 *Spiranthes spiralis* (L.) Chevall. G rhiz, Europ.-Cauc.
U (Funtana Arile): Wet meadows

Iridaceae

- 34 *Crocus minimus* DC. G bulb, Endem. Sa-Co
C: Pastures
- 35 *Iris pseudacorus* L. G rhiz, Euras.
U (Su Pranu): Flooded meadows, ponds

- 36 *Romulea columnae* Sebast. & Mauri subsp. *columnae* G bulb, Stenomedit.
C: Pastures
- 37 *Romulea requienii* Parl. G bulb, Endem. Sa-Co
C: Pastures

Asphodelaceae

- 38 *Asphodelus ramosus* L. subsp. *ramosus* G rhiz, Stenomedit.
C: Perennial grasslands, pastures, garrigues

Amaryllidaceae

- 39 *Allium chamaemoly* L. subsp. *chamaemoly* G bulb, W-Stenomedit.
L: Annual grasslands (lower altitudes)
- 40 *Allium guttatum* subsp. *sardoum* (Moris) Stearn G bulb, Stenomedit.
C: Pastures, meadows
- 41 *Allium parviflorum* Viv. G bulb, Endem. Sa-Co
L: Garrigues, rocky habitats
- 42 *Allium subhirsutum* L. G bulb, W-Stenomedit.
C: Perennial grasslands
- 43 *Allium triquetrum* L. G bulb, W-Stenomedit.
C: Fringes, woods
- 44 *Allium vineale* L. G bulb, Eurimedit.
L: Perennial grasslands
- 45 *Leucojum aestivum* subsp. *pulchellum* (Salisb.) Briq. G bulb, Endem. Sa-Co-BI
L: Wet meadows
Notes: This taxon is reported also in the Var (Southern France) (see: Tison and de Foucault 2014, Arrigoni 2006–2015; Pignatti 2017–2018) whereas the Euro+Med Plantbase considers it exclusive only in Sardinia, Corsica and the Balearic Islands.
- 46 *Pancratium illyricum* L. G bulb, Endem. Sa-Co-AT
L: Garrigues

Asparagaceae

- 47 *Asparagus acutifolius* L. G rhiz, Stenomedit.
L: Woods and shrubland (lower altitudes)
- 48 *Drimys pancration* (Steinh.) J. C. Manning & Goldblatt G bulb, W-Stenomedit.
L: Grasslands
- 49 *Leopoldia comosa* (L.) Parl. G bulb, Eurimedit.
C: Grasslands, pastures
- 50 *Ornithogalum corsicum* Jord. & Fourr. G bulb, Endem. Sa-Co
C: Pastures

- 51 *Ornithogalum pyrenaicum* L. G bulb, Eurimedit.
C: Deciduous woods
- 52 *Prospero autumnale* (L.) Speta G bulb, Eurimedit.
C: Grasslands, pastures
- 53 *Ruscus aculeatus* L. G rhiz, Eurimedit.
C: Woods

Poales

Typhaceae

- 54 *Typha angustifolia* L. G rhiz, Circumbor.
L: Artificial lake, flooded areas, streams

Juncaceae

- 55 *Juncus articulatus* L. G rhiz, Circumbor.
C: Wet meadows, temporary ponds
- 56 *Juncus bufonius* L. T caesp, Cosmop.
C: Temporary ponds, wet soils
- 57 *Juncus capitatus* Weigel T scap, Medit.-Atl.
C: Temporary ponds
- 58 *Juncus effusus* L. subsp. *effusus* H caesp, Cosmop.
C: Wet meadows, temporary ponds
- 59 *Juncus hybridus* Brot. T caesp, Medit.-Atl.
C: Temporary ponds
- 60 *Luzula forsteri* (Sm.) DC. H caesp, Eurimedit.
C: Woods

Cyperaceae

- 61 *Carex caryophyllea* Latourr. H scap, Euras.
C: Wet pastures and meadows
- 62 *Carex distachya* Desf. H caesp, Stenomedit.
C: Woods
- 63 *Carex divisa* Huds. G rhiz, Medit.-Atl.
C: Wet meadows and pastures, temporary ponds, ditches
- 64 *Carex divulsa* Stokes H caesp, Eurimedit.
C: Fringes
- 65 *Carex microcarpa* Moris He, Endem. Sa-Co-AT-Itc
L: *Alnus glutinosa* woods, riparian vegetation
- 66 *Carex remota* L. H caesp, Europ.-Cauc.
U (Badu Addes): *Alnus glutinosa* wood
- 67 *Cyperus longus* L. G rhiz, Paleotemp.
C: Wet meadows, riparian vegetation
- Notes: some authors exclude the presence of this species from Sardinia (Desfayes 2004, Arrigoni 2006–2015, Bartolucci et al. 2018) and consider the pres-

ence of *Cyperus badius* Desf. instead. In the Euro+Med Plantbase, *C. badius* is considered a heterotypic synonym of *C. longus*.

- 68 *Eleocharis palustris* (L.) Roem. & Schult. subsp. *palustris* G rhiz, Subcosmop.

L: Wet meadows

Gramineae (*nom. altr.* Poaceae)

- 69 *Aegilops geniculata* Roth T scap, Stenomedit.-Turan.

L: Annual grasslands

- 70 *Agrostis capillaris* L. H caesp, Circumbor.

L: Wet pastures and meadows

Notes: this taxon is new for the Sardinian flora following Pignatti (1982), Conti et al. (2005), Arrigoni (2006–2015), Pignatti (2017–2018), Bartolucci et al. (2018) and the Euro+Med PlantBase.

- 71 *Aira caryophyllea* L. subsp. *caryophyllea* T scap, Subtrop.

C: Annual grasslands

- 72 *Alopecurus bulbosus* Gouan subsp. *bulbosus* H caesp, Eurimedit.-Subatl.

L: Wet pastures and meadows

- 73 *Anisantha diandra* (Roth) Tutin T scap, Eurimedit.

C: Annual grasslands

- 74 *Anisantha madritensis* (L.) Nevski subsp. *madritensis* T scap, Eurimedit.

C: Annual grasslands, pastures

- 75 *Anthoxanthum odoratum* L. H caesp, Euras.

C: Wet pastures and meadows

- 76 *Arrhenatherum elatius* subsp. *sardoum* (Em. Schmid) Gamisans H caesp, W-Stenomedit.

L: Garrigues, rocky habitats (higher altitudes)

- 77 *Avena barbata* Link subsp. *barbata* T scap, Eurimedit.

C: Annual grasslands

- 78 *Brachypodium retusum* (Pers.) P. Beauv. H caesp, W-Stenomedit.

C: Perennial grasslands on rocky or stony soils

- 79 *Brachypodium sylvaticum* (Huds.) P. Beauv. subsp. *sylvaticum* H caesp, Paleotemp.

C: Woods, fringes

- 80 *Briza maxima* L. T scap, Subtrop.

C: Annual grasslands, pastures

- 81 *Briza minor* L. T scap, Subcosmop.

U (near Mt. Masiennera): Wet pastures and meadows

- 82 *Bromus hordeaceus* L. subsp. *hordeaceus* T scap, Subcosmop.

C: Annual grasslands, pastures

- 83 *Bromus scoparius* L. T scap, Stenomedit.

U (Top of Mt. Masiennera): Annual grasslands

- 84 *Catabrosa aquatica* (L.) P. Beauv. G rhiz, Circumbor.

L: Wet soils

- 85 *Cynodon dactylon* (L.) Pers. G rhiz, Cosmop.
C: Wet pastures and meadows
- 86 *Cynosurus cristatus* L. H caesp, Europ.-Cauc.
C: Wet pastures and meadows
- 87 *Cynosurus echinatus* L. T scap, Eurimedit.
C: Annual grasslands, fringes
- 88 *Cynosurus effusus* Link T scap, Stenomedit.
C: Annual grasslands, fringes
- 89 *Dactylis glomerata* subsp. *hispanica* (Roth) Nyman H caesp, Stenomedit.
C: Perennial grasslands
- 90 *Danthonia decumbens* (L.) DC. subsp. *decumbens* H caesp, Europ.
L: Wet pastures and meadows
- 91 *Dasypyrum villosum* (L.) P. Candargy T Scap, Eurimedit.-Turan.
L: Annual grasslands
- 92 *Festuca morisiana* Parl. subsp. *morisiana* H caesp, Endem. Sa
L: Wet meadows and pastures
- 93 *Glyceria notata* Chevall. G rhiz, Subcosmop.
L: Wet habitats
- 94 *Holcus lanatus* L. subsp. *lanatus* H caesp, Circumbor.
C: Wet meadows
- 95 *Hordeum geniculatum* All. T scap, Stenomedit.
C: Wet meadows and pastures, temporary ponds
- 96 *Lagurus ovatus* L. subsp. *ovatus* T scap, Eurimedit.
C: Annual grasslands, pastures
- 97 *Lolium perenne* L. subsp. *perenne* H caesp, Euras.
C: Wet pastures
- 98 *Lolium rigidum* Gaudin subsp. *rigidum* T scap, Subtrop.
C: Pastures on arid soil
- 99 *Melica ciliata* L. subsp. *ciliata* H caesp, Eurimedit.
U (Mt. Masiennera): Rocky habitats
- 100 *Melica minuta* L. H caesp, Stenomedit.
C: Fringes
- 101 *Melica uniflora* Retz. H caesp, Paleotemp.
L: Deciduous woods, fringes
- 102 *Neoschischkinia pourrettii* (Willd.) Valdés & H. Scholz T scap, W-Steno-
medit.
L: Temporary ponds
- 103 *Piptatherum miliaceum* (L.) Coss. subsp. *miliaceum* H caesp, Stenomedit.
L: Road edges (lower altitudes)
- 104 *Poa annua* L. subsp. *annua* T caesp, Cosmop.
C: Annual grasslands, pastures
- 105 *Poa balbisii* Parl. H caesp, Endem. Sa-Co
U (Mt. Masiennera): Garrigues, rocky habitats

- 106 *Poa bulbosa* L. subsp. *bulbosa* H caesp, Paleotemp.
C: Pastures
- 107 *Poa infirma* Kunth T caesp, Eurimedit.
C: Mud, wet soils
- 108 *Poa nemoralis* L. subsp. *nemoralis* H caesp, Circumbor.
C: Woods
- 109 *Poa trivialis* L. subsp. *trivialis* H caesp, Euras.
C: Wet meadows
- 110 *Vulpia ligustica* (All.) Link T caesp, Stenomedit.
C: Pastures
- 111 *Vulpia myuros* (L.) C. C. Gmel. subsp. *myuros* T caesp, Subcosmop.
C: Pastures
- 112 *Vulpia sicula* (C. Presl) Link H caesp, W-Medit.-Mont.
C: Pastures, grasslands

Ranunculales

Papaveraceae

- 113 *Fumaria bastardii* Boreau T scap, Subatl.
C: Annual grasslands, fringes
- 114 *Fumaria officinalis* L. subsp. *officinalis* T scap, Paleotemp.
C: Annual grasslands, fringes
- 115 *Papaver rhoeas* L. subsp. *rhoeas* T scap, E-Medit.
C: Pastures, grasslands

Ranunculaceae

- 116 *Anemone hortensis* L. subsp. *hortensis* G bulb, N-Medit.
RR (Su Tatharesu): Perennial grasslands
- 117 *Clematis vitalba* L. P lian, Europ.-Cauc.
C: Woods, mantles
- 118 *Ficaria verna* Huds. subsp. *verna*. G bulb, Euras.
C: Woods
- 119 *Ranunculus bulbosus* subsp. *aleae* (Willk.) Rouy & Foucaud H scap, Euras.
C: Grasslands, fringes, woods
- 120 *Ranunculus bullatus* L. subsp. *bullatus* H ros, Stenomedit.
C: Annual grasslands
- 121 *Ranunculus cordiger* Viv. subsp. *cordiger* H scap, Endem. Sa-Co
L: Wet meadows, temporary ponds
- 122 *Ranunculus macrophyllus* Desf. H scap, SW-Medit.
L: Wet meadows
- 123 *Ranunculus muricatus* L. T scap, Eurimedit.
C: Mud, wet meadows
- 124 *Ranunculus ophioglossifolius* Vill. T scap, Eurimedit.
L: Mud, temporary ponds

- 125 *Ranunculus paludosus* Poir. subsp. *paludosus* H scap, Stenomedit.
C: Pastures
- 126 *Ranunculus sardous* Crantz T scap, Eurimedit.
C: Mud, temporary ponds

Saxifragales

Paeoniaceae

- 127 *Paeonia corsica* Tausch G rhiz, Endem. Sa-Co
L: Woods, clearings

Saxifragaceae

- 128 *Saxifraga tridactylites* L. T scap, Eurimedit.
L: Annual grasslands

Crassulaceae

- 129 *Sedum caeruleum* L. T scap, SW-Medit.
C: Rocky habitats, annual grasslands
- 130 *Sedum cepaea* L. T scap, Submedit.-Subatl.
C: Rocky habitats, annual grasslands
- 131 *Sedum rubens* L. T scap, Eurimedit.-Subatl.
C: Rocky habitats, annual grasslands
- 132 *Sedum stellatum* L. T scap, Stenomedit.
C: Rocky habitats, annual grasslands
- 133 *Sedum villosum* subsp. *glandulosum* (Moris) P. Fourn. H scap, Endem.
Sa-Ag
C: Rocky habitats, annual grasslands
- 134 *Umbilicus rupestris* (Salisb.) Dandy subsp. *rupestris* G bulb, Medit.-Atl.
C: Rocky habitats

Fabales

Leguminosae (nom. altr. Fabaceae)

- 135 *Cytisus villosus* Pourr. P caesp, W-Stenomedit.
C: Shrubland, mantles
- 136 *Dorycnium rectum* (L.) Ser. H scap, Stenomedit.
L: Wet habitats
- 137 *Genista corsica* (Loisel.) DC. NP, Endem. Sa-Co
L: Garrigues on rocky soils
- 138 *Genista desoleana* Vals. NP, Endem. Sa-Co-Its
C: Garrigues, dwarf shrubs
Specimens examined: Punta Chelchidores, Anela, 18 July 1972, F. Valsecchi (3 specimens, SS)
- 139 *Lathyrus aphaca* L. T scap, Eurimedit.
C: Pastures, fringes

- 140 *Lathyrus sphaericus* Retz. T Scap, Eurimedit.
L: Pastures
- 141 *Lotus alpinus* (DC.) Ramond H scap, Orof. S-Europ.
C: Wet pastures and meadows
- 142 *Lotus angustissimus* L. T scap, Eurimedit.
L: Temporary ponds
- 143 *Lotus conimbricensis* Brot. T scap, W- Stenomedit.
C: Annual grasslands
- 144 *Lotus hispidus* DC. T scap, W-Medit.
C: Annual grasslands
- 145 *Lupinus angustifolius* L. subsp. *angustifolius* T scap, Stenomedit.
C: Annual grasslands
- 146 *Medicago polymorpha* L. T scap, Eurimedit.
C: Pastures, annual grasslands
- 147 *Ononis spinosa* L. subsp. *spinosa* Ch suffr, Eurimedit.
C: Grasslands, pastures
- 148 *Ornithopus compressus* L. T scap, Eurimedit.
C: Annual grasslands
- 149 *Ornithopus pinnatus* (Mill.) Druce T Scap, Medit.-Atl.
L: Pastures
- 150 *Trifolium angustifolium* L. T scap, Eurimedit.
C: Annual grasslands
- 151 *Trifolium arvense* L. T scap, Paleotemp.
C: Pastures
- 152 *Trifolium campestre* Schreb. T scap, Paleotemp.
C: Annual grasslands
- 153 *Trifolium glomeratum* L. T Scap, Eurimedit.
L: Pastures
- 154 *Trifolium incarnatum* subsp. *molinerii* (Hornem.) Syme T scap, Eurimedit.
C: Grasslands, pastures
- 155 *Trifolium micranthum* Viv. T scap, Paleotemp.
C: Annual grasslands
- 156 *Trifolium nigrescens* Viv. subsp. *nigrescens* T scap, N-Medit.
C: Pastures
- 157 *Trifolium pratense* L. H scap, Eurosib.
C: Wet meadows and pastures
- 158 *Trifolium repens* subsp. *prostratum* Nyman H rept, Eurimedit.
C: Wet meadows and pastures
- 159 *Trifolium spumosum* L. T scap, Stenomedit.
C: Annual grasslands
- 160 *Trifolium squarrosum* L. T scap, Eurimedit.
L: Pastures
- 161 *Trifolium stellatum* L. T scap, Eurimedit.
C: Annual grasslands, pastures

- 162 *Trifolium subterraneum* subsp. *yanninicum* Katzn. & F. H. W. Morley
T rept, E-Medit.
C: Pastures
- 163 *Trifolium tomentosum* L. T rept, Paleotemp.
C: Annual grasslands, pastures
- 164 *Vicia cracca* L. subsp. *cracca* H scap, Euras.
C: Fringes
- 165 *Vicia lathyroides* L. T scap, Eurimedit.
C: Fringes
- 166 *Vicia lutea* L. subsp. *lutea* T scap, Eurimedit.
C: Fringes
- 167 *Vicia villosa* subsp. *ambigua* (Guss.) Kerguélen H Scap, W-Stenomedit.
L: Fringes
- 168 *Vicia villosa* Roth subsp. *villosa* T scap, Eurimedit.
C: Fringes

Rosales

Rosaceae

- 169 *Agrimonia eupatoria* L. subsp. *eupatoria* H scap, Subcosmop.
C: Fringes
- 170 *Crataegus monogyna* Jacq. P caesp, Paleotemp.
C: Shrublands, woods, mantles
- 171 *Fragaria vesca* L. subsp. *vesca* H rept, Eurosib.
C: Deciduous woods, fringes
- 172 *Geum urbanum* L. H scap, Circumbor.
C: Deciduous woods, fringes
Specimen examined: Caserma Forestale Anela, sine die, Barba (SS)
- 173 *Malus pumila* Mill. P scap, CW-Euras.
L: Woods, mantles
Notes: in accordance with Bagella and Urbani (2006), this is the valid name for *Malus domestica* Borkh. (nom. illeg.), also reported in the Euro+Med Plant-Base. Yet Galasso et al. (2018) call a taxon *Malus domestica*, considering it as a non-native species, while Camarda and Valsecchi (2008), Arrigoni (2006–2015) and Pignatti (2017–2018) still call it *M. dasycphylla*. Finally, Bartolucci et al. (2018) report the taxon *M. sylvestris* in Sardinia. *Malus pumila* is reported as a synonym of *M. domestica* by Galasso et al. (2018), it is excluded from the Sardinian flora by Arrigoni (2006–2015), finally, it was not mentioned by Camarda and Valsecchi (2008). In the Euro+Med Plantbase, *Malus pumila* Mill. is the valid name for *Malus domestica* Borkh. The populations we have examined in the Marghine-Goceano range (not only the forest domain of Anela) have the characters of *Malus domestica*, not *M. sylvestris*.
- 174 *Potentilla reptans* L. H ros, Paleotemp.
C: Wet meadows

- 175 *Prunus avium* (L.) L. P scap, Pontic
L: Woods
- 176 *Prunus domestica* subsp. *insititia* (L.) Bonnier & Layens P scap
U (Su Cantareddu): Mantles
- 177 *Prunus spinosa* L. subsp. *spinosa* P caesp, Europ.-Cauc.
C: Shrublands
- 178 *Pyrus communis* subsp. *pyraster* (L.) Ehrh. P scap, Euras.
L: Woods, mantles
- 179 *Pyrus spinosa* Forssk. P caesp, Stenomedit.
C: Shrublands, mantles, woods
- 180 *Rosa canina* L. NP, Paleotemp.
C: Shrublands
- 181 *Rosa sempervirens* L. NP, Stenomedit.
L: Woods, shrublands (lower altitudes)
- 182 *Rosa subcanina* (Christ) Vuk. NP, Europ.
C: Shrublands
- 183 *Rubus ulmifolius* Schott NP, Eurimedit.
C: Shrublands, woods
- 184 *Sanguisorba minor* subsp. *balearica* (Bourg. ex Nyman) Muñoz Garm. & C.
Navarro H scap, Eurimedit.
C: Grasslands

Ulmaceae

- 185 *Ulmus minor* Mill. subsp. *minor* P caesp, Europ.-Cauc.
L: Woods

Cannabaceae

- 186 *Celtis australis* L. subsp. *australis* P scap, Eurimedit.
RR (Pedru Addes): Wood edge

Moraceae

- 187 *Ficus carica* L. subsp. *carica* P scap, Medit.-Turan.
U (Badu Edras): Riparian vegetation

Urticaceae

- 188 *Parietaria lusitanica* L. subsp. *lusitanica* T rept, Stenomedit.
C: Buildings, fringes
- 189 *Urtica atrovirens* Loisel. H scap, Endem. Sa-Co-BI-AT-Itc
L: Ruderal vegetation
- 190 *Urtica dioica* L. subsp. *dioica* H scap, Subcosmop.
C: Ruderal vegetation

Fagales

Fagaceae

- 191 *Quercus ilex* L. P scap, Stenomedit.
C: Woods
- 192 *Quercus pubescens* Willd. agg. P caesp, SE-Europ.
C: Woods
Notes: There are many controversial treatments for describing the variation within *Q. pubescens* (Mossa et al. 1998, 1999). Until the various treatments are resolved, we prefer to treat this variation as a complex (or aggregate) within *Q. pubescens* s.l.
- 193 *Quercus suber* L. P scap, W-Eurimedit.
L: Woods

Betulaceae

- 194 *Alnus glutinosa* (L.) Gaertn. subsp. *glutinosa* P scap, Paleotemp.
L: Streams, wet places, springs

Oxalidales

Oxalidaceae

- 195 *Oxalis corniculata* L. subsp. *corniculata* H rept, Eurimedit.
L: Walls, buildings

Malpighiales

Guttiferae (nom. altr. Clusiaceae)

- 196 *Hypericum androsaemum* L. NP, W-Eurimedit.-Subatl.
L: Wet habitats, springs
- 197 *Hypericum hircinum* L. subsp. *hircinum* NP, Endem. Sa-Co-AT
L: Springs, streams, *Alnus glutinosa* woods
Notes: *H. hircinum* includes several subspecies, amongst which the subsp. *hircinum* is exclusive of Sardinia, Corsica and the Tuscan Archipelago (Carta and Peruzzi 2015)
- 198 *Hypericum perforatum* L. subsp. *perforatum* H scap, Paleotemp.
C: Fringes, road edges

Violaceae

- 199 *Viola alba* subsp. *dehnhardtii* (Ten.) W. Becker H ros, Eurimedit.
C: Woods, fringes
- 200 *Viola reichenbachiana* Jord. ex Boreau H scap, Eurosib.
C: Deciduous woods
Notes: it was excluded for the Sardinian flora by Arrigoni (2006–2015), but later confirmed by Mereu (2012) for the Gennargentu massif

Salicaceae

- 201 *Salix cinerea* subsp. *oleifolia* Macreight P caesp, W-Medit.-Atl.
L: Streams, springs
- 202 *Salix purpurea* L. P scap, Euras.
L: Ditches

Euphorbiaceae

- 203 *Euphorbia characias* L. subsp. *characias* NP, Stenomedit.
C: Woods, shrublands (lower altitudes)
- 204 *Euphorbia helioscopia* L. subsp. *helioscopia* T scap, Cosmop.
C: Annual grasslands
- 205 *Euphorbia pithyusa* subsp. *cupanii* (Guss. ex Bertol.) Radcl.-Sm. G rhiz,
Endem. Sa-Co-Si
C: Perennial grasslands, pastures
- 206 *Euphorbia semiperfoliata* Viv. G rhiz, Endem. Sa-Co
L: Woods, fringes

Linaceae

- 207 *Linum bienne* Mill. H bienn, Eurimedit.
C: Annual grasslands

Geraniales**Geraniaceae**

- 208 *Erodium chium* (L.) Willd. T scap, Eurimedit.
L: Pastures
- 209 *Erodium ciconium* (L.) L'Hér. T scap, Eurimedit.-Pontic
C: Pastures
- 210 *Erodium cicutarium* (L.) L'Hér. T scap, Subcosmop.
C: Pastures
- 211 *Geranium purpureum* Vill. T scap, Eurimedit.
C: Woods, fringes
- 212 *Geranium robertianum* L. T scap, Subcosmop.
C: Woods, fringes
- 213 *Geranium rotundifolium* L. T scap, Paleotemp.
C: Woods, fringes

Myrtales**Lythraceae**

- 214 *Lythrum portula* (L.) D. A. Webb T rept, S-Europ.-S-Sib.
L: Temporary ponds

Onagraceae

- 215 *Epilobium montanum* L. H scap, Euras.
C: Woods

Sapindales

Sapindaceae

- 216 *Acer monspessulanum* L. subsp. *monspessulanum* P caesp, Eurimedit.
L: Woods and mantles

Malvales

Malvaceae

- 217 *Althaea hirsuta* L. T scap, Eurimedit.
L: Annual grasslands
- 218 *Malva olbia* (L.) Alef. P caesp, Stenomedit.
C: Shrublands on wet soils
- 219 *Malva sylvestris* L. H scap, Eurosib.
C: Grasslands, fringes

Cistaceae

- 220 *Cistus monspeliensis* L. NP, Stenomedit.
C: Garrigues (lower altitudes)
- 221 *Cistus salviifolius* L. NP, Stenomedit.
C: Garrigues
- 222 *Tuberaria guttata* (L.) Fourr. T scap, Eurimedit.
C: Annual grasslands

Brassicales

Resedaceae

- 223 *Sesamoides purpurascens* subsp. *spathulata* (Moris) Lambinon & Kerguelén
H Scap, W-Medit.-Mont.
C: Dirty tracks, trampled places

Cruciferae (*nom. altr.* Brassicaceae)

- 224 *Arabidopsis thaliana* (L.) Heynh. T scap, Paleotemp.
C: Annual grasslands, pastures
- 225 *Capsella bursa-pastoris* (L.) Medik. subsp. *bursa-pastoris* H bienn, Cos-
mop.
C: Annual grasslands, pastures
- 226 *Cardamine flexuosa* With. H scap, Circumbor.
C: Fringes
- 227 *Cardamine hirsuta* L. T scap, Cosmop.
C: Fringes
- 228 *Draba muralis* L. T scap, Circumbor.
L: Cliffs, road edges
- 229 *Erophila verna* subsp. *praecox* (Steven) Walters T scap, Eurimedit.
C: Annual grasslands
- 230 *Morisia monanthos* (Viv.) Asch. H ros, Endem. Sa-Co
U (Near Mt. Masiennera): Wet meadows

- 231 *Nasturtium officinale* (L.) R. Br. H scap, Cosmop.
L: Muds, streams
- 232 *Raphanus raphanistrum* L. subsp. *raphanistrum* T scap, Eurimedit.
C: Grasslands
- 233 *Sisymbrium officinale* (L.) Scop. T scap, Paleotemp.
C: Pastures
- 234 *Teesdalia coronopifolia* (J.P. Bergeret) Thell. T scap, Eurimedit.
C: Pastures

Santalales

Santalaceae

- 235 *Osyris alba* L. NP, Eurimedit.
L: Woods, clearings, rocky habitats

Caryophyllales

Plumbaginaceae

- 236 *Armeria sardoa* Spreng. subsp. *sardoa* Ch suffr, Endem. Sa
L: Garrigues, rocky habitats

Polygonaceae

- 237 *Rumex bucephalophorus* L. subsp. *bucephalophorus* T scap, Eurimedit.-Macar.
C: Annual grasslands
- 238 *Rumex crispus* L. H scap, Subcosmop.
C: Wet meadows
- 239 *Rumex pulcher* L. subsp. *pulcher* H scap, Eurimedit.
C: Wet meadows
- 240 *Rumex scutatus* subsp. *glaucescens* (Guss.) Brullo, Scelsi & Spamp. H scap, Endem. Sa-Si
L: Rocky habitats
- 241 *Rumex thyrsoides* Desf. H scap, W-Medit.
C: Fringes

Caryophyllaceae

- 242 *Arenaria balearica* L. Ch suffr, Endem. Sa-Co-Bl-AT
L: Shady rocks and cliffs
Specimens examined: S'Isfundadu, Anela, 25 May 1966, B. Corrias (2 specimens, SS); S'Isfundadu, Anela, 18 June 1965, F. Valsecchi (1 specimen, SS).
- 243 *Cerastium gibraltarium* Boiss. Ch suffr, Orof. W-Medit.
L: Garrigues
Notes: in the Euro+Med Plantbase, *Cerastium boissierianum* Greuter et Burdet is considered a synonym of *C. gibraltarium*
- 244 *Cerastium glomeratum* Thuill. T scap, Eurimedit.
C: Pastures

- 245 *Cerastium ligusticum* subsp. *palustre* (Moris) P. D. Sell et Whitehead T scap,
Endem. Sa-Co
RR (near Mt. Masiennera): Wet pastures and meadows
- 246 *Corrigiola telephiiifolia* Pourr. H Ros, W-Medit.
L: Trampled sites, dirty roads
Specimen examined: Badu Addes, Anela, September 1962 (sine die), sine coll. (SS)
- 247 *Dianthus ichnusae* subsp. *toddei* Bacch., Brullo, Casti et Giusso H scap,
Endem. Sa
L: Garrigues, rocky habitats
Notes: this taxon is exclusive for the Goceano mountain range (Bacchetta et al. 2010).
- 248 *Moenchia erecta* (L.) P. Gaertn., B. Mey. & Scherb. subsp. *erecta* T scap,
Medit.-Atl.
C: Pastures
- 249 *Petrorhagia dubia* (Raf.) G. López & Romo T scap, S-Medit.
C: Pastures
- 250 *Petrorhagia saxifraga* (L.) Link H caesp, Eurimedit.
C: Garrigues, rocky habitats
- 251 *Sagina apetala* Ard. T scap, Eurimedit.
L: Annual grasslands, dirty tracks
- 252 *Sagina procumbens* L. H caesp, Subcosmop.
L: Wet places, springs
Specimen seen: Badu Addes, Anela, sine die, Barba (SS)
- 253 *Sagina subulata* (Sw.) C. Presl H caesp, Medit.-Atl.
L: Wet meadows, rocky habitats (higher altitudes)
Notes: for this taxon, recently the name *S. alexandrae* Iamónico has been proposed (Iamónico 2016)
- 254 *Silene gallica* L. T scap, Eurimedit.
C: Pastures
- 255 *Silene laeta* (Aiton) Godr. T scap, W-Stenomedit.
L: Muddy places, wet meadows, temporary ponds
- 256 *Silene latifolia* Poir. H bienn, Paleotemp.
C: Fringes
- 257 *Silene vulgaris* (Moench) Garcke subsp. *vulgaris* H scap, Paleotemp.
C: Fringes
- 258 *Spergula arvensis* L. T scap, Subcosmop.
C: Pastures
- 259 *Stellaria media* (L.) Cirillo subsp. *media* T rept, Cosmop.
C: Ruderal vegetation, woods, fringes

Amaranthaceae

- 260 *Chenopodium album* L. subsp. *album* T Scap, Subcosmop.
Not found in the field during this research

Specimens examined: Badu Addes, Anela, 09 September 1962, Barba (2 specimens, SS).

Portulacaceae

- 261 *Montia fontana* subsp. *amporitana* Sennen T scap, Medit-Mont. Subatl.
C: Mud, flooded soils

Ericales

Primulaceae

- 262 *Anagallis arvensis* L. T rept, Eurimedit.
C: Annual grasslands
- 263 *Asterolinon linum-stellatum* (L.) Duby T Scap, Stenomedit.
L: Annual grasslands, pastures
- 264 *Cyclamen repandum* Sibth. & Sm. subsp. *repandum* G bulb, NW-Stenomedit.
C: Woods

Ericaceae

- 265 *Arbutus unedo* L. P caesp, Stenomedit.
RR (Littu Majore): Wood
- 266 *Erica arborea* L. P caesp, Stenomedit.
C: Shrublands, woods

Gentianales

Rubiaceae

- 267 *Cruciata glabra* (L.) Ehrend. H scap, Euras.
C: Grasslands, pastures
Specimen examined: Badu Addes, Anela, 18 July 1972, B. Corrias, S. Diana, F. Valsecchi (SS).
- 268 *Galium aparine* L. subsp. *aparine* T scap, Euras.
C: Fringes
- 269 *Galium corsicum* Spreng. H scap, Endem. Sa-Co
L: Rocky habitats
- 270 *Galium debile* Desv. H scap, Eurimedit.
L: Wet habitats
- 271 *Galium rotundifolium* L. H scap, Orof.-W-Euras.
L: Woods (higher altitudes)
- 272 *Rubia peregrina* L. subsp. *peregrina* P lian, Stenomedit.-Macaron.
C: Woods
- 273 *Sherardia arvensis* L. T scap, Eurimedit.
C: Pastures, annual grasslands
- 274 *Theligonum cynocrambe* L. T scap, Stenomedit.
C: Annual grasslands, fringes

Gentianaceae

- 275 *Exaculum pusillum* (Lam.) Caruel T scap, W-Eurimedit.
RR (Minda 'e Bassu): Temporary pond

Boraginales**Boraginaceae**

- 276 *Anchusa hybrida* Ten. H scap, Stenomedit.
Not found in the field during this research
Specimens examined: Badu Addes, Anela, 22 October 1963, F. Valsecchi, Barba (3 specimens, SS).
- 277 *Cynoglossum creticum* Mill. H bienn, Eurimedit.
L: Fringes
- 278 *Echium plantagineum* L. T Scap, Eurimedit.
C: Pastures, grasslands
- 279 *Myosotis arvensis* (L.) Hill subsp. *arvensis* T scap, Europ.-W-Asian
C: Annual grasslands, pastures
- 280 *Myosotis sicula* Guss. T scap, N-Eurimedit.
L: Wet meadows, temporary ponds

Convolvulaceae

- 281 *Convolvulus althaeoides* L. H scand, Stenomedit.
C: Perennial grasslands
- 282 *Convolvulus arvensis* L. G rhiz, Paleotemp.
C: Perennial grasslands
- 283 *Cuscuta epithymum* subsp. *corsicana* (Yunck.) Lambinon T par, Endem.
Sa-Co
L: Garrigues (mainly parasite on *Genista desoleana*)

Solanales**Solanaceae**

- 284 *Solanum dulcamara* L. NP, Paleotemp.
U (Su Pranu): Riparian vegetation

Lamiales**Oleaceae**

- 285 *Phillyrea latifolia* L. P caesp, Stenomedit.
C: Woods, shrubland (lower altitude)

Plantaginaceae

- 286 *Callitriche stagnalis* Scop. I rad, Euras.
L: Temporary ponds, springs, muddy soils
- 287 *Cymbalaria aequitriloba* (Viv.) A. Chev. subsp. *aequitribloba* Ch rept, Endem.
Sa-Co-BI-AT
L: Shady rocks and cliffs

- 288 *Digitalis purpurea* L. subsp. *purpurea* H scap, W-Eurimedit.
C: Fringes, clearings
- 289 *Linaria arvensis* (L.) Desf. T scap, Submedit.-Subatl.
C: Annual grasslands
- 290 *Linaria pelisseriana* (L.) Mill. T scap, Medit.-Atl.
C: Pastures
- 291 *Plantago coronopus* L. T scap, Eurimedit.
C: Grasslands, pastures
- 292 *Plantago lagopus* L. subsp. *lagopus* T scap, Stenomedit.
C: Annual grasslands, pastures
- 293 *Plantago lanceolata* L. H ros, Euras.
C: Grasslands
- 294 *Plantago major* L. subsp. *major* H ros, Euras.
L: Wet meadows
- 295 *Plantago weldenii* Rchb. T scap, Stenomedit.
C: Annual grasslands
- 296 *Veronica anagallis-aquatica* L. subsp. *anagallis-aquatica* H scap, Cosmop.
L: Mud, springs, ditches
Specimen examined: Punta Chelchidores est, Anela, 18 July 1972, B. Corrias, S. Diana, F. Valsecchi (SS)
- 297 *Veronica arvensis* L. T scap, Subcosmop.
C: nitrophilous vegetation
- 298 *Veronica hederifolia* L. subsp. *hederifolia* T scap, Euras.
C: Woods, fringes
- 299 *Veronica verna* subsp. *brevistyla* (Moris) Rouy T scap, Endem. Sa-Co
L: Pastures (higher altitudes)

Scrophulariaceae

- 300 *Scrophularia trifoliata* L. H caesp, Endem. Sa-Co-AT
L: Rocky habitats
Specimen examined: Badu Addes, Anela, 18 July 1972, F. Valsecchi (SS)
- 301 *Scrophularia umbrosa* Dumort. subsp. *umbrosa* H Scap, Euras.
Not found in the field during this research
Specimens examined: Badu Addes, Anela, 18 July 1973, F. Valsecchi (3 specimens, SS)
- 302 *Verbascum pulverulentum* Vill. H bienn, Europ.
C: Clearings, fringes

Labiatae (nom. altr. Lamiaceae)

- 303 *Clinopodium nepeta* subsp. *glandulosum* (Req.) Govaert H scap, Stenomedit.
C: Fringes
- 304 *Clinopodium vulgare* subsp. *orientale* Bothmer H scap, E-Stenomedit.
C: Fringes

Notes: The Italian Flora Checklists (Conti et al. 2005, Bartolucci et al. 2018) consider the subsp. *arundanum* (Boiss.) Nyman as present in Sardinia, whereas, the Euro+Med PlantBase considers subsp. *arundanum* absent from the island (and the whole Italian peninsula) and that, instead, subsp. *orientale* is present. Our specimens fit well with the diagnostic characters of subsp. *orientale* as described by Bothmer (1967).

- 305 *Glechoma sardoa* (Bég.) Bég. H rept, Endem. Sa
L: Woods, fringes
- 306 *Lamium maculatum* (L.) L. H scap, Euras.
U: Forest near forestry headquarters, under *Quercus ilex*
Notes: according to Arrigoni (2006–2015), this taxon was not found in Sardinia in recent years
- 307 *Lamium purpureum* L. T scap, Euras.
C: Fringes
- 308 *Lavandula stoechas* L. subsp. *stoechas* NP, Stenomedit.
C: Garrigues
- 309 *Mentha aquatica* L. H scap, Paleotemp.
L: Wet meadows
- 310 *Mentha pulegium* L. subsp. *pulegium* H scap, Eurimedit.
C: Wet meadows, temporary ponds
- 311 *Mentha requienii* Benth. subsp. *requienii* H rept, Endem. Sa-Co
RR (Su Cantareddu spring): Wet rocks, spring
- 312 *Mentha suaveolens* subsp. *insularis* (Req. ex Gren. & Godr.) Greuter H scap, Endem. Sa-Co-AT-BI
U (Funtana Arile spring): Fringes
- 313 *Micromeria graeca* (L.) Benth. subsp. *graeca* Ch suffr, Stenomedit.
C: Garrigues
- 314 *Prunella vulgaris* L. subsp. *vulgaris* H scap, Circumbor.
C: Wet meadows, fringes, clearings
- 315 *Salvia verbenaca* L. H scap, Medit.-Atl.
C: Grasslands
Notes: following the Euro+Med PlantBase, in this taxon we include ecotypes referred to *Salvia clandestina* L.
- 316 *Stachys arvensis* (L.) L. T scap, Europ.
L: Annual grasslands, pastures
- 317 *Stachys corsica* Pers. H rept, Endem. Sa-Co
L: Shady rocks and cliffs
Specimens examined: S'Isfundadu, Anela, 18 June 1965, F. Valsecchi (SS); Badu Addes, Anela, 18 July 1972, B. Corrias, S. Diana, F. Valsecchi (SS)
- 318 *Stachys glutinosa* L. Ch frut, Endem. Sa-Co-AT
L: Garrigues, rocky habitats
- 319 *Teucrium chamaedrys* L. subsp. *chamaedrys* Ch suffr, Eurimedit.
U (near the helicopter base): Pastures, grasslands

- 320 *Thymus herba-barona* Loisel. Ch rept, Endem. Sa-Co-BI
C: Garrigues

Orobanchaceae

- 321 *Orobanche hederæ* Duby T par, Eurimedit.
C: Woods
- 322 *Orobanche minor* Sm. T par, Paleotemp.
C: Grasslands, pastures
- 323 *Orobanche nana* (Reut.) Beck T par, Medit.-Macaron.
L: Grasslands, pastures
- 324 *Orobanche ramosa* L. T par, Paleotemp.
L: Road sides, pastures
- 325 *Orobanche rapum-genistæ* Thuill. T par, Subatl.
L: Garrigues with *Genista* sp.
- 326 *Orobanche rigens* Loisel. T par, Endem. Sa-Co
L: Garrigues with *Genista* sp.
- 327 *Parentucellia latifolia* (L.) Caruel subsp. *latifolia* T scap, Eurimedit.
C: Pastures
- 328 *Parentucellia viscosa* (L.) Caruel T scap, Medit.-Atl.
C: Annual grasslands

Aquifoliales

Aquifoliaceae

- 329 *Ilex aquifolium* L. P caesp, Submedit.-Subatl.
C: Woods

Asterales

Campanulaceae

- 330 *Jasione montana* L. H scap, Europ.-Cauc.
C: Pastures and rocky habitats

Compositae (nom. altr. Asteraceae)

- 331 *Achillea ligustica* All. H scap, W-Stenomedit.
C: Fringes
- 332 *Anthemis arvensis* L. subsp. *arvensis* T scap, Stenomedit.
C: Pastures
- 333 *Arctium minus* (Hill) Bernh. H bienn, Eurimedit.
C: Fringes, clearings
- 334 *Bellis annua* L. subsp. *annua* T scap, Stenomedit.
C: Annual grasslands on wet soils
- 335 *Bellis perennis* L. H ros, Europ.-Cauc.
C: Wet meadows
- 336 *Bellis sylvestris* Cirillo H ros, Stenomedit.
L: Perennial grasslands (lower altitudes)

- 337 *Bellium bellidioides* L. H ros, Endem. Sa-Co-BI-AT
C: Temporary ponds, wet soils
- 338 *Carlina corymbosa* L. H scap, Stenomedit.
C: Pastures
- 339 *Carthamus lanatus* L. subsp. *lanatus* T scap, Eurimedit.
C: Pastures, nitrophilous vegetation near sheep pens
- 340 *Centaurea calcitrapa* L. subsp. *calcitrapa* H bienn, Eurimedit.
C: Pastures
- 341 *Chamaemelum fuscatum* (Brot.) Vasc. T scap, W-Stenomedit.
L: Temporary ponds
- 342 *Chondrilla juncea* L. H scap, S-Europ.-S-Sib.
C: Pastures
- 343 *Cichorium intybus* L. subsp. *intybus* H scap, Paleotemp.
L: Perennial grasslands
- 344 *Cirsium scabrum* (Poir.) Bonnet & Barratte H scap, SW-Medit.
L: Fringes, road edges (lower altitudes)
- 345 *Cirsium vulgare* subsp. *silvaticum* (Tausch) Arènes H bienn, Eurimedit.
C: Fringes, road edges
- 346 *Crepis bellidifolia* Loisel. T scap, W-Stenomedit.
L: Pastures
- 347 *Crepis leontodontoides* All. H ros, W-Medit.-Mont.
C: Pastures
- 348 *Crepis vesicaria* L. subsp. *vesicaria* T scap, Submedit.-Subatl.
C: Pastures
- 349 *Crupina vulgaris* Cass. T scap, S-Sib.-Eurimedit.
L: Pastures, perennial grasslands
- 350 *Filago gallica* L. T scap, Eurimedit.
C: Annual grasslands
- 351 *Filago germanica* (L.) Huds. T scap, Paleotemp.
U (S. Giorgio): Annual grasslands
- 352 *Galactites tomentosus* Moench H bienn, Stenomedit.
C: Pastures
- 353 *Glebionis coronaria* (L.) Spach. T scap, Stenomedit.
L: Pastures, annual grasslands (lower altitudes)
- 354 *Helichrysum italicum* subsp. *tyrrhenicum* (Bacch., Brullo et Giusso) Herrando,
J.M. Blanco, L. Sáez & Galbany Ch frut., Endem. Sa-Co-BI
C: Garrigues
Notes: for this taxon, we follow Herrando-Moraira et al. (2016)
- 355 *Hyoseris radiata* L. H ros, Stenomedit.
C: Pastures, meadows
- 356 *Hypochaeris achyrophorus* L. T scap, Stenomedit.
C: Annual grasslands
- 357 *Hypochaeris cretensis* (L.) Bory & Chaub. H scap, NE-Medit.-Mont.
L: Dry pastures and rocky habitats

- 358 *Hypochaeris glabra* L. T scap, Eurimedit.
C: Pastures, meadows
- 359 *Hypochaeris radicata* L. subsp. *radicata* H ros, Europ.-Cauc.
C: Pastures, meadows
- 360 *Hypochaeris robertia* (Sch. Bip.) Fiori H ros, Endem. Sa-Co-Si-It
L: Wet rocks and cliffs
- 361 *Lactuca muralis* (L.) Gaertn. H scap, Europ.-Cauc.
C: Woods, fringes
- 362 *Leontodon tuberosus* L. H ros, Stenomedit.
C: Grasslands, pastures
- 363 *Pilosella ziziana* (Tausch) F. W. Schultz & Sch. Bip. H scap, Europ. (?)
L: Grasslands
- 364 *Ptilostemon casabonae* (L.) Greuter H scap, Endem. Sa-Co-AT-Hy
U (Entrance of the Domain): Road edge
- 365 *Pulicaria odora* (L.) Rchb. H scap, Eurimedit.
C: Woods, fringes (lower altitude)
- 366 *Reichardia picroides* (L.) Roth H scap, Stenomedit.
L: Rocky habitats (lower altitudes)
- 367 *Rhagadiolus stellatus* (L.) Gaertn. T scap, Eurimedit.
C: Annual grasslands
- 368 *Scolymus hispanicus* L. subsp. *hispanicus* H bienn, Eurimedit.
C: Pastures
- 369 *Senecio vulgaris* L. subsp. *vulgaris* T scap, Eurimedit.
C: Pastures, ruderal vegetation
- 370 *Sonchus asper* (L.) Hill subsp. *asper* T scap, Euras.
C: Ruderal vegetation
- 371 *Sonchus oleraceus* L. T scap, Euras.
C: Ruderal vegetation
- 372 *Silybum marianum* (L.) Gaertn. H bienn, Medit.-Turan.
C: Ruderal vegetation, pastures
- 373 *Taraxacum* sect. *Erythrosperma* (H. Lindb.) Dahlst. or *Taraxacum* sect. *Scariosa*
Hand.-Mazz. H ros, Circumbor.
C: Wet meadows
- 374 *Urospermum dalechampii* (L.) F.W. Schmidt H scap, Eurimedit.
C: Grasslands

Dipsacales

Adoxaceae

- 375 *Sambucus ebulus* L. G rhiz, Eurimedit.
L: Streams
- 376 *Sambucus nigra* L. P caesp, Europ.-Cauc.
C: Woods, shrublands

Caprifoliaceae

- 377 *Dipsacus ferox* Loisel. H bienn, Endem. Sa-Co-Itc
C: Pastures
- 378 *Valerianella eriocarpa* Desv. T scap, Stenomedit.
C: Annual grasslands

Apiales

Araliaceae

- 379 *Hedera helix* L. P lian, Eurimedit.
C: Woods

Umbelliferae (*nom. altr.* Apiaceae)

- 380 *Bunium corydalinum* DC. G bulb, Endem. Sa-Co
C: Garrigues, rocky habitats
- 381 *Chaerophyllum temulum* L. T scap, Euras.
L: Woods, fringes
- 382 *Eryngium campestre* L. H scap, Eurimedit.
C: Pastures
- 383 *Ferula communis* L. subsp. *communis* H scap, S-Eurimedit.
L: Pastures, clearings (lower altitudes)
- 384 *Oenanthe crocata* L. H scap, Medit.-Atl.
L: *Alnus glutinosa* woods, streams
- 385 *Oenanthe lisae* Moris H scap, Endem. Sa
U (Funtana Arile spring): Wet meadows
Specimen examined: Funtana Arile, Anela, 08 June 1980, B. Corrias, S. Diana (SS)
- 386 *Oenanthe pimpinelloides* L. H scap, Medit.-Atl.
C: Woods, fringes
- 387 *Sanicula europaea* L. H scap, Paleotemp.
C: Woods, fringes
- 388 *Smyrniium perfoliatum* subsp. *rotundifolium* (Mill.) Bonnier & Layens
H bienn, Stenomedit.
C: Fringes, woods
- 389 *Thapsia garganica* L. subsp. *garganica* H scap, S-Medit.
C: Pastures, grasslands
- 390 *Torilis africana* Spreng. T scap, Medit.-Macaron.
C: Pastures, annual grasslands
- 391 *Torilis nodosa* (L.) Gaertn. T scap, Medit.-Turan.
C: Pastures, annual grasslands

Ecological and biogeographical analysis of the indigenous flora of Anela

Here we assess the presence in the forest domain of Anela of 391 taxa, belonging to 32 orders and 74 families.

Of the listed taxa, 5 (*Anacamptis longicornu* (Orchidaceae), *Anchusa hybrida* (Boraginaceae), *Chenopodium album* subsp. *album* (Amaranthaceae), *Dactylorhiza insularis* (Orchidaceae), *Scrophularia umbrosa* (Scrophulariaceae)) were not found during our investigation. Excluding these species, then we recorded a total of 386 indigenous taxa within the domain. Two species are new for the Sardinian flora (*Agrostis capillaris*, *Asplenium adiantum-nigrum*) and, for 17 taxa, our findings determine an important enlargement of their known range on the island (*Arrhenatherum elatius* subsp. *sardoum*, *Asplenium foreziense*, *Clinopodium vulgare* subsp. *orientale*, *Colchicum nanum*, *Danthonia decumbens* subsp. *decumbens*, *Euphorbia semiperfoliata*, *Exaculum pusillum*, *Festuca morisiana* subsp. *morisiana*, *Lamium maculatum*, *Mentha requienii* subsp. *requienii*, *Morisia monanthos*, *Poa balbisii*, *Prunus domestica* subsp. *insititia*, *Ranunculus cordiger* subsp. *cordiger*, *Rosa subcanina*, *Veronica verna* subsp. *brevistyla*, *Viola reichenbachiana*).

Overall, we found 141 hemicryptophytes (36.1%), 137 therophytes (35.0%), 56 geophytes (14.3%), 27 phanaerophytes (6.9%), 15 nano-phanaerophytes (3.8%), 11 chamaephytes (2.8%), 3 hydrophytes (0.8%), and 1 helophyte (0.3%).

A total of 239 taxa belong to the Mediterranean element (61.1%), 53 are Eurasian *sensu lato* (including the true Eurasian, plus European, Euro-Siberian, Euro-Caucasian and Pontic district: overall 13.6%), 42 are Boreal-Temperate taxa (paleotemperate + circumboreal: 10.7%), 36 are widespread (cosmopolitan, sub-cosmopolitan and subtropical: 9.2%) and 19 are Atlantic (4.9%). We were not able to assign a geographical category to *Prunus domestica* subsp. *insititia*.

Hemicryptophytes dominate within the Boreal-Temperate and the Eurasian components; annual species prevail within the widespread and the Mediterranean-Atlantic groups. The Mediterranean component hosts similar percentages of annuals and hemicryptophytes (Fig. 2).

The Mediterranean component is dominated by the euri-Mediterranean sub-element (94 taxa, 24.0% of the whole flora), followed by the steno-Mediterranean (77 taxa, 19.7%) and the endemics (45 entities, 11.5%). A total of 23 Mediterranean taxa belonged to other chorotypes (mountain-Mediterranean, Mediterranean-Turanian, Mediterranean-Macaronesian).

The endemic component of the flora of Anela is dominated by those of the Sardinian-Corsican biogeographic province (*sensu* Bacchetta et al. 2012) accounting for 28 taxa (endemics *sensu stricto*, 7.4%), of which 19 taxa are Sardinian-Corsican (42.2% of the endemic component), followed by Sardinian entities (5, 11.1%) and those present on Sardinia, Corsica and the Tuscan Archipelago (4, 8.9%). Tyrrhenian or Hercynian endemics (those present in Sardinia, Corsica, Tuscan Archipelago, the Balearic and Hyeres Islands and Sicily) account 12 (26.7%) and, finally, 11.1% is constituted by 5 entities with larger ranges including some continental areas (Sardinia and northern Africa or Sardinia and Italy).

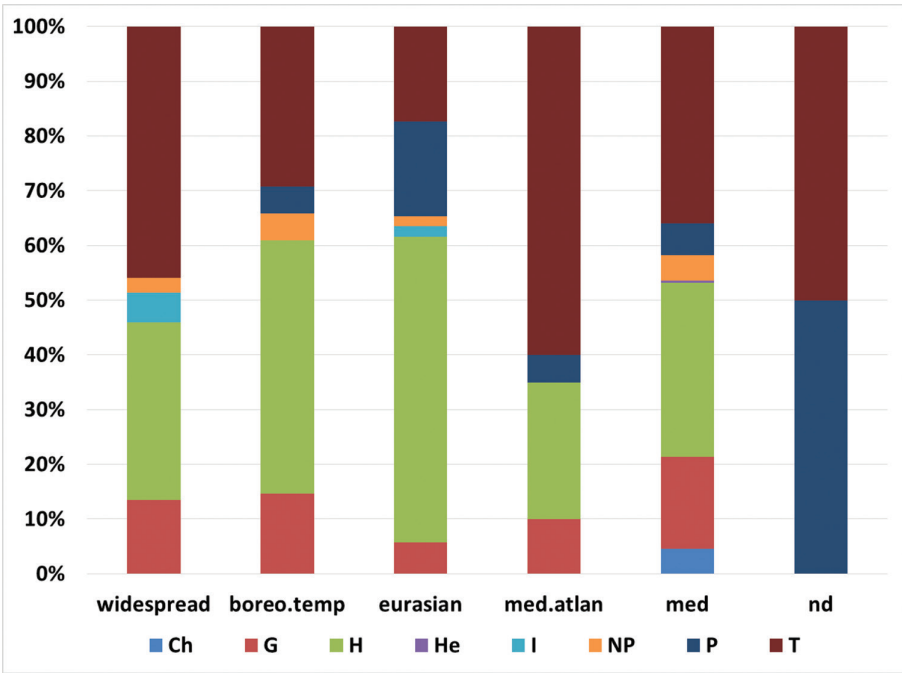


Figure 2. Percentage of biological types for each chorologic element detected in the vascular flora of Anela (390 taxa). boreo.temp = Boreal-temperate taxa; med.atlan = Mediterranean-Atlantic taxa; med = Mediterranean; nd = not determined.

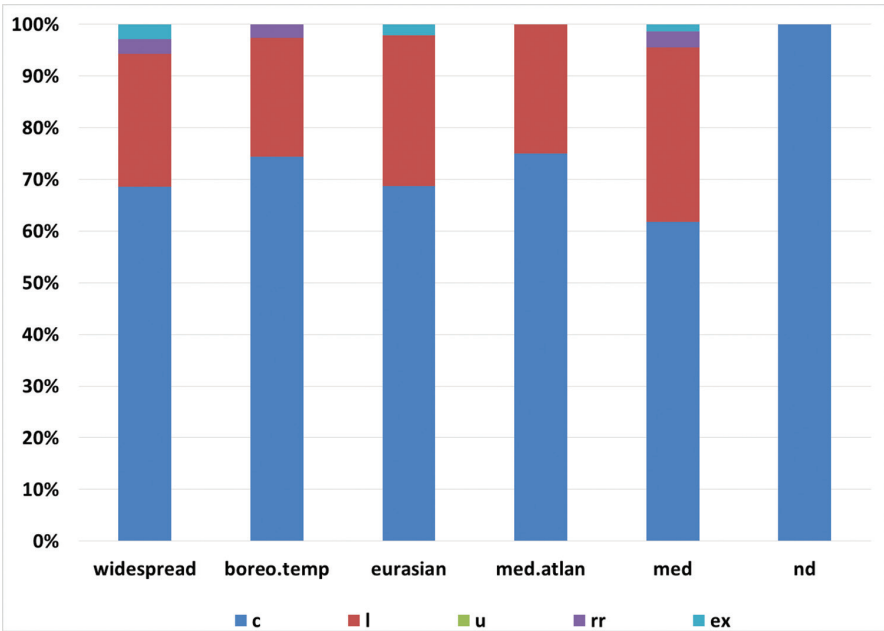


Figure 3. Percentage of abundance categories for each chorologic element detected in the vascular flora of Anela (390 taxa). c = common; l = localized; u = uncommon; rr = range restricted; ex = extinct. ; boreo.temp = Boreal-temperate taxa; med.atlan = Mediterranean-Atlantic taxa; med = Mediterranean; nd = not determined.

On the basis of our criteria, 241 taxa (61.6%) can be considered common at the local level, 113 (28.9%) are localised, 23 (5.9%) are uncommon, 9 (2.3%) are range restricted and 5 (1.3%) are locally extinct in the last 50 years. Common taxa are the dominant category in all the geographic groups, whereas range restricted taxa are found only in the widespread, Boreal-Temperate and the Mediterranean groups (Fig. 3).

A total of 176 out of 387 taxa were found mainly in grasslands habitats (45.5%) including dry pastures (61 taxa), annual and perennial grasslands (52 and 31 taxa, respectively) and wet pastures and meadows (32 taxa). Woodland habitats hosted 97 taxa (25.1%), comprising woods (57 taxa), fringes and clearings (30 taxa) and shrubs (10 taxa). Wet habitats (including *Alnus glutinosa* woods, springs, temporary ponds, ditches, muds, streams) hosted 53 taxa (13.7%). Rocky habitats (cliffs, rocks, screes) harbour 24 taxa (6.2%), then the garrigues hosted 21 taxa (5.4%) and finally the anthropogenic habitats (ruderal vegetation, buildings, walls, trampled sites, road edges) were the main habitat for 15 taxa (3.9%).

Discussion

Biogeographical description of the mountain

Our research discovered a high species density at the study area (30.6 taxa km⁻²), that is one of the highest ever documented in the Sardinian mountain floras (Table 1). Even if there is a clear inverse relationship between the area investigated and species' density, we should note that, for areas having a comparable surface (~ 10 km²), the floristic density recorded at our study area is second only to the Mt. Gonare complex (Camarda 1984a, 1984b). It is noteworthy that the summit area of Sardinia (> 1500 m a.s.l.), having a surface of 16.8 km², hosts "only" 214 taxa of which 66 are considered endemics (Arrigoni and Camarda 2015). So we can argue that areas at the edge between the Mediterranean and the temperate bioclimates, like Foresta Demaniale Anela and Mt. Gonare, host floristic components from both the two bioclimatic – biogeographic regions, having therefore more abundant floras than areas located in coastal or summit zones.

The hemicryptophytes/therophytes (H/T) ratio, as previously noted by Arrigoni and Camarda (2015), underlines the co-presence of two main elements, the perennial and the annual herbs, having very different life-cycles and summing 71.1% of our flora. The H/T ratio, that in Sardinia peaks at 2.5 at the summit of Gennargentu (Arrigoni and Camarda 2015), but decreases to 0.74 as the regional average, is at Anela 1.03. Limestone mountains like Mt. Albo, with a karst geology and consequently a pronounced summer drought, have a H/T ratio even lower than the regional average, whereas mountain complexes with impermeable substrates (plutonic, volcanic, metamorphic) approaching 1000 m a.s.l. have a H/T ratio ~ 1 gradually increasing with elevation (Table 1). This means that at 1000 m a.s.l., the co-presence of two large groups of non-woody plants, having an annual or perennial life cycle, has been detected: the annuals have a greater prevalence at lower altitudes, the perennials at higher altitudes and their ratio ~ 1 at 1000 m a.s.l. underlines the transition character of this altimetric level in Sardinia.

Table 1. Synthetic data on mountain floras from Sardinia and the regional flora, based on different sources (see notes below).

Site	Altitudinal interval	Area (km ²)	No. taxa	Taxa / km ²	H/T	No. endemics	% endemics	Source
Anela forest domain	600–1158	12.8	391	30.6	1.03	45	11.5	This work
Gennargentu	1500–1834	16.8	214	12.7	2.5	66	30.8	Arrigoni and Camarda 2015
Gennargentu	1000–1834	240	675	2.8	1.25	105	15.6	Arrigoni and Camarda 2015
Gennargentu	1000–1834	500	897 [†]	1.8	1.03 [‡]	n.d.	28 [§]	Bacchetta et al. 2013
Supramontes	0–1463	335	n.d.	n.d.	n.d.	138	30 [§]	Fenu et al. 2010
Mt. Albo	900–1127	68	659	9.7	0.61	48	7.3	Camarda 1984a
Mt. Gonare	538–1083	10	520	52	0.85	23	4.4	Camarda 1984b
Mt. Limbara	160–1359	166.24	923	5.5	0.75	80	8.7	Calvia and Ruggero unpublished
Mt. Limbara	800–1359	49.46	687	13.9	0.84	72	10.5	Calvia and Ruggero unpublished
Mt. Limbara	500–1359	n.r.	506	n.d.	1.18	55	10.9	Veri and Bruno 1974
Sardinia	0–1834	24090	2028	0.084	0.70	n.d.	7.1	Pignatti 1995
Sardinia	0–1834	24090	2400	0.099	n.d.	n.d.	n.d.	Arrigoni (2006–15)
Sardinia	0–1834	24090	2408	0.1	0.74 [*]	290 [*]	12	Various (see notes)
Sardinia	0–1834	24090	2149	0.09	n.r.	290	13.5	Médail 2017, table 2
Sardinia	0–1834	24090	2301	0.095	n.r.	331	14.4	Bartolucci et al. 2018

[†]Bacchetta et al. (2013) list 948 entities, including 10 varieties, 3 hybrids and 38 aliens: here we therefore consider 897 native taxa; [‡]calculated by Arrigoni and Camarda 2015; [§]Cañadas et al. 2014; ^{||}Conti et al. 2005; ^{*}Arrigoni and Camarda 2015; ^{*}Fenu et al. 2014; n.r. not reported; n.d. not determined.

Important differences with the regional (Sardinian) value (Pignatti 1995) have also been detected for the Mediterranean floristic component, particularly the steno-Mediterranean taxa having a 28.9% regional percentage and 19.7% at the Anela forest domain; contrarily, the euri-Mediterranean component has 16.1% regional average but increases to 24% at our study area, the same percentage (24.3%) reached by the sum of the Boreal-Temperate and the Eurasian floristic components. Whereas lower altitude floras have a dominant steno-Mediterranean component and the floras at the summit of Mediterranean mountains show the prevalence of southern-European and Mediterranean orophytes and narrow endemics (Cañadas et al. 2014; Arrigoni and Camarda 2015), our flora is a good example of transition areas, having the 80% of taxa quite equally distributed amongst steno-Mediterranean, euri-Mediterranean, Boreal-Temperate and Eurasian and the endemic contingents. High species density, H/T ratio ~ 1, balance amongst different chorologic groups and endemic percentage ~ 10% can be considered characteristic features of mountain areas at the transition between the Mediterranean and the temperate bioclimates.

The composition of the flora of the Forest Domain of Anela is also peculiar because it is one of the few examples, not only in Sardinia but in the whole Mediterranean area, with no native Gymnosperms. Junipers (*Juniperus phoenicea* subsp. *turbinata* (Guss.) Nym. and *J. oxycedrus* subsp. *macrocarpa* (Sibth. & Sm.) Neilr.) in NW Sardinia are mainly confined in coastal areas (Farris et al. 2017), but Yew (*Taxus baccata* L.) and Prickly Juniper (*Juniperus oxycedrus* L. subsp. *oxycedrus*) are usually present in high hills

and mountains. However junipers are not present in NW Sardinia inland areas (Farris et al. 2017), but the Yew is occurring in all the massifs and mountain ranges, including the two forest domains bordering Anela, the Fiorentini Forest Domain to the east (municipality of Bultei) and the Mt. Pisanu Forest Domain to the west (municipality of Bono, see Farris and Filigheddu 2008). The total absence of Gymnosperms in the native flora of the Anela forest domain is therefore surprising, most probably anomalous and it seems likely to be linked to the management history of the area rather than a natural pattern (Sechi and Falchi 2013).

Despite the fact that in 2004 (last forest census) 90.4% of the domain area was covered by forest or shrub communities (Sechi and Falchi 2013), it is striking that the 45% of the detected taxa were linked mainly to herbaceous habitats (annual and perennial grasslands, dry and wet pastures and meadows), already described for their peculiar and original floristic composition (Farris et al. 2013). Traditional grazing, particularly ovine pastoralism characterised by low flock density and transhumance, has been proven to be beneficial for the plant biodiversity of Mediterranean silvo-pastoral systems, whereas abandonment is detrimental even at short temporal scales (Farris et al. 2010a). The forest domain of Anela is a typical case where ovine stocks had a dramatic decrease in a short period: between 1990 and 2007, a decrease from 0.77 sheep ha⁻¹ to 0.13 sheep ha⁻¹ has been recorded (-83%, Farris et al. 2010a), whereas wood and shrub communities linked to potential natural vegetation (*sensu* Farris et al. 2010b) are recovering very fast, following a trend common to all Italy (Falcucci et al. 2007) and particularly to Sardinia (Puddu et al. 2012).

Conservation issues of this Flora

Even if rarity is not always linked to threat (de Lange and Norton 1998, Bacchetta et al. 2012), it is an important feature to consider when setting conservation priorities within long lists of taxa (Bacchetta et al. 2012, Le Berre et al. 2018), as in the case of the flora of the Anela forest domain. Additionally, 14 out of 32 uncommon and range-restricted taxa found in this flora are linked to wet habitats: some belong to the Mediterranean and endemic contingents (*Cerastium ligusticum* subsp. *palustre*, *Exaculum pusillum*, *Isoetes hystrix*, *Mentha suaveolens* subsp. *insularis*, *Mentha requienii* subsp. *requienii*, *Morisia monanthos*, *Oenanthe lisae*), others to the Eurasian and Boreal-Temperate contingents (*Struthiopteris spicant*, *Carex remota*, *Iris pseudacorus*, *Solanum dulcamara*, *Spiranthes spiralis*). Those habitats are supposed to be highly vulnerable (Filipe et al. 2013), as changes in land use and modification of water balance (because of climate change or human use) are amongst the most important threats to wetlands. Moreover, little is known about the resilience of associated plant communities, a threat increased by the high spatial isolation of such places within a Mediterranean context. At the study site, we detected several species having a contraction of range or local extinctions caused by the capture of surface or underground water for human use, as for example *Struthiopteris spicant*, *Cerastium ligusticum* subsp. *palustre*, *Mentha requienii*

subsp. *requienii* and the localized fern *Osmunda regalis* for which we documented a local decrease > 50% in the last 20 years. Other species had a decrease directly caused by drainage of temporary ponds (*Exaculum pusillum*, *Isoetes hystrix*, *Morisia monanthos*). Water management in a climatic changing scenario is and will increasingly be a key issue for the conservation of biodiversity in the Mediterranean basin (Casazza et al. 2014), a climatic change hotspot at the global scale (Giorgi 2006, Giorgi and Lionello 2008), where wet habitats and the species linked are amongst the most threatened (Ghosn et al. 2010, Pérez-Luque et al. 2015).

The 5 taxa, locally extinct, have no relationship with a particular habitat or human use from which they are (were) dependent for their survival in the area, with the exception of *Chenopodium album* whose disappearance could be explained with the above-mentioned abandonment of pastoral activities, as it is a nitrophilous species. Their disappearance in the last decades, inferred from herbarium records, can be therefore a normal turnover in the composition of the local indigenous flora or an artifact derived from our sampling method (in the sense that these taxa are maybe still present in the area but we were not able to find them during our monthly sampling excursions).

Amongst the flora we inventoried, it is worth mentioning that several populations represent peripheral populations regarding the overall distribution of the taxa. First, a group of uncommon or range restricted species in the domain, are common plants in the Mediterranean bioclimate areas of Sardinia and sometimes in the whole basin. They are here confined to warm niches in the mountain area under study (*Anemone hortensis*, *Arbutus unedo*, *Arisarum vulgare*, *Arum pictum*, *Celtis australis*, *Ficus carica*, *Ptilostemon casabonae*), places relatively scattered through this mountain landscape. Oppositely, several Boreal-Temperate and Eurasian taxa confined in this sub-Mediterranean bioclimate island represent peripheral populations isolated sometimes by over 1000 km of their northern range. Those constitute rear edge populations (Hampe and Petit 2005) which may contain unique genetic variation, inherited from ancient species distribution and particular ecological conditions. These two contrasted situations have been highlighted several times within the Mediterranean flora (Lavergne et al. 2005, 2006) and are characteristic of those climatic transition areas. These plants all share the characteristic of occurring as fragmented, disjunct and often highly isolated populations, which restrain gene flow with central population (Pironon et al. 2017) and enhance amongst-population differentiation (Papuga et al. 2018). Thus, the relative isolation associated with potentially marginal ecological conditions highlight their evolutionary potential (Thompson 1999, Anacker and Strauss 2014), as it has recently been shown in Sardinia and Corsica for some marginal and peripheral populations of *Cyclamen repandum* (Thompson et al. 2018). Additionally, these groups of taxa are often found in different macro-habitats which have very different links with human activities, therefore leading to different threats and management issues (Lavergne et al. 2006). Thus, conservation policies need to integrate such complex entities within their framework (Lesica and Allendorf 1995, Brunnell et al. 2004, Leppig and White 2006). Finally, those transition areas also contain numerous endemics, which render those places original and of high value for conservation.

Even if biodiversity hot-spots definition at multiple spatial scales is commonly based on the presence, density and distribution of endemic taxa (Myers et al. 2000, Cañadas et al. 2014), the data here presented support that other parameters should also be taken into account to more precisely define priority areas for conservation, as taxonomic complexity (Ennos et al. 2005) of floras and evolutionary potential of populations (Thompson et al. 2010), detected within continuous schemes of biodiversity monitoring (Marignani et al. 2014). This is particularly urgent in southern European mountains, whose biodiversity is threatened by both climate and land use changes (Bravo et al. 2008, Benito et al. 2011, Pauli et al. 2012, Vogiatzakis et al. 2016).

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Medinilla theresae (Melastomataceae), a new species from ultramafic soils in the Philippines

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Abstract

A new species, *Medinilla theresae* Fernando, from ultramafic soils on Dinagat and Mindanao Islands, Philippines is described and illustrated. The species is characterized by its terrestrial erect habit, non-setose nodes, 3-plinerved, lanceolate and coriaceous leaves arranged in whorls, cauline or axillary and pendulous inflorescences, rounded flower buds, 4-merous flowers, and straight anthers. It is compared with other similar species in the *Medinilla pendula* Merr. complex.

Keywords

Dinagat Island, *Medinilla*, Melastomataceae, Mt Hamiguitan, ultramafic soils

Introduction

Medinilla Gaudich. (Melastomataceae) is a genus of terrestrial and epiphytic shrubs and climbers occurring from Tropical Africa, Madagascar, to India, Sri Lanka, Myanmar, southern China and Taiwan, throughout Southeast Asia, New Guinea, northern Australia, Micronesia, Solomons, Vanuatu, Fiji, and Samoa with about 375 species (Bodegom and

Veldkamp 2001; Mabberley 2017). In the Philippines, Merrill (1913) early on attributed just 28 species, then later 125 species (Merrill 1923). In the revision of the Philippine species of this genus, Regalado (1995) recognized 80 species with 90% endemism. These species were divided into 12 informal species groups based on a combination of indumentum, leaf, stem, and inflorescence characters, and within each group additional characters of the stem, leaf, inflorescence, and flower were used to delimit species.

Since Regalado's (1995) revision only one species, *Medinilla dalliciana* Fernando & Balete (Fernando and Balete 2013) belonging to Group 5, has been added to the Philippine list.

In this paper, we describe a new species, *Medinilla theresae*, a terrestrial, erect, cauliflorous shrub from ultramafic soils on Dinagat and Mindanao Islands, Philippines.

Materials and methods

This new species of *Medinilla* was discovered while undertaking a field survey of the ultramafic flora of Dinagat Island. Photographic records were taken and herbarium specimens collected. The morphological description of the species is based on vegetative and reproductive characters. Field characters were recorded on site; vegetative characters were observed and measured from press-dried specimens and seedlings and reproductive characters from fresh specimens and from material preserved in 70% ethanol. All morphological measurements were made using digital calipers and a calibrated eye piece under a dissecting microscope. Herbarium specimens were also examined and compared at CAHUP, CMUH, LBC, MO, PNH, and PUH, including additional material, e.g. images of type specimens of Philippine *Medinilla* available online at A, CAS, GH, K, L, NY, UC, and US. All photographs, except where indicated, were taken in the field in the natural habitat of the species.

Taxonomy

Medinilla theresae Fernando, sp. nov.

urn:lsid:ipni.org:names:60477661-2

Figures 1–4

Diagnosis. This species is most similar to the *Medinilla pendula* species complex in its whorled leaves, 4-merous flowers, and pendulous inflorescences. It differs, however, in its secondary veins of leaves being distinct only on the adaxial surface, cauline or axillary inflorescences, and straight anthers.

Type. PHILIPPINES. Dinagat Island: Municipality of Loreto, Mt Redondo, 10°35'34.2"N, 125°63'49.0"E, 840 m elevation, dwarf forest on ultramafic soil, flower buds and open flowers, 29 September 2015, *E.S. Fernando 3831* (holotype PNH; isotypes LBC, PUH).

Description. Terrestrial, erect *shrub* up to 1.5 m tall. *Stem* 1–2 cm diameter near the base of the plant, terete, internodes to 12 cm long, shorter on the distal branches; nodes rather thickened, knobby, not setose, although small barbules may sometimes appear on younger nodes; bark generally smooth, becoming striate on older stems; young stems terete, about 3 mm in diameter, green. *Leaves* simple, petiolate, in whorls of 3 or 4 per node; petiole ascending, about 3–5 mm thick, 0.5–2 cm long, pale light green, sometimes with dark purplish-red or maroon tinge on the adaxial side; lamina lanceolate, 5–12 × 1.5–4 cm, glossy dark green adaxially, paler abaxially, succulent when fresh, coriaceous when dry; base obtuse, apex acuminate; 3-plinerved, the pair of secondary veins diverging about 2–5 mm from the leaf base, in fresh specimens only visible on the adaxial surface, very faintly so and only near the leaf base on the abaxial surface, in dry specimens visible only on the adaxial surface; transverse veins faintly visible on adaxial surface in fresh and dry specimens, indistinct or absent abaxially; margins smooth, revolute at the edges. *Inflorescences* cauline, not terminal, arising from leafless nodes, sometimes near the base of the stem, or from leafy nodes, pendulous, usually solitary, or sometimes two or three per node; peduncle about 2.5–6 cm long, enlarged towards the distal end, bright red at maturity, bracteate, each bract 4 × 3 mm; flowers up to 15 or more per inflorescence, usually clustered in a whorl of short, 3-flowered cymes only at the enlarged, distal end of the peduncle, sometimes in 2–3 whorls; 10 or so arranged in umbellately cymose clustered branches up to about 1 cm long, also subtended by bracts; secondary bracts spatulate, 3 × 2 mm; total inflorescence length about 7 cm. *Flower buds* ± rounded at the tips, the petals imbricate. *Flowers* 4-merous, petal 8 × 4 mm, oblique-oblong, often reflexed, orange-red, red, or pink; stamens 8, usually positioned above the style, anthers linear-lanceolate, 2.5–4 mm long, rather straight, purple, with a yellow dorsal spur of 0.6 mm long on the connective and a pair of partly joined stout, ventral appendages at the base of the anther sac; filament 4 mm long, pale white; style terete, 10 mm long, pale white; hyp-anthium campanulate, the rim generally truncate or sometimes very shallowly lobed, pale or light green, 3–4 × 3–4 mm; pedicel pale pink or red, about 7 mm long. *Fruit* a subglobose berry, 4–6 × 5–7 mm, light green when young and with bright red calyx rim, entirely purplish-black when ripe; the peduncle and pedicels red. *Seeds* numerous, embedded in pulpy tissue, ovoid, 1–1.5 × 0.5–1 mm, chestnut brown. *Seedling* with epigeal germination, phanerocotylar, cotyledons foliaceous, 2–3 × 2 mm, broadly ovate, apex rounded or obtuse, sometimes shallowly emarginate; eophylls simple, opposite, broadly elliptic-ovate to orbicular, 3–7 × 3–5 mm.

Additional specimens examined. PHILIPPINES. Dinagat Island, Municipality of Loreto, Mt Redondo, 10°35'06.3"N, 125°63'03.6"E, 700 m elevation, flower buds, 1 September 2016, *Fernando* 4166 (LBC, PNH, PUH); 700 m elevation, flowers, 30 September 1991, *Gaerlan*, *Sagcal*, & *Fernando* PPI 4651 (MO [MO5547927], PNH); 10°35'19.3"N, 125°63'24.2"E, 800 m elevation, juvenile fruits, 1 September 2016, *Fernando* & *Matute* 4217 (LBC). Mindanao Island, Pujada Peninsula, Davao Oriental Province, Municipality of San Isidro, Mt Hamiguitan, 900 m elevation, flowers, 25 February 2005, *Amoroso* & *Aspiras* CMUH 04922 (CMUH); 6°44'16.728"N,

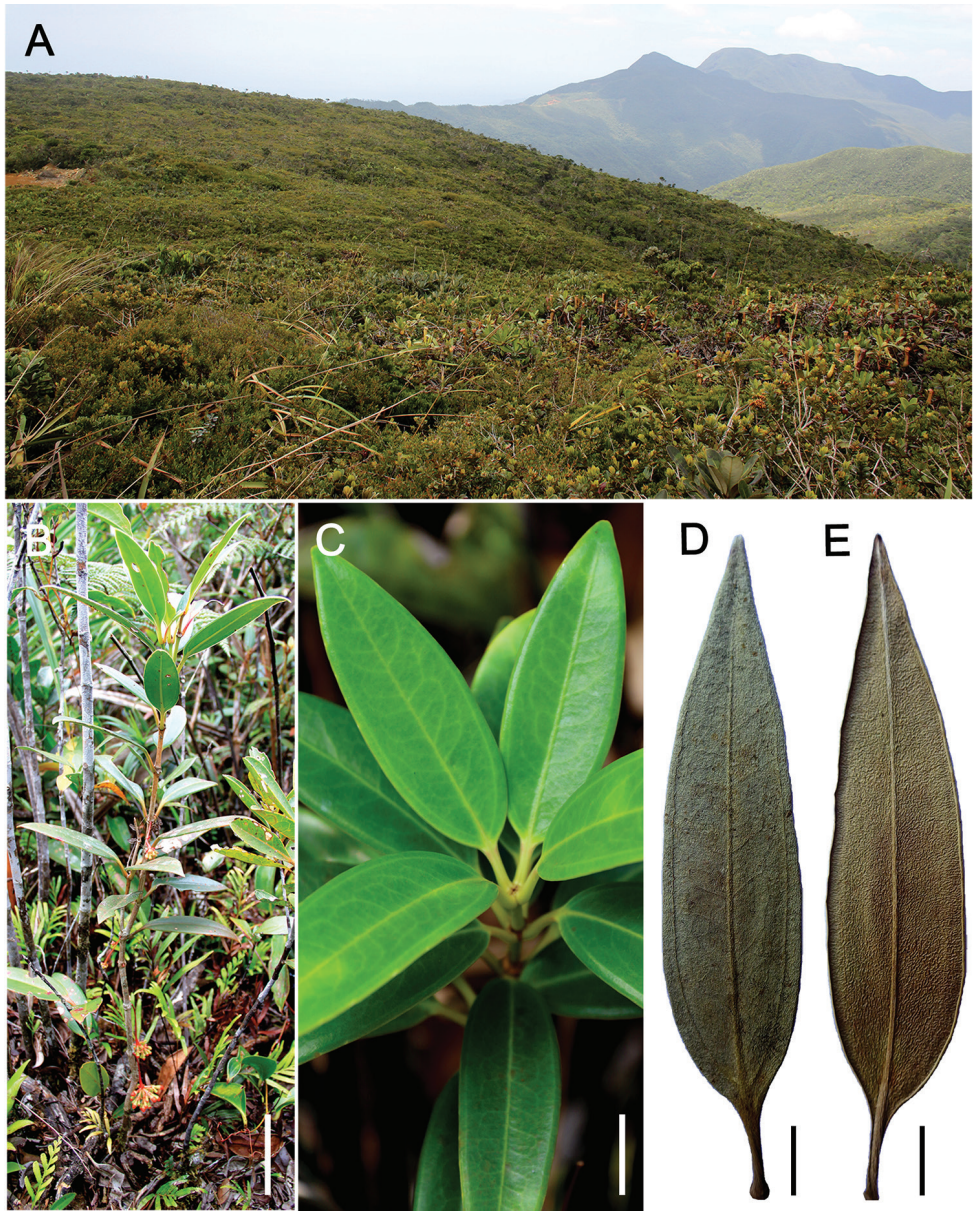


Figure 1. *Medinilla theresae* Fernando **A** Habitat at type locality, dwarf forest on ultramafic soils, c. 840 m elevation, Mt Redondo with Mt Kambinliw in the background **B** Terrestrial, erect growth habit **C** Leafy branch showing leaves arranged in a whorl and secondary veins faintly visible on adaxial surface **D** Dried leaf showing adaxial surface with distinct pair of secondary veins **E** Abaxial surface of same leaf in D without the distinct pair of secondary veins. **B, D, E** from *Fernando 3831* (LBC), **C** from *Fernando 4166* (LBC). Scale bars: 10 cm (**B**); 2 cm (**C–E**). All photos by Edwino S. Fernando.

126°10'1.02"E, 1326 m elevation, fruits, 23 June 2015, *Fritsch et al.* 2025 (CAS [CAS493220], CMUH). Cultivated: Luzon Island, Laguna Province, Municipality of Los Baños, seedlings grown from seeds of *Fernando 3831* germinated in nursery, 4 May 2016, *Fernando 3831A* (LBC).

Some photos of Leonard L. Co from Mt Hamiguitan taken in January 2005 and appearing in PhytoImages (www.phytoimages.siu.edu) with five of these identified as *Medinilla surigaoensis* (DOL nos. 27282–27284, 27439, and 27534) and several others as *Medinilla* sp. (DOL nos. 27278–27281 and 27533) (Pelser et al. 2011) belong to this new species. Unfortunately, we have been unable to find at PUH, where Mr Co was based, the specimens or his field notes associated with the photos. The vouchers are likely among approximately 6,000 unprocessed specimens still wrapped in about 200 plastic bags.

Habitat and ecology. On Mt Redondo, Dinagat Island, this species occurs in dense, dwarf forest 1–2 m tall on ultramafic soils on gentle slopes at *c.* 700–840 m elevation (Figure 1A). This dwarf forest is about 527 hectares (5.27 km²) with more than 90% of the trees having stem diameter of less than 10 cm (Fernando et al. 2017). The rhizospheric soil (*c.* 30 cm) here reveal, on average, up to 396,024 ppm iron (Fe); 1,344 ppm nickel (Ni); 425 ppm copper; 10,875 ppm chromium; and 4,453 ppm manganese (elemental analyses obtained by x-ray fluorescence, unpublished data). On Mt Hamiguitan, it occurs at the edges of the upper montane forest at 900 m elevation, up to the so-called ‘mossy-pygmy forest’ at 1160–1200 m and 1460–1600 m elevation (Figure 4A), also on ultramafic soils, where the trees are 0.5–2.5 m tall and with an average stem diameter of 8 cm and dominated by species of *Leptospermum* (Myrtaceae), *Weinmannia* (Cunoniaceae), *Elaeocarpus* (Elaeocarpaceae), and *Dacrydium* (Podocarpaceae) (Amoroso and Aspiras 2011), and also including the heavy metal indicator *Scaevola micrantha* C.Presl (Goodeniaceae) (Fernando et al. 2008; Amoroso and Aspiras 2011).

The small trees and shrubs associated with *Medinilla theresae* at the type locality on Dinagat Island include, among many others, *Leptospermum amboinense* Blume (Myrtaceae), *Psychotria surigaoensis* Sohmer & A.P.Davis (Rubiaceae), *Scaevola micrantha*, *Rhodomyrtus surigaoensis* Elmer (Myrtaceae), *Calophyllum cucullatum* Merr. (Calophyllaceae), *Ternstroemia gitingensis* Elmer (Pentaphylacaceae), *Fagraea gitingensis* Elmer (Gentianaceae), *Gardenia barnesii* Merr. (Rubiaceae), *Timonius valetonii* Elmer (Rubiaceae), *Dacrydium beccari* Parl. (Podocarpaceae), *Falcatifolium gruezoi* de Laub. (Podocarpaceae), and various species of *Syzygium* (Myrtaceae). There are also vines such as *Dischidia major* (Vahl) Merr. (Apocynaceae), *Flagellaria indica* L. (Flagellariaceae), *Nepenthes mindanaensis* Sh.Kurata (Nepenthaceae), and species of *Freycinetia* (Pandanaceae).

Distribution. Thus far, this new species is known only from Mt Redondo on Dinagat Island and Mt Hamiguitan in the Pujada Peninsula on Mindanao Island, Philippines. Dinagat Island, Surigao del Norte Province, and the Pujada Peninsula form part of the same belt of the Eastern Philippine Cretaceous ophiolite and ophiolite complexes (Balce et al. 1976; Yumul et al. 2003, 2008; Tamayo et al. 2004) that are now large areas of ultramafic landscapes with metallic ore deposits (e.g., iron, nickel, chromium) and hosting a unique type of forest formation (Fernando et al. 2008).

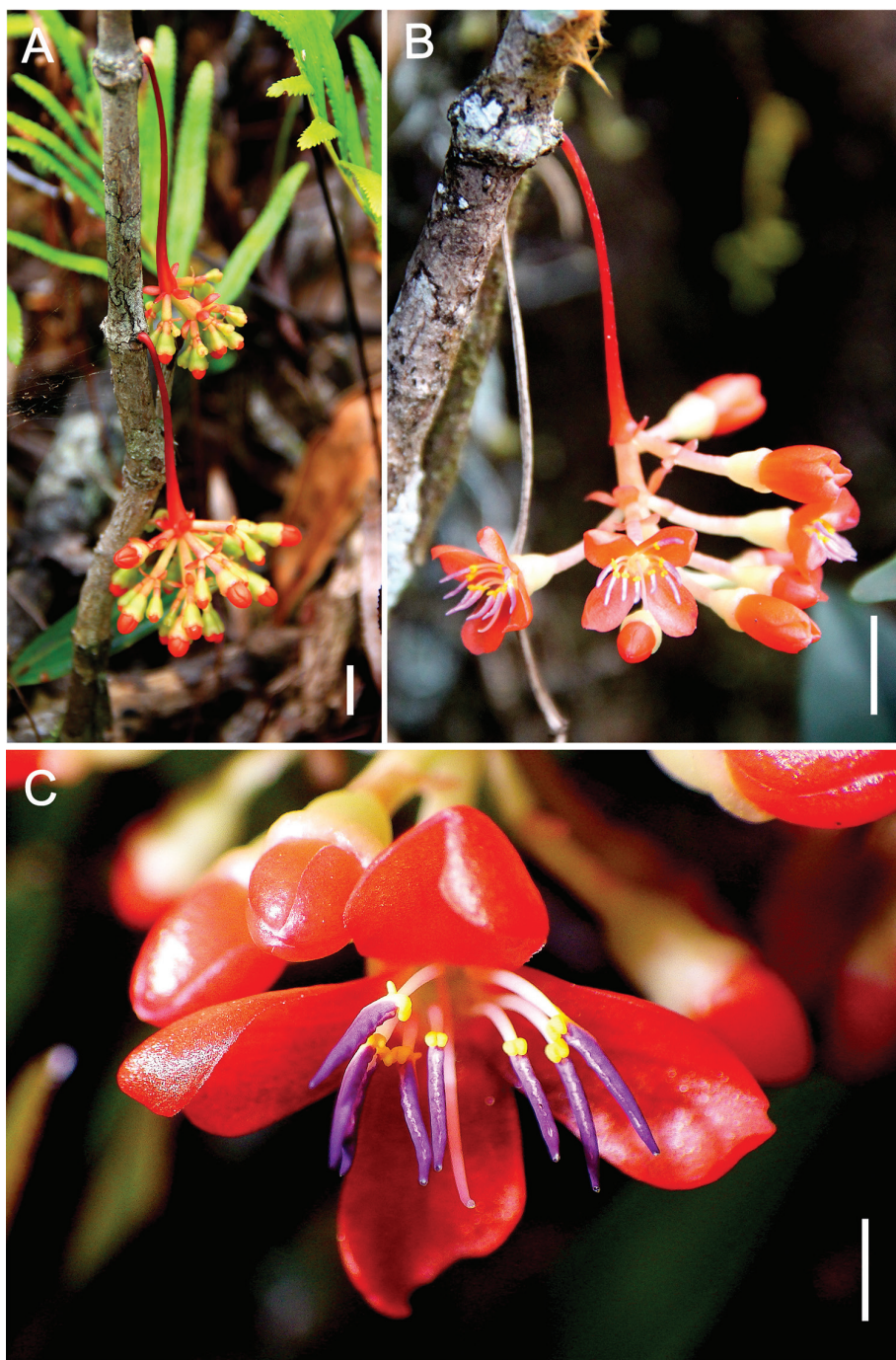


Figure 2. *Medinilla theresae* Fernando **A** Pendulous inflorescences arising from nodes near base of main stem and showing flower buds with rounded tips **B** Inflorescence with buds and open flowers **C** Close up of open flower. **A** from *Fernando 4166* (LBC) **B**, **C** from *Fernando 3831* (LBC). Scale bars: 1 cm (**A**); 8 mm (**B**); 2 mm (**C**). All photos by Edwino S. Fernando.

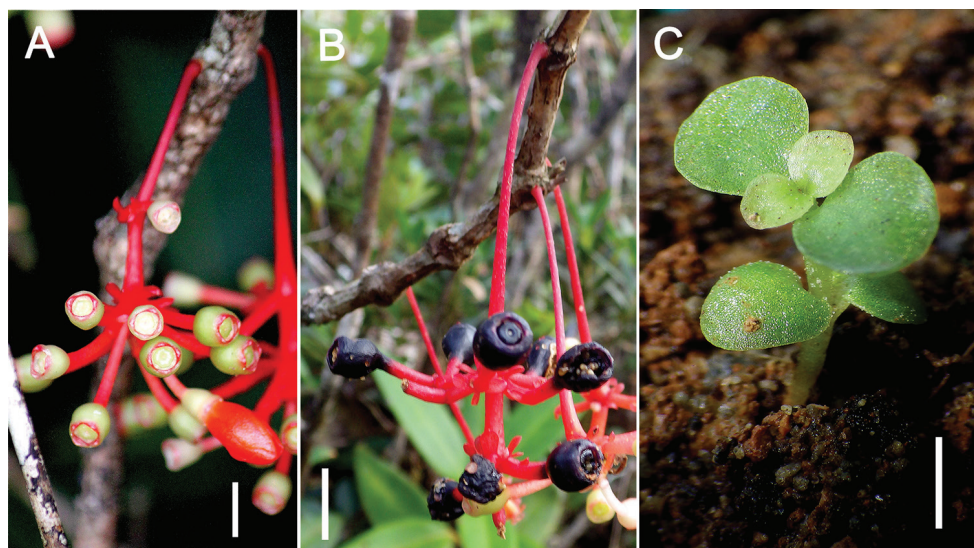


Figure 3. *Medinilla theresae* Fernando **A** Young infructescence showing light green fruits with bright red calyx rim **B** Mature purplish-black fruits **C** Seedling showing foliaceous cotyledons and first two pairs of eophylls, c. 20 weeks old, grown in nursery from seed of *Fernando 3831*. **A** from *Fernando 4217* (LBC) **B** from *Fernando 3831* (LBC). Scale bars: 1 cm (**A**, **B**); 2 mm (**C**). All photos by Edwin S. Fernando.

Etymology. This beautiful new species is named in honor of Dr Theresa Mundita S. Lim, former Director of the Biodiversity Management Bureau, Department of Environment and Natural Resources of the Philippines, and now Executive Director of the ASEAN Centre for Biodiversity, whose dedication and commitment to protecting Philippine biodiversity is admirable. Director Lim has also been active in the international biodiversity conservation sector.

Notes. In the glabrous nature of the plant and whorled leaves, this new species belongs in Group 1 of Regalado (1995) being most similar to *Medinilla pendula* Merr. (Merrill 1905) under which Regalado (1995) reduced to synonymy four species viz., *Medinilla elmeri* Merr. from Mt Sto. Tomas, Benguet Province, Luzon Island (Elmer 1911); *Medinilla subsessilis* Merr. from Melamey, Bontoc, Luzon Island (Merrill 1912); *Medinilla gitingensis* Elmer from Mt Giting-giting, Sibuyan Island (Elmer 1911); and *Medinilla merrillii* Elmer from Mt Apo, Mindanao Island (Elmer 1911). Of these, our new species is most similar to *Medinilla merrillii* in its non-setose nodes and 3-plinerved leaves, but differs in its terrestrial, erect habit, leaf secondary veins distinct on adaxial side only, cauline inflorescences arising from leafless nodes, shorter inflorescence, and straight anthers. It is also similar to *Medinilla gitingensis* in its terrestrial, erect habit, non-setose nodes, and 3-plinerved leaves, but differs in its leaf secondary veins distinct on adaxial side only, shorter cauline and sometimes axillary inflorescences, rounded flower buds, and straight anthers (see Table 1). *Medinilla theresae* can be readily distinguished by the combination of whorled leaves and non-terminal pendulous inflorescences.

Table 1. Diagnostic characters separating *Medinilla theresae* from species in the *Medinilla pendula* complex.

	<i>Medinilla theresae</i>	<i>Medinilla merrillii</i>	<i>Medinilla gitingensis</i>	<i>Medinilla pendula</i> (s.str.)
Stem diameter (cm)	1–2	3	7.5	–
Nodes	not setose	not setose	not setose	setose
Number of leaves per node	3–4	several, 3–5	3	4 or 5
Petiole (mm)	5–20	17–20	15–25	10–15(–20)
Lamina shape	lanceolate	narrowly elliptic	narrowly elliptic	narrowly elliptic
Leaf venation (based on dried specimens)	3-plinerved; secondary veins distinct on adaxial side only	3-plinerved; secondary veins distinct on both sides	3-plinerved; secondary veins distinct on both sides	generally 5-, rarely 7-plinerved; secondary veins distinct on both sides
Inflorescence position	cauline, not terminal, arising from leafless or leafy nodes	axillary	terminal	terminal, sometimes axillary
Inflorescence length (cm)	7	20	10–20	12–25
Flower in bud	± rounded	± rounded	pointed	± rounded
Anthers	straight	curved	curved	curved

The cauline and many-flowered inflorescences also puts this new species in Regalado’s (1995) Group 5 where it is most similar to *Medinilla aurantiflora* Elmer (1911) from Negros, Panay, and Sibuyan Islands in its erect habit and 4-merous flowers, but our new species is distinguishable by its ternate to quaternate smaller leaves, shorter hypanthia, and straight anthers. The combination of terrestrial erect habit and cauline, many-flowered inflorescences is also known in *Medinilla lagunae* S.Vidal and in *Medinilla philippensis* (Cham. & Schtdl.) Merr., the latter was synonymized by Regalado (1995) under *Medinilla venosa* (Blume) Blume but recommended by Quakenbush (2016) to be reinstated as a distinct species. In all these species, the leaves are 7–11-plinerved, while in *Medinilla theresae* they are 3-plinerved. Elsewhere in Southeast Asia, the terrestrial erect habit and cauline, many-flowered inflorescences is also known in *Medinilla tapete-magicum* Cámara-Leret & Veldk. (Cámara-Leret and Veldkamp 2011) from Sulawesi. However, in this species the flowers are 5-merous and borne on very compact inflorescences arising from the stem at or near ground level forming a dense mat around the base of the plant.

Two other species of *Medinilla* also grow in the Mt Redondo area of Dinagat Island (Fernando et al. 2017). At about the same elevation as the new species described here is one referable to *Medinilla myrtiformis* (Naudin) Triana, an epiphytic shrub with prominently divaricate branches and opposite leaves, widespread in most upper montane rain forests in the Philippines and is also known from Sulawesi and Moluccas (Regalado 1995). On the lower slopes of the mountain at 300–650 m elevation is the scandent *Medinilla quadrifolia* (Blume) Blume, regarded as a widespread and highly variable, polymorphic species (Regalado 1995).

In the Surigao del Norte area, at low elevations (c. 150 m), also on ultramafic soils, ternate to quaternate and 3-plinerved leaves are also known in *Medinilla surigaoensis*

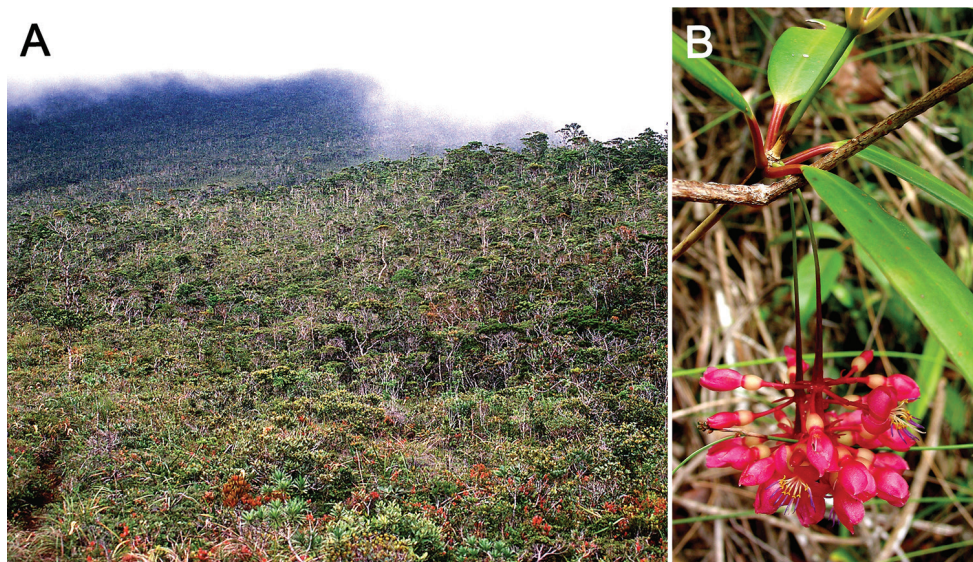


Figure 4. *Medinilla theresae* Fernando **A** Habitat on Mt Hamiguitan, forest on ultramafic soils, c. 1200 m elevation **B** Plant on Mt Hamiguitan with branch showing node with four leaves in a whorl and a pair of pendulous inflorescences. **A** photo by Edwino S. Fernando **B** photo by Leonard L. Co.

Regalado, a species belonging to Group 6 (Regalado 1995). However, this species is an epiphytic scandent shrub and has generally smaller leaves that are ovate to elliptic-obovate and with secondary veins distinct on both surfaces of the lamina, sulcate branchlets, and the fruits have prominent outgrowths or protuberances on the surface. It is uncertain if this species is an ultramafic endemic as Regalado (1995) also recorded it from Luzon and Polillo Islands.

Medinilla palawanensis Regalado was earlier described as an edaphic endemic on ultramafic rock slopes on Mt Beaufort near Puerto Princesa in Palawan (Regalado 1995). However, since then this epiphytic shrub has been found on nearby Mt Cleopatra, not an ultramafic site (J.P. Quakenbush, personal observation). *Medinilla capitata* Merr. and *Medinilla ferruginea* Merr. were both originally described from ultramafic soils at low elevations on Dinagat Island (Merrill 1920). *M. capitata* has now also been recorded from likely an ultramafic site in Samar (Pelser et al. 2011) and there are additional herbarium records in PNH. Similarly, for *M. ferruginea* there are specimens at PUH (from Surigao, Mindanao) and MICH (from Camarines, Luzon), as well as, records from Pelser et al. (2011) in southern Samar that may possibly correlate with ultramafic soils. Further field work in these sites is needed to confirm the restriction of these two species to such edaphic conditions. *M. gitingensis*, although presently treated as *M. pendula*, was only known from an ultramafic location. No Philippine species of *Medinilla* are otherwise known by us to be endemic to ultramafic soils.

Conservation status. *Medinilla theresae* is an edaphic-endemic, thus far restricted to forests on ultramafic soils at elevations of c. 700–1326 m. The species is known only from two locations, Mt Redondo and Mt Hamiguitan, over 400 km apart. Using the

online GeoCAT conservation assessment tool (<http://geocat.kew.org/>) with the default 2×2 km grid calculated an EOO (extent of occurrence) of more than 100 km² but less than 5,000 km² and AOO (area of occupancy) of 16 km² which are thresholds for the Endangered category (IUCN 2012). Following IUCN (2012) and the *Guidelines for Using the IUCN Red List Categories and Criteria* (IUCN Standards and Petitions Subcommittee 2017), we regard this species as Endangered [EN B1+2ab(ii,iii,v)]. In both the two currently known locations of this species a continuing decline is inferred in area of occupancy, the area, extent and/or quality of habitat, and number of mature individuals. On Mt Redondo, the dwarf forest is within a mineral reservation that was previously subject to open pit mining for the heavy metal chromium. If mining is allowed to continue here, the species will be at high risk. Mt Hamiguitan, on the other hand, is a declared protected area, formally known as the Mt Hamiguitan Range Wildlife Sanctuary (MHRWS) and is a UNESCO World Heritage Site which may provide the species with some protection. MHRWS is popular site for nature trekking enthusiasts, but some hiking trails lead through the pygmy forest where this species occurs.

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