

# New species of *Uvariopsis* (Annonaceae) and *Laccosperma* (Arecaceae/Palmae) from Monts de Cristal, Gabon

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Academic editor: Pavel Stoev | Received 16 June 2016 | Accepted 19 July 2016 | Published 2 August 2016

**Citation:** Couvreur TLP, Niangadouma R (2016) New species of *Uvariopsis* (Annonaceae) and *Laccosperma* (Arecaceae/Palmae) from Monts de Cristal, Gabon. PhytoKeys 68: 1–8. doi: 10.3897/phytokeys.68.9576

## Abstract

Monts de Cristal National Park in northwest Gabon is one of the most species rich places in Central Africa. Here, we describe two new species, one in Annonaceae and one in palms. *Uvariopsis citrata* Couvreur & Niangadouma, **sp. nov.** is unique in the genus by emitting a strong lemon scent from the crushed leaves and young branches. *Laccosperma cristalensis* Couvreur & Niangadouma, **sp. nov.** is a rattan that lacks acanthophylls on the cirrus and has few pinnae. Complete descriptions, photographic illustrations, ecological information and preliminary IUCN conservation status are provided. For both species a data deficient (DD) status is proposed. These new species underline once again that the Monts de Cristal National Park is yet incompletely known botanically.

## Keywords

Annonaceae, lemon scent, national park, rattan, Gabon

## Introduction

The Monts de Cristal National Park, in northwestern Gabon, is located less than 100 km from the capital Libreville. Monts de Cristal is one of the most plant species-rich areas in Central Africa (Sosef et al. 2006). Because of its prime locality, it is often



**Figure 1.** Monts de Cristal National Park, view from Tchimbéle. Photo Thomas L.P. Couvreur

visited by botanists and is one of the most densely botanically collected areas in Gabon (Wieringa and Sosef 2011). However, new species have been regularly described from the national park (e.g. Ječmenica et al. 2016; Stévant et al. 2014), including a new genus of Annonaceae, *Sirdavidia* (Couvreur et al. 2015) which was recently awarded the top 10 new species of 2016 (International Institute for Species Exploration 2016). Here, we describe two new species collected during a botanical trip to the Monts de Cristal National Park in June 2016, one Annonaceae and one rattan.

The genus *Uvariopsis* (Annonaceae) contains a total of 18 species restricted to Africa (Couvreur and Luke 2010; Gereau and Kenfack 2000; Kenfack et al. 2003). *Uvariopsis* is unique in African Annonaceae as most of its species have one whorl of 2 sepals and one whorl of 4 petals, in contrast to the typical Annonaceae pattern of 3 sepals, and 2 whorls of 3 petals. *Uvariopsis* belongs to the Monodoreae tribe and is recovered as sister to the genus *Monocyclanthus* (Chatrou et al. 2012; Couvreur et al. 2008).

*Laccosperma* is one of the four rattan genera found in Africa (Sunderland 2007). *Laccosperma* contains six species and belongs to the subtribe Ancistrophyllinae which also contains two other genera: *Oncocalamus* and *Eremospatha* (Sunderland 2007; Sunderland 2012). *Laccosperma* is distinguished from the latter two by the robust and rounded spines on its leaf sheath and stems coupled with hermaphroditic flowers (Sunderland 2012). *Laccosperma* was recently shown to be sister to *Eremospatha* (Faye et al. 2016).

## Results

### *Uvariopsis citrata* Couvreur & Niangadouma, sp. nov.

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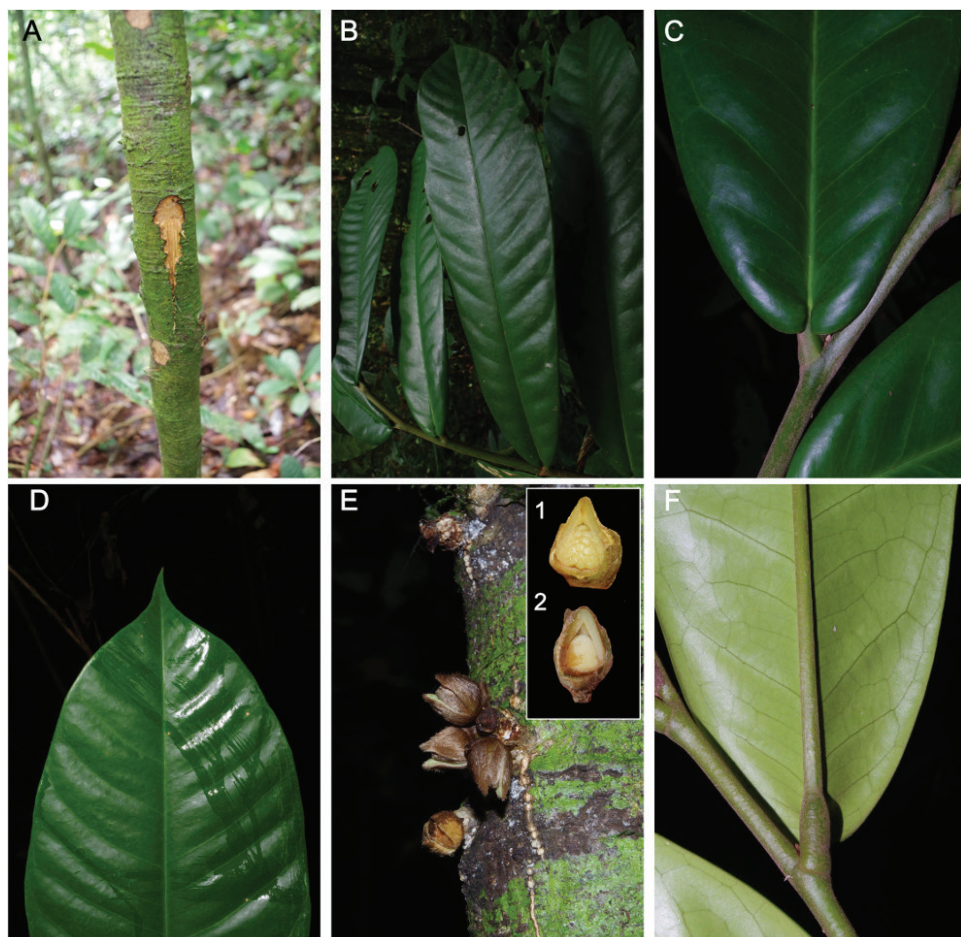
Figure 2

**Type.** GABON, Estuaire, Monts de Cristal, near first bridge after Kingué village, 0°46'66"N, 10°27'81"E, 14 Jun 2016, *T.L.P. Couvreur 1143* (holotype: WAG!; isotypes: LBV!, P!).

**Diagnosis.** Resembles *Uvariopsis sessiliflora* (Mildbraed & Diels) Robyns & Ghesquière by the (sub) sessile flowers. Differs from *U. sessiliflora* by the strong lemon scent of its crushed leaves or young branches (vs no lemon scent), larger leaves (40 cm vs 10–18 cm), cordate leaf base (vs acute leaf base) and ovoid-conic flowers (vs globose).

**Description.** Tree 4–7 m tall, 3–5 cm in diameter at breast height (d.b.h.), slash light cream with a black ring, old branches grey, glabrous, young branches light green, pubescent. Leaves distichous, simple, entire, pinnately veined. Petiole 4–5 mm long, 4 mm in diameter, pubescent with short appressed hairs when young, grooved on top, leaf lamina inserted on top. Lamina 45–50 cm long, ca. 12 cm wide, length:width ratio 3.5–4.1, narrowly elliptic to elliptic to narrowly ovate, apex long acuminate, acumen 2–3 cm long, base cordate, coriaceous, glabrous above, glabrous below, strong scent of lemon in crushed leaves; mid rib sunken above, glabrous above, sparsely pubescent below, secondary veins 17–19 pairs, arching 4–5 mm from the margins, tertiary venation network like, raised above and under. Inflorescences cauliflorous (no ramiflorous flowers seen), sparsely spaced along the trunk, more towards the lower half of the trunk, with one to three flowers. Flowers actinomorphic, monoecious, with 6 tepals in total, differentiated in one whorl of 2 sepals and 1 whorl of 4 petals. Male and female flowers similar in size, ovoid-conic, preanthetic flowers seen only. Flowering pedicels male or female 1–2 mm when present, densely covered with short appressed hairs, light brown, up to three bracts tightly packed, covered with short appressed hairs. Sepals male or female 1.3–1.5 cm long, 4 mm wide, length:width ratio 3.5, narrowly ovate, fused for 1/5 to 1/3 of their length, valvate, apex acute, outside densely pubescent with hairs appressed, brown, inside densely pubescent with curly hairs, glabrous towards base. Petals male or female 1.3–1.5 cm long, 7–8 mm wide, 2 mm thick, length:width ratio 3.5, narrowly ovate, apex acute, base truncate, outside densely pubescent with appressed hairs, inside glabrous. In staminate flowers, receptacle conical, 7 mm long, 5 mm wide, stamens numerous, immature, 0.5 mm long, connective truncate, pale yellow. In carpellate flowers, carpels ca. 60, 4–5 mm long, ca. 0.5 mm wide, densely pubescent with long appressed hairs, ovules not observed (preanthetic), stigma cylindrical coiled, glabrous. Fruits unknown.

**Preliminary conservation status.** Data deficient. DD. *Uvariopsis citrata* is only known by two collections and three individuals collected in the same area. The type locality is located in a mature forest within the National Park Monts de Cristal, Mbé sector, close to the road that links Kingué and Tchimbélé villages. However, the lo-



**Figure 2.** *Uvariopsis citrata*. **A** Trunk with slash (Couvreur 1126) **B** Entire leaf **C** Leaf base upper side **D** Leaf apex, upper side **E** Pre anthetic flower buds on trunk, 1: female flower, 2: male flower **F** Leaf base, lower side. (Couvreur 1143). Photos Thomas L.P. Couvreur.

cality does not seem under threat to date and no changes in habitat have been seen in the last few years. However, because it is close to the road and Kinguéle the future of these populations are not certain.

**Distribution.** Only known to date from Gabon, from one locality in the Monts de Cristal National Park, Mbé sector. 200–300 m in altitude.

**Habitat.** This species grows in mature or old secondary forests near rivers in periodically inundated soils, or on slopes near rivers.

**Etymology.** Named after the strong lemon scent of the crushed leaves and young branches one of the diagnostic characters for this species.

**Paratypes. GABON, Estuaire:** Monts de Cristal National Park, Mbé Sector, near first bridge after Kinguéle village, 0°46'66"N, 10°27'81"E, 14 Jun 2016, T.L.P. Couvreur 1126 (WAG!, LBV!, P!)



**Discussion.** *Uvariopsis citrata* is unique in the genus by the strong lemon smell of its leaves, young branches and young flowers when crushed. This character is rare in African Annonaceae only reported in one other species, also endemic to Gabon, *Uvari-odendron molundense* (Diels) R.E.Fries var. *citrata* Le Thomas (Le Thomas 1969). This latter species grows in the region of Belinga. To date it remains unclear why some species have this character. Other plants around the type locality did not present this same scent. In addition, *U. citrata* has sessile flowers, a character it shares with *U. sessiliflora* (Kenfack et al. 2003) endemic to Cameroon. All other *Uvariopsis* species have pedicilate flowers. However, *U. sessiliflora* has smaller leaves (10–15 cm) and globose flower buds, while *U. citrata* has leaves to 50 cm and ovoid-conic ones. The total number of species in *Uvariopsis* is now 19.

***Laccosperma cristalensis* Couvreur & Niangadouma, sp. nov.**

urn:lsid:ipni.org:names:77156704-1

Figure 3

**Type.** GABON, Estuaire: Monts de Cristal National Park, Mbé sector, forest around the antenna in Tchimbélé, ca. 40 km from Kingué, 0°36'21.240"N; 10°24'42.480"E, 13 Jun 2016, *T.L.P. Couvreur 1142* (holotype: WAG!; isotypes: LBV!, P!, G!, K!).

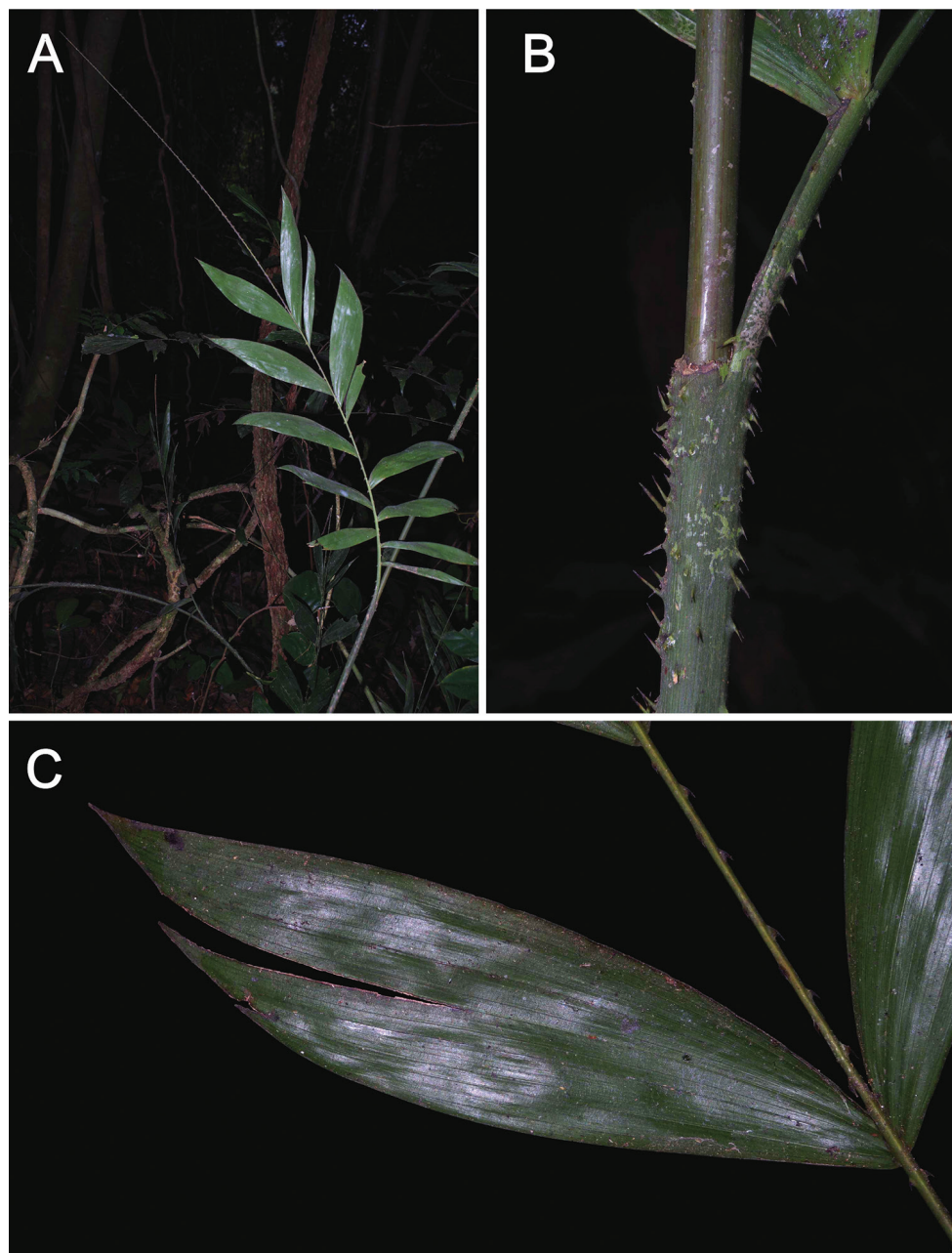
**Diagnosis.** Resembles *Laccosperma korupensis* Sunderland by the lack of acanthophylls on the cirrus. Differs from *L. korupensis* by the fewer pinnae (5–8 vs 10–18) sigmoid in shape (vs lanceolate) lacking spines along the margin (vs with spines) and the short 3–5 mm truncated ocrea (vs 8 cm long and tapering to a point).

**Description.** Clustered, slender palm climbing to 15 m. Stem, circular to oval in cross section, 5–8 mm in diameter; internodes 10–20 cm long. Leaf sheath finely striate, sparsely to moderately armed with fine, green, black tipped, downward and upward pointing spines; sheaths near leaf junction occasionally unarmed; ocrea 3–5 mm long, truncate, round, green, armed with very fine black-tipped spines. Leaves up to 80 cm long; petiole to 3–4 cm long × 4 mm wide, abaxially rounded, adaxially grooved, armed abaxially with short 2–4 mm long, inequidistant, reflexed black spines; rachis to 30 cm long, angular in cross section, armed as the petiole; cirrus to 45 cm long armed as the rachis, although spines become smaller distally; pinnae, 5–8 on each side of the rachis, inequidistant, usually sub-equidistant proximally and borne in pairs distally, sigmoid, finely acuminate at apex, bluntly cuneate at base, 15–16 cm long, 3–4 cm broad at widest point, prominent transverse veinlets, margins lacking spines; acanthophylls absent. Flowers and fruits unknown.

**Distribution.** Only known to date from Gabon, from one locality in the Monts de Cristal National Park, Mbé sector, Tchimbélé.

**Habitat.** This species was found growing in an old secondary forest, on a slope.

**Preliminary conservation status.** Data deficient. DD. *Laccosperma cristalensis* is only known by a single collection, thus it is hard to provide an accurate status here. By providing a name to this species, we hope that others will be able to



**Figure 3.** *Laccosperma cristalensis*. **A** Leaf, notice lack of acanthophylls on cirrus **B** Detail of leaf sheath and ocrea **C** Detail of sigmoid pinnae. (Couvreur 1142). Photos Thomas L.P. Couvreur.

identify potential past collections. The type locality is located in an old secondary forest within the National Park Monts de Cristal, Mbé sector, near Tchimbélé. This forest is, however, close to the telephone antenna area which is regularly maintained

by cutting. Important hunting activity was also seen there, suggesting important human activity.

**Etymology.** Named after the Monts de Cristal National Park in northwestern Gabon, home to an important number of plant species and endemics.

**Discussion.** *Laccosperma cristalensis* closely resembles *L. korupensis* by the absence (or near absence) of acanthophylls on the cirrus (extension of the leaf rachis). These are the only two species of African rattans (subtribe Ancistrophyllinae) to share this character. However, *L. cristalensis* is easily distinguished from *L. korupensis* by having fewer pinnae (5–8 versus 10–18) which are sigmoid versus lanceolate, lacking spines along the margin versus presence of spines along the margin and an ocrea that is 3–5 mm long and truncated versus 7–10 cm long and tapering to a point (Sunderland 2012). To date none of these species have been collected flowering or fruiting, however, the vegetative characters alone suffice to clearly distinguish them. The total number of species in *Laccosperma* is now 7, although new species are yet to be described from West Africa (Faye et al. 2016).

## Acknowledgments

We are grateful to the Centre National de la Recherche Scientifique et Technique (CENAREST) in Gabon and the Agence National des Parques Nationaux (ANPN) for delivering the necessary research permits. Prof. Paul Henri Bourobou Bourobou is thanked for his assistance in obtaining the research permits. Field work in Gabon was supported by the Agence Nationale de la Recherche (grant number ANR-15-CE02-0002-01) to TLPC. We thank Bill Baker and Paul Hoekstra for useful comments on a previous version of the manuscript. Finally, we are also very grateful to Jean Grégoire (aka Petit Jean) Kayoum for his driving skills and help in the field.

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# Seed micromorphology of *Orchis* Tourn. ex L. (Orchidaceae) and allied genera growing in Edirne province, Turkey

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Academic editor: Murielle Simo-Droissart | Received 5 April 2016 | Accepted 22 July 2016 | Published 2 August 2016

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**Citation:** Güler N (2016) Seed micromorphology of *Orchis* Tourn. ex L. (Orchidaceae) and allied genera growing in Edirne province, Turkey. *PhytoKeys* 68: 9–25. doi: 10.3897/phytokeys.68.8746

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## Abstract

In this study, the seed micromorphologies of eight taxa of *Anacamptis*, *Neotinea* and *Orchis* growing around Edirne province (Turkey) were investigated using light microscopy and scanning electron microscopy (SEM). Slides prepared with glycerin jelly were used for measurements under the light microscope and fine details of seed testae characteristics were observed with SEM. Seeds of the investigated orchid taxa are fusiform shaped and of different shades of brown. Their lengths and widths are different among the taxa and range between 0.263–0.640 mm and 0.118–0.208 mm, respectively. Testa surfaces of *Orchis mascula* subsp. *mascula*, *O. purpurea* subsp. *purpurea* and *O. simia* subsp. *simia*, are smooth while those of *Anacamptis coriophora*, *A. laxiflora* subsp. *laxiflora*, *A. morio* subsp. *morio*, *A. papilionacea* and *Neotinea tridentata* subsp. *tridentata* are reticulate. An identification key based on seed morphologies and sizes is suggested for the first time, including testae structures of orchids growing in Edirne province. The overall results of the study showed that morphological structures of orchid's seeds could be used as diagnostic characters in identification.

## Keywords

*Anacamptis*, *Neotinea*, *Orchis*, Orchidaceae, seed micromorphology

## Introduction

Orchidaceae are one of the most diversified and evolved families in the flowering plants (Cribb and Govaerts 2005). According to a recent survey (Govaerts et al. 2016) the number of the accepted species currently amounts to 24,000 but might reach 30,000, in view of the ever accelerating rate of new species descriptions every year (Tyteca and Klein 2008). The systematics have undergone many changes along the last few decades (Gamarra et al. 2010). The latter taxonomic proposals were published by Dressler (1993) and Szlachetko (1995). In the subfamily Orchidoideae, Dressler (1993) divided the tribe Orchideae into two subtribes: Orchidinae with 34 genera and 370 species, and Habenariinae with 23 genera and 930 species (Gamarra et al. 2010). The genus *Orchis* Tourn. ex L. and allied genera *Anacamptis* Rich. and *Neotinea* Rchb.f. are some of the most controversial groups belonging to the tribe Orchideae (Orchidaceae). The original genus *Orchis* s.l. used to include more than 1,300 taxa and in its broad concept, had a complex taxonomic history (Vermeulen 1972, Klein 1989, 2004, Bateman et al. 1997, 2003, Buttler 2001, Szlachetko 2002, Baumann and Lorenz 2006, Kretzschmar et al. 2007, Tyteca and Klein 2008, Delforge 2009). Since *Orchis* has been proven to be polyphyletic, several species were separated into distinct genera (Bateman et al. 1997). Also, in many guides and floras (see Tutin et al. 1980, Sezik 1984, Renz and Taubenheim 1984, Buttler 1986, Kreutz 1998, Delforge 2006, Buttler 2007) the number of *Orchis* taxa varies considerably, including species that previously belong to other genera, such as *Aceras* R.Br., *Anacamptis* Rich., *Dactylorhiza* Neck. ex Nevski, *Neotinea* Rchb.f. and *Vermeulenia* Á.Löve & D.Löve (Gamarra et al. 2012). Recently, molecular analyses have changed the taxonomy of several species in the genus *Orchis* (Bateman et al. 1997, 2003, Pridgeon et al. 1997). The genera *Anacamptis* and *Neotinea* were traditionally considered each as a monotypic genus, represented by *A. pyramidalis* (L.) Rich. and *N. maculata* (Desf.) Stearn respectively. Afterwards, the molecular analyses published by Pridgeon et al. (1997) and Bateman et al. (1997) confirmed the polyphyletic status of *Orchis* s.l., and many species were placed into the expanded genera *Anacamptis* and *Neotinea* (Gamarra et al. 2012), such as *Anacamptis morio* (L.) R.M.Bateman, Pridgeon & M.W.Chase subsp. *morio*, *A. laxiflora* (Lam.) R.M.Bateman, Pridgeon & M.W.Chase subsp. *laxiflora*, *A. coriophora* (L.) R.M.Bateman, Pridgeon & M.W.Chase, *A. papilionacea* (L.) R.M.Bateman, Pridgeon & M.W.Chase and *Neotinea tridentata* (Scop.) R.M.Bateman, Pridgeon & M.W.Chase, etc. In the molecular phylogenetic analyses published by Bateman et al. (1997) and Pridgeon et al. (1997), some *Orchis* species were nested in *Anacamptis* and *Neotinea*. However, based on either morphological or molecular data, the (old) genus *Orchis* has been split into three genera: *Herorchis* D.Tyteca & E.Klein, *Androrchis* D.Tyteca & E.Klein and *Odontorchis* D.Tyteca & E.Klein (see Tyteca and Klein 2008). According to these authors, *Neotinea* and *Anacamptis* returned to their former monotypic position with the species *N. maculata* and *A. pyramidalis* respectively. The genera *Herorchis* and *Odontorchis* included the

rest of the species of *Anacamptis* and *Neotinea* cited respectively, by Kretzschmar et al. (2007), and the genus *Androrchis* contained all the species of the genus *Orchis*, except the group with an anthropomorphic labellum, which is retained in *Orchis* (including *Aceras*). Later, Tyteca and Klein (2008) adopted the enlarged genera *Anacamptis* and *Neotinea* sensu Bateman et al. (1997, 2003), but reaffirmed the segregated genus *Androrchis* (Gamarra et al. 2012). Delforge (2009) published a new classification of *Orchis* s.l. and accepts the taxonomical position of *Orchis* and *Neotinea* sensu Bateman et al. (1997, 2003); however, he did not support the expanded genus *Anacamptis*, considering this genus as monotypic (*A. pyramidalis*), and segregating the rest of the species into the genera *Herorchis*, *Vermeulenia*, *Anteriorchis* E. Klein & Strack and the new genus *Paludorchis* P. Delforge (Gamarra et al. 2012). In this study, we have chosen the species delimitation of Bateman et al. (1997), because it requires the fewest change in nomenclature.

According to Kretzschmar et al. (2007), the genus *Anacamptis* has three part lip, but undivided middle lob, at base, in front of the spur entrance are two raised disks or longitudinal ridges; bracts from at least half as long to (mainly) longer than the ovary. The genera *Orchis* and *Neotinea* have three part lip with +/- divided middle lob, without raised disks or ridges at the base; bracts either clearly shorter or at most as long as the ovary. The genus *Orchis* differs from *Neotinea* with uniform, round or trapezoid stigmatic cavity, longish column and without genuine winter rosette. The distribution area of the genus *Anacamptis* reaches to the Atlantic in the west and to the Hebrides and southern Scandinavia in the north. It includes the North African mountains in its southwest border, whereas other parts of North Africa and the Canaries remain blank, although it penetrates along the Levant considerably further to the south. The genus in the east reaches to Lake Balchaš in central Asia and its representatives are also found on all the larger islands of the Mediterranean. The ecological demands of the different species are various, but all commonly prefer to settle within biotopes that have seasonal changes, really humid winters, which temporarily become very dry in summer (Delforge 2006, Kretzschmar et al. 2007, Govaerts et al. 2016). The genus *Anacamptis* have 11 accepted species and 20 subspecies (Kretzschmar et al. 2007, Govaerts et al. 2016).

The genus *Orchis* (Orchidaceae, Orchidinae) is limited in its distribution exclusively to the northern hemisphere. Its mainly distribution area is Mediterranean Basin where the maximum density of species is reached; however, other part of Europe are also settled to great extent. In addition the genus with some species, divert out of its main range and reaches northwards to Scandinavia, whilst in an easterly direction to Mongolia and reaches last Lake Baikal. On the north coast of Africa the eastern part is blank to great extent due to the absence of suitable biotopes; however, areas of Asia Minor and further on to Iraq and Iran are included. The ecological demands of the different species are various (Delforge 2006, Kretzschmar et al. 2007, Govaerts et al. 2016). The genus *Orchis* have 21 accepted species and 16 subspecies (Kretzschmar et al. 2007, Govaerts et al. 2016).

The genus *Neotinea* is limited to Europe, Asia Minor, the Caucasus and the north-west coastal regions of North Africa. The ecological demands of the different species are various (Delforge 2006, Kretzschmar et al. 2007, Govaerts et al. 2016). The genus *Neotinea* comprises four accepted species and two subspecies (Kretzschmar et al. 2007, Govaerts et al. 2016).

Seed morphology is one of the important taxonomic characters of orchids. Beer (1863) published the first study about the seed morphology in Orchidaceae, while, the taxonomic importance of the seed characteristics was first pointed out by Clifford and Smith (1969). Arditti et al. (1979) established the methodology for quantitative analyses, related to the sizes and volumes of seeds and embryos. Orchid seeds are characterized by minute and consist of an elliptical embryo enclosed within a generally transparent and often fusiform testa. Testae and embryos of different genera and species may vary in size, shape, color or the ratios between their volumes. The walls of testa cells can be smooth or reticulate and when reticulation is present, its patterns may be distinctive (Arditti 1967, Arditti et al. 1979, 1980, Healey et al. 1980, Chase and Pippen 1988).

The rather small sizes of seeds make them difficult to study their details and to compare some features with only light microscopy. Therefore, making comparisons and determining details that could be used as taxonomical characters without SEM techniques appear to be a challenging task (Arditti et al. 1979). However, if some characters are investigated only by SEM, then this may lead to obtaining of some wrong data. Therefore, relying on the use of both techniques, light microscopy and SEM, complementary to each other will be a better option for a researcher to get a clear picture of the studied question.

Most of the studies performed on orchid seeds were based on tropical orchids whereas the non-tropical species were generally neglected (Arditti 1967, Arditti et al. 1979, 1980, Healey et al. 1980, Chase and Pippen 1987, 1988, Rasmussen and Whigham 1993, Kurzweil 1993, Molvray and Kores 1995, Swamy et al. 2004, 2007, Gamarra et al. 2007, 2010, 2012, Chaudhary et al 2014, Galán Cela et al. 2014).

Several authors published different papers about seed morphology in the genera of *Orchis*, *Anacamptis* and *Neotinea*. Wildhaber (1972) initiated the morphological study of the seeds in the genera *Orchis* and *Neotinea* using light microscopy to obtain a key for the species based principally on the morphology and length of the seeds. Barthlott (1976) confirmed the taxonomic value of the periclinal walls in the genera *Orchis* and *Neotinea*. Ziegler (1981) recognized the characteristic seeds of the genus *Orchis* as *Orchis*-type. Tohda (1983) analyzed the differences in the sculpturing of the testa seeds in some *Orchis* species using SEM images and recognized three groups, two with slanting stripes and one with smooth periclinal walls. Mrkvicka (1994) analyzed quantitative and qualitative data of European *Orchis* using light microscopy, revealing a high diversity in the seed coat micromorphology. Molvray and Kores (1995) provided data on the number of testa cells in *Orchis spectabilis* (L.) Raf. Arditti and Ghani (2000) reviewed the purely numerical and physical characteristics of orchid seeds and their biological implications; among of them *Anacamptis collina*



(Banks & Sol. ex Russell) R.M.Bateman, Pridgeon & M.W.Chase (as *O. collina* Banks & Sol.), *A. coriophora* (as *O. coriophora*), *A. morio* (as *Orchis morio*), *A. morio* subsp. *longicornu* (Poir.) H.Kretzschmar, Eccarius & H.Dietr. (as *O. longicornu*), *Orchis mascula*, *O. purpurea* and *O. simia*. Gamarra et al. (2007) analyzed the morphology of the seed and of the anticlinal and periclinal walls using SEM in the genus *Neotinea*. Gamarra et al. (2012) analyzed seeds of 24 taxa belonging to the genera *Anacamptis* and *Orchis*.

Few studies exist on seed morphology of Turkish orchids. One of them was performed by Olgun and Aybeke (1996) on Edirne *Ophrys* L. species using SEM. There are also light microscopy studies on *Ophrys* species (see Aybeke 1997) and *Orchis* species (see Güler 1997) in Edirne Province. The present study aimed to reveal the relationship between *Orchis* and allied genera *Anacamptis* and *Neotinea* species growing naturally in Edirne region and to contribute to species classification based on seed measurement and morphological data.

## Materials and methods

We analyzed seeds of eight taxa belonging to the genera *Orchis*, *Anacamptis* and *Neotinea*. The study material consisting of specimens of eight orchid taxa were collected from the region within Edirne provincial borders in 1995 and 1996 and are kept in EDTU Herbarium. A list of voucher specimens and localities is given in the Table 1. Fresh seeds were dried and stored in small paper envelopes. The identification of the specimens was performed according to local flora and monographs (Tutin et al. 1980, Sezik 1984, Renz and Taubenheim 1984, Buttler 1986, Kreutz 1998, Delforge 2006). The seeds obtained from mature and opened fruits were used for seed morphology investigations. For this purpose, permanent slides of seeds were prepared with glycerin jelly solution on a heating plate (Ozban and Ozmutlu 1994) and the slides were investigated under a light microscope for morphological evaluations. The seeds were measured and then photographed. The color of the seeds were observed and described in annotated subjective terms with the help of optical microscope (Gamarra et al 2012, Chaudhary et al 2014, Galán Cela 2014). The specimens used for SEM were dried and examined for fine structure details.

The terminology and methods were adopted from those of Arditti (1967), Arditti et al. (1979, 1980), Healey et al. (1980), Chase and Pippen (1987, 1988), Kurzweil (1993), Molvray and Kores (1995) and Arditti and Ghani (2000). Measurements of seed embryos for morphometric data were taken using an Olympus BH2 light microscope equipped with a micrometric ocular. Statistical analyses were performed by NCSS 2013 (Version 9.0.5) for Windows. Seed and testa volumes were calculated using the formulations in Arditti et al. (1979). Since all seeds studied were fusiform, closely approximating two cones joined at their bases, their volumes were calculated using the formula:  $V_t = 2[(w/2)^2(1/2 L)(1.047)]$  where  $w$  is the seed width,  $L$  is the seed

**Table 1.** The locality and EDTU code details of the studied orchid taxa.

Species	EDTU	Source Locality	Collectors	Date Received
<i>A. coriophora</i>	6075	Kesan, Yayla village	N. Güler	02.06.1995
<i>A. laxiflora</i> subsp. <i>laxiflora</i>	6074	Kesan, Mecidiye village	N. Güler & M. Aybeke	06.05.1995
<i>A. morio</i> subsp. <i>morio</i>	6056	Kesan, Yerlisu village	N. Güler & M. Aybeke	22.04.1995
<i>A. morio</i> subsp. <i>morio</i>	6058	Kesan, Camlica village	N. Güler & M. Aybeke	06.05.1995
<i>A. morio</i> subsp. <i>morio</i>	6059	Kesan, Camlica-Gökçetepe villages	N. Güler & M. Aybeke	06.05.1995
<i>A. morio</i> subsp. <i>morio</i>	6062	Kesan, Mecidiye village	N. Güler & M. Aybeke	06.05.1995
<i>A. morio</i> subsp. <i>morio</i>	6063	Kesan, Yayla village	N. Güler & M. Aybeke	07.05.1995
<i>A. morio</i> subsp. <i>morio</i>	6065	Enez, Haskoy village	N. Güler	09.05.1995
<i>A. morio</i> subsp. <i>morio</i>	6067	Lalapasa, Hanliyence village	N. Güler	16.05.1995
<i>A. morio</i> subsp. <i>morio</i>	6265	Enez, Abdürrahim village	N. Güler & M. Kirec	02.05.1996
<i>A. morio</i> subsp. <i>morio</i>	6267	Kesan, Kizkapan village	N. Güler & M. Aybeke	11.05.1996
<i>A. papilionacea</i>	6079	Kesan, Yayla village	N. Güler	02.06.1995
<i>O. mascula</i> subsp. <i>mascula</i>	6132	Enez, Candir village	N. Güler & M. Kirec	02.05.1996
<i>O. purpurea</i> subsp. <i>purpurea</i>	6119	Uzunköprü, Turnaci village	N. Güler & M. Aybeke	27.05.1995
<i>O. purpurea</i> subsp. <i>purpurea</i>	6103	Hasanaga village	N. Güler	25.04.1995
<i>O. purpurea</i> subsp. <i>purpurea</i>	6110	Kesan, Suluca village	N. Güler & M. Aybeke	09.05.1995
<i>O. purpurea</i> subsp. <i>purpurea</i>	6116	Lalapasa, Dogankoy village	N. Güler	19.05.1995
<i>O. simia</i> subsp. <i>simia</i>	6080	Kesan, Yerlisu village	N. Güler & M. Aybeke	15.04.1995
<i>N. tridentata</i> subsp. <i>tridentata</i>	6136	Kesan, Yayla village	N. Güler & M. Aybeke	11.05.1996
<i>N. tridentata</i> subsp. <i>tridentata</i>	6120	B. Ismailice village	N. Güler	19.05.1995
<i>N. tridentata</i> subsp. <i>tridentata</i>	6092	Kesan, Kizkapan village	N. Güler & M. Aybeke	07.05.1995

length, and 1.047 is equal to  $p/3$ . The volumes of the embryos elliptical in their cross section were calculated by using the formula:

$$V_e = \frac{4}{3}pab^2$$

where  $a$  is  $1/2$  of embryo length,  $b$  is  $1/2$  of embryo width, and  $\frac{4}{3}p$  is equal to 4.188. Percentage air space was calculated by using the formula:  $[(V_t - V_e)/V_t] \cdot 100$ .

## Results and discussion

All investigated orchid seeds were fusiform in shape and had transparent and elliptical embryos (Figures 1–4). Their testae colors were different shades of brown. The measurements of the seeds as revealed by light microscopy investigations are given in Table 2.

When testae and embryos were investigated for their colors, the following patterns were obtained: *Orchis mascula* subsp. *mascula* and *Anacamptis laxiflora* subsp. *laxiflora* were light brown, *A. coriophora*, *A. morio* subsp. *morio* and *A. papilionacea* were brown, *O. purpurea* subsp. *purpurea* and *Neotinea tridentata* subsp. *tridentata* were dark brown and *O. simia* subsp. *simia* was darker brown than the rest.

It is possible to divide the orchid species found in Edirne into two groups according to their testa morphologies. The first group includes *Anacamptis coriophora* (Fig. 1A–1C), *A. laxiflora* subsp. *laxiflora* (Fig. 1D–1F), *A. morio* subsp. *morio* (Fig. 2A–2C), *A. papilionacea* (Fig. 2D–2F) and *Neotinea tridentata* subsp. *tridentata* (Fig. 4D–4F) which are the taxa whose anticlinal and periclinal walls of testa cells have reticulations. The second group consists of *Orchis mascula* subsp. *mascula* (Fig. 3A–3C), *O. purpurea* subsp. *purpurea* (Fig. 3D–3F) and *O. simia* subsp. *simia* (Fig. 4A–4C) whose their testa cell walls are smooth and without reticulations.

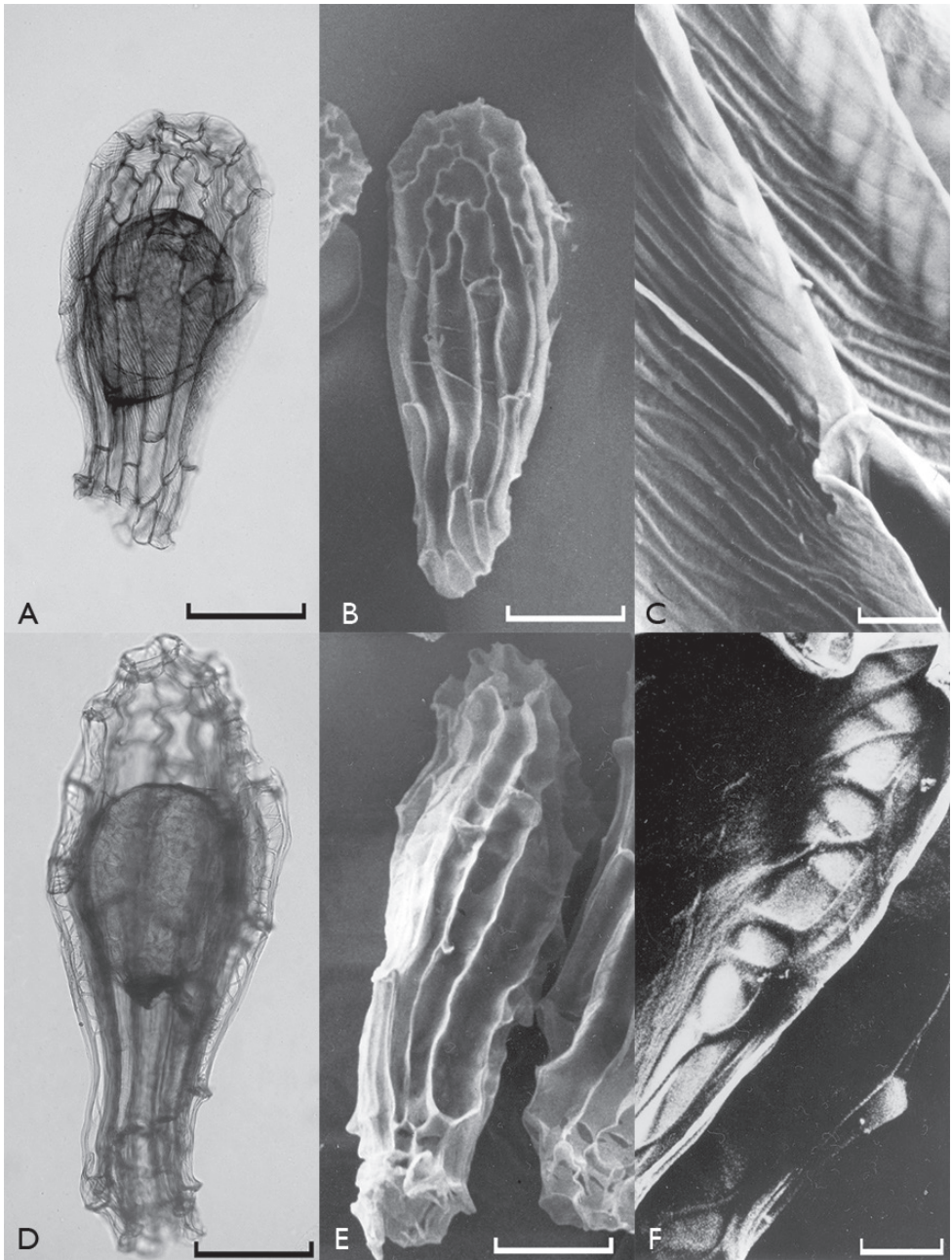
When the reticulations were analyzed, it appeared that they showed minute anastomosis. Some orchids, especially the tropical ones, have conspicuous reticulations such as *Calypso bulbosa* (L.) Oakes (Arditti and Ghani 2000), but this was not the case in the Turkish species we included in the present study. Reticulation directions showed differences among species. It was more or less transverse in *Neotinea tridentata* subsp. *tridentata* (Fig. 4f), diagonal in *Anacamptis coriophora* (Fig. 1C) and longitudinally diagonal in *A. papilionacea* (Fig. 2F). Reticulations in these species were conspicuous particularly in their periclinal walls. On the other hand, reticulations in *A. morio* subsp. *morio* were inconspicuous since they were thin and transversely diagonal (Fig. 2C). Testa cells of *A. laxiflora* subsp. *laxiflora* appeared to be different from those of the other species. Anticlinal walls of their testa cells were fairly thick and showed unbranched thickenings (Fig. 1F). The periclinal wall investigations showed that the walls were smooth in some species while in some others they had fine reticulations. Additionally, in some seeds, one could barely see fine and inconspicuous reticulations, and then only in basal cells. Testa cell walls of the species with no reticulations generally showed thickenings in their joining regions (*Orchis mascula* subsp. *mascula* (Fig. 3C), *O. purpurea* subsp. *purpurea* (Fig. 3F) and *O. simia* subsp. *simia* (Fig. 4C)). Among these, folds in periclinal walls could sometimes be observed.

**Table 2.** Measurement data of orchid seeds and embryos.

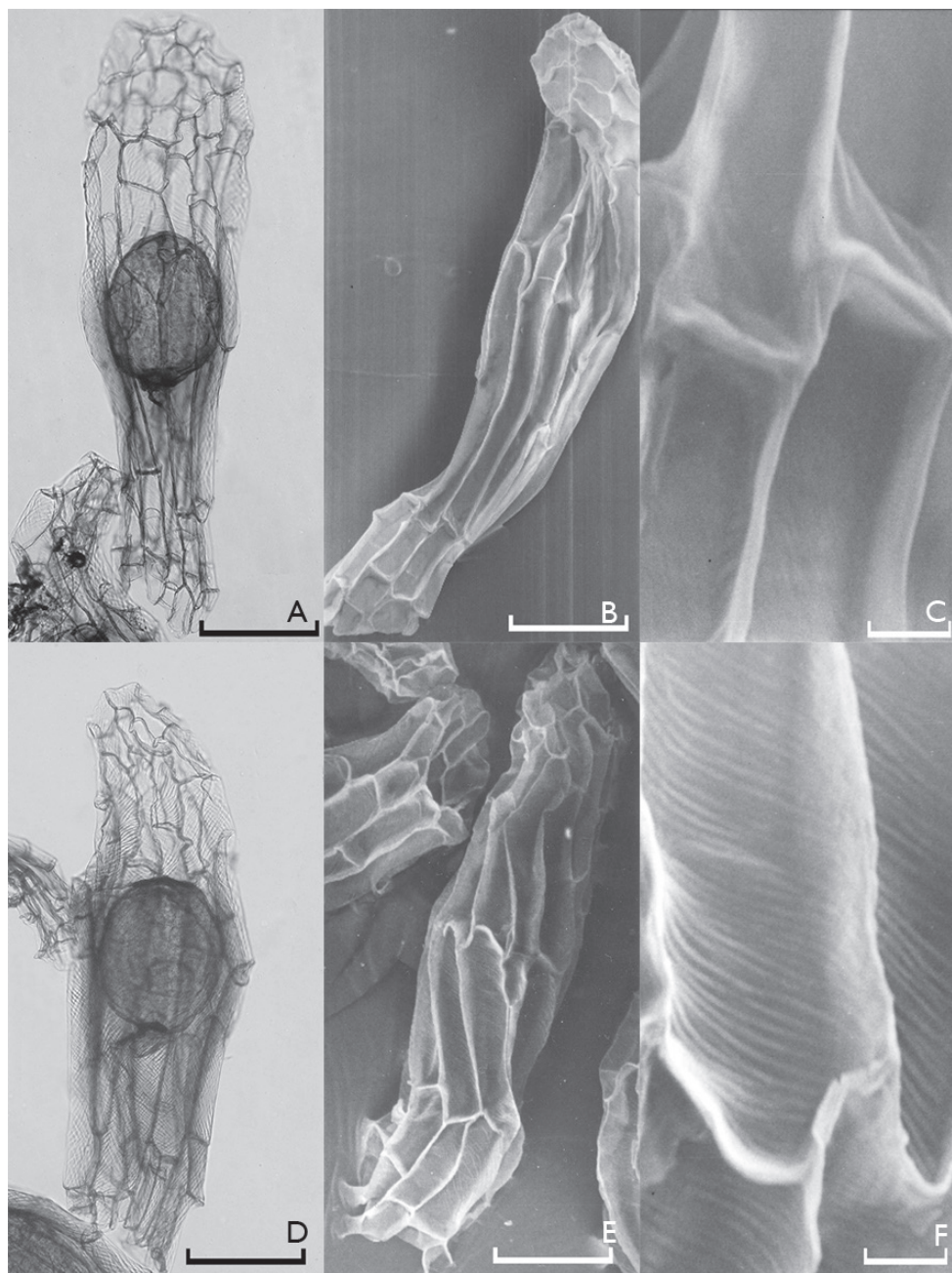
Species	EDTU	Figure	Embryos		Seeds		Vs/Ve (mm3 x10-3)	Percent Air Space		
			L/S.D. (mm)	W/S.D. (mm)	L/W	L/S.D. (mm)			W/S.D. (mm)	L/W
<i>A. coriophora</i>	6075	1A–1C	0.177/0.015	0.116/0.014	1.532	0.397/0.040	0.186/0.021	2.137	3.59/1.24	65.60
<i>A. laxiflora</i>	6074	1D–1F	0.225/0.039	0.140/0.015	1.606	0.599/0.097	0.208/0.022	2.880	6.78/2.31	65.98
<i>A. morio</i> subsp. <i>morio</i>	6056		0.124/0.011	0.092/0.011	1.351	0.400/0.051	0.142/0.007	2.824	2.10/0.54	74.19
<i>A. morio</i> subsp. <i>morio</i>	6058		0.137/0.015	0.097/0.007	1.413	0.420/0.053	0.143/0.089	2.927	2.26/0.68	70.11
<i>A. morio</i> subsp. <i>morio</i>	6059		0.158/0.019	0.118/0.018	1.339	0.376/0.045	0.171/0.024	2.191	2.89/1.15	60.34
<i>A. morio</i> subsp. <i>morio</i>	6062		0.173/0.020	0.129/0.014	1.344	0.513/0.037	0.161/0.018	3.196	3.46/1.50	56.82
<i>A. morio</i> subsp. <i>morio</i>	6063		0.156/0.026	0.097/0.017	1.609	0.640/0.067	0.152/0.017	4.197	3.89/0.76	80.41
<i>A. morio</i> subsp. <i>morio</i>	6065	2A–2C	0.152/0.012	0.115/0.011	1.319	0.506/0.068	0.147/0.019	3.435	2.87/1.05	63.38
<i>A. morio</i> subsp. <i>morio</i>	6067		0.142/0.019	0.106/0.017	1.335	0.452/0.031	0.141/0.023	3.209	2.34/0.83	64.50
<i>A. morio</i> subsp. <i>morio</i>	6265		0.183/0.014	0.128/0.011	1.425	0.573/0.095	0.177/0.023	3.247	4.67/1.57	66.43
<i>A. morio</i> subsp. <i>morio</i>	6267		0.160/0.026	0.106/0.012	1.517	0.503/0.077	0.148/0.018	3.398	2.88/0.93	67.60
Average for <i>A. morio</i>			0.157	0.103	1.526	0.482	0.156	3.096	3.08/1.07	65.14
<i>A. papilionacea</i>	6079	2D–2F	0.138/0.027	0.104/0.022	1.327	0.451/0.076	0.162/0.027	2.778	3.11/0.78	74.84
<i>O. mascula</i> subsp. <i>mascula</i>	6132	3A–3C	0.124/0.016	0.104/0.016	1.191	0.326/0.035	0.195/0.032	1.674	3.24/0.70	78.32
<i>O. purpurea</i> subsp. <i>purpurea</i>	6103	3D–3F	0.138/0.022	0.086/0.012	1.602	0.450/0.030	0.144/0.017	3.119	2.45/0.53	78.21
<i>O. purpurea</i> subsp. <i>purpurea</i>	6110		0.119/0.016	0.086/0.009	1.381	0.356/0.082	0.142/0.018	2.514	1.87/0.46	75.30
<i>O. purpurea</i> subsp. <i>purpurea</i>	6116		0.118/0.014	0.079/0.008	1.484	0.263/0.026	0.118/0.012	2.221	0.96/0.39	59.50
<i>O. purpurea</i> subsp. <i>purpurea</i>	6119		0.143/0.016	0.098/0.008	1.461	0.480/0.042	0.166/0.014	2.902	3.44/0.72	79.16
Average for <i>O. purpurea</i>			0.129	0.111	1.169	0.387	0.142	2.719	2.18/0.53	75.90
<i>O. simia</i> subsp. <i>simia</i>	6080	4A–4C	0.148/0.017	0.093/0.015	1.593	0.357/0.029	0.166/0.022	2.147	2.58/0.67	73.92
<i>N. tridentata</i> subsp. <i>tridentata</i>	6092		0.158/0.024	0.125/0.024	1.260	0.578/0.075	0.185/0.025	3.117	5.19/1.29	75.12
<i>N. tridentata</i> subsp. <i>tridentata</i>	6120	4D–4F	0.145/0.016	0.101/0.012	1.428	0.448/0.050	0.157/0.029	2.865	2.87/0.78	72.96
<i>N. tridentata</i> subsp. <i>tridentata</i>	6136		0.157/0.013	0.104/0.013	1.511	0.449/0.044	0.153/0.017	2.942	2.73/0.89	67.24
Average for <i>N. tridentata</i>			0.153	0.110	1.391	0.492	0.165	2.983	3.60/0.99	72.55
Average for orchids studied			0.151	0.106	1.430	0.454	0.160	2.853	3.152/0.942	70.00

\*S.D. standard deviation





**Figure 1.** Light microscope (**A, D**) and scanning electron microscope (**B, C, E, F**) photographs of *Anacamptis coriophora* (**A, B, C**) and *A. laxiflora* subsp. *laxiflora* (**D, E, F**) seeds. Scale bars: 0.1 mm (**A, B, D, E**) and 0.01 mm (**C, F**).



**Figure 2.** Light microscope (**A**, **D**) and scanning electron microscope (**B**, **C**, **E**, **F**) photographs of *Anacamptis morio* subsp. *morio* (**A**, **B**, **C**) and *A. papilionacea* (**D**, **E**, **F**) seeds. Scale bars: 0.1 mm (**A**, **B**, **D**, **E**) and 0.01 mm (**C**, **F**).

Seed lengths and widths ranged between 0.263–0.640 mm and 0.118–0.208 mm, respectively. The length and width measurements for embryos were 0.118–0.225 mm and 0.079–0.140 mm, respectively. All species are listed in Table 2.

When the mean values of orchid seed morphometry obtained in the present study were compared to those reported in Arditti and Ghani (2000), it appeared that both data were similar. The measurement data given for orchids in Arditti and Ghani (2000) is as follows; testa length 0.49 ( $\pm 0.17$ ) mm, width 0.17 ( $\pm 0.06$ ) mm and volume  $3.93 \pm 3.24 \text{ mm}^3$ , embryo length 0.18 ( $\pm 0.05$ ) mm, width  $0.12 \pm 0.04$  mm and volume  $1.22 (\pm 0.77) \times 10^{-3} \text{ mm}^3$  and percentage air space  $43.01 (\pm 35.16) \text{ mm}^3$ . When these measurement data are compared to the present findings (Table 2), one can see that they are quite similar and support each other. Similarly, the current morphometric data on *Anacamptis coriophora*, *A. morio* subsp. *morio*, *Orchis purpurea* subsp. *purpurea* and *O. simia* subsp. *simia* was found to be almost identical, with only a few differences, to the ones reported in Arditti and Ghani (2000).

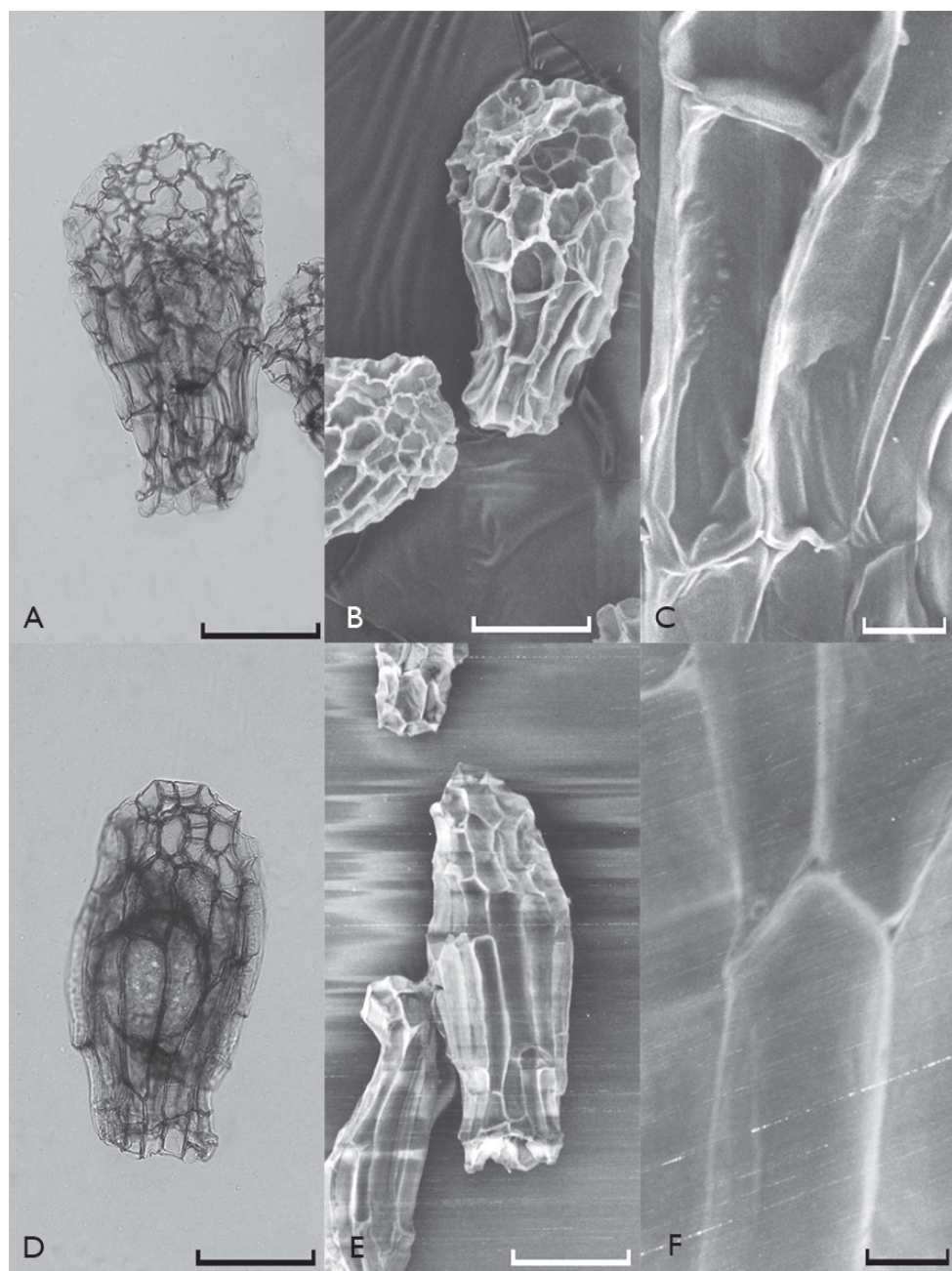
$L/W$  ratios provide data on the relative degree of truncation (Arditti 1979). The lowest  $L/W$  of 1.674 in *Orchis mascula* subsp. *mascula* showed that seeds of this species were the most truncate seeds. This species is followed by *O. simia* subsp. *simia*, *Anacamptis coriophora* and *O. purpurea* subsp. *purpurea* with their low  $L/W$  ratios implying a high truncate nature. On the other hand, higher  $L/W$  values were obtained for *A. papilionacea*, *A. laxiflora* subsp. *laxiflora* and *Neotinea tridentata* subsp. *tridentata* indicating that they have more elongate seeds. The highest  $L/W$  ratio of *A. morio* subsp. *morio* seeds (4.197) shows that the seeds of this species are elongate.

The mean lengths and widths of the embryos of the investigated eight taxa were 0.151 mm and 0.106 mm, respectively. The embryos were found to be elliptical with an average  $L/W$  value of 1.43. The lowest  $L/W$  value of *O. mascula* subsp. *mascula* led us to conclude that the embryos of this species were sphere-like. This species is followed by *Anacamptis papilionacea*. The high  $L/W$  values of the other species is an indication that their embryos are elliptical rather than spherical.

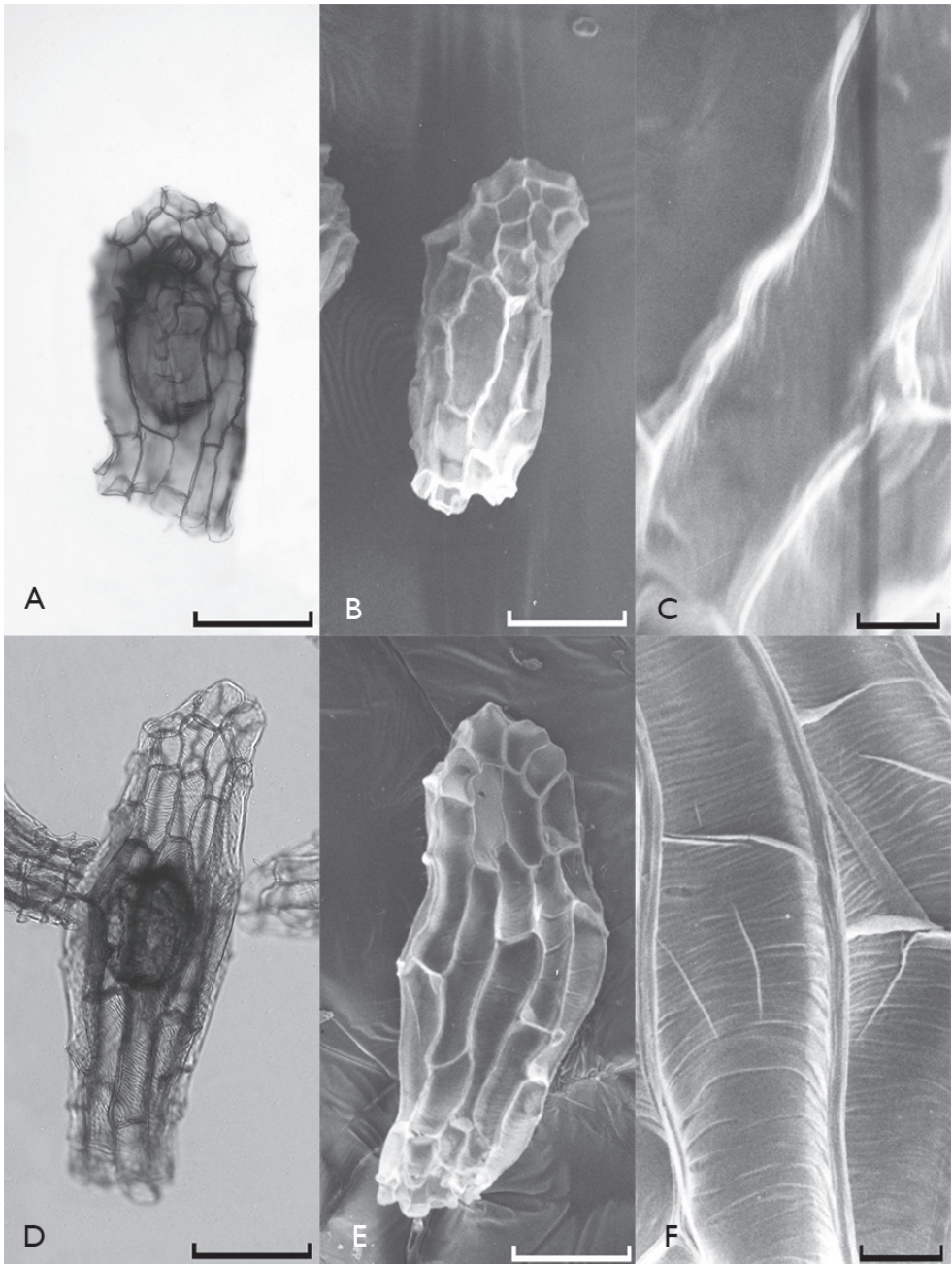
Percentage air space affects the length of time the orchid seeds are in air. Specimens with high percentage air space values are known to spread over longer distances via wind (Arditti 1967, Healey et al. 1980, Chase and Pippen 1988, Kurzweil 1993). The highest percentage air space determined for the seeds investigated ranged from 56% to 80%. *Anacamptis morio* subsp. *morio* seeds, a taxon sampled in most of the visited localities, had both the highest and the lowest percentage air space values. The mean air space value for orchid taxa in Edirne province is 70% and *A. morio* subsp. *morio*, *A. coriophora* and *A. laxiflora* subsp. *laxiflora* were determined to have the lowest value of approximately 65%. *Orchis mascula* subsp. *mascula*, on the other hand, whose seeds were short and wide, had the highest mean value of 78%.

As shown in previous studies on orchids, there are a number of diagnostic and phylogenetically informative characters present in orchid seeds. In this study, seed morphologies of eight orchids taxa growing in Edirne province were investigated and criteria that could be used to differentiate the seeds are presented. Also, a key is constructed below, based on seed morphology.





**Figure 3.** Light microscope (**A, D**) and scanning electron microscope (**B, C, E, F**) photographs of *Orchis mascula* subsp. *mascula* (**A, B, C**) and *O. purpurea* subsp. *purpurea* (**D, E, F**) seeds. Scale bars: 0.1 mm (**A, B, D, E**) and 0.01 mm (**C, F**).



**Figure 4.** Light microscope (**A, D**) and scanning electron microscope (**B, C, E, F**) photographs of *Orchis simia* subsp. *simia* (**A, B, C**) and *Neotinea tridentata* subsp. *tridentata* (**D, E, F**) seeds. Scale bars: 0.1 mm (**A, B, D, E**) and 0.01 mm (**C, F**).

## Identification key of the eight orchid taxa growing in Edirne province

1	Testa walls reticulate .....	2
–	Testa walls smooth .....	6
2	Reticulations occurring in periclinal walls more or less conspicuous or not at all .....	3
–	Reticulations occurring in periclinal walls conspicuous .....	4
3	Thickenings in anticlinal walls rather conspicuous .....	
	..... <i>A. laxiflora</i> subsp. <i>laxiflora</i>	
–	Thickenings in anticlinal walls inconspicuous .....	<i>A. morio</i> subsp. <i>morio</i>
4	Reticulations in testa cells transversely .....	<i>N. tridentata</i> subsp. <i>tridentata</i>
–	Reticulations different.....	5
5	Reticulations in testa cells transversely diagonal .....	<i>A. coriophora</i>
–	Reticulations in testa cells longitudinally diagonal .....	<i>A. papilionacea</i>
6	Seed fusiform.....	<i>O. purpurea</i> subsp. <i>purpurea</i>
–	Seed fusiform-oblong.....	7
7	Seed light brown.....	<i>O. mascula</i> subsp. <i>mascula</i>
–	Seed dark brown .....	<i>O. simia</i> subsp. <i>simia</i>

## Acknowledgements

The author would like to thank Scientific Research Projects Unit of Trakya University for supporting this research with the project N° TUBAP- 2016/110. The author is indebted to Prof. Dr. Ekrem Sezik, Prof. Dr. Göksel Olgun and Dr. Nesibe Başak for their comments and advices. He also wish to thank Dr. Volkan Aksoy for translation and TUTAGEM (Trakya University Technology Research, Development and Application Center) staffs for SEM photographs.

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# GuiaTreeKey, a multi-access electronic key to identify tree genera in French Guiana

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Academic editor: Ricarda Riina | Received 2 April 2016 | Accepted 21 July 2016 | Published 2 August 2016

**Citation:** Engel J, Brousseau L, Baraloto C (2016) GuiaTreeKey, a multi-access electronic key to identify tree genera in French Guiana. *PhytoKeys* 68: 27–44. doi: 10.3897/phytokeys.68.8707

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## Abstract

The tropical rainforest of Amazonia is one of the most species-rich ecosystems on earth, with an estimated 16000 tree species. Due to this high diversity, botanical identification of trees in the Amazon is difficult, even to genus, often requiring the assistance of parataxonomists or taxonomic specialists. Advances in informatics tools offer a promising opportunity to develop user-friendly electronic keys to improve Amazonian tree identification.

Here, we introduce an original multi-access electronic key for the identification of 389 tree genera occurring in French Guiana *terra-firme* forests, based on a set of 79 morphological characters related to vegetative, floral and fruit characters. Its purpose is to help Amazonian tree identification and to support the dissemination of botanical knowledge to non-specialists, including forest workers, students and researchers from other scientific disciplines.

The electronic key is accessible with the free access software *Xper*<sup>2</sup>, and the database is publicly available on figshare: <https://figshare.com/s/75d890b7d707e0ffc9bf> (doi: 10.6084/m9.figshare.2682550).

## Keywords

Electronic key, trees identification, *Xper*<sup>2</sup>, morphological characters, Neotropics, French Guiana, Amazonia

## Introduction

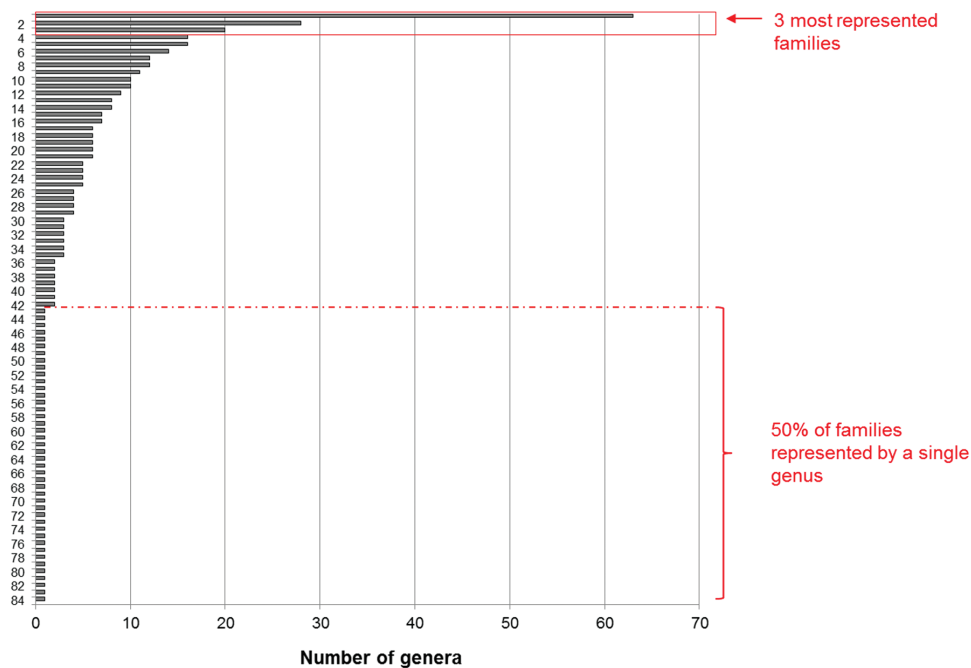
The tropical rainforest of Amazonia is one of the most species-rich ecosystems on earth, with an estimated 16000 tree species and often more than 200 species of trees per hectare (ter Steege et al. 2013). Due to this high diversity, the botanical identification of Amazonian trees is very difficult and often requires the consultation of taxonomic specialists. Taxonomists usually specialize in only one or few families or genera (Bacher 2012; Joppa et al. 2011) with few botanical experts, including generalist taxonomists and parataxonomists (Schmiedel et al. 2016), able to identify specimens of various families to the genus level. As a result, the number of specimens incorrectly named or unnamed is still very high in many forest inventories and more widely in the world's plant collections (Goodwin et al. 2015). Also, traditional dichotomous keys impose constraints on identifying tree samples because they rely on a hierarchical and fixed organization of characters that hampers the identification of a sample when one or several characters are not observed at the time of collection. Moreover, traditional keys often focus on Linnaean characters (flowers and fruits, Rejmánek and Brewer 2001), and only few tools aid the identification of plant species based on vegetative characters (Belhumeur et al. 2008). The identification of sterile samples is therefore difficult even though sterile samples are much more common than fertile ones (the proportion of sterile specimens commonly reaches 90-95%, Aymard et al. 2009; Martinez and Phillips 2000) and taxonomists are often unwilling to review sterile material. Furthermore, printed keys are static and are not frequently revised and republished to reflect taxonomic changes. Here we attempt to modernize botanical identification in Amazonia, by developing a user-friendly electronic key to help tree identification in French Guiana.

French Guiana is a French overseas department of about 85000 km<sup>2</sup> located in the eastern Guiana shield; it is home to approximately 2000 tree and palm species belonging to 404 genera (updated checklist by Molino et al. 2009). We introduce an original multi-access electronic key for the identification of tree genera occurring in French Guiana *terra-firme* forests based on a set of 79 morphological characters related to vegetative, floral and fruit characters that can be selected in any order. In addition, almost all characters and genera are described and illustrated. Its purpose is to help the identification of tree samples and to disseminate botanical knowledge to non-specialists.

## Taxonomic coverage

The key includes all tree genera occurring in French Guiana *terra-firme* forests with a diameter at breast height (d.b.h)  $\geq 10$  cm. Monocots (i.e., palms) and tree genera occurring in other habitats (e.g., mangroves, savannas) are excluded. A total of 389 genera belonging to 84 families are treated, see Suppl. material 1: 'Taxonomic ranks'. The taxonomic validity of genera and families has been checked via the Taxonomic Name Resolution Service (Boyle et al. 2013).





**Figure 1** Taxonomic coverage: Number of genera by families: 1 Fabaceae (63); 2 Rubiaceae (27); 3 Euphorbiaceae (20); 4 Annonaceae (16); 5 Malvaceae (16); 6 Lauraceae (14); 7 Apocynaceae (12); 8 Moraceae (12); 9 Myrtaceae (11); 10 Sapindaceae (10); 11 Sapotaceae (10); 12 Rutaceae (9); 13 Chrysobalanaceae (8); 14 Salicaceae (8); 15 Clusiaceae (7); 16 Melastomataceae (7); 17 Anacardiaceae (6); 18 Lecythidaceae (6); 19 Olacaceae (6); 20 Violaceae (6); 21 Burseraceae (5); 22 Capparaceae (5); 23 Humiriaceae (5); 24 Ochnaceae (5); 25 Phyllanthaceae (5); 26 Meliaceae (4); 27 Myristicaceae (4); 28 Urticaceae (4); 29 Vochysiaceae (4); 30 Bignoniaceae (3); 31 Calophyllaceae (3); 32 Celastraceae (3); 33 Malpighiaceae (3); 34 Polygonaceae (3); 35 Proteaceae (3); 36 Achariaceae (2); 37 Bixaceae (2); 38 Combretaceae (2); 39 Linaceae (2); 40 Nyctaginaceae (2); 41 Primulaceae (2); 42 Simaroubaceae (2); 43 Aquifoliaceae (1); 44 Araliaceae (1); 45 Boraginaceae (1); 46 Canellaceae (1); 47 Cannabaceae (1); 48 Cardiopteridaceae (1); 49 Caricaceae (1); 50 Caryocaraceae (1); 51 Dichapetalaceae (1); 52 Ebenaceae (1); 53 Elaeocarpaceae (1); 54 Emmotaceae (1); 55 Erythroxylaceae (1); 56 Goupiaceae (1); 57 Hernandiaceae (1); 58 Hypericaceae (1); 59 Icacinaceae (1); 60 Ixonanthaceae (1); 61 Lacistemataceae (1); 62 Lamiaceae (1); 63 Lepidobotryaceae (1); 64 Loganiaceae (1); 65 Lythraceae (1); 66 Monimiaceae (1); 67 Oleaceae (1); 68 Opiliaceae (1); 69 Pentaphylacaceae (1); 70 Picramniaceae (1); 71 Piperaceae (1); 72 Putranjivaceae (1); 73 Rhabdodendraceae (1); 74 Rhamnaceae (1); 75 Rhizophoraceae (1); 76 Rosaceae (1); 77 Sabiaceae (1); 78 Siparunaceae (1); 79 Solanaceae (1); 80 Stemonuraceae (1); 81 Styracaceae (1); 82 Symplocaceae (1); 83 Ulmaceae (1); 84 Verbenaceae (1).

Figure 1 graphically displays the number of tree genera in each family. The families with the highest number of genera are the Fabaceae (63 genera), Rubiaceae (27 genera) and Euphorbiaceae (20 genera), whereas 42 families (50%) are represented by a single genus.

## Spatial coverage

### General spatial coverage

French Guiana is bordered to the east and south by Brazil and to the west by Suriname (Figure 2). About 90% of the region is covered by evergreen rainforest occurring principally on *terra-firme* soils of granitic or sedimentary origins. The relief is fairly flat with a mean altitude of 140 m and few peaks exceeding 800 m. The climate is equatorial, characterized by a mean annual temperature of 26°C and annual rainfall varying from 2000 mm in the south and west to 4000 mm in the northeast. The rainy season usually occurs between May and August and the dry season between December and January (Guitet et al. 2014).



**Figure 2.** Location of French Guiana in South America.

This key covers French Guiana, but the geographical usefulness is by no means restricted to French Guiana: 99% of the genera included in this key are also present in Brazil (Reflora - Virtual Herbarium. Available at: <http://reflora.jbrj.gov.br/reflora/herbarioVirtual/> Accessed on 21/3/2016), more than 90% in Suriname and Guyana, and more than 80% in the Venezuelan states of Amazonas and Bolívar (Funk et al. 2007). The electronic key may thus also be used in and easily extended to these other regions, although users should keep in mind that these regions also include many other tree genera not covered by this key.

## Coordinates

2°6'42.8"N and 5°45'28.4"N Latitude; 51°38'3.2"W and 54°36'2.7"W Longitude

## Methods

### Electronic key implementation

The electronic key is implemented by a genus × character matrix where the 389 genera are displayed in rows and the 79 characters are displayed in columns, totaling 30731 cells (with less than 3% of missing values). The characters were scored using a comprehensive bibliographic survey of various flora and botanic publications covering the entire region of Amazonia (Acevedo-Rodríguez 2003; Acevedo-Rodríguez 2012; Alford 2009; Alves-Araújo and Alves 2012; Archer and Lombardi 2013; Aymard C and Ireland 2010; Barneby 1989; Barneby et al. 2011; Berg 1972; Berg et al. 1990; Berg and Rosselli 2005; Berry and Wiedenhoeft 2004; Boom 1989; Brandbyge 1986; Chanderbali 2004; 2009; Cornejo 2009; Cowan 1967; Cowan and Lindeman 1989; Da Ribeiro et al. 1999; Da Silva 1986; Da Silva et al. 2010; Daly 1987; De Carvalho-Sobrinho and De Queiroz 2010; De Fraga and Saavedra 2006; Delprete et al. 2010; Díaz 2013; Endress et al. 2014; Esser 2009a; b; Every 2009; 2010; Fernando and Quinn 1995; França 2009; Garcia-Villacorta and Hammel 2004; Gentry 1992; 1993; Graham 2014; Graham and Cavalcanti 2009; Groppo 2010; Groppo et al. 2014; Grose and Olmstead 2007; Guimarães and Monteiro 2010; Gustafsson 2009; Hayden 1990; Hekking 1988; Hiepko 1993; 2000; Hopkins ; Iltis and Cornejo 2011; Jansen-Jacobs 1988; 2007; Jansen-Jacobs and Meijer 1995; Kaastra 1982; Kallunki 1998; Kårehed 2001; Kubitzki and Renner 1982; Landrum and Kawasaki 1997; Maas and Maas-van de Kamer 2012; Maas and Westra 1992; Maas et al. 2003; Madrinan 2004; Marciano-Berti 1998; Mazine and De Faria 2013; McKenna et al. 2011; Melo and França 2009; Mesquita et al. 2009; Michelangeli 2005; Mitchell 1997; Monro and Rodríguez 2009; Morales 2007; Mori et al. 2005; Mori and Prance ; Mori and Prance 1993; Morley 1976; Nee 2001; Pendry 2003; Pennington 1981; 1990; Poppendieck 1981; Prance 1972a; b; 1973; Prance 1986; Prance 2009a; b; c; d; Prance and

Mori 1979; Prance and Stace ; Ramos and Lombardi 2009; Redden 2008; Renner and Hausner 2005; Ribeiro et al. 2015; Rodrigues and Goulart de Acevedo Tozzi 2006; Rodrigues and Goulart de Acevedo Tozzi 2008; Rohwer 1993; Romanov et al. 2007; Rudd 1981; Santo et al. 2012; Sastre 2007; Scharf et al. 2008; Schneider and Zizka 2012a; b; Secco 2004; Shepherd and Alverson 1981; Silva 2009; Silverstone-Sopkin 2015; Sleumer 1980; 1984; Sothers et al. 2014; Steyermark et al. 1995; 1997; 1998; 1999; 2001; 2003; 2004; 2005; Teichert et al. 2012; Vasquez Martinez 2013; Westra and Maas 2012; Woodgyer 2009; Wurdack et al. 1993; Zappi 2009).

The characters are grouped into four main sections: ‘leaves’, ‘other vegetative characters’, ‘flowers’, and ‘fruits and seeds’. A substantial proportion of characters (33 of 79) is related to leaves which are almost always observable. In addition, many vegetative characters rarely used in classical dichotomous keys are suggested (e.g., presence of latex, type of trichomes, leaf base venation). Almost all genera and characters are defined and illustrated with more than 9000 photographs (mainly herbarium specimens). Among the 79 characters, 74 are qualitative and 5 are quantitative. Qualitative characters are scored by the presence or absence of the character (e.g., opposite leaves), while quantitative characters are scored by the minimum and maximum number of modalities potentially observable for each genus (e.g., number of calyx segments ranging from three to five): the user may thus select the exact number of modalities observed in the sample.

### Genera-characters matrix file description

The electronic key consists of a genus  $\times$  character matrix consultable with *Xper<sup>2</sup>*, a software dedicated to taxonomic descriptions and computer-aided identification (Ung et al. 2010). *Xper<sup>2</sup>* is a user-friendly management system for creating interactive identification keys available on Windows, Mac or Linux in French, English or Spanish versions. It is free software and the botanical keys can be installed locally in order to be used without an internet connection, which is not allowed in the most recent version of the program (*Xper<sup>3</sup>*).

Object name: ‘GuiaTreeKey’

Distribution:

- *Xper<sup>2</sup>* download page: <http://www.infosyslab.fr/lis/?q=en/resources/software/cai/xper2/downloads/last>
- ‘GuiaTreeKey’ dataset & User Manual: <https://figshare.com/s/75d890b7d7-07e0ffc9bf> (doi: 10.6084/m9.figshare.2682550).

Publication date of data: 23.02.2016

Language: English

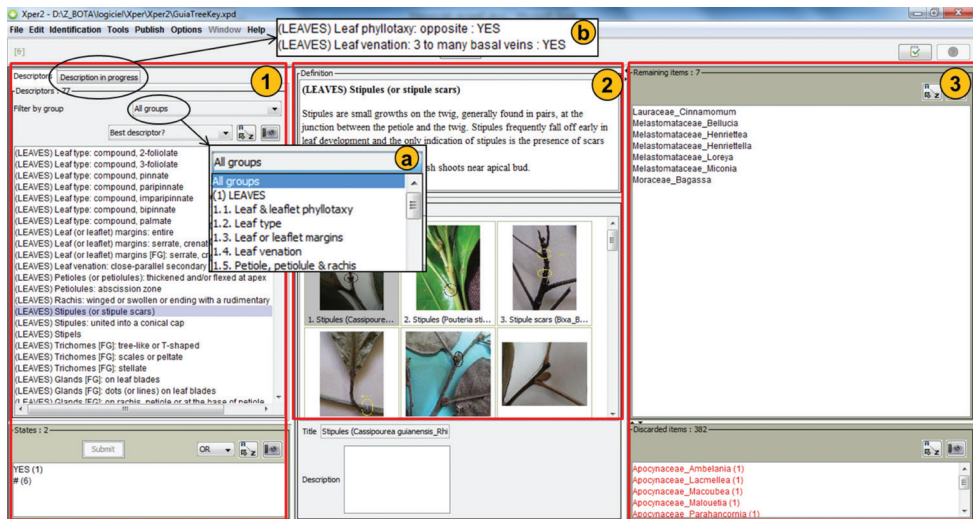
Licenses of use: The ‘GuiaTreeKey’ dataset is made available under the Creative Commons Attribution Non-commercial (CC-BY-NC) 4.0 License.

## Software overview and technical features (Figure 3)

**PANE 1: Characters box:** In the left pane, the characters are listed and organized by categories and sub-categories (i.e. 'leaves', 'other vegetative characters', 'flowers', and 'fruits and seeds', Box a). The user is invited to describe his/her sample using the characters listed in this pane. During the identification process, the user can access a summary of the characters that have been selected (Box b).

**PANE 2: Definition and illustration box:** The middle pane displays the definition and illustration of characters and retained genera.

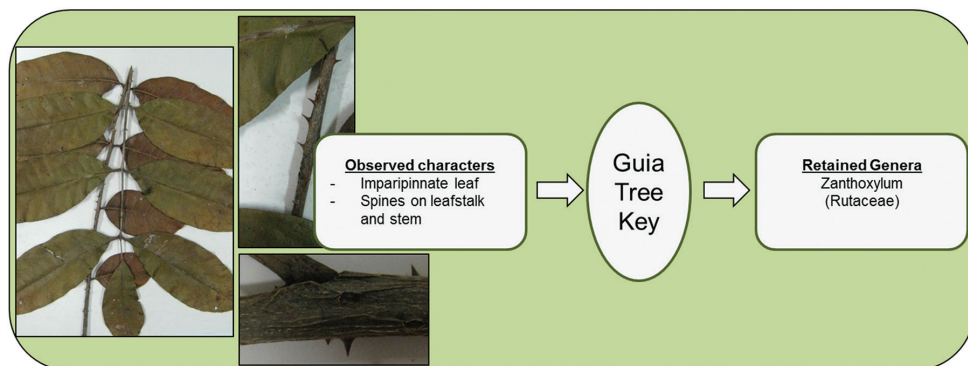
**PANE 3: Results box:** The right pane displays the results in real time. It lists the genera that fit the selected characters. Genera are listed in alphabetic order and they are combined with their family name. A botanical description and photographs of each genus may be displayed in pane 2 by clicking on the genus.



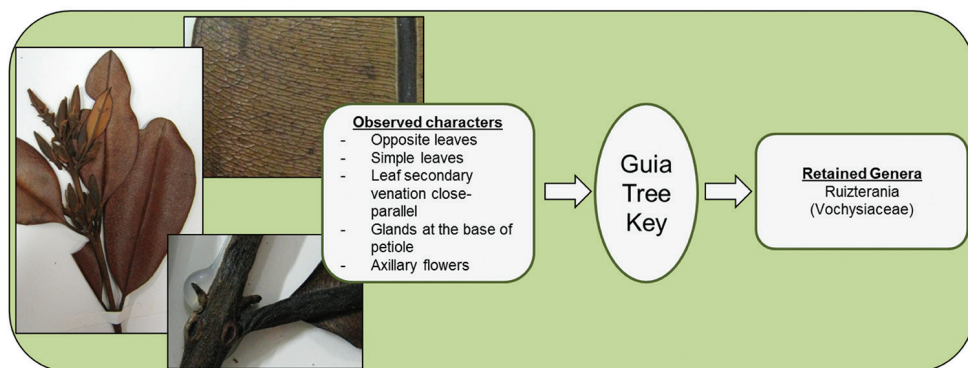
**Figure 3.** GuiaTreeKey overview.

## Examples of identification using GuiaTreeKey

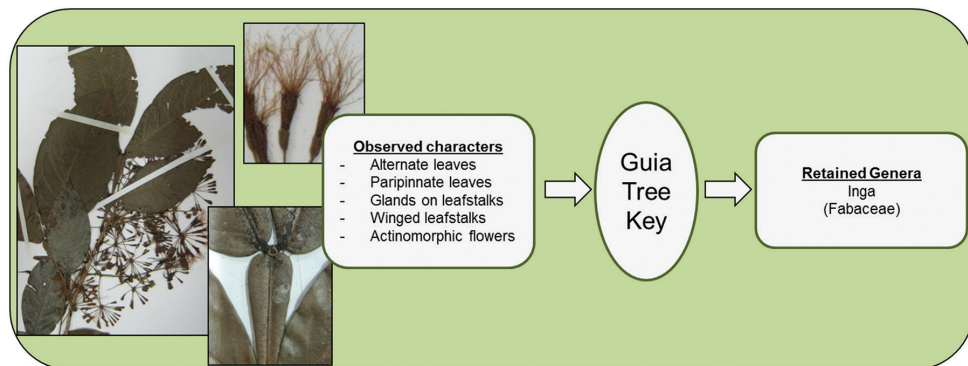
In this section, we provide several examples of identification using the electronic key (Figures 4–7).



**Figure 4.** Identification of *Zanthoxylum pentandrum* (Rutaceae).

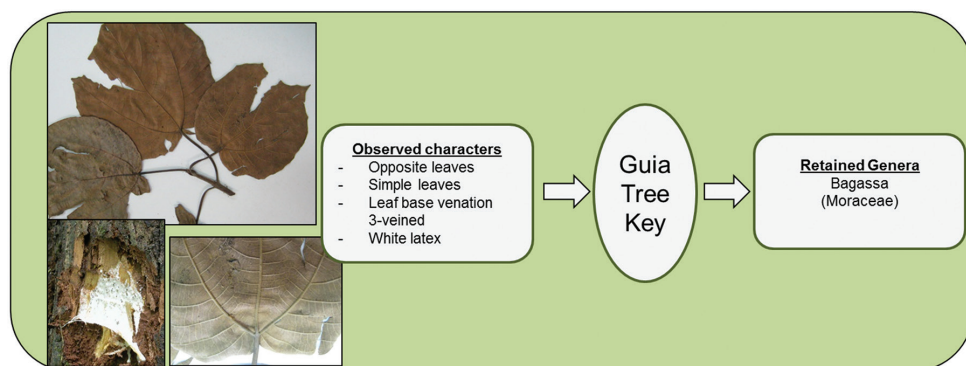


**Figure 5.** Identification of *Ruizterania ferruginea* (Vochysiaceae).



**Figure 6.** Identification of *Inga umbellifera* (Fabaceae).





**Figure 7.** Identification of *Bagassa guianensis* (Moraceae).

## Acknowledgements

We thank Stéphane Guitet for his help in editing the map of French Guiana. We thank Dr Douglas C. Daly, Dr Gerardo A. Aymard C., Dr Paul E. Berry, Dr Ricarda Riina and Dr Paul V.A. Fine for their useful and constructive feedback. We also thank Dr Douglas C. Daly for his help in improving the definition of characters in the electronic key. This work has benefited from an 'Investissement d'Avenir' grant managed by Agence Nationale de la Recherche (CEBA, ref. ANR-10-LABEX-0025). Louise Brousseau was funded by a Young Scientist Contract (INRA, 'Contrat Jeune Scientifique' CJS).

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## Supplementary material I

### Taxonomic ranks

Authors: Julien Engel, Louise Brousseau, Christopher Baraloto

Data type: list of genera

Explanation note: Taxonomic coverage of the electronic key 'GuiaTreeKey': Kingdom, Phylum, Class, Order, Family, Genus

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# *Hoya isabelchanae* Rodda & Simonsson, a new, showy species of *Hoya* R.Br. (Apocynaceae, Asclepiadoideae) with pomegranate red flowers from Sulawesi, Indonesia

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Academic editor: Pavel Stoev | Received 11 April 2016 | Accepted 27 June 2016 | Published 2 August 2016

**Citation:** Rodda M, Simonsson Juhonewe N (2016) *Hoya isabelchanae* Rodda & Simonsson, a new, showy species of *Hoya* R.Br. (Apocynaceae, Asclepiadoideae) with pomegranate red flowers from Sulawesi, Indonesia. PhytoKeys 68: 45–50. doi: 10.3897/phytokeys.68.8803

## Abstract

A new species of *Hoya* R.Br. from Sulawesi (Indonesia), *H. isabelchanae* Rodda & Simonsson, is described and illustrated. It is one of the largest flowered species in *Hoya* section *Acanthostemma* (Blume) Kloppenb. Its flowers are of comparable size to those of *Hoya benchaii* Gavrus et al., *Hoya kloppenburgii* T.Green, *Hoya rundumensis* (T.Green) Rodda & Simonsson and *Hoya sigillatis* T.Green ssp. *sigillatis*, all from Borneo. Among Sulawesi species it is compared with the vegetatively similar *Hoya brevialata* Kleijn & van Donkelaar and *Hoya pallilimba* Kleijn & van Donkelaar.

## Keywords

Borneo, Cultivation, Gunung Boliohutu, Malesia, Marsdeniaceae

## Introduction

The *Hoya* R.Br. diversity of Sulawesi (Indonesia) was investigated rather comprehensively by Kleijn and van Donkelaar (2001) who supported their herbarium studies with extensive field investigations throughout Sulawesi and not only collected herbarium specimens but also made extensive collections of sterile plants for growing *ex situ*.



They estimated that Sulawesi might have up to 20 species and provided a description for eight species, three of which are new, *Hoya brevialata* Kleijn & van Donkelaar, *Hoya myrmecopa* Kleijn & van Donkelaar and *Hoya pallilimba* Kleijn & van Donkelaar. The new species were all based on specimens bloomed in cultivation in Wageningen (Netherlands). Cultivation has long been considered an essential step in the identification of *Hoya* species, that otherwise rarely bloom in the wild (Lamb et al. 2014; Rintz 1978), and that are difficult to study from exsiccates alone. In 2004 a further new species from Sulawesi was named *Hoya tomataensis* T.Green & Kloppenb., and in 2010 the element identified as *Hoya camphorifolia* Warburg by Kleijn and van Donkelaar (2001: 467–468) was named *Hoya paulshirleyi* T.Green & Kloppenb. Both species were described based on cultivated plants.

A further sterile plant collected in Sulawesi by Steve Scott and brought into cultivation at the Royal Botanic Garden Edinburgh is regarded to represent a new species and it is here described as *Hoya isabelchanae* Rodda & Simonsson.

## Species treatment

### *Hoya isabelchanae* Rodda & Simonsson, sp. nov.

urn:lsid:ipni.org:names:77156823-1

Figs 1, 2

**Diagnosis.** Among Sulawesi *Hoya* species similar to *H. brevialata* and *H. pallilimba* in habit (prostrate and pendant epiphyte), lamina shape (convex round to elliptic) and inflorescence type (positively geotropic, convex) but separated because both *H. brevialata* and *H. pallilimba* have smaller flowers (c. 5 vs. 8–10 mm in diameter in *H. isabelchanae*) with a finely pubescent corolla (vs. setose corolla in *H. isabelchanae*).

**Type.** Indonesia, Sulawesi, Gorontalo, Gunung Boliohutu, 400 m, 23 Apr 2002, S.M. Scott 02-116, grown on at the Royal Botanic Garden Edinburgh (Acc no. 20021229), Sep 2012, *C.E. Berthold 0013* (holotype: E; isotype: SING)

**Description.** Epiphytic climber with white latex in all vegetative parts. *Stems* slender, prostrate, pendant, internodes (2)4–6(–10) cm × 1–1.5 mm, dull green or brown, pubescent when young, rarely almost glabrous when mature; *adventitious root* sparsely produced along the stem and just under the nodes where they are usually paired. *Leaves* petiolate; petiole recurved, round, 4–6(–8) × ca. 1.5 mm, pale green, pubescent; *lamina* orbicular-ovate (to elliptic), convex, fleshy and stiff (1.5–)2–4(–7) × (1–)1.5–2.5 cm, base cuneate (round), apex obtuse (round), pale to mid-green green above, with or without grey spots, pubescent on young leaves only, paler green underneath, pubescent; penninerved, secondary veins obscure; *colleters* (one) two at each lamina base, triangular to ovate 0.2–0.4 × 0.3–0.5 mm. *Inflorescence* positively geotropic, pseudo-umbellate, slightly concave; *peduncle* (1–)2–4(–7) cm × 1.5–2 mm in diameter, dull green to brown, pubescent when young; rachis indeterminate. *Flowers* 10–15 each inflorescence; *pedicel* variable in length, the internal ones ca. 8 mm long, the external



**Figure 1.** *Hoya isabelchanae* photographed in cultivation in Thailand (reference specimen *M. Rodda MR573*, SING). **A** Branch and inflorescence, side view **B** Inflorescence, from underneath **C** A single flower, front view **D** A single flower, lateral view **E** Corolla from underneath with calyx removed **F** Calyx **G** Anther **H** Pollinarium. (Photographs by M. Rodda).

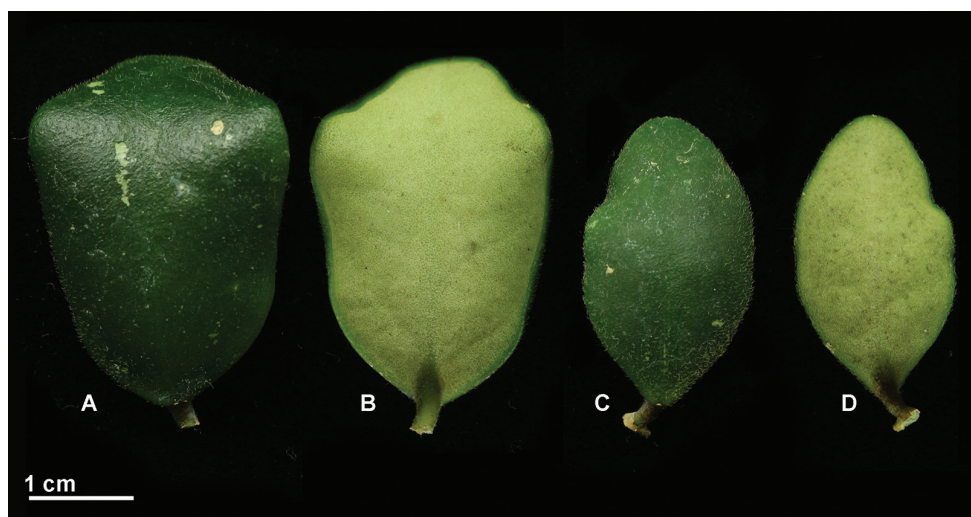
ones 2.5–3 cm × 1.2–1.5 mm in diameter, bright green, glabrous. *Calyx* lobes triangular, 1.2–1.6 × 1–0.8 mm wide, apex round, light green or brownish, glabrous; *basal colleter* one in each calyx lobe sinus, ovate, 300–400 × ca. 100 µm. *Corolla* revolute, 8–10 mm in diameter, ca. 16 mm when flattened; *corolla lobes* basally fused, tube 3–4 mm long, pomegranate red, from almost glabrous at the base to thinly pubescent becoming setose towards the distal part of the inner side of the tube, glabrous outside, lobes broadly ovate, 5–6 × 4–5 mm, pomegranate red with a paler edge, inside setose with a glabrous tip, outside glabrous. *Corona* staminal, 7–8 mm in diameter, 3–3.5 mm high; *corona lobes* ovate, ca. 3.5 × 2 mm, slightly convex above, underneath sulcate, inner process apex acuminate, outer process apex divided in an upper round part and a lower bifid part, upper part cream yellow with a pinkish inner process tip, lower part and bilobed outer process reddish. *Anthers* with apical translucent appendages, broadly triangular, c. 1.2 × 1.2 mm. *Pollinia* oblong, 250–300 × 130–150 µm, base obliquely truncate, apex round, sterile edge all along the outer edge of the pollinium; *corpusculum* oblong, 120–140 × 50–60 µm; *caudicle* broad, spatulate, 180–200 × 100 µm at the widest point. *Style-head* 5 angled in cross section, c. 2.5 mm in diameter, with 5 lobes alternating with the stamens, style-head apex mamillate, ca. 1 × 0.5 mm broad at the base; *ovary* ovoid, shortly beaked, 1.5–1.7 mm long, each carpel ca. 0.7 mm wide at the base, pale green, glabrous. *Fruit* and *seed* not observed.

**Etymology.** *Hoya isabelchanae* is named after Isabel Claire Chan Yuen Ching, late daughter of Elisabeth Chan, Singaporean patron of botanical research and a gardener with an interest in *Hoya*.

**Distribution and ecology.** *Hoya isabelchanae* is only known from the base of Gunung Boliohutu, Sulawesi, where it was collected as a sterile cutting in 2002 and brought into cultivation at the Royal Botanic Garden Edinburgh where it regularly blooms in a heated greenhouse from May to October. The species was collected in primary forest and it was growing in shaded but exposed area on a decaying tree 12 m tall. A further collection is widely available in cultivation under Gerard Paul Shirley number GPS10161 and 7-35 [http://www.paulshirleysucculents.nl/shop\\_hoyas.htm](http://www.paulshirleysucculents.nl/shop_hoyas.htm) [accessed on 24 June 2016]. This accession is apparently also from Sulawesi but no further collection information is available.

**Conservation status.** The only localised specimen of *Hoya isabelchanae* is the type collection. No information is available on the extent of the wild population in Sulawesi and the threats to its habitat therefore its conservation status is Data Deficient (DD) (IUCN 2014). *Hoya isabelchanae* is at present in cultivation at the Royal Botanic Gardens Edinburgh (type collection, acc. no. 20021229) and at the Singapore Botanic Gardens (unlocalised collection, vouchered as M. Rodda MR573).

**Notes.** *Hoya isabelchanae* belongs to *Hoya* section *Acanthostemma* (Blume) Kloppeburg whose members have revolute corolla lobes, bilobed outer corona lobes and pollinaria with broad, spatulate caudicles. With a corolla 8–10 mm in diameter, *H. isabelchanae* is one of the largest flowered species in *Acanthostemma*, only comparable with *Hoya benchaii* Gavrus et al. (corolla 9–12 mm in diameter) *Hoya kloppenburgii* T.Green (10–12 mm), *Hoya rundumensis* (T.Green) Rodda & Simonsson (7–10 mm)



**Figure 2.** Leaves of *Hoya isabelchanae* photographed in cultivation in Singapore (reference specimen *M. Rodda* MR573, SING). **A** Larger leaf, from above **B** Larger leaf, from underneath **C** Smaller leaf, from above **D** Smaller leaf, from underneath (Photographs by M. Rodda).

and *Hoya sigillatis* T.Green ssp. *sigillatis* (7–10 mm), all from Borneo. All these can be separated from *H. isabelchanae* because their corolla is puberulent while *H. isabelchanae* has a setose corolla (Fig. 1).

Among Sulawesi *Acanthostemma* members, *H. isabelchanae* is vegetatively similar to *H. brevialata* and *H. pallilimba*, that make large clumps of prostrate and pendant stems and have convex round to elliptic laminas. They also have similar positively geotropic convex inflorescences. However *H. isabelchanae* can be separated from *H. brevialata* and *H. pallilimba* because it has much larger flowers, both *H. brevialata* and *H. pallilimba* have flowers c. 5 mm across while *H. isabelchanae* has flowers 8–10 mm in diameter. The corona of *H. isabelchanae* has almost flat lobes while the coronas of *H. brevialata* and *H. pallilimba* have the inner lobe held much higher than the outer lobe process. Further, the corolla of *H. brevialata* and *H. pallilimba* is finely pubescent while the corolla of *H. isabelchanae* is setose.

**Additional specimens examined.** Indonesia, Sulawesi, (live collection numbers 7-35 and GPS10161), grown in Thailand, Ratchaburi, 23 Mar 2014, M. Rodda MR573 (SING).

## Acknowledgements

The National Parks Board Singapore is thanked for supporting this research by sponsoring field expeditions and numerous herbaria study trips. We would like to thank the curators of A, BK, BKF, BISH, BM, BRUN, FI, G, K, KEP, KUN, HBG, IBSC,

L, M, MO, P, SAN, SAR, SNP, SING, TO, UC, US, W, WRSL and WU herbaria for allowing access and/or for providing high quality images of herbarium specimens and Ulrich Meve for his contributions to the text. Elisabeth Chan is thanked for her continuous support of the research of both authors and for the English revision. Lastly we are grateful to Papaschon Chamwong for donating a live specimen of *Hoya isabelchanae* to the Singapore Botanic Gardens.

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# Vegetation and fire in lowland dry forest at Wa'ahila Ridge on O'ahu, Hawai'i

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Academic editor: *Pavel Stoev* | Received 12 November 2015 | Accepted 28 July 2016 | Published 5 August 2016

**Citation:** Lu P-L, DeLay JK (2016) Vegetation and fire in lowland dry forest at Wa'ahila Ridge on O'ahu, Hawai'i. *PhytoKeys* 68: 51–64. doi: 10.3897/phytokeys.68.7130

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## Abstract

Long-term ecological studies are critical for providing key insights in ecology, environmental change, natural resource management and biodiversity conservation. However, island fire ecology is poorly understood. No previous studies are available that analyze vegetative changes in burned and unburned dry forest remnants on Wa'ahila Ridge, Hawai'i. This study investigates vegetation succession from 2008 to 2015, following a fire in 2007 which caused significant differences in species richness, plant density, and the frequency of woody, herb, grass, and lichens between burned and unburned sites. These findings infer that introduced plants have better competitive ability to occupy open canopy lands than native plants after fire. This study also illustrates the essential management need to prevent alien plant invasion, and to restore the native vegetation in lowland areas of the Hawaiian Islands by removing invasive species out-planting native plants after fire.

## Keywords

Fire ecology, island ecology, O'ahu, restoration, vegetation ecology

## Introduction

Fire has a significant influence on global ecosystems (Pyne et al. 1996, Robertson et al. 2015). Fire influences global vegetation patterns, shapes species characteristics, and reduces the plant biomass (Riano et al. 2002, Bond et al. 2005). Some plants have developed traits to cope with recurrent fires as fire intolerant species (Pausas et al. 2004,

Pausas and Keeley 2009). On the other hand, many plants belong to fire tolerant or fire resistant species such as Ponderosa Pine and Mountain Grey Gum tree (Knox and Clark 2005, Fitzgerald 2005, Kolb et al. 2007, Wesolowski et al. 2014). Understanding the factors that govern the distribution of tropical dry forest and invasive species has important implications for projecting the response of Hawai'i lowland landscapes to disturbance regimes and managing lowland dry forest ecosystems after fire.

Islands are good locations to study the influence of biological mechanisms on ecosystem-level properties (Carlquist 1974, Vitousek et al. 1995). Island ecosystems are susceptible to species invasion (Vitousek 1988, Glen et al. 2013, Meng et al. 2014). The Hawaiian Islands are the most remote archipelago on Earth and a hotspot for biodiversity (Wagner et al. 1990, 2012; Gustafson 2014). Although many lineages of plants are species rich in Hawai'i, few of them have been studied in detail (Mueller-Dombois and Fosberg 1998, Ziegler 2002, Mueller-Dombois and Boehmer 2013, Sherwood et al. 2014). One approach to the study of vegetation structure is to analyze diversity after a disturbance, such as a fire or a storm (Keeley 1986, Chen et al. 2013, Huston 2014, Pausas 2015, Burkle et al. 2015).

The mesic and dry forests of the Hawaiian Islands have been reduced due to habitat loss, including development, and the introduction and spread of invasive plants and animals (Gagne and Cuddihy 1999, Mayer et al. 2004, Wichman and Clark 2013). The island of O'ahu has the highest human population density of all the islands. One major concern is balancing development and natural resource conservation (State of Hawai'i data book 2007, 2015). Governmental and non-government organizations (NGOs) have been involved in preserving native ecosystems, the current vegetation structure on O'ahu, particularly in lowlands, is not well-preserved and thus very difficult to understand their structure. The 2007 fire on Wa'ahila Ridge provided an opportunity to study vegetation succession.

While agriculture and alien plant invasion are responsible for significant landscape transformations in the Hawai'i, fires cause dramatic and immediate changes to the original vegetation (Ziegler 2002). Wa'ahila Ridge, the southern side of Mānoa Valley, is characterized by a wetter winter and drier summer. It is a State Recreation Area on O'ahu. Little previous research on the vegetation ecology of this area has been reported. In 2007, there was a wild fire disturbance on Wa'ahila Ridge (State of Hawai'i 2007). This provided an opportunity to observe the post-fire vegetation structure and document the original vegetation on the unburned area. This research is a pioneer study to understand the effect of fire disturbance on the mesic forest on the lowland of O'ahu. This study was conducted after two fires occurred in the same location in the spring of 2015 (State of Hawai'i 2015).

In this study, the impacts of fire were examined by comparing the difference between burned and unburned plots. Plot level studies can provide an understanding of general post-fire sequences in forest ecosystems, landscape-scale monitoring, and analysis of post-fire recovery trajectories (Keeley and Keeley 1981, Keeley et al. 1981). Three hypotheses were tested. The first hypothesis is that the dominant species on unburned sites are woody plants because woody plants are the major component of in

mesic forests in the lowlands; grass plants are dominant on burned sites because grasses are good pioneer species. The second hypothesis is that native plants are less frequent at burned sites because alien plants have better competitive ability to occupy open spaces after a fire even though the reproductive periods of native and alien plants are similar. The third hypothesis is that species richness and plant density are greater on unburned sites than burned sites because the recovery time has only been one year and thus not enough for some plants to recolonize the area.

## Methods

The study site is in Wa'ahila Ridge State Recreation Area on O'ahu in Hawai'i, at 21°18'1"N and 157°48'41"W. The average elevation of burned and unburned sites is about 100 m. Mean annual precipitation is 1039-2400 mm, with 64-80% falling October through March (Giambelluca et al. 2013). Mean annual temperature is 24°C. The soil type is an Andisol (Woodcock et al. 1999).

The date of fire was July 5, 2007. It burned for at least 6 hours and covered about 20 hectares (State of Hawai'i 2007). Seven years of data were collected on the following occasions: Oct. 2, 2008; Oct. 12, 2009; Nov. 1, 2010; Oct. 1, 2011; Oct. 7, 2012; Oct. 5, 2013; and Oct. 4, 2014. Fifty unburned and 50 burned 1 m<sup>2</sup> plots were examined. The plots were randomly distributed within unburned and burned sites, but at the same site from year to year. Species richness, plant density, species dominance (based on frequency), and species diversity were examined on unburned area and burned areas.

Sampling followed the protocol of The Nature Conservancy of Hawai'i for long-term vegetation monitoring (The Nature Conservancy 1993). The number of individuals of each species expressed as percentage of total was used as a measure of relative density in the plots. Species composition and abundance was measured in each plot. Plant species richness, plant density, plant dominance, frequency of native plants, woody plants, forb plants, grass plants, and lichens were calculated for unburned and burned sites. Species composition was identified based on taxonomy and then documented. The only previous record of a major disturbance on Wa'ahila Ridge was a fire in 1888 (Hillebrand 1888); however, it is not clear whether the current study sites were involved. Means, standard deviations, and paired T-tests were used to compare burned and unburned sites, and were calculated with MiniTab 17.

## Results

One year after the fire, the proportion of alien species on unburned and burned sites was similar (Table 1). The dominant species on unburned sites is the alien woody plant, *Leucaena leucocephala*, and on burned sites, the alien invasive grass, *Urochloa maxima* dominates (Table 2). The species frequency indicates *Leucaena leucocephala*

**Table 1.** Species re-sprouting and seed regenerating on unburned and burned sites one year after the fire. *Heteropogon contortus* and *Waltheria indica* are native species in Hawai’i. *Heteropogon contortus*, *Chloris barbata*, and *Urochloa maxima* are grass species. T is tree. G is grass. F is forb.

Unburned site	Type	Burned site	Type
<i>Haematoxylum campechianum</i>	T	<i>Stapelia gigantea</i>	F
<i>Leucaena leucocephala</i>	T	<i>Urochloa maxima</i>	G
<i>Chloris barbata</i>	G	<i>Leucaena leucocephala</i>	T
<i>Grevillea robusta</i>	T	<i>Chamaecrista nictitans</i>	F
<i>Heteropogon contortus</i>	G	<i>Agave attenuata</i>	F
<i>Pimenta dioica</i>	T	<i>Chloris barbata</i>	G
<i>Urochloa maxima</i>	G	<i>Waltheria indica</i>	F
Lichens (additional information)		<i>Fucrea foetida</i>	F
		<i>Kalanchoe pinnata</i>	F
		<i>Hyptis pectinata</i>	F
		<i>Senna septemtrionalis</i>	F
		<i>Murraya paniculata</i>	F

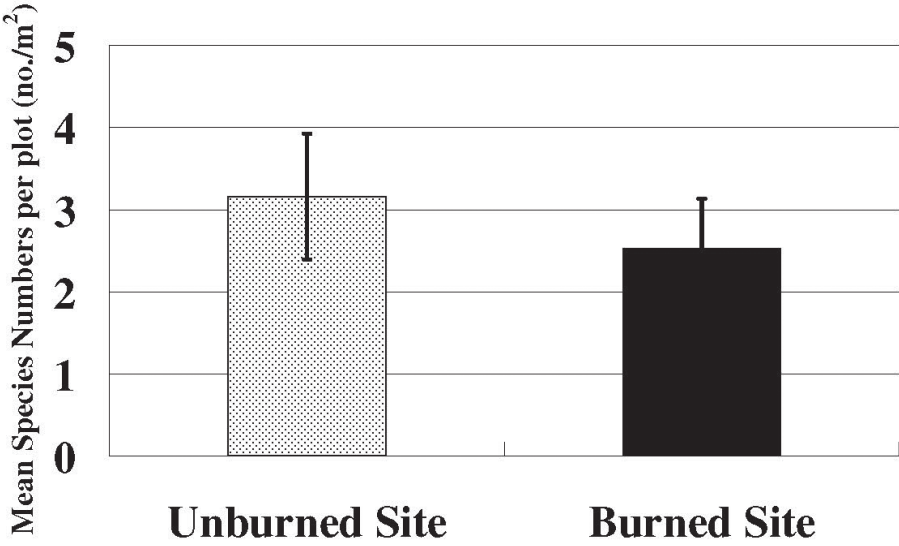
**Table 2.** Dominant species on burned and unburned sites one year after the fire.

Unburned site	Burned site
Woody plant: <i>Leucaena leucocephala</i>	Grass plant: <i>Urochloa maxima</i>
Individuals: 427	Individuals: 333
48/50 plots	49/50 plots

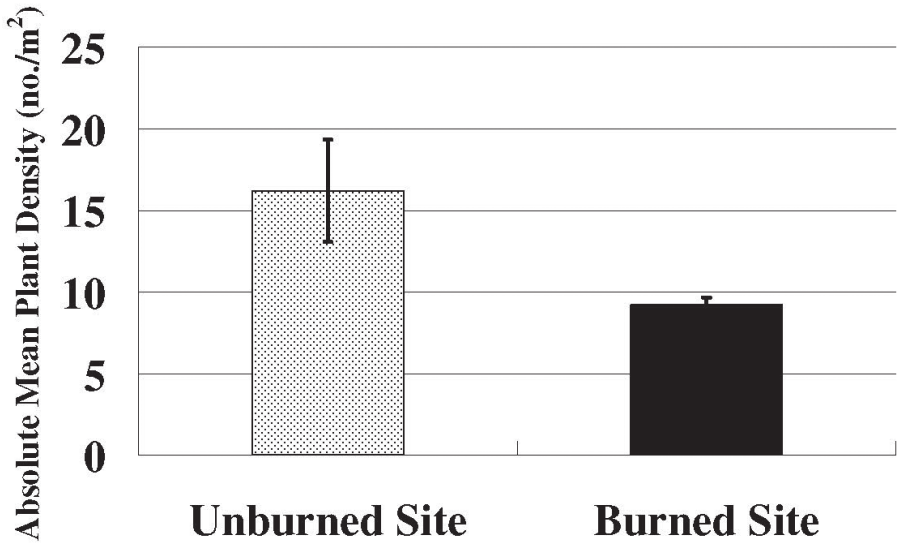
**Table 3.** Percentage (%) Frequency of species on unburned and burned sites one year after the fire.

Unburned site %		Burned Site %	
<i>Haematoxylum campechianum</i>	12	<i>Stapelia gigantea</i>	6
<i>Leucaena leucocephala</i>	96	<i>Urochloa maxima</i>	98
<i>Chloris barbata</i>	2	<i>Leucaena leucocephala</i>	10
<i>Grevillea robusta</i>	18	<i>Chamaecrista nictitans</i>	4
<i>Heteropogon contortus</i>	52	<i>Agave attenuata</i>	4
<i>Pimenta dioica</i>	4	<i>Chloris barbata</i>	2
<i>Urochloa maxima</i>	40	<i>Waltheria indica</i>	26
Lichens (additional information)	94	<i>Fucrea foetida</i>	22
		<i>Kalanchoe pinnata</i>	6
		<i>Hyptis pectinata</i>	2
		<i>Senna septemtrionalis</i>	2
		<i>Murraya paniculata</i>	8

and lichens are high on unburned sites and *Urochloa maxima* is highest on burned sites (Table 3). The only woody species found in burned site is white lead-tree (*Leucaena leucocephala*). The frequency of this species at burned sites was much lower compared to unburned sites and partially indicates this species’ fire resistance. The only native grass, *Heteropogon contortus*, completely disappeared after this fire.



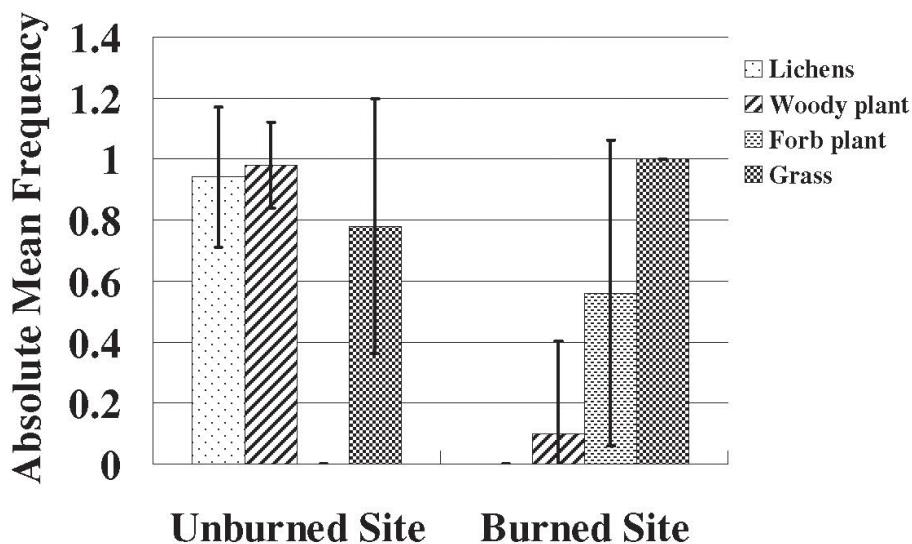
**Figure 1.** The species richness on the unburned site and the burned site per 1 m<sup>2</sup>. Error bars are ± SD (n=50). T-value= 4.70, P-value < 0.001.



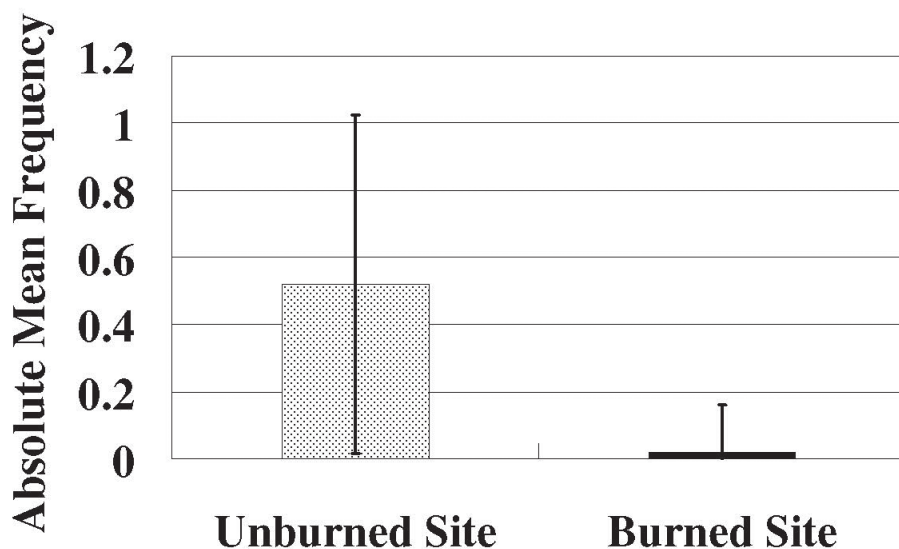
**Figure 2.** The plant density on the unburned site and the burned site per 1 m<sup>2</sup>. Error bars are ± SD (n=50). T-value = 6.75. P-value < 0.001.

Species richness and plant density are greater on unburned sites than burned sites (Figs 1, 2) which supported the hypothesis. Frequency of lichens, woody plants, and native plants was greater on unburned sites than burned sites (Figs 3, 4). Frequencies of forbs and grasses are lower on unburned sites than burned sites (Fig. 3). All



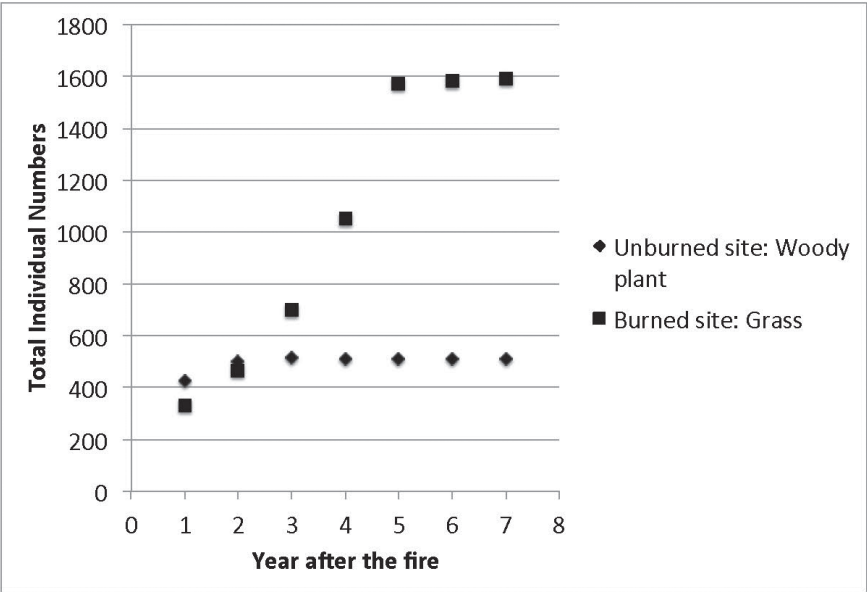


**Figure 3.** The frequency of lichens, woody plants, forb plants, grass on the unburned site and the burned site per 1 m<sup>2</sup>. Error bars are  $\pm$  SD (n=50). Lichens: T-value = 27.71; P-value < 0.001. Woody plants: T-value = 18.96; P-value < 0.001. Forb plants: T-value = -7.90; P-value < 0.001. Grass: T-value = -3.72; P-value = 0.001.

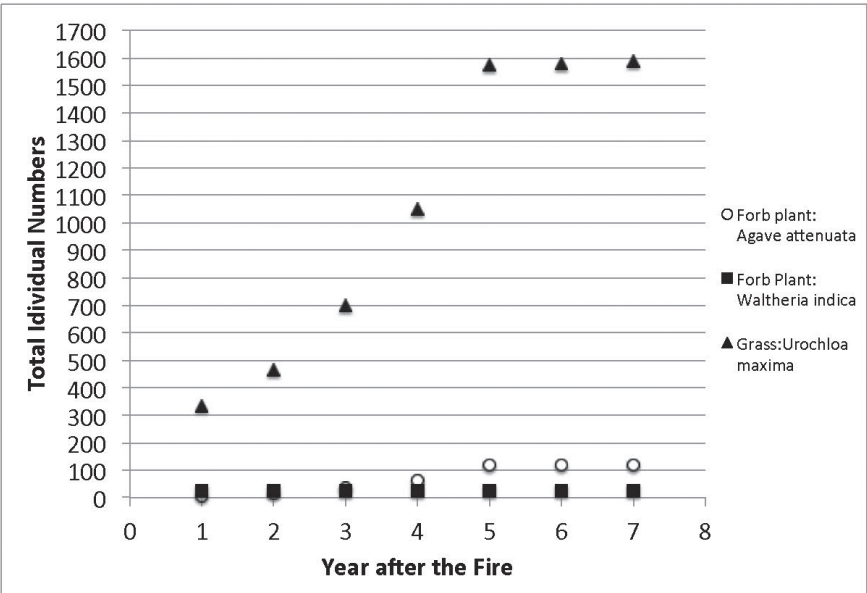


**Figure 4.** The frequency of native plants on the unburned site and the burned site per 1 m<sup>2</sup>. Error bars are  $\pm$  SD (n=50). T-value = 6.50. P-value < 0.001.

differences were significant between burned and unburned sites. Figure 5 shows the individual numbers of dominant species at the burned and unburned sites from 2008 to 2015. With increasing time, the gap between woody plants and grasses was get-

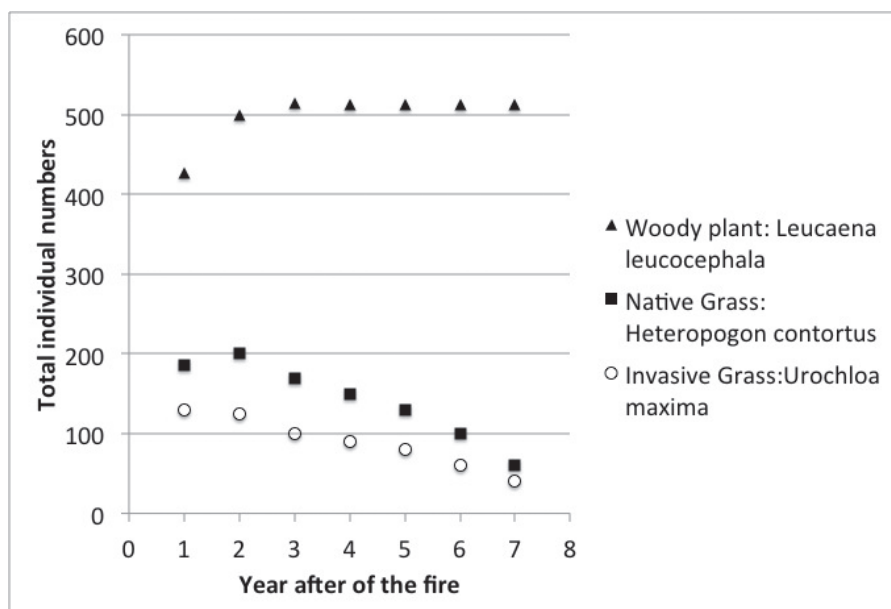


**Figure 5.** The total individual numbers of dominant species on the unburned site and the burned site from 2008–2015.



**Figure 6.** The total individual numbers of the top three dominant species on the burned site from 2008–2015.

ting larger. It appears the grass in burned site fills its niche 5 years after the fire but tree species in unburned site had not filled their niche yet. Figure 6 shows the major components in burned site. It indicates that among the three most abundant plants



**Figure 7.** The total individual numbers of the top three dominant species on the unburned site from 2008–2015.

in burned site, *Agave* and *Waltheria* forbs were less abundant than the invasive grass. Figure 7 shows that in unburned plots, the tree frequency is similar from 2008 to 2015 with a positive trend. Native grass decreased but was not replaced by invasive grass, indicating woody plant encroachment in former native grass areas. In addition, if the species establish in the open canopy one year after the fire, not only are native species completely replaced by alien or invasive species, but competition for space becomes a limiting factor, particularly when the invasive grass achieves its optimal establishment after five years.

## Discussion

Understanding long-term succession and fire ecology is essential interpreting ecosystem fire responses and planning vegetation restoration. The results indeed supported the three hypotheses. The vegetation structure indicates that invasive plants were favored by the fire disturbance on Wa'ahila Ridge which created open spaces for pioneer species to establish seedlings more easily. Additionally, the environment surrounding the burned area was already dominated by invasive species which dominate the seed bank and few native species existed in the vicinity to contribute to the seed bank. Alien plants invasions in native ecosystems have become a topic of great concern in recent years, particularly in isolated island ecosystems such as the Hawaiian Islands (Loop and Mueller-Dombois 1989, Vitousek et al. 1987, McDaniel et al. 2008, Loope et al.

2013, Vorsino et al. 2014). More than 800 introduced plant species that have become naturalized in the Hawaiian Islands (Vitousek et al. 1987, Wagner et al. 1990, 2012). This study site is an example where invasion is a serious issue.

The invasive grass *Urochloa maxima* was the dominant species on burned sites, whereas the alien woody plant *Leucaena leucocephala* was the dominant species on unburned sites. However, a high proportion of the native grass *Heteropogon contortus*, and *U. maxima* was also present on unburned sites. This indicates that after the fire *U. maxima* has a better competitive ability than the woody alien species *Leucaena leucocephala* and the other alien grass species *Agave attenuata* to colonize quickly burned sites. Notably, many species occurred on burned sites that were not present on unburned sites. That suggests that the invasive plants on Wa'ahila Ridge have greater opportunity and ability to replace native plants in the short term after a fire.

*Leucaena leucocephala* is dominant in, and has highest frequency on, unburned sites. It indicates that this species has the ability to establish a large population on Wa'ahila Ridge. In addition, the native grass, *Heteropogon contortus* coexists equally with the invasive grass, *Urochloa maxima* on unburned sites, which infers that *Leucaena leucocephala* may play a critical role in the coexistence. In contrast, on burned sites, the invasive grass, *Urochloa maxima* has the highest frequency and other species have low frequency, which shows that the burned area is primarily occupied by the single species of *U. maxima*. Year by year, the burned site became dominated this single invasive species, with scattered *Agave attenuata*, another dryland invasive species recently occurring in Hawai'i.

Although total species numbers on burned sites are higher than on unburned sites, the species numbers per plot are higher on unburned sites than burned sites. The results indicates that the species tends to be concentrated more in plots on the burned sites, but are more equally distributed over all plots on unburned sites. A possible explanation is that burned sites are dominated by grass and unburned sites are dominated by trees.

Plant density is greater on unburned sites. This indicates that a one-year recovery time is not enough for plant species to reach their maximum population density and burned materials may not provide enough nutrients to seedlings of the other types of plants, or after the fire disturbance invasive plants quickly occupy those open canopy and do not allow other species to dominate those areas. However, the plant density is trending towards similarity on burned and unburned sites year by year.

The results of this study support the findings of previous research on vegetation in the lowlands, which have a similar dynamic structure. For example, herbaceous species dominate the immediate post-burn environment, but most generally disappear after three to four years because they were shaded out by the recovering shrubs and trees in California (Keeley and Keeley 1981; Keeley et al. 1981). It has been documented that recurrent fires promote the presence of herbaceous species in Mediterranean type ecosystems in Spain and in California (Zedler et al. 1983, Faraco et al. 1993). Lichens have been promoted as a useful environmental indicator (Giordani et al. 2012, Li et al. 2013). No lichens exist on burned sites, but almost 100% of plots in the unburned sites have lichens. Records show that the unburned sites have not had any major distur-

bances for few years so that the pre-fire vegetative structure on Wa'ahila Ridge was well established (Armstrong 2015, Merinero et al. 2015). In the post-fire recovery phase, the first to third year after the fire played important roles in determining the probability of invasive or native tree, shrub, and grass recovery, contraction, or loss. (Ruiz et al. 2013, Pausas 2015). Dispersal affects the short-term and long-term persistence of patchily distributed species with patchily distributed resources in a highly temporally variable environment. Dispersal over even small distances reduce the opportunity of consequent density dependent interactions by moving seeds away from the immediate vicinity of parent plants but retaining them in a favorable area (Howe and Smallwood 1982, Schupp 1995). Longer-distance dispersal involves risk, as few seeds typically reach sites suitable for germination and growth (Venable and Lawlor 1980) although the most invasive species tend to be very good at long distance dispersal. However, according to other research reports, when local populations are subject to extinction or struggling to survive, in line with metapopulation theory, long-distance dispersal is required for populations to expand into new areas to discover better environments, and between-patch movement allows the persistence of subdivided populations (Hanski and Gilpin 1991, Cain et al. 2000, Howe and Miriti 2004). In this study, threatened native or endemic species were not observed establishing in the open canopy, indicating the competitive advantage of invasive or alien species.

In conclusion, this study provides primary data but fundamental information for policy makers develop appropriate conservation strategies to mitigate the serious loss of native habitats on O'ahu, Hawai'i and also provides useful information for island ecosystems and tropical vegetation ecology. Seven years of field data show the vegetation changes over time. It suggests the vegetation will not be recovering to the pre-fire state and even worse. Other studies have shown that post-fire vegetative structure does tend to return to its pre-fire state (Keeley 1986, Ireland and Petropoulos 2015), however, those are because of the environment is full of relatively high proportion native species. Thus, the content of native vs. invasive species around the fire disturbance plays a very significant role for vegetation succession. In this study, the pre-fire environment was already depauperate in native species and thus after the fire disturbance, the seed bank provided more invasive species than native species. Future studies should address spatial factors in studies of post-fire vegetation dynamics, as the spatial arrangement of patches in the landscape and the seed dispersal mechanisms are crucial processes influencing plant dispersal and colonization.

## Acknowledgements

Professor Donald R. Drake and Lara S. Reynolds gave helpful suggestions in this study. Neeva Shrestha, Professor Chalita Bundhuwong, and Asheshwor Man Shrestha assisted with the fieldwork. Thanks also to Professor Clifford W. Morden for identifying species and providing commentary.

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# *Cirsium semzinanicum* (Asteraceae), a new species from Hakkâri, Turkey

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Academic editor: Peter de Lange | Received 5 April 2016 | Accepted 26 July 2016 | Published 5 August 2016

**Citation:** Firat M (2016) *Cirsium semzinanicum* (Asteraceae), a new species from Hakkâri, Turkey. PhytoKeys 68: 65–72. doi: 10.3897/phytokeys.68.8745

## Abstract

*Cirsium semzinanicum* **sp. nov.** (Asteraceae) is described as a new species from Hakkâri, Turkey. The new species is a part of the sect. *Epitrachys* (Cardueae) and similar to *Cirsium karduchorum*, from which it differs in morphological characters such as leaves, involucre, phyllaries, corolla, achenes and pollen morphology. Geographical distribution, habitat and IUCN conservation status of this species are given.

## Keywords

Asteraceae, *Epitrachys*, *Cirsium*, Hakkari, Turkey, taxonomy

## Introduction

The genus *Cirsium* Mill. is one of the largest genera of Asteraceae, and it comprises more than 250 perennial, biennial, or rarely annual spiny species distributed in the northern hemisphere in Europe; North Africa; East, Central, and Southwest Asia; and North and Central America (Charadze 1963, Davis and Parris 1975, Petrak 1979, Kadereit and Jeffrey 2007).

The last revision on *Cirsium* species growing in Turkey was carried out by Davis and Parris (1975) for the Flora of Turkey. In that study, 52 species (65 taxa) were given under 3 sections [*Cirsium*, *Epitrachys* DC., and *Cephalonoplos* (Neck.) DC.]. Additional taxonomic treatments have dealt with the distribution of the genus in supplements and 5 new species (6 taxa) were given (Davis et al. 1988; Güner et al. 2000).

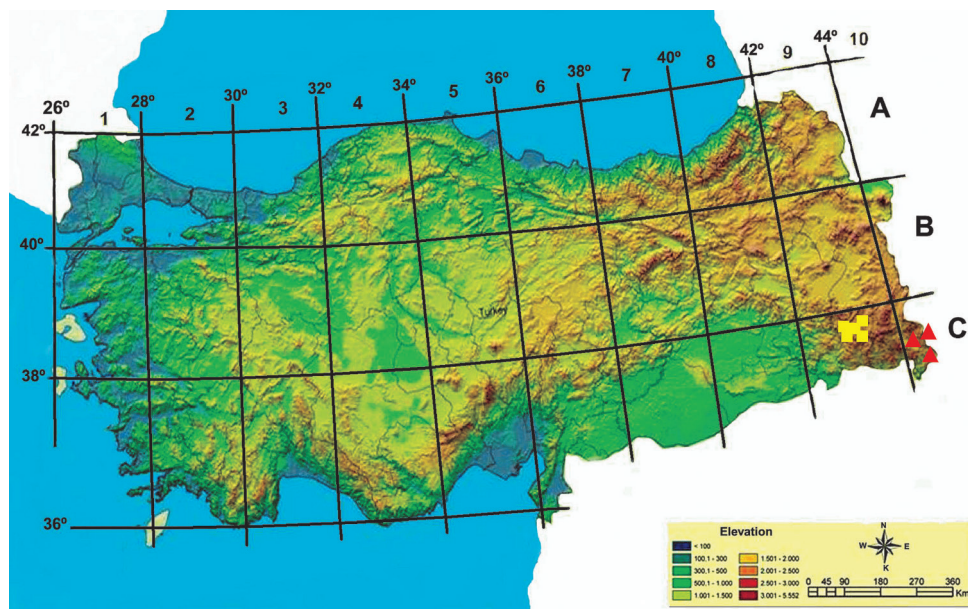
Finally, the Turkish members of the genus were established as 66 species (78 taxa) according to Yıldız (2012) and Yıldız et al. (2013).

Between 2011 and 2015 new populations of *Cirsium* sp. similar to *C. karduchorum* were discovered at 3 sites in south-east Turkey. Here the morphological and micro-morphological characters of these new populations are presented and their taxonomic treatment is proposed.

## Materials and methods

The specimens were collected by the author in July 2011 and August 2015 during the field trips to Şemdinli (Fig. 1) in Hakkâri, in the southeast of Turkey. In total 10 herbarium specimens of the presumed new species were collected from three adjacent localities and deposited in the herbaria of VANE, ANK and E. A formal name is provided accompanied by a detailed description and illustration.

At first glance, on the basis of the characters of leaves, involucre, phyllaries, corolla and achenes, seemed to be similar to *C. karduchorum*. The newly collected specimens were therefore cross-checked with the keys provided by de Candolle (1838), Boissier (1875), Petrak (1910), Davis and Parris (1975), Davis et al. (1988) and Güner et al. (2000). They were compared with the related specimens stored in VANE, GAZI, ANK and HUB herbaria.



**Figure 1.** Distribution map of *Cirsium semzinanicum* sp. nov. (▲) and also closely related species *C. karduchorum* (■) in Turkey.

Images of the collected material were taken with a Sony DSCR1, digital camera. The SEM micrographs were taken with a ZEISS supra55. The terminologies for pollen morphology were used in accordance with Faegri and Iversen (1989) and Punt et al. (1994). Geographical positions were identified using a Magellan explorer 710 GPS. According to the grid system (Davis 1965), especially the new species which are present in Hakkâri province falls within the C10 square (Davis 1965). The conservation status of the new species was assessed according to IUCN criteria (IUCN 2014).

## Taxonomy treatment

### *Cirsium semzinanicum* Firat, sp. nov.

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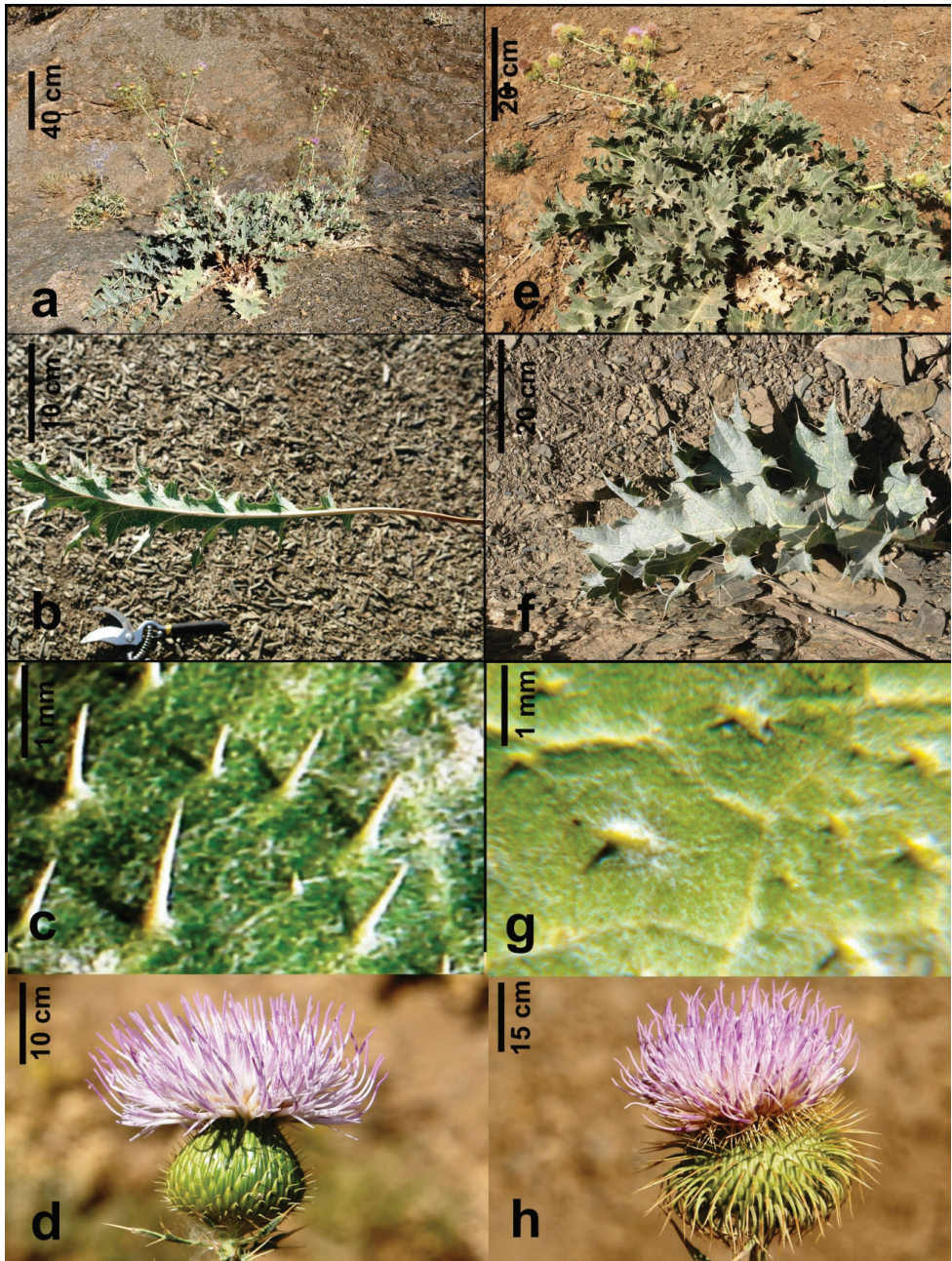
Figs 2–3

**Type.** Turkey. C10 Hakkâri: Şemdinli, Bêgoz village, Kaduna region, rocky slopes, eroded slopes, 37°17'15"N, 44°25'25"E, 1717 m, 26 July 2011, *M. Firat 27257* (holotype VANF!, isotypes ANKA, E, and Hb. M. Firat).

**Diagnosis.** *Cirsium semzinanicum* clearly differs from *C. karduchorum* Petr. in its stems 100–150 cm tall (vs. 50–100 cm tall, robust), basal leaves 15–25 × 9–14 cm “excluding 10–18 petiole”, green, (vs. 30–40 × 15–20 cm “excluding 15–20 cm petiole”, bluish-green), involucre 15–25 × 20–30 mm ovoid to subglobose (vs. 25–30 × (30–)40–50 mm depressed subglobose to broadly obovoid), phyllaries 9–12-seriate ± erecto-reflexed (vs. 11–14-seriate reflexed or recurved), achen brownish 7–9 × 3–4 mm (vs. bright grayish brown 6–7.5 × 3 mm).

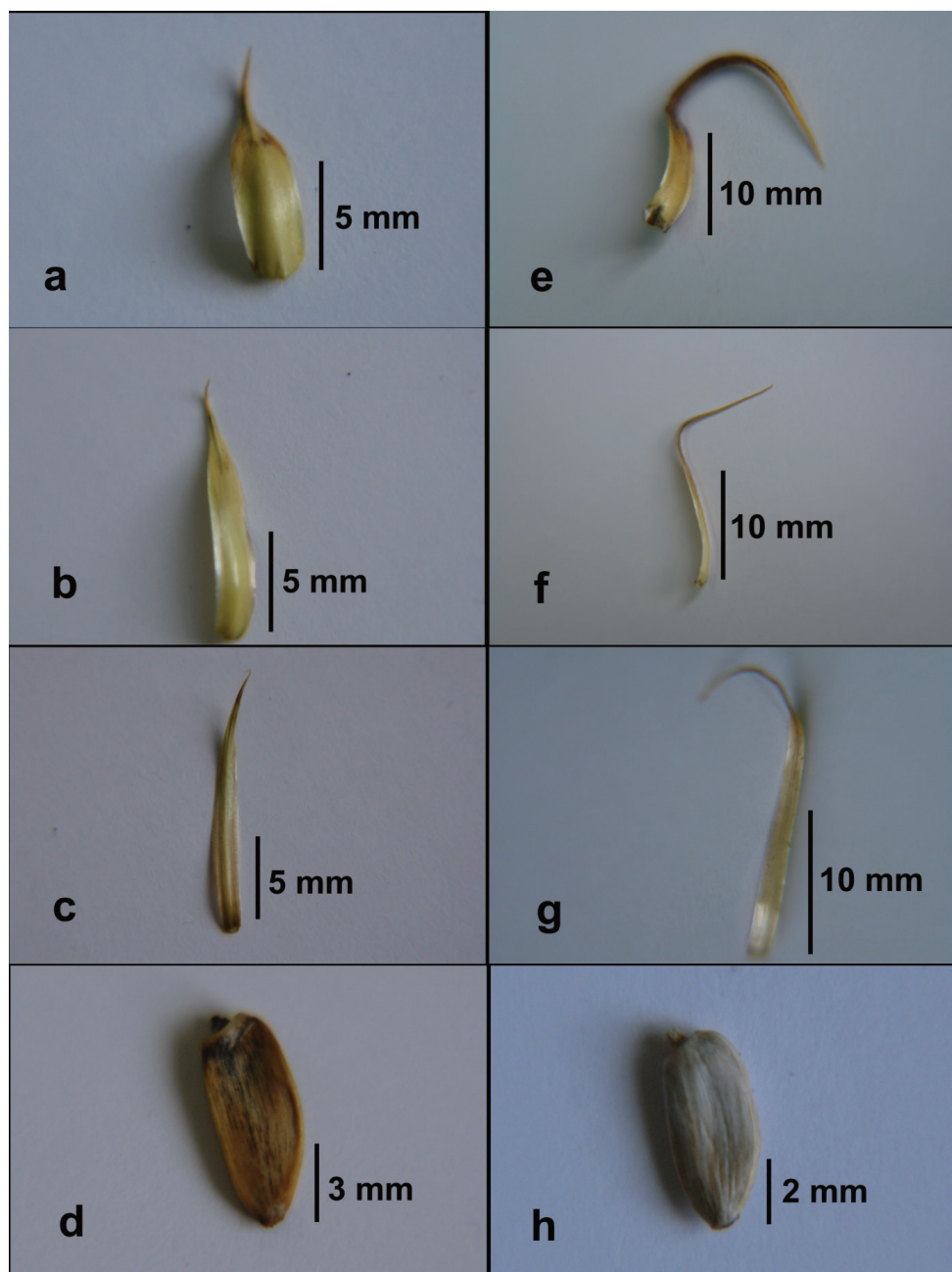
**Description.** Perennial, few stemmed from base, erect, 100–150 cm tall, unwinged but longitudinally striate, glabrous–glaucous, with few branches above, sterile shoots at the base. Basal leaves long-petiolate, petioles 10–18 cm long, winged, with large auricles; lamina broadly elliptic in outline, 15–25 × 9–14 cm, green, very sparsely spinulose–strigose above with 0.5–0.9 mm long, adpressed setae, ca 1–3 per 2 mm square, otherwise densely arachnoid; lower surface very sparsely arachnoid, 3/4 pinnatifid with 4–5-paired, 5–8 × 2–5 lateral and terminal lobes with stout 7–12 mm apical spine. Middle cauline leaves similar but smaller to basal leaves, petioles 1–6 cm long, lamina broadly elliptic in outline 4–8 × 2.5–4 cm long, lateral and terminal lobes 3/4 pinnatifid with 3–5 lobes, spinulose–strigose above with 0.7–1.2 mm long, adpressed setae, ca 4–6 per 2 mm square, otherwise densely arachnoid with stout 6–9 mm apical spine. Upper cauline leaves similar middle cauline leaves but smaller and sessile, shortly auriculate. Uppermost (involucral) leaves 2–3, 1–3 cm long, linear-lanceolate with sinuate-dentate margin, shorter than involucre, sessile. Capitula erect, 1(–2) on each branch, compound corymbose with 15–30-capitula, 26–35 mm × 2–30 mm, sessile or peduncles 1–2 cm long; involucre 15–25 × 20–30 mm, ovoid to subglobose; phyllaries 9–12-seriate, adpressed, glabrous, greenish–yellowish, ± erecto-reflexed, the outer 8–10 × 2–3 mm, with reflexed, ovate-oblong, 3–5 × 0.3–0.4 mm long apical spine;





**Figure 2.** *Cirsium semzinanicum* sp. nov.: **a** habits **b** basal leaf **c** upper leaf surface **d** capitulum. *Cirsium karduchorum*: **e** habit **f** basal leaf **g** upper leaf surface **h** capitulum.

the median  $10\text{--}14 \times 2\text{--}3$  mm long, with  $\pm$ reflexed, oblong-lanceolate,  $4\text{--}6 \times 0.2\text{--}0.3$  mm long apical spine; the inner  $16\text{--}21 \times 1\text{--}2$  mm, linear-lanceolate,  $5\text{--}7 \times 0.1\text{--}0.2$  mm long apical spine. Corolla pinkish-whitish, 26–32 mm long. lobed to  $1/4\text{--}1/5$ .



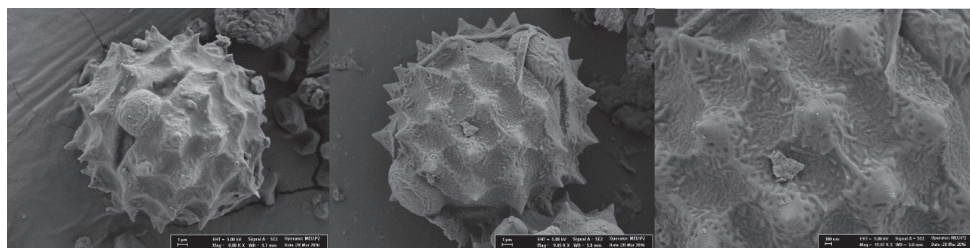
**Figure 3.** *Cirsium semzinanicum* sp. nov.: **a** outer phyllary **b** median phyllary **c** inner phyllary **d** achene. *Cirsium karduchorum*: **e** outer phyllary **f** median phyllary **g** inner phyllary **h** achene.

Style 15–19 mm long, exerted, shortly bilobed; filaments 5–7 mm long, densely hairy; Achenes brownish, 7–9 × 3–4 mm, oblong, asymmetric, slightly compressed. Pappus 16–18 mm long, plumose, dirty white, or light brown.

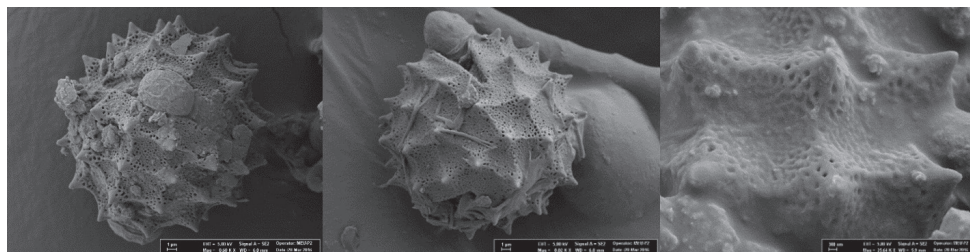


**Micromorphology.** Pollen grains are tricolporate, pollen shapes P/E: spheroidal, amb circular, polar axis  $36.72\ \mu\text{m}$ , equatorial axis  $36.60\ \mu\text{m}$ , exine  $1.62\ \mu\text{m}$  thick, ornamentation echinate. Tectum complete structured, spines conic and pointed, 5–6 per  $100\ \mu\text{m}^2$ ,  $2.83\ \mu\text{m}$  long, base diameter  $3.45\ \mu\text{m}$ , intine  $1.02\ \mu\text{m}$ , colpi margins are straight and distinct with pointed ends,  $10\ \mu\text{m}$  long (Fig. 4).

Pollen grains are tricolporate, pollen shapes P/E: spheroidal, amb circular, polar axis  $36.21\ \mu\text{m}$ , equatorial axis  $38.25\ \mu\text{m}$ , exine  $1.73\ \mu\text{m}$  thick, ornamentation echinate, tectum complete structured, perforate with spines conic and pointed, 5–6 per  $100\ \mu\text{m}^2$ ,  $2.70\ \mu\text{m}$  long, base diameter  $3.45\ \mu\text{m}$ , intine  $0.95\ \mu\text{m}$ , colpi margins are straight and distinct with pointed ends,  $17.5\ \mu\text{m}$  long (Fig. 5).



**Figure 4.** SEM Microphotograph of pollen of *Cirsium karduchorum*.



**Figure 5.** SEM Microphotograph of pollen of *Cirsium semzinanicum* sp. nov.

**Phenology.** Flowering and fruiting, from July to September.

**Vernacular name.** *Cirsium* spp. are called as “Kîvar” by the local people of the Hakkâri province (Firat 2013).

**Etymology.** The specific epithet is derived from the name of the Şemzinan (Şemdinli) province where type material was collected.

**Distribution and conservation status.** *Cirsium semzinanicum* is endemic to Hakkâri province in Turkey. The number of mature individuals is approximately 600 and is known from 3 locations (criteria B2ab [i.iii]). Therefore, it should be regarded as belonging to the IUCN Vulnerable (VU) threat category (IUCN 2014).

**Habitat and ecology.** The new species grows in Oak openings, slopes and eroded slopes at c. 1600–1900 m elevation with plants such as *Quercus libani*, *Daphne oleoides* subsp. *kurdica*, *Satureja bachtiarica*, *Dianthus orientalis*, *Echinops tournefortii*, *Astragalus* sp., *Eryngium billardierei*.

## Discussion

*Cirsium semzinanicum* is morphologically similar to *C. karduchorum* because of having similar habitus, lesser involucre and phyllaries, corolla and achen size, but it is easily distinguished from its stems 100–150 cm tall (not 50–100 cm tall, robust), basal leaves 15–25 × 9–14 cm “exculiding 10–18 petiole”, green, (not 30–40 × 15–20 cm “exculiding 15–20 petiole”, bluish-green), involucre 15–25 × 20–30 mm ovoid to subglobose (not 25–30 × (30–)40–50 mm depressed subglobose to broadly obovoid), phyllaries 9–12-seriate  $\pm$ erecto-reflexed (not 11–14-seriate reflexed or recurved), achen brownish 7–9 × 3–4 mm (not bright grayish brown 6–7.5 × 3 mm). Additional morphological differences between the new species and *C. karduchorum* are given in Table 1. Pollen morphology of both of species shows similarity. Pollen grains are isopolar, tricolporate, pollen shapes are spheroidal. Colpus length of *C. semzinanicum* is longer than *C. karduchorum*, while tectum completely structured, spines conic and pointed in *C. karduchorum*, the tectum complete structured, perforate with spines conic and pointed in *C. semzinanicum* (Figs 4 and 5).

## Additional specimens examined

*Cirsium semzinanicum*: Turkey. C10 Hakkâri: Şemdinli, above Benavok village, Gerdi şapatan region, rocky slopes, eroded slopes, 37°09'53"N, 44°26'00"E, 1692 m, 8 August 2013, *M. Fırat* 30332 (VANF! and Hb. M. Fırat); C10 Hakkâri: Şemdinli, Berxoşe region, rocky slopes, 37°20'62"N, 44°34'64"E, 2072 m, 4 August 2014, *M. Fırat* 30958 (Hb. M. Fırat)

*Cirsium karduchorum*: Turkey. C9 Hakkâri: Karadağ mountain above Hakkâri, eroded slopes, 2438 m, 13 August 1954, *Davis & Polunin* 24326 (ANK!, E! and W!); Hakkâri: from Hakkâri to Berçelan plateau, eroded slopes, 2150 m, 5 September 2007, *M. Fırat & T. Dirmenci* 3579 (Hb. M. Fırat); Hakkâri: from Hakkâri to Berçelan plateau, eroded slopes, 37°36'00"N, 43°44'50"E, 2130 m, 16 August 2008, *M. Fırat, T. Dirmenci, B. Yıldız* 16932 (Hb. M. Fırat); Hakkâri: Kotranis region, eroded slopes, 37°44'12"N, 43°44'51"E, 2277 m, 16 August 2011, *M. Fırat* 27767 (Hb. M. Fırat); Hakkâri: from Hakkâri to Berçelan plateau, eroded slopes, 37°36'00"N, 43°44'50"E, 2130 m, 16 August 2013, *M. Fırat* 30439 (Hb. M. Fırat).

## Acknowledgements

Thanks are due to Dr. Rıza Binzet for helping with pollen studies.

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# Taxonomic implications from morphological and anatomical studies in the section *Stenodiptera* from the genus *Grammosciadium* (Apiaceae)

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Academic editor: Pavel Stoev | Received 5 May 2016 | Accepted 27 July 2016 | Published 9 August 2016

**Citation:** Bani B, Ulusoy F, Karakaya MA, Koch MA (2016) Taxonomic implications from morphological and anatomical studies in the section *Stenodiptera* from the genus *Grammosciadium* (Apiaceae). *PhytoKeys* 68: 73–89. doi: 10.3897/phytokeys.68.9089

## Abstract

*Grammosciadium pterocarpum* subsp. *bilgilitii* and *G. pterocarpum* subsp. *sivasicum* from Turkey are herein described as two new subspecies, and the species *G. schischkinii* is synonymied under *G. pterocarpum* subsp. *pterocarpum*. Quantitative variation of morphological and anatomical characters have been analysed to provide discriminative characters between the taxa of section *Stenodiptera* and to provide a key to the species. The taxonomic status of the taxa has been discussed in light of these morphological and fruit anatomical data using multivariate statistics such as MANOVA and Principal Component Analysis. The results are also used to present a critical discussion of characters used to distinguish and determine different taxa within *Grammosciadium*. MANOVA showed that ten characters, except stylopodium and style length, differed significantly among the taxa, and the results were confirmed by Tukey tests and PCA analysis (except the character of fruit number). However, only ranges of the characters of sepal length, fruit length, fruit width, fruit width/wing width ratio, and width of fruit wing are not overlapped. Qualitative characters of petiolate stipular segments of lower leaves and presence of funicular oil ducts in transvers section of mericarps were found as diagnostic characters.

## Keywords

*Grammosciadium*, MANOVA, PCA, *Stenodiptera*, taxonomy, Turkey



## Introduction

The genus *Grammosciadium* DC. is a taxonomically difficult group of taxa within tribe Scandiceae, subtribe Careae (Apiaceae) (Spalik et al. 2001, Spalik and Downie 2007, Ajani et al. 2008). It falls within the “apioid superclade” (Spalik and Downie 2007) and is closely related with *Fuernroberia* K.Koch, *Carum* L. and other taxonomically critical taxa. As an example, in particular the genus *Carum* has been recently shown to be polyphyletic in its current circumscription, and its various members are even found in different tribes of subfamily Apioideae (Zakharova et al. 2012). The stem group age of Careae is of about 22 million years and has a center of origin in the Irano-Turanian region (Banasiak et al. 2013), and a long-term and spatio-temporally shared evolutionary history of the various lineages is likely. Accordingly, taxonomy and systematics of these groups of taxa are still unsolved, because morphological characters often display high levels of homoplasy, and phylogenetic inference is scarce (e.g. Downie et al. 2010, Zakharova et al. 2012).

The genus *Grammosciadium* is actually considered to be represented by two subgenera (*Grammosciadium* and *Caropodium* (Stapf & Wettst.) Tamamsch. & V.M.Vinogr.), which are further split into six sections in total (Bani and Koch 2015); however, this has been done with limited available phylogenetic evidence so far and applying an extreme taxonomically splitting concept above the species level. Subgenus *Caropodium* has been further splitted into two sections, namely sects. *Caropodium* and *Stenodiptera* (Koso-Pol.) Tamamsch. & V.M.Vinogr. (for a detailed overview refer to Bani and Koch 2015).

The section *Stenodiptera* of the genus *Grammosciadium* DC. has typical mericarps with winged lateral ribs. Additional important characters are the presence of erect stems, white flowers, and 4-6-pinnatisect, narrowly linear-elliptic leaves. The section *Stenodiptera* morphologically resembles section *Caropodium* because of the winged fruits, which are absent in other members of the genus *Grammosciadium* (Tamamschian and Vinogradova 1969a, b, 1970, Vinogradova 1995). However, the section *Caropodium* mainly differs from section *Stenodiptera* by its more branched and distinctly sulcate stems (Hedge and Lamond 1972).

Both sections are also anatomically different from each other: section *Caropodium* has funicular oil ducts in transvers section of mericarps (funicular oil ducts absent in section *Stenodiptera*) (Tamamschian and Vinogradova 1969a, b, 1970, Vinogradova 1995). Also fruit surface ornamentations is different in both sections (Bani et al. 2016). Since both of these sections are included in subgenus *Caropodium* of genus *Grammosciadium* in the actual literature (Tamamschian and Vinogradova 1969a, b, 1970, Vinogradova 1995), we still follow the concepts of sections and subgenera for pragmatic reasons, but being fully aware that this is an artificially splitting concept and is awaiting phylogenetic analysis (work in progress).

The section *Stenodiptera* has three species which are distributed mainly in Turkey, and are additionally found in adjacent areas of Anatolia and Iran (Hedge and Lamond 1972, Vinogradova 1970, Bani and Koch 2015). All members are characteristic plants

of the Irano-Turanian phytogeographic region (Takhtajan 1986, Hedge and Lamond 1972, Tamamschian 1987, Bani and Koch 2015). Among them, *Grammosciadium schischkinii* (V.M.Vinogr. & Tamamsch.) V.M.Vinogr. and *G. haussknechtii* Boiss. are endemic to Turkey and the third species, *G. pterocarpum* Boiss., can be regarded as subendemic plant with smaller distribution ranges outside Turkey (Vinogradova 1970, Pimenov and Leonov 2004, Pimenov and Sutory 2014).

After the first record of the genus *Grammosciadium* has been provided (Candolle 1829) Boissier (1844, 1872) described the three species *G. pterocarpum*, *G. haussknechtii* and *G. platycarpum* Boiss. & Hausskn. in addition to the other members of the genus [*G. daucooides* DC., *G. aucheri* Boiss. (currently accepted as synonym of *G. daucooides*), *G. scabridum* Boiss., *G. longilobum* Boiss. & Hausskn. (currently accepted as synonym of *G. scabridum*), and *G. macrodon* Boiss.]. Boissier indicated in his *Flora Orientalis*, that these three species are different from the other members of the genus by their winged mericarps (Boissier 1872). Later in 1886, *Caropodium* was established as a new genus with a single species (*C. meoides* Stapf and Wettst.) collected by Polak from Iran (Stapf and Wettstein 1886). However Bornmueller (1906) synonymised *C. meoides* under *G. platycarpum*. Freyn (1901) published a subspecies of *G. pterocarpum* from Turkey, namely subsp. *longipes*. The respective type material provides only flowering material and no fruits are available, and, therefore, this taxon is currently accepted as synonym of *G. pterocarpum* (Pimenov and Sutory 2014). Koso-Poliansky established *Stenodiptera* Koso-Pol. with all these three winged species as an independent genus (Koso-Poliansky 1914, 1915). Moreover he divided his genus *Stenodiptera* into two sections with *Euryptera* including *S. pterocarpa* (Boiss.) Koso-Pol. and *Eustenodiptera* including *S. haussknechtii* (Boiss.) Koso-Pol. and *S. platycarpa* (Boiss. & Hausskn.) Koso-Pol., which is mostly based on breadth of wings of mericarps (Koso-Poliansky 1914, 1915). Although a species named *S. armena* Bordz., which was collected from Turkey, was published by Bordzilowski (1915), Koso-Poliansky (1916) synonymised this species under *S. haussknechtii* one year later. According to Schischkin (1923) Koso-Poliansky's idea of establishing a new genus with the winged members was appropriate, but he added and highlighted an important taxonomic aspect: if a new genus has been established with winged fruited species separated from genus *Grammosciadium* sensu Boissier, then this must be with the earlier published name *Caropodium* rather than *Stenodiptera*. Hence, he reduced the genus *Stenodiptera* into synonymy of the genus *Caropodium* and also re-established *C. armenum* (Bordz.) Schischkin on species rank (Schischkin 1923). Vinogradova and Tamamschian (1968) accepted that "*C. armenum* is identical to *C. pterocarpum* (Boiss.) Schischkin" and they also described *C. pterocarpum* var. *schischkinii* V.M.Vinogr. & Tamamsch. as a new taxon based on a specimen collected from Turkey in 1916. This variety was distinguished by its broader and more undulated wings of the fruits (Vinogradova and Tamamschian 1968). Later Tamamschian and Vinogradova (1969b and 1970) reduced *Caropodium* to the rank of a subgenus and recognized section *Stenodiptera* including the taxa *G. pterocarpum*, *G. pterocarpum* var. *schischkinii* and *G. haussknechtii* within this subgenus. In *Flora of Turkey*, Hedge and Lamond (1972) presented *G. pterocarpum* var.

*schischkinii* and *G. haussknechtii* as synonyms of *G. pterocarpum*. Finally, Vinogradova (1995) increased *G. schischkinii* to species rank and also *G. haussknechtii* was accepted as independent species again.

In summary, there are five taxa in section *Stenodiptera* that have been described so far: *Grammosciadium pterocarpum*, *G. haussknechtii*, *G. pterocarpum* subsp. *longipes* Freyn, *G. armenum* and *G. schischkinii*. However, for more than a whole century botanists are wondering of how to distinguish and how to classify them.

The taxa are morphologically very similar to each other and original descriptions are often based on insufficient material (*Grammosciadium haussknechtii*, *G. schischkinii* and *G. pterocarpum* subsp. *longipes* only known from the types, *G. armenum* is known from the type and some very few additional individuals).

According to the most recent treatments, *Grammosciadium pterocarpum*, *G. haussknechtii* and *G. schischkinii* are currently accepted as distinct species and the other taxa of *G. armenum* and *G. pterocarpum* subsp. *longipes* were synonymised under *G. pterocarpum* (Vinogradova 1995, Pimenov and Sutory 2014, Bani and Koch 2015).

Numerous specimens were collected from the whole distribution areas, which reflect the morphological and presumably also genetic variation limits of the taxa of section *Stenodiptera* in Turkey for the purpose of a phylogenetic-taxonomic revision of the members of the whole genus *Grammosciadium* between the years of 2011 and 2014. We observed a large number of intermediate forms during our field work. Moreover, we encountered many problems during the identification process of the specimens. The previous diagnostic characters mostly overlapped and some of the populations and specimens were not identified unambiguously. Additionally two populations were discovered recently from Turkey (one is from Sivas province, the other one is from Eskişehir province), and although they are very similar to *Grammosciadium pterocarpum* in terms of their habits, these populations do not match with available species descriptions.

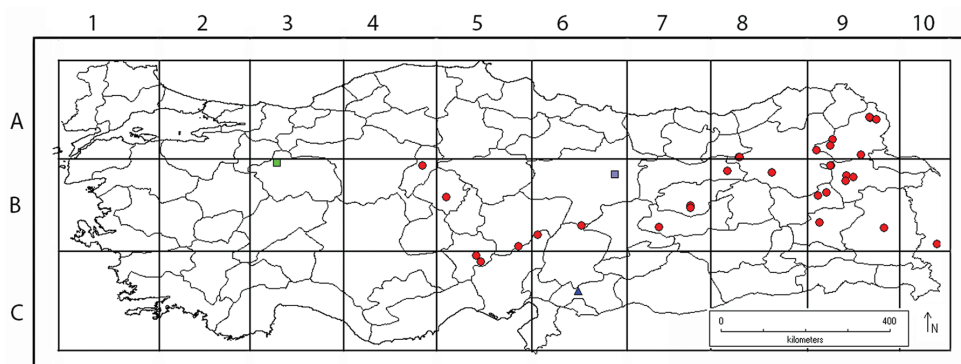
The aims of this study were (1) to examine quantitatively pattern of morphological variation of the members of section *Stenodiptera* based on a representative and population-based sampling with 133 individuals from 17 populations in total, (2) to determine diagnostic morphological and anatomical characters for correct discrimination of the putative taxa, and (3) to provide a taxonomic concept for the newly discovered morphotypes.

## Materials and methods

133 specimens (individuals) from the members of section *Stenodiptera* were examined and used as operational taxonomic units (OTUs) in the multivariate analyses. *Grammosciadium pterocarpum* (102 individuals from 14 populations), *G. haussknechtii* (11 individuals from one population; because it is known from only one locality), and populations of two new subspecies collected from Eskişehir (*B. Bani* 6983) and Sivas (*B. Bani* 6985) provinces of Turkey (10 individuals from one population, respectively). These specimens, which are

**Table 1.** Morphological characters and their statistics (mean  $\pm$  standard deviation (SD), min-max range and range with 95% CI: confidence interval) for the four groups (N: number of individuals used for morphological measurements). Characters that differ significantly ( $P < 0.05$ ) among the taxa as shown by MANOVA are marked with asterisks. Superscript letters indicate the results of Tukey tests, with taxa in the same homogeneous subset ( $P < 0.05$ ) sharing the same letter.

Characters			<i>Grammosciadium pterocarpum</i>			<i>G. haussknechtii</i> N=11
			subsp. pterocarpum (incl. the type specimen of <i>G.</i> <i>schischkinii</i> and one accession of <i>G. armenum</i> ) N=102	subsp. <i>sivasicum</i> N=10	subsp. <i>bilgili</i> N=10	
1	Ray number*	mean $\pm$ SD min-max 95% CI	9.9 $\pm$ 1.7 <sup>C</sup> 6.0–15.0 9.6–10.2	8.5 $\pm$ 1.1 <sup>BC</sup> 7.0–11.0 7.4–9.5	6.8 $\pm$ 1.3 <sup>A</sup> 5.0–9.0 5.7–7.8	8.2 $\pm$ 1.6 <sup>AB</sup> 6.0–10.0 7.2–9.2
2	Ray length (cm)*	mean $\pm$ SD min-max 95% CI	4.7 $\pm$ 1.34 <sup>B</sup> 1.8–9.4 4.5–5.0	3.2 $\pm$ 0.86 <sup>A</sup> 2.0–5.0 2.4–4.0	4.2 $\pm$ 0.86 <sup>AB</sup> 3.5–5.0 3.4–5.0	4.8 $\pm$ 0.73 <sup>B</sup> 3.8–6.2 4.0–5.5
3	Fruiting pedicel length (mm)*	mean $\pm$ SD min-max 95% CI	5.2 $\pm$ 1.37 <sup>B</sup> 3–10 5.0–5.5	3.9 $\pm$ 0.92 <sup>A</sup> 2–5 3.1–4.7	4.2 $\pm$ 0.42 <sup>AB</sup> 3.5–5.0 3.4–5.0	3.3 $\pm$ 1.05 <sup>A</sup> 2–6 2.5–4.1
4	Fruit number*	mean $\pm$ SD min-max 95% CI	6.7 $\pm$ 2.36 <sup>A</sup> 2–13 6.2–7.1	6.3 $\pm$ 2.3 <sup>A</sup> 2–10 4.8–7.7	11.4 $\pm$ 2.17 <sup>B</sup> 9–13 9.9–12.8	7.9 $\pm$ 1.57 <sup>A</sup> 6–11 6.5–9.2
5	Fruit length (cm)*	mean $\pm$ SD min-max 95% CI	1.10 $\pm$ 0.15 <sup>B</sup> 0.7–1.5 1.10–1.16	1.00 $\pm$ 0.05 <sup>A</sup> 0.9–1.0 0.9–1.11	0.8 $\pm$ 0.94 <sup>A</sup> 0.7–1.1 0.7–0.97	1.3 $\pm$ 1.15 <sup>C</sup> 1.2–1.7 1.2–1.4
6	Fruit width (mm)*	mean $\pm$ SD min-max 95% CI	1.0 $\pm$ 0.16 <sup>A</sup> 0.8–1.5 1.0–1.1	1.0 $\pm$ 0.03 <sup>A</sup> 1.0–1.1 0.9–1.1	1.0 $\pm$ 0.00 <sup>A</sup> 1.0–1.0 0.8–1.1	1.32 $\pm$ 0.23 <sup>B</sup> 1.0–1.6 1.2–1.4
7	Fruit width/ length ratio*	mean $\pm$ SD min-max 95% CI	1.0 $\pm$ 0.18 <sup>AB</sup> 0.6–1.4 1.0–1.1	0.9 $\pm$ 0.06 <sup>AB</sup> 0.9–1.0 0.8–1.0	0.8 $\pm$ 0.09 <sup>A</sup> 0.7–1.1 0.7–0.9	1.07 $\pm$ 0.18 <sup>B</sup> 0.8–1.4 0.9–1.1
8	Fruit wing width (mm)*	mean $\pm$ SD min-max 95% CI	1.7 $\pm$ 0.5 <sup>A</sup> 1–3.1 1.6–1.8	0.85 $\pm$ 0.19 <sup>B</sup> 0.5–1.1 0.5–1.1	0.6 $\pm$ 0.1 <sup>B</sup> 0.5–0.8 0.3–0.9	0.5 $\pm$ 0.0 <sup>B</sup> 0.4–0.6 0.2–0.7
9	Fruit width/ wing width ratio*	mean $\pm$ SD min-max 95% CI	0.6 $\pm$ 0.18 <sup>A</sup> 0.3–1.2 0.60–0.61	1.2 $\pm$ 0.34 <sup>B</sup> 0.9–2.0 1.0–1.4	1.6 $\pm$ 0.31 <sup>C</sup> 1.2–2.0 1.5–1.8	2.6 $\pm$ 0.5 <sup>D</sup> 2.0–3.7 2.5–2.8
10	Sepal length (mm)*	mean $\pm$ SD min-max 95% CI	0.5 $\pm$ 0.25 <sup>B</sup> 0.1–1.65 0.5–0.59	0.4 $\pm$ 0.12 <sup>AB</sup> 0.1–0.5 0.3–0.67	0.3 $\pm$ 0.12 <sup>A</sup> 0.1–0.5 0.1–0.44	0.8 $\pm$ 0.20 <sup>C</sup> 0.5–1.0 0.7–1.00
11	Stylopodium length (mm)	mean $\pm$ SD min-max 95% CI	0.5 $\pm$ 0.07 <sup>A</sup> 0.2–0.7 0.51–0.54	0.5 $\pm$ 0.03 <sup>A</sup> 0.5–0.6 0.4–0.5	0.5 $\pm$ 0.00 <sup>A</sup> 0.5–0.5 0.4–0.5	0.5 $\pm$ 0.09 <sup>A</sup> 0.5–0.8 0.50–0.6
12	Style length (mm)	mean $\pm$ SD min-max 95% CI	0.9 $\pm$ 0.15 <sup>A</sup> 0.6–1.50 0.9–0.1	1.0 $\pm$ 0.00 <sup>A</sup> 0.9–1.0 1.0–1.0	0.9 $\pm$ 0.08 <sup>A</sup> 0.8–1.0 0.8–1.0	1.0 $\pm$ 0.03 <sup>A</sup> 1–1.1 1.0–1.0



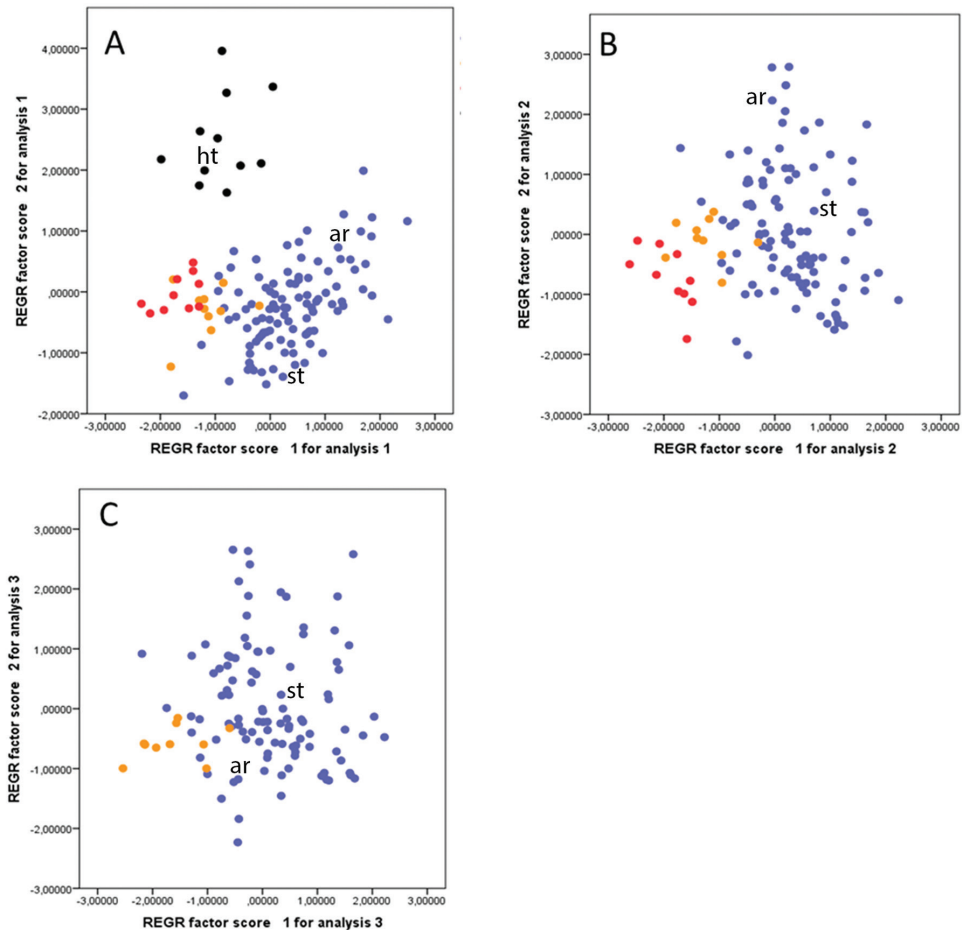
**Figure 1.** Distribution map of the populations and taxa of section *Stenodiptera* in Turkey analysed herein (*Grammosciadium pterocarpum* subsp. *pterocarpum* ●, *G. pterocarpum* subsp. *bilgili* ■, *G. pterocarpum* subsp. *sivasicum* ■, *G. haussknechtii* ▲).

listed in the Suppl. material 1 and marked with asteriks, include the types of two taxa (*G. haussknechtii* and *G. schischkinii* see Table 1) and reflected the morphological variability exhibited by the species and populations from throughout its geographic range (Figure 1). Characters used in the multivariate analyses were based on previous taxonomic treatments and our own examination of collected specimens. 12 quantitative characters were selected (Table 1). Characters were scored at the same developmental stage on each plant (fruiting stage). Measurements were taken from the best developed infructescence available on a given specimen. Three data sets were constructed and analyzed: (1) a matrix which included all specimens (133 OTUs and 12 characters), (2) and (3) were created by excluding the OTU's of *G. haussknechtii* and the new subspecies (collected from Eskişehir) from data set 1, respectively. The MANOVA was performed with IBM SPSS Statistics for Windows, Version 20.0. (Armonk, NY), using "Type III sum of squares", and was followed by "Tukey tests" using the harmonic mean sample size to determine patterns of significant differences between the taxa. The F-test was used to determine which, if any, characters differed significantly among the taxa studied. The PCA was conducted also using IBM SPSS Statistics for Windows, Version 20.0. (Armonk, NY). Identical parameters and procedures were used for all analyses on the three different data sets.

## Results

### Statistical analysis

Descriptive statistics for the 12 morphological characters are presented in Table 1. The MANOVA showed that 10 characters, except stylopodium and style length, differed significantly ( $P < 0.05$ ) among the taxa and newly discovered populations, and this was confirmed by Tukey tests (Table 1). Furthermore, only ranges of the characters of sepal length, fruit length, fruit width, Fruit width/wing width ratio, width of fruit wing are not overlapped. Other six characters are overlapped (Table 1).



**Figure 2.** PCA 1-3 with 12 morphological characters. **A** Dataset (1): All the taxa **B** Dataset (2) *Grammosciadium pterocarpum* subsp. *pterocarpum*, subsp. *bilgiliti* and subsp. *sivasicum* **C** Dataset (3) subsp. *pterocarpum* and subsp. *sivasicum*. *Grammosciadium haussknechtii* (●), *G. pterocarpum* subsp. *pterocarpum* (●), subsp. *bilgiliti* (●) and subsp. *sivasicum* (●) st: type specimen of *G. schischinii*, ar: *G. armenum*, ht: type specimen of *G. haussknechtii*.

The three Principal Component Analyses of the different datasets, which were performed for OTU's of *Grammosciadium haussknechtii*, *G. pterocarpum*, subsp. *bilgiliti* and subsp. *sivasicum* with fruiting characters are given in Figure 2 (the first PCA: 12 characters for 133 plots of all the taxa, the second PCA: 12 characters for 122 plots by excluding the plots of *G. haussknechtii*, the third PCA: 12 characters for 112 plots by excluding the plots of subsp. *bilgiliti*). The results of the PCA analyses are as follows: the first two components account for a total of (23.78% and 17.82%) 41.60% (dataset 1), (29.90% and 14.90%) 44.80% (dataset 2) and (27.08% and 15.55%) 42.63% (dataset 3) of the variance, respectively. The factor loadings of the first two components for each PCA are given in Table 2.



**Table 2.** Factor loadings for the 12 fruiting characters on the first two components for the 84 OTUs of section *Stenodiptera* members. The values with larger magnitudes are shown in bold for each PC.

	1 <sup>st</sup> PCA		2 <sup>nd</sup> PCA		3 <sup>rd</sup> PCA	
	PC1	PC2	PC1	PC2	PC1	PC2
Sepal length	.286	<b>.660</b>	.441	.125	.293	.167
Fruit length	<b>.550</b>	.702	<b>.805</b>	-.250	<b>.779</b>	-.173
Fruit width	.020	.511	.248	<b>.722</b>	.129	<b>.791</b>
Fruit width/length ratio	<b>.539</b>	.206	<b>.545</b>	-.766	<b>.566</b>	-.768
Fruit width/wing ratio	-.647	<b>.675</b>	-.815	-.053	-.747	-.049
Fruits wing width	<b>.780</b>	-.367	<b>.806</b>	.127	<b>.752</b>	.210
Stylopodium length	.182	.028	.213	.021	.148	.058
Style length	.062	-.046	.079	.021	.035	-.002
Fruiting pedicel length	<b>.634</b>	-.152	<b>.580</b>	.121	<b>.553</b>	.285
Ray length	<b>.710</b>	.394	<b>.707</b>	-.202	<b>.814</b>	.060
Fruit number	-.145	.222	-.166	-.414	.308	-.187
Ray number	.433	-.292	.396	<b>.597</b>	.103	<b>.650</b>

Description of two new subspecies

Based on the morphometric results we can significantly distinguish and characterize the following new subspecies of *Grammosciadium pterocarpum*:

*Grammosciadium pterocarpum* Boiss. subsp. *bilgili* B.Bani, subsp. n.

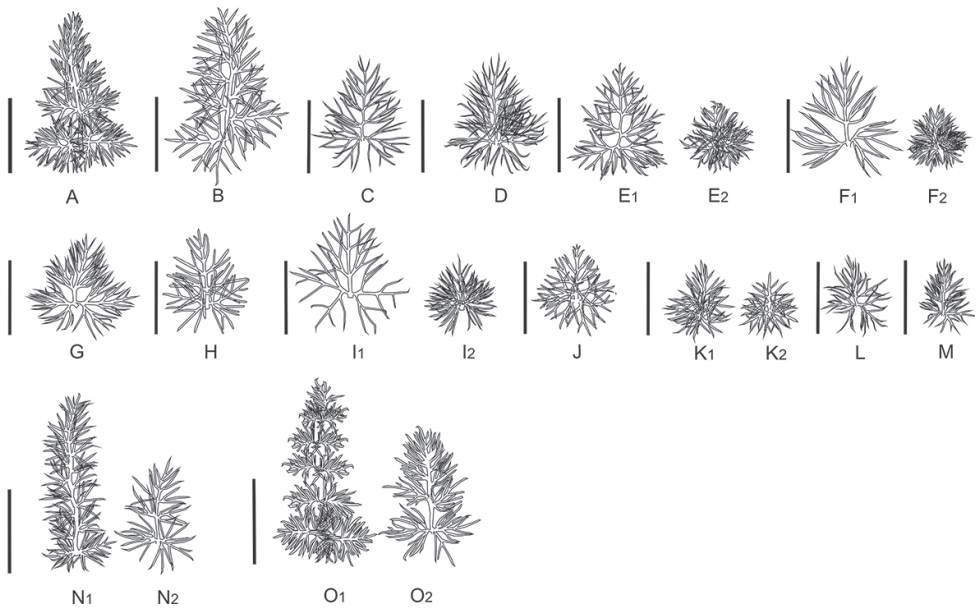
urn:lsid:ipni.org:names:60472798-2

Figs 3–6

**Diagnosis.** The new subspecies is similar to *Grammosciadium pterocarpum* subsp. *pterocarpum*, but mainly differs from it by the fruits with the narrower wings of lateral ribs (0.5–0.8 mm, not 1–3.1 mm).

**Type.** Turkey. B3 Eskişehir: around of Yarımca village, clearings of oak woodland, 1250 m, 20.06.2014, *B.Bani* 6983, *E.D.Güner* (holotype GAZI!).

Perennial, erect, branched (at third node or above) herbs. Rootstock with remain- ing of elder leaf bases. Stem 35–50 cm long and 0.15–0.40 mm broad (just below the first node), angular, prominently or slightly striate, always smooth, white, green or purplish at base. Basal leaves petiolate; petioles 2.5–8 cm long, broadly sheathed towards base, always smooth, prominently ribbed, canaliculate or flat, angular or tri- angular. Lamina 5–pinnatisect, 5.5–12 cm long, glabrous, linear-elliptic in outline; primary segments 0.5–1.3 cm long, distance between primary segments 0.4–1.5 cm long; ultimate segments 2–4 mm long, mucronate at apex. Lower leaf sheaths mostly connate at base, with stipular segments at margins; stipular segments sessile or shortly petiolate. Upper leaves similar but decreasing in size upwards. Bracts 3–6, trisect or up to 1–3–pinnatisect, 0.6–1.6 cm long; rarely narrowly sheathed; segments 0.3–0.7 cm,



**Figure 3.** Primer segments of basal leaves in the section *Stenodiptera*. **A–M** *Grammosciadium pterocarpum* subsp. *pterocarpum* (**A** B.Bani 6966 **D** B.Bani 6825 **E** B.Bani 6820 **F** B.Bani 6997 **G** B.Bani 6999 **H** B.Bani 6994 **I** B.Bani 6931 **J** B.Bani 6977 **K** B.Bani 6976 **L** B.Bani 6932 **M** B.Bani 6926) **B** subsp. *bilgili* (B.Bani 6983) **C** subsp. *sivasicum* (B.Bani 6985) **N** *G. haussknechtii* (B.Bani 6903) **O** *G. platycarpum* (B.Bani 6810). Scale bar represents 5 mm.

always smooth, mucronate at apex. Rays 5–9, unequal, 2.5–5.5 cm. Bracteoles 5–7, trisect to 1–pinnatisect, 0.35–0.65 cm long, always smooth. Flowers male only or hermaphrodite, 8–18, slightly radiate. Pedicels of male flowers 0.15–0.6 cm long. Sepals 0.14–0.5 mm long, smooth, patent or erect. Petals cordate, with long central oil duct, largest petal 2.8–3.5 mm long. Stamens 5; longest filament 1.3–2 mm long. Fruiting pedicels 3.5–5 mm long. Fruits, 9–16 per umbellule, oblong or narrowly lanceolate, 0.7–1.1 × 0.1 cm; each mericarp has 5 primary ribs and four secondary ribs alternating with the primary ribs; lateral ribs winged; wings 0.5–0.8 mm. Stylopodium minute up to 0.5 mm long. Styles divergent, 0.8–1 mm, uninerved on outer side. Flowering May–June; fruiting June–July.

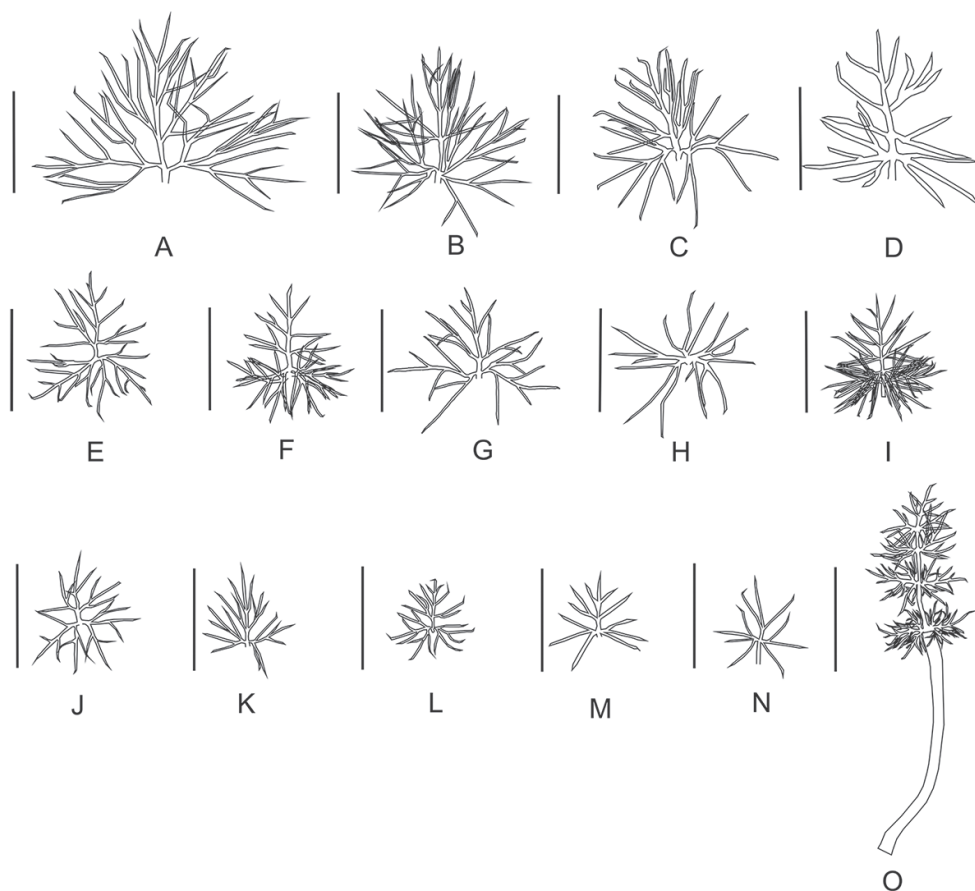
**Etymology.** We dedicate this new subspecies in memory of our dear colleague Dr. Bilgehan Bilgili who passed away in 2015.

***Grammosciadium pterocarpum* Boiss. subsp. *sivasicum* B.Bani, subsp. n.**

urn:lsid:ipni.org:names:60472799-2

Figs 3–6

**Diagnosis.** The new subspecies is similar to *Grammosciadium pterocarpum* subsp. *pterocarpum* and *G. platycarpum*, but mainly differs from *G. pterocarpum* subsp. *pterocar-*

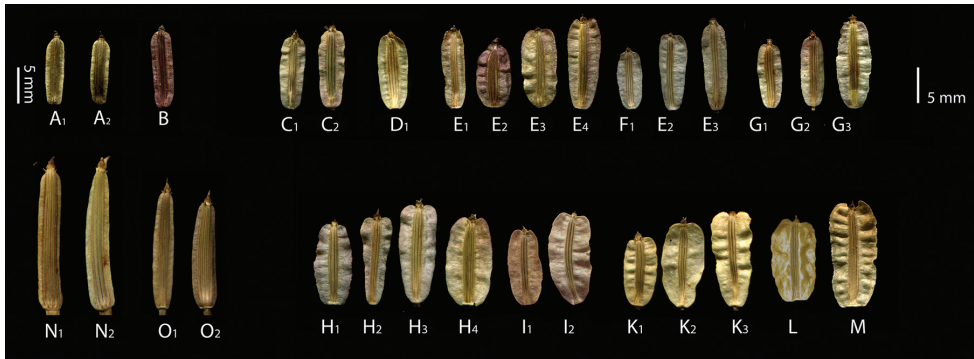


**Figure 4.** Stipular segments of lower leaf sheaths in the section *Stenodiptera*. **A–M** *Grammosciadium pterocarpum* subsp. *pterocarpum* (**A** B.Bani 6969 **B** B.Bani 6932 **D** B.Bani 6966 **E** B.Bani 6825 **F** B.Bani 6820 **G** B.Bani 6977 **H** B.Bani 6994 **J** B.Bani 6912 **K** B.Bani 6926 **L** B.Bani 6931 **M** B.Bani 6997) **C** subsp. *bilgii* (B.Bani 6983) **I** subsp. *sivasicum* (B.B.6985) **N** *G. haussknechtii* (B.Bani 6903), **O**: *G. platycarpum* (B.Bani 6810). Scale bar represents 5 mm.

*pum* by the fruits with two oil ducts in funiculus, and it differs from *Grammosciadium platycarpum* by its shorter fruits (0.9–1.1 cm, not 1.2–1.8 cm) and lower leaf sheaths without distinctly stalked stipular segments.

**Type.** Turkey. B6 Sivas: Zara, around of Taşgöze village, steppe, 1920 m, 07.07.2014, B.Bani 6985, M.A.Karakaya (holotype GAZI!).

Perennial, erect, branched (at third node or above) or unbranched herbs. Root-stock with remaining of elder leaf bases. Stem 23–46 cm long and 0.2–0.4 mm broad (just below the first node), angular, prominently or slightly striate, scabrid or smooth, white, green or purplish at base. Basal leaves petiolate; petioles 6.5–11.5 cm long, broadly sheathed towards base; always smooth, prominently ribbed, canaliculate or flat, angular or triangular. Lamina 4–5-pinnatisect, 5.5–12 cm long, glabrous, gla-

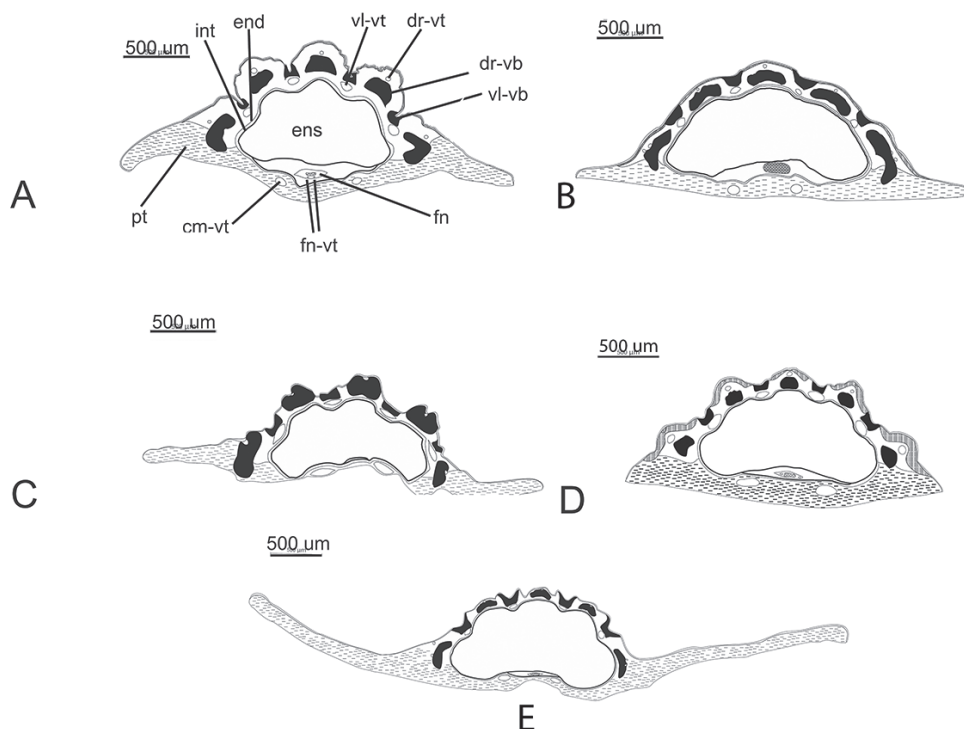


**Figure 5.** Fruit variations in the section *Stenodiptera* members. **A** *Grammosciadium pterocarpum* subsp. *bilgili* (B.Bani 6983) **B** *G. pterocarpum* subsp. *sivasicum* (B.Bani 6985) **C–M** subsp. *pterocarpum* (**C** B. Bani 6969 **D** B.Bani 6926 **E** B.Bani 6932 **F** B.Bani 6999 **G** B.Bani 6994 **H** B.Bani 6977 **I** B.Bani 6885 **K** B.Bani 6931 **L** Type of *G. schischkinii* **M** B.Bani 6872) **N** *G. platycarpum* (B.Bani 6850) **O** *G. haussknechtii* (B.Bani 6903).

brous, linear-elliptic in outline; primary segments 0.4–1 cm long, distance between primary segments 0.7–1.3 cm long; ultimate segments 3–5 mm long, mucronate at apex. Upper leaves similar but decreasing in size upwards. Bracts 3–6, trisect or up to 1–2 pinnatisect, (0.7–2.3 cm long; never with hyaline margin; segments 0.3–0.75 cm, always glabrous, mucronate at apex. Rays 7–11, unequal, 2–5 cm. Bracteoles 5–8, mostly simple and rarely trisect or 1-pinnatisect, 0.3–1 cm long, always glabrous. Flowers male only or hermaphrodite, 8–14, slightly radiate. Pedicels of male flowers 0.3–0.5 cm long. Sepals 0.1–0.5 mm long, smooth, patent or erect. Petals cordate, with long central oil duct, largest petal to 3 mm long. Stamens 5; longest filament to 1.5 mm long. Fruiting pedicels 2–5 mm long. Fruits, 2–10 per umbellule, linear-oblong, 0.9–1.1×0.1–0.11 cm long; each mericarp has 5 primary ribs and four secondary ribs alternating with the primary ribs; lateral ribs winged; wings 0.5–1.1 mm. Stylopodium minute up to 0.6 mm long. Styles divergent, ca. 1 mm, uninerved on outer side. Flowering May–June; fruiting June–July.

**Etymology.** The epithet of this new subspecies derived from Sivas province of Turkey where this taxon is distributed.

Primary leaf segments of basal leaves are shown in Figure 3. *Grammosciadium haussknechtii* is distinctly different with the linear oblong leaf segments. *G. platycarpum*, *G. pterocarpum* subsp. *bilgili* and one population of *G. pterocarpum* subsp. *pterocarpum* (B.Bani 6966) have lanceolate primary segments. The others do have ovate-lanceolate to orbicular leaf shapes. Stipular segments which are shown in Figure 4 are quite similar each other except stipular segments of *G. platycarpum* which are long pedicellate. As shown in Figure 5, the fruits are ordered from narrowly winged to broadly winged one. The width of fruit wings is very highly variable character. It is impossible to distinguish *G. schischkinii* with wider fruit wings which was previously used as diagnostic character. This species has clearly similar fruits with fruits of subsp. *ptero-*



**Figure 6.** Transvers section of mericarps. **A** *Grammosciadium pterocarpum* subsp. *sivasicum* (B.Bani 6985) **B** *G. haussknechtii* (B.Bani 6903) **C** *G. pterocarpum* subsp. *bilgii* (B.Bani 6983) **D** *G. platycarpum* (B.Bani 6810) **E** *G. pterocarpum* subsp. *pterocarpum* (B.Bani 6932). cm-vt: commissural vittae. dr-vb: dorsal vascular bundle. dr-vt: dorsal vittae. end: endepidermis. ens: endosperm. fn: funiculus. fn-vt: funicular vittae. int: integument. pt: pterenchyma. vl-vb: vallecular vascular bundle. vl-vt: vallecular vittae.

*carpum*. *G. haussknechtii*, *G. platycarpum* and *G. pterocarpum* subsp. *bilgii* and subsp. *sivasicum* have relatively narrow winged fruits than the fruits of subsp. *pterocarpum*. Figure 4 present the fruit anatomical structure of all taxa in the section *Stenodiptera*. *G. platycarpum* and *G. pterocarpum* subsp. *sivasicum* share similar character of presence of two funicular oil ducts in transverse section of mericarps (Figure 6).

## Discussion

Historically the species have been distinguished by a combination of quantitative and qualitative characters (Boissier 1844, 1872, Freyn 1901, Bordzilowski 1915, Vinogradova and Tamamschian 1968, Tamamschian and Vinogradova 1969, 1969a, 1970, Vinogradova 1995, Bani and Koch 2015, Bani et al. 2016).

Boissier (1844) described *Grammosciadium pterocarpum* with the following diagnosis based on Aucher's specimen (with immature fruits) collected from Turkey: stem

8–13 cm, fibrous collar present at base, leaves 4.5×0.6 cm and resembling the leaves of *Carum verticillatum* W.D.J.Koch. Fruits are nearly 1 cm long, and fruit wings are 1.5 mm broad. *G. haussknechtii*: stems are 30 cm long, leaves are 8 cm long and less than 0.4 cm broad, fruits are 1–1.2 cm long. *G. haussknechtii* is close to *G. pterocarpum*, but it differs by its narrower leaves, narrower wings of fruits and shorter calyx teeth (Boissier 1872). This species known only from type material located with various herbaria (WU, E, K, LE). *G. pterocarpum* subsp. *longipes* was described by Frey in 1901 based on the specimens which were collected by Kronenburg from Van province in Turkey in 1889 (Frey 1901). The lectotype was designated by Pimenov and Sutory (2014) from the herbaria of BRNM (lectotype) and WU (isotype). The diagnostic characters are as follows: large pointed calyx teeth and longer pedicels (these specimens have longer pedicels in contrast to the other specimens of *G. pterocarpum*) (Frey 1901). This subspecies is currently under synonymy of *G. pterocarpum* (Pimenov and Sutory 2014). According to Bordzilowski (1915) in its original diagnosis *G. armenum* is close to *G. pterocarpum* and *G. haussknechtii*. It differs from both, by its broader leaves, shorter fruits and marginate stylopodium. It slightly differs from *G. pterocarpum* by larger stature, rotundate fruit apex (not truncate) and narrower wings of mericarps, and it differs from *G. haussknechtii* in having broader wings of fruits. The type of this species is deposited in KW and few vouchers are found in LE herbarium. *G. schischkinii* is close to *G. pterocarpum* but differs from it in having more undulated and broader fruit wings (2.5–3.5 mm not 1.5–2 mm), fewer number of fruits (1–4 compared to 4–9), and a more branched stem (Vinogradova 1995). This species has been described based on one specimen only and is kept in LE herbarium. There is no any other collection.

Although the characters of fruit number, width of fruit wings and undulation of wings have been used previously to distinguish *Grammosciadium schischkinii* from the other species (Vinogradova 1995), our data demonstrates that the measurements obtained from the type specimen of *G. schischkinii* clearly overlapped with characters of *G. pterocarpum* subsp. *pterocarpum* (Table 1). Also undulation of fruit wings is common in nearly all populations. We also achieved similar results for *G. armenum*, which has been previously recognized as synonym of *G. pterocarpum*. We did not find any qualitative or quantitative character to distinguish these species. The type of *G. pterocarpum* subsp. *longipes* is also identical with subsp. *pterocarpum*. Length of calyx teeth and length of pedicels, which has been used as diagnostic characters (Frey 1901) are overlapping with the other taxa and do not allow reliable differentiation. It is obvious from this study that sufficient fruiting and flowering material is needed for its proper taxonomic treatment.

MANOVA demonstrated that most of the characters differ statistically among the groups (Table 1), and the range values of the various characters (sepal length, fruit length, fruit width, fruit width/wing ratio and width of fruit wings) can be used to distinguish the various taxa significantly. Fruit length and sepal length separate *Grammosciadium haussknechtii* from subsp. *sivasicum* and subsp. *bilgii*. Fruit width is distinguishing between *G. haussknechtii* and subsp. *bilgii*. *G. haussknechtii* is clearly different from the all others by its higher Fruit width/wing width ratio also separates



subsp. *bilgilitii* from subsp. *pterocarpum*. Another diagnostic character is width of fruit wings, which discriminates subsp. *pterocarpum* from all other taxa.

According to PCA on dataset 1 (complete dataset), individuals of *G. haussknechtii* are clearly distinguished from all other taxa as a distinct group mostly because of their larger ratio of fruit width/wing width (2–3.7 mm not 0.3–2 mm). Fruit length, fruit width/length ratio, fruit width/wing ratio, fruiting pedicel and ray length are the most discriminative characters with the largest eigenvalues (Figure 2A, Table 2). With PCA on dataset 2 (subsp. *pterocarpum*, subsp. *sivasicum* and subsp. *bilgilitii*) individuals of subsp. *bilgilitii*, are clearly distinguished from subsp. *pterocarpum* by the narrower wings of fruit (0.5–0.8 mm, not 1–3.1 mm). However, individuals of subsp. *sivasicum* are placed with an intermediate position between these two groups (Figure 2B). Fruit length, fruit width/length ratio, width of fruit wing, fruiting pedicel, ray length, fruit number and ray number are the characters with highest eigenvalues (Table 2). Similarly, the PCA on the third dataset (subsp. *pterocarpum* and subsp. *sivasicum*) separates both taxa from each other, but few individuals of both groups are overlapping (Figure 2C). PCA on dataset 2 and 3 show the same discriminative characters (except fruit number) (Table 2). But as indicated above, subspecies *sivasicum* has two funicular oil ducts in the funiculus in transverse section of mericarps resembling a unique character within the section *Stenodiptera*.

#### Currently accepted taxa with the synonyms and a key to the members of section *Stenodiptera*

- 1 Funicular oil duct present in transverse section of mericarps ..... ***Grammosciadium pterocarpum* subsp. *sivasicum***
- Funicular oil duct absent in transverse section of mericarps ..... **2**
- 2 Fruit wings more than 1 mm ..... ***Grammosciadium pterocarpum* subsp. *pterocarpum***
- Fruit wings less than 1 mm ..... **3**
- 3 Fertile part of fruits 0.7–1.1×1 mm ..... ***Grammosciadium pterocarpum* subsp. *bilgilitii***
- Fertile part of fruits 1.2–1.7×1–1.6 mm ... ***Grammosciadium haussknechtii***

**1. *Grammosciadium pterocarpum* Boiss. subsp. *pterocarpum*** in Ann. Sci. Nat. ser. 3, 2: 68 (1844).

Syn: *Stenodiptera pterocarpa* (Boiss.) Koso-Pol. in Bot. Zhurn. 1–2: 13 (1915)

*Caropodium pterocarpum* (Boiss.) Schischkin in Not. Syst. (Leningrad) 4: 30 (1923) *Grammosciadium pterocarpum* (Boiss.) subsp. *longipes* Freyn in Bull. Herb. Boiss. 2(1): 245–289 (1901)

*Stenodiptera armena* Bordz. in Mem. Soc. Nat. Kiev 25(1): 96 (1915)

*Caropodium armenum* (Bordz.) Schischkin in Not. Syst. (Leningrad) 4: 30 (1923)

*Grammosciadium schischkinii* (Vinogr. & Tamamsch) Vinogr. in Bot. Zhurn. (1995) **syn. n.**

*Caropodium pterocarpum* (Boiss.) Schischkin var. *schischkinii* Vinogr. & Tamamsch. in Notes R.B.G. Edinb. 28: 203 (1968)

**2. *Grammosciadium pterocarpum* subsp. *bilgii* subsp. n.**

**3. *Grammosciadium pterocarpum* subsp. *sivasicum* subsp. n.**

**4. *Grammosciadium haussknechtii* Boiss. in Fl. Or. 2:901 (1872)**

Syn: *Stenodiptera haussknechtii* (Boiss.) Koso-Pol., in Bot. Zhurn. (1-2): 13 (1915)

*Caropodium haussknechtii* (Boiss.) Schischkin in Not. Syst. (Leningrad) 4: 30 (1923)

## Acknowledgements

The authors are grateful to Dr. Bilal Şahin (Çankırı University), Hüseyin Eroğlu (Yüzüncü Yıl University), Dr. Ebru Doğan Güner (Gazi University) and Dr. Bilgehan Bilgili (Kastamonu University) for their kind assistance and help during the field studies. Also many thanks go to Dr. Nezaket Adıgüzel (Gazi University) for her valuable comments. This work was supported by the ‘TUBİTAK’ under Grant number 114Z094.

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## Supplementary material I

### Herbarium specimens of members of section *Stenodiptera* distributed in Turkey

Authors: Barış Bani, Fatma Ulusoy, Muhammet Ali Karakaya, Marcus A. Koch

Data type: Specimens data (doc file)

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# The mosses (Bryophyta) of Capitán Prat Province, Aisén Region, southern Chile

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Academic editor: Matt von Konrat | Received 12 May 2016 | Accepted 25 July 2016 | Published 16 August 2016

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**Citation:** Larraín J (2016) The mosses (Bryophyta) of Capitán Prat Province, Aisén Region, southern Chile. *PhytoKeys* 68: 91–116. doi: 10.3897/phytokeys.68.9181

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## Abstract

The bryophytes of Capitán Prat province have remained one of the least explored in Chile. The eventual construction of several dams on the rivers Baker and Pascua required prospection of all groups of organisms including bryophytes, work that was facilitated by the recent construction of vehicular roads that now offer easy access to previously almost inaccessible locations. The results of intense bryophyte collecting during the austral summer of 2007 are here presented. A total of 260 moss taxa are reported for the province, corresponding to 256 species and four infraspecific taxa, of which 211 are new records for the province, 54 are new for Aisén Region, and two are new records for continental Chile (*Pohlia longicollis* (Hedw.) Lindb. and *Rigodium toxarion* var. *robustum* (Broth.) Zomlefer). Twelve species extend their known distribution ranges to the north, whereas 49 extend them to the south.

## Keywords

Biodiversity, checklist, range extensions, new records, southern South America

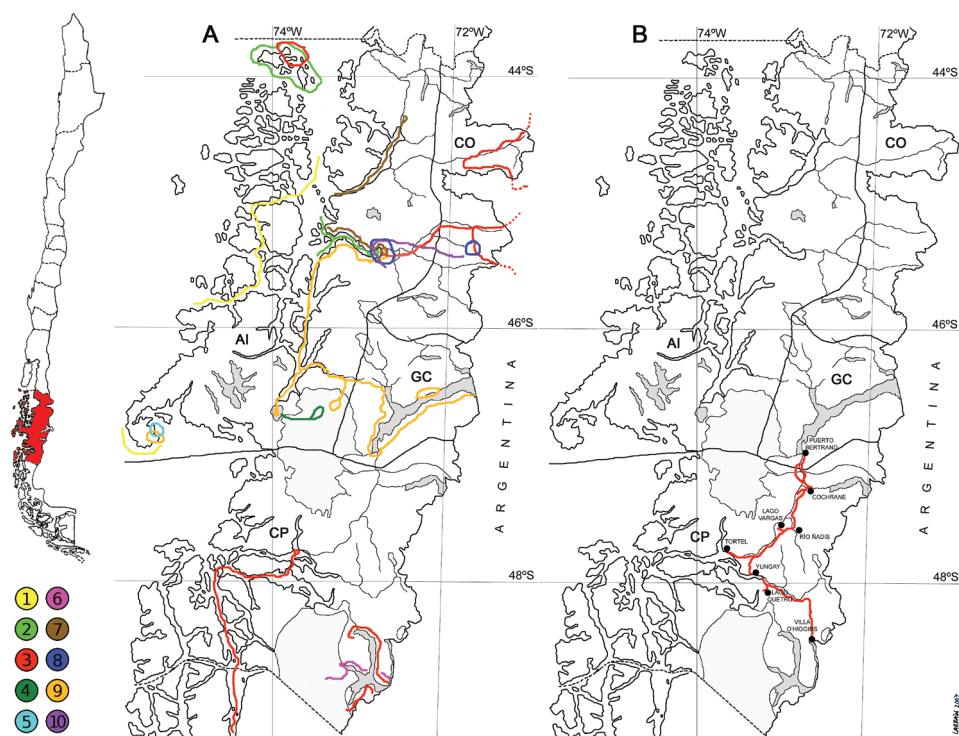


## Introduction

The Aisén Region is divided into four administrative provinces, including Capitán Prat as the southernmost province of the Region, bordering by the south with Última Esperanza Province in the Magallanes Region. It is of particular botanical interest due to: (i) the diversity of climates, ranging from the per-humid temperate rainforests along the coast line and the western archipelago, to the extremely dry steppe in the eastern border with Argentina, and (ii) it is the southernmost ice-free area of continental Chile before the beginning of the massive Southern Patagonian Ice Field that partially isolates it from the neighboring Magallanes Region.

Although the Aisén Region has received considerable exploration by bryologists, and there is even a moss flora already published (Seki 1974, published under the incorrect title of “Provincia de Aisén”), the southernmost province of the region has received very few visits by moss collectors (Fig. 1A). Surprisingly, to date, only two expeditions have collected mosses in the province, i.e., those by Carl Skottsberg at Canal Baker (Caleta Hale, Caleta Connor and Puerto Cueri-Cueri) in the austral winter of 1908, and at Lago O’Higgins in the summer of 1909 (Skottsberg 1916), and those by Arturo Donat at Lago O’Higgins on 1933, as part of the Argentinian expedition “Gaea” (Donat 1936a, 1936b). The first bryophytes reported for the province were 15 liverwort species (Stephani 1911), based on Skottsberg’s collections of 1908. The main scope of Skottsberg’s work was investigating vascular plants, yet Skottsberg (1916) reported 19 moss species, 38 liverworts, and some lichens. Skottsberg’s collections were further studied by Cardot and Brotherus (1923), who reported five new records for the localities mentioned above. Later, Donat reported 12 additional moss species (Donat 1936a), including six new to science (although one of them in the Argentinian side of Lago O’Higgins, locally named there Lago San Martín), and in a second work describing the flora of the western shore of O’Higgins lake (Donat 1936b), he added five more species, making a total of 40 moss species known for the province by 1936. In his moss flora of Aisén Region, Seki (1974) did not report a single locality that belonged to Capitán Prat Province. More recently, Bell et al. (2007) described a new genus of mosses, *Ombronesus* N.E.Bell, N.Pedersen & A.E.Newton, based on collections gathered by the Raleigh International expedition of 2003 in Katalalixar National Reserve, near Caleta Tortel. The floristic results of the latter expedition have not yet been published.

Unfortunately, in his checklist of Chilean mosses, Müller (2009a) reports most of the species listed by Cardot and Brotherus (1923) and all those reported by Donat (1936a) as belonging to Aisén Province, and did not mention the works by Skottsberg (1916) or by Donat (1936b). The result is that Müller (2009a) reports only seven taxa for Capitán Prat Province in his checklist. This partial information led Cuvertino et al. (2012) to report a new record for the province, *Distichium capilla-ceum* (Hedw.) Bruch & Schimp., although this taxon was already reported 100 years ago by Skottsberg (1916) from the NE shore of Lago O’Higgins. With the descrip-



**Figure 1.** Map of Aisén Region showing the four provinces (AI = Aisén; CO = Coihaique; GC = General Carrera; CP = Capitán Prat) and the itinerary of bryological expeditions. **A** Expeditions that collected mosses previous to this study: 1. Charles Darwin, 1834; 2. Per Dusén, 1896–97; 3. Carl Skottsberg, 1908–09; 4. Federico Reichert and Cristóbal Hicken, 1921; 5. Heikki Roivainen, 1929; 6. Arturo Donat, 1933; 7. Gerhard Schwabe, 1939–41; 8. Rolf Santesson, 1940–41; 9. Tarow Seki, 1967; 10. Hironori Deguchi, 1981 **B** Explored area during the 2007 expedition where collections reported here were made. Inset: map of Chile showing in red the location of Aisén Region. (dotted line = regional border; continuous line = provincial limit).

tion of the new species *Ombrotesus stuvensis* (Bell et al. 2007), *Ulota billbuckii* Garilleti, Mazimpaka & F.Lara and *U. streptodon* Garilleti, Mazimpaka & F.Lara (Garilleti et al. 2012), and *U. larrainii* Garilleti, Mazimpaka & F.Lara (Garilleti et al. 2015), and the new reports of *Lepyrodon patagonicus* (Cardot & Broth.) B.H.Allen (Allen 1999), *Brachythecium subpilosum* (Hook.f. & Wilson) A.Jaeger (Cuvertino et al. 2012), *Hedwigia ciliata* var. *nivalis* Hampe (Ellis et al. 2014), *Philonotis esquelensis* Matteri (Jimenez et al. 2014), and *P. brevifolia* Herzog (Jimenez et al. 2016), the moss taxa known for the province rises to 49. This number is in contrast with the 250 moss taxa known from the neighboring Última Esperanza Province, or with the 311 taxa reported for Aisén Province (Müller 2009a).

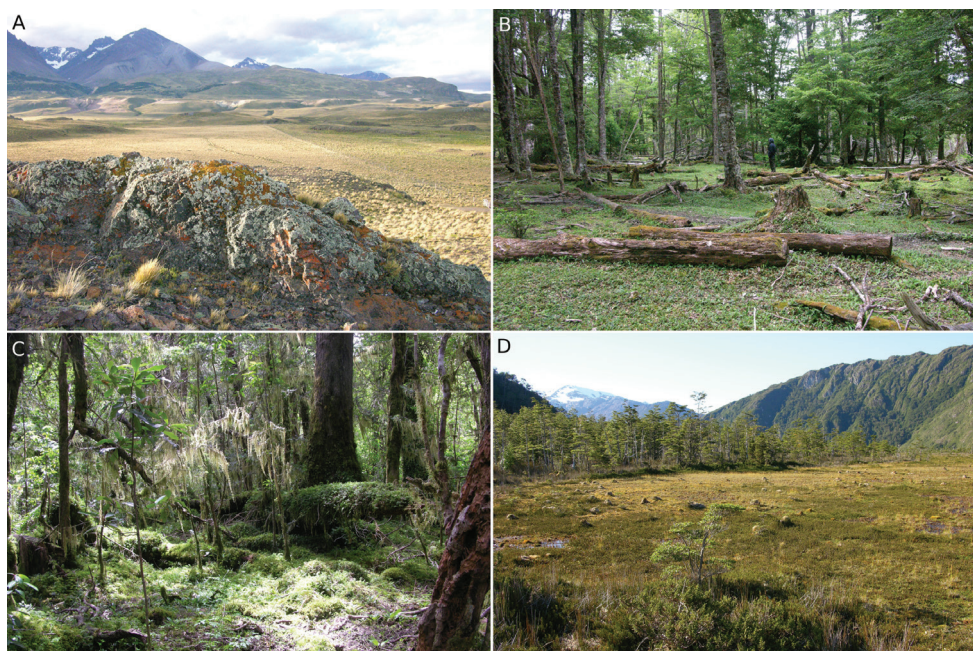
## Methods

### Study site

Capitan Prat Province lies in the southern portion of Aisén Region (XI) in southern Chile, spanning between lat. 46°57'–49°09'S and long. 71°51'–75°36'W, with a total area of 37200 km<sup>2</sup>. The province is crossed by three major river basins from north to south (the rivers Baker, Bravo and Pascua), with Baker river the largest river in Chile in terms of the volume of water. The province shows a remarkable heterogeneity of landscapes and climates (Fig. 2), ranging from extremely rainy areas in the western archipelago with rainfall measured up to 4266 mm a year at San Pedro station, to 191 mm in the steppe habitats in the easternmost areas, measured at Chile Chico, in adjacent General Carrera Province (di Castri and Hajek 1976), the closest available weather station in the easternmost side. Temperatures are mild, with a mean annual temperature measured at 8.2 °C at San Pedro and 11.5 °C at Chile Chico (di Castri and Hajek 1976). The geography is very rough, with snow-capped mountains dominating the landscape, Mt. San Lorenzo being the highest peak in the province, at 3706 m a.s.l. The province is flanked by the Northern and Southern Patagonian Ice Fields, and to the west it sinks into the Pacific Ocean in a large number of islands, fjords and channels, many of them still barely explored. It is one of the least populated provinces of Chile with a little more than 3000 people as measured by the 2012 census, and with more than twice the area of the whole Metropolitan Region of Chile, where more than 7 million people live.

In terms of the vegetation that dominates the landscape, there is a clearly marked gradient from east to west, mostly determined by the extreme variation in rainfall as explained above. In the easternmost parts of the province the vegetation fits into Gajardo's (1984) concept of the "Patagonian Steppe of Aisén", dominated by low shrubs and grasses, where the dominant species are *Baccharis patagonica* Hook. & Arn., *Stipa neaei* Nees ex Steud., *Festuca simpliciuscula* (Hack.) E.B.Alexeev, *Mulinum spinosum* Pers., *Adesmia longipes* Phil., and *Azorella incisa* Wedd., among others. This dry vegetation can be found in Estancia Chacabuco, around Lago Cochrane, and in Tamango National Reserve.

Descending in altitude, and towards the west, the vegetation is dominated by deciduous forests and shrublands, inserted in what Gajardo (1984) calls "Deciduous Forest of Aisén". This vegetation is very heterogeneous depending on the degree of disturbance of the land and in the local variations in soils, exposition, slopes and drainage. The dominant tree species are *Nothofagus pumilio* (Poepp. & Endl.) Krasser, *N. betuloides* (Mirb.) Oerst., *N. antarctica* (G.Forst.) Oerst., and *Embothrium coccineum* J.R.Forst. & G.Forst. In the drier places shrublands can be found, dominated mostly by *Gaultheria mucronata* Hook. & Arn., *Chiliodendron diffusum* (G.Forst.) Kuntze, *Berberis microphylla* G.Forst. and *Escallonia serrata* Sm. In the areas with stronger grazing impact, and where the forest has been cut, fields of *Taraxacum officinale* F.H.Wigg.,



**Figure 2.** Different habitats of Capitán Prat. **A** Steppe at Estancia Chacabuco **B** *Nothofagus dombeyi*–*N. antarctica*–*Pilgerodendron uviferum* forest at Lago Vargas **C** *Nothofagus dombeyi*–*Drimys winteri*–*Podocarpus nubigenus* forest at Río Bravo **D** Peatland at Lago Leal.

*Holcus lanatus* L. and *Dactylis glomerata* L. are common. The mosaic formed by these plant formations is frequent at mid altitude and is where most of the farming activity of the province is developed, mostly in the middle part of Río Baker.

Moving further towards the west, the vegetation changes into what Gajardo (1984) classifies as the region of “Evergreen Forests and Peatlands”. Several different kinds of forests coexist here, and there is a marked gradient too in its composition that relates with the available rainfall. The less humid forests are dominated by *Nothofagus dombeyi* (Mirb.) Oerst. and *N. nitida* (Phil.) Krasser, whereas the most humid are dominated by *Podocarpus nubigenus* Lindl., *Drimys winteri* J.R.Forst. & G.Forst., *Weinmannia trichosperma* Cav., *Raukua laetevirens* (Gay) Frodin, and several Myrtaceae species. Areas with little drainage are dominated by *Pilgerodendron uviferum* (D.Don) Florin, *Tepualia stipularis* (Hook. & Arn.) Griseb., and *Sphagnum magellanicum* Brid. peatlands. Moving even further to the west the vegetation is dominated by cushion plants and shrubs like *Astelia pumila* (G.Forst.) Gaudich., *Donatia fascicularis* J.R.Forst. & G.Forst., *Oreobolus obtusangulus* Gaudich., *Empetrum rubrum* Vahl ex Willd. and *Lepidothamnus fonckii* Phil. (Gajardo 1984), which alternates with very humid evergreen forests in the ravines and protected places. This vegetation can be found along the coastline at Caleta Tortel, Puerto Yungay, and around Lago Quetru.



## Data collection

Two field trips were made during the Austral summer of 2007, making up a total of 13 full days of collecting. During these expeditions a total of 1283 bryophyte collections were made throughout the area between the localities of Puerto Bertrand and Villa O'Higgins, most of them adjacent to the main vehicular roads (Route 7, the road to Tortel, and the road to Villa O'Higgins) spanning the whole basin of Baker River and some sites along the Bravo and Pascua River basins (Fig. 1B), distributed in 56 collecting sites. Of this total, 1091 collections corresponded to mosses, with the remainder being liverworts and hornworts. Additionally, 74 recent moss collections from this same area kept at the Universidad de Concepción herbarium (CONC) were examined (Suppl. material 1).

The collecting localities were arbitrarily chosen, attempting to include the largest number of different floristic associations and landscapes, both in the driest and the wettest areas of the province and throughout all the gradients in between, from the coast line to about 700 m a.s.l.

The specimens were identified with the monographs or taxonomic revisions currently available for each group, and comparing with reference material kept at CONC, NY, and F herbaria. Additionally, many colleagues helped with the identification of difficult material, or for groups where there are no revisions available: María Jesús Cano and Mayte Gallego (Pottiaceae), Ricardo Garilleti (*Ulota*), Paco Lara (*Orthotrichum*), Lars Hedenäs (Amblystegiaceae), John Spence (*Bryum*), Barbara Murray (*Andreaea*), Guillermo Suárez (*Pohlia*), Soledad Jimenez (*Philonotis*) and Barbara Andreas (*Blindia*). All vouchers are deposited in the Universidad de Concepción herbarium (CONC).

The species list is given below in alphabetical order, indicating the new records for Chile (\*\*\*), for Aisén Region (\*\*) and for Capitán Prat Province (\*). A systematic arrangement of the taxa, including habitat information, altitude where taxa were found, frequency in the studied area, global and Chilean distribution, and a list of studied specimens, is presented in the Suppl. material 1.

For the analysis of the distribution patterns, the many different patterns observed were reduced into five major categories for simplification: (1) Wide distribution (WD), meaning cosmopolitan or subcosmopolitan species present in both hemispheres and in both tropical and temperate areas of the planet; (2) Bipolar, meaning species distributed in the temperate areas of both hemispheres with eventual isolated populations at high altitudes in the tropics; (3) Austral, meaning species with various distribution patterns along the Southern Hemisphere - this is the most heterogeneous group because it includes both species with very wide circumsubantarctic distributions to narrow "sub-endemics" maybe recorded from a few populations in southern South America and South Africa, for example; (4) Andean, meaning species mostly distributed throughout the Andes but incidentally extending into Antarctica, Africa or some subantarctic Islands; and (5) Endemic, meaning species only known from southern South America and eventually extending into Juan Fernández or the Falkland and South Georgia Islands.

## Results

A total of 260 moss taxa belonging to 256 species and 4 infraspecific taxa, in 42 botanical families are reported for Capitán Prat Province (Suppl. material 1). The most diverse families were the Orthotrichaceae with 33 taxa, the Pottiaceae with 24 and the Bryaceae with 20 taxa. The most species rich genera were *Bryum* with 20 species, *Ulot*a with 15 and *Syntrichia* with 11 species. Two taxa are reported for continental Chile for the first time, 54 for Aisén Region, and 211 are for the first time reported for Capitán Prat Province, with 12 taxa extending their known distribution limits to the north, and 49 to the south.

- \**Achrophyllum anomalum* (Schwägr.) H. Rob. var. *anomalum*
- Achrophyllum anomalum* var. *pallidum* (Cardot & Broth.) S. He
- \**Achrophyllum haesselianum* (Matteri) Matteri
- \**Achrophyllum magellanicum* (Besch.) Matteri (Figure 3G)
- Acrocladium auriculatum* (Mont.) Mitt. (Figure 3C)
- \*\**Acroschisma wilsonii* (Hook. f.) A. Jaeger
- \**Amphidium tortuosum* (Hornsch.) Cufod.
- \**Ancistrodes genuflexa* (Müll. Hal.) Crosby
- Andreaea alpina* Hedw.
- Andreaea fuegiana* (Cardot) S. W. Greene
- Andreaea regularis* Müll. Hal.
- Andreaea vaginalis* Herzog
- Arbusculohypopterygium arbuscula* (Brid.) M. Stech, T. Pfeiff. & W. Frey
- \**Bartramia ithyphylloides* Schimp. ex Müll. Hal.
- Bartramia mossmaniana* Müll. Hal.
- Bartramia patens* Brid.
- \**Bartramia robusta* Hook. f. & Wilson
- \**Bartramia stricta* Brid.
- \**Blindia contecta* (Hook. f. & Wilson) Müll. Hal.
- Blindia magellanica* Schimp.
- Brachytheciastrum paradoxum* (Hook. f. & Wilson) Ignatov & Huttunen
- \**Brachythecium albicans* (Hedw.) Schimp.
- \**Brachythecium austroglareosum* (Müll. Hal.) Paris
- \**Brachythecium austrosalebrosum* (Müll. Hal.) Paris
- Brachythecium subpilosum* (Hook. f. & Wilson) A. Jaeger
- \**Brachythecium subplicatum* (Hampe) A. Jaeger
- \**Breutelia angustiretis* E. B. Bartram
- \**Breutelia aureola* (Besch. ex Müll. Hal.) Besch.
- \**Breutelia dumosa* Mitt.
- Breutelia integrifolia* (Taylor) A. Jaeger
- \**Breutelia plicata* Mitt.
- \**Breutelia subplicata* Broth.



- \*\**Bryum algovicum* Sendtn. ex Müll.Hal.
- \*\**Bryum archangelicum* Bruch & Schimp.
- \**Bryum australe* Hampe
- \*\**Bryum billarderi* Schwägr. (Figure 4E)
- \**Bryum caespiticium* Hedw.
- \*\**Bryum canariense* Brid.
- \**Bryum capillare* Hedw.
- Bryum clavatum* (Schimp.) Müll.Hal.
- \**Bryum coronatum* Schwägr.
- Bryum crassinervium* Lorentz
- \*\**Bryum dichotomum* Hedw.
- Bryum donatii* Thér.
- Bryum gemmatum* Müll.Hal.
- \**Bryum laevigatum* Hook.f. & Wilson
- \**Bryum macrophyllum* Cardot & Broth.
- \**Bryum perlimbatum* Cardot
- \*\**Bryum platyphyllum* (Schwägr.) Müll.Hal.
- Bryum pseudotriquetrum* (Hedw.) Schwägr.
- \*\**Bryum puconense* Herzog & Thér.
- \**Bryum subapiculatum* Hampe
- \**Calypotropogon mnioides* (Schwägr.) Broth.
- \**Camptodontium cryptodon* (Mont.) Reimers
- \*\**Campylium stellatum* (Hedw.) C.E.O.Jensen
- \**Campylopodium euchlorum* (Mont.) Matteri
- \**Campylopodium medium* (Duby) Giese & J.-P.Frahm
- \**Campylopus acuminatus* Mitt.
- \**Campylopus clavatus* (R.Br.) Wilson
- \**Campylopus incrassatus* Müll.Hal.
- \**Campylopus introflexus* (Hedw.) Brid.
- Campylopus purpureocaulis* Dusén
- \**Campylopus pyriformis* (Schultz) Brid.
- \**Campylopus vesticaulis* Mitt.
- \**Catagonium nitens* (Brid.) Cardot
- \**Ceratodon purpureus* (Hedw.) Brid. subsp. *purpureus*
- \**Ceratodon purpureus* subsp. *convolutus* (Reichardt) Burley
- Chorisodontium aciphyllum* (Hook.f. & Wilson) Broth.
- \**Chorisodontium dicranellatum* (Dusén) Roiv.
- \**Chorisodontium spegazzinii* (Müll.Hal.) Roiv.
- \*\**Chrysoblastella chilensis* (Mont.) Reimers
- \**Conostomum pentastichum* (Brid.) Lindb.
- Cratoneuropsis relaxa* (Hook.f. & Wilson) M.Fleisch. ex Broth. subsp. *minor* (Hook.f. & Wilson) Ochya
- \**Cryphaea consimilis* Mont.

- \**Cryphaeophilum molle* (Dusén) M.Fleisch.
- \**Daltonia gracilis* Mitt.
- \**Daltonia trachydonta* Mitt.
- \**Dendroligotrichum dendroides* (Hedw.) Brid.
- Dendroligotrichum squamosum* (Hook.f. & Wilson) Broth. ex Cardot
- \**Dicranella campylophylla* (Taylor) A.Jaeger
- \**Dicranella hookeri* (Müll.Hal.) Cardot
- \*\**Dicranella pseudorufescens* Cardot & Broth.
- Dicranoloma billardieri* (Brid.) Paris
- \**Dicranoloma chilense* (De Not.) Ochyra & Matteri
- \*\**Dicranoloma imponens* (Mont.) Renauld
- \**Dicranoloma menziesii* (Hook.f. & Wilson) Paris
- \**Dicranoloma perremotifolium* (Dusén) Broth.
- Dicranoloma robustum* (Hook.f. & Wilson) Paris
- \**Didymodon andreaeoides* Cardot & Broth.
- \**Didymodon australasiae* (Hook. & Grev.) R.H.Zander
- \**Didymodon fuscus* (Müll.Hal.) J.A.Jiménez & M.J.Cano
- Distichium capillaceum* (Hedw.) Bruch & Schimp.
- \**Distichophyllum dicksonii* (Hook. & Grev.) Mitt.
- \**Ditrichum cylindricarpum* (Müll.Hal.) F.Muell.
- \**Ditrichum difficile* (Duby) M.Fleisch.
- \**Ditrichum ditrichoideum* (Cardot) Ochyra
- \**Ditrichum heteromallum* (Hedw.) E.Britton
- \*\**Drepanocladus aduncus* (Hedw.) Warnst.
- \**Drepanocladus longifolius* (Mitt.) Broth. ex Paris
- \**Drepanocladus polygamus* (Schimp.) Hedenäs
- \**Dryptodon austrofunalis* (Müll.Hal.) Ochyra & Żarnowiec
- \**Dryptodon humilis* (Mitt.) Ochyra & Żarnowiec
- \**Dryptodon navicularis* (Herzog) Ochyra & Żarnowiec
- Dryptodon trichophyllus* (Grev.) Brid.
- \**Encalypta ciliata* Hedw.
- \*\**Encalypta rhaptocarpa* Schwägr.
- \**Eriodon conostomus* Mont.
- \**Eucamptodon perichaetialis* (Mont.) Mont.
- \**Eurhynchiella acanthophylla* (Mont.) M.Fleisch.
- \**Eustichia longirostris* (Brid.) Brid
- \*\**Fabronia jamesonii* Taylor
- \**Fissidens curvatus* Hornsch.
- \**Fissidens rigidulus* Hook.f. & Wilson
- \**Funaria hygrometrica* Hedw.
- \**Glyphothecium sciuroides* (Hook.) Hampe
- \**Gymnostomum calcareum* Nees & Hornsch.
- \*\**Hebantia rigida* (Lorentz) G.L.Merr.

- Hedwigia ciliata* Hedw. var. *nivalis* Hampe (Figure 4D)  
 \*\**Hennediella antarctica* (Ångström) Ochyra & Matteri  
 \**Hennediella arenae* (Besch.) R.H.Zander  
 \*\**Hennediella heimii* (Hedw.) R.H.Zander  
 \**Hymenodontopsis mnioides* (Hook.) N.E.Bell, A.E.Newton & D.Quandt (Figure 4H)  
*Hymenoloma crispulum* (Hedw.) Ochyra  
*Hymenoloma turpe* (Cardot) Cardot & Broth.  
 \**Hymenostylium recurvirostrum* (Hedw.) Dixon  
 \**Hypnodendron microstictum* Mitt. ex A.Jaeger & Sauerb.  
 \**Hypnum chrysogaster* Müll.Hal.  
 \**Hypnum cupressiforme* Hedw. var. *cupressiforme*  
 \*\**Hypnum cupressiforme* var. *filiforme* Brid.  
 \**Hypnum cupressiforme* var. *mossmanianum* (Müll.Hal.) Ando  
 \**Hypnum skottsbergii* Ando  
 \**Hypopterygium didictyon* Müll.Hal.  
 \**Kiaeria pumila* (Mitt.) Ochyra  
 \**Leptobryum pyriforme* (Hedw.) Wilson  
 \*\**Leptodontium longicaule* Mitt. var. *microruncinatum* (Dusén) R.H.Zander  
 \*\**Leptostomum menziesii* R.Br.  
*Leptotheca gaudichaudii* Schwägr.  
 \**Lepyrodon hexastichus* (Mont.) Wijk & Margad.  
*Lepyrodon lagurus* (Hook.) Mitt.  
*Lepyrodon patagonicus* (Cardot & Broth.) B.H.Allen  
 \**Lepyrodon tomentosus* (Hook.) Mitt.  
 \*\**Looseria orbiculata* (Thér.) D.Quandt, Huttunen, Tangney & M.Stech  
 \**Lopidium concinnum* (Hook.) Wilson  
 \*\**Macromitrium pertriste* Müll.Hal.  
 \*\**Mahua enervis* W.R.Buck  
 \**Matteria gracillima* (Besch.) Goffinet  
 \**Matteria papillosula* (Thér.) Goffinet  
 \**Neckera scabridens* Müll.Hal.  
 \**Notoligotrichum minimum* (Cardot) G.L.Sm. (Figure 4A)  
 \**Notoligotrichum trichodon* (Hook.f. & Wilson) G.L.Sm.  
 \**Oligotrichum austroaligerum* G.L.Sm.  
*Ombrodesus stuvensis* N.E.Bell, N.Pedersen & A.E.Newton  
 \*\**Orthodontium lineare* Schwägr.  
 \**Orthotrichum assimile* Müll.Hal.  
 \**Orthotrichum brotheri* Dusén ex Lewinsky  
 \**Orthotrichum elegantulum* Schimp. ex Mitt.  
 \*\**Orthotrichum hortense* Bosw.  
 \**Orthotrichum incanum* Müll.Hal.  
 \**Orthotrichum ludificans* Lewinsky  
 \*\**Orthotrichum pariatum* Mitt.

- \**Orthotrichum rupestre* Schleich. ex Schwägr.
- \**Parahacocarpus patagonicus* (Broth.) J.-P.Frahm
- Philonotis brevifolia* Herzog
- Philonotis esquelensis* Matteri
- \**Philonotis krausei* (Müll.Hal.) Broth.
- \*\**Philonotis polymorpha* (Müll.Hal.) Kindb.
- \*\**Philonotis scabrifolia* (Hook.f. & Wilson) Braithw.
- Philonotis vagans* (Hook.f. & Wilson) Mitt.
- \*\**Pilopogon schilleri* Herzog & Thér.
- \*\**Plagiothecium lucidum* (Hook.f. & Wilson) Paris
- \**Platyneuron praealtum* (Mitt.) Ochyra & Bednarek-Ochyra (Figure 3H)
- Pohlia cruda* (Hedw.) Lindb.
- \*\*\**Pohlia longicollis* (Hedw.) Lindb.
- \**Pohlia nutans* (Hedw.) Lindb. (Figure 3A)
- \**Pohlia wahlenbergii* (F.Weber & D.Mohr) A.L.Andrews (Figure 4G)
- \**Polytrichadelphus magellanicus* (Hedw.) Mitt. (Figure 4B)
- \*\**Polytrichastrum alpinum* (Hedw.) G.L.Sm.
- \**Polytrichastrum longisetum* (Sw. ex Brid.) G.L.Sm.
- \**Polytrichum juniperinum* Hedw.
- Polytrichum piliferum* Hedw. (Figure 4C)
- \*\**Polytrichum strictum* Menzies ex Brid.
- \**Porotrichum arbusculans* (Müll.Hal.) Ochyra
- \**Pseudocrossidium crinitum* (Schultz) R.H.Zander
- Ptychomniella ptychocarpon* (Schwägr.) W.R.Buck, C.J.Cox, A.J.Shaw & Goffinet
- \**Ptychomnion cygnisetum* (Müll.Hal.) Kindb.
- \**Racomitrium didymum* (Mont.) Lorentz (Figure 3B)
- Racomitrium geronticum* Müll.Hal. (Figure 3F)
- \**Racomitrium heterostichoides* Cardot
- Racomitrium laevigatum* A.Jaeger
- \**Racomitrium lamprocarpum* (Müll.Hal.) A.Jaeger (Figure 4F)
- \**Racomitrium orthotrichaceum* (Müll.Hal.) Paris
- \**Racomitrium pachydictyon* Cardot
- \**Racomitrium rupestre* (Hook.f. & Wilson) Wilson & Hook.f.
- \**Racomitrium subcrispipilum* (Müll.Hal.) A.Jaeger
- \**Rhacocarpus purpurascens* (Brid.) Paris
- \*\**Rhaphidorrhynchium amoenum* (Hedw.) M.Fleisch.
- \**Rhaphidorrhynchium callidum* (Mont.) Broth. (Figure 3D)
- \**Rhaphidorrhynchium dendroligotrichum* (Dusén) Broth.
- \**Rigodium adpressum* Zomlefer
- \**Rigodium brachypodium* (Müll.Hal.) Paris
- \**Rigodium pseudothuidium* Dusén
- \**Rigodium tamarix* Müll.Hal.
- \**Rigodium toxarion* (Schwägr.) A.Jaeger var. *toxarion*





**Figure 3.** Mosses of Capitán Prat Province. **A** *Pohlia nutans* **B** *Racomitrium didymum* **C** *Acrocladium auriculatum* **D** *Rhabidorrhynchium callidum* **E** *Tetraplodon fuegianus* **F** *Racomitrium geronticum* **G** *Achrophyllum magellanicum* **H** *Platyneuron praealtum*.





**Figure 4.** Mosses of Capitán Prat Province. **A** *Notoligotrichum minumum* **B** *Polytrichadelphus magellanicus* **C** *Polytrichum piliferum* **D** *Hedwigia ciliata* var. *nivalis* **E** *Bryum billarderi* **F** *Racomitrium lamprocarpum* **G** *Pohlia wahlenbergii* **H** *Hymenodontopsis mnioides*.



- \*\*\**Rigodium toxarion* var. *robustum* (Broth.) Zomlefer
- \**Sanionia uncinata* (Hedw.) Loeske
- \**Sauloma tenella* (Hook.f. & Wilson) Mitt.
- Schistidium andinum* (Mitt.) Herzog
- \*\**Sciuro-hypnum plumosum* (Hedw.) Ignatov & Huttunen
- \*\**Scorpidium revolvens* (Sw.) Rubers
- Scouleria patagonica* (Mitt.) A.Jaeger
- \**Sematophyllum scorpiurus* (Mont.) Mitt.
- \**Sphagnum falciculatum* Besch.
- Sphagnum fimbriatum* Wilson
- Sphagnum magellanicum* Brid.
- Straminergon stramineum* (Dicks. ex Brid.) Hedenäs
- Syntrichia anderssonii* (Ångström) R.H.Zander
- \*\**Syntrichia costesii* (Thér.) R.H.Zander
- \*\**Syntrichia epilosa* (Broth. ex Dusén) R.H.Zander
- \*\**Syntrichia fragilis* (Taylor) Ochyra
- \*\**Syntrichia glacialis* (Kunze ex Müll.Hal.) R.H.Zander
- \**Syntrichia lithophila* (Dusén) Ochyra & R.H.Zander
- \**Syntrichia magellanica* (Mont.) R.H.Zander
- \**Syntrichia princeps* (De Not.) Mitt.
- \**Syntrichia pseudorobusta* (Dusén) R.H.Zander
- \*\**Syntrichia ruralis* (Hedw.) F.Weber & D.Mohr
- \*\**Syntrichia scabrella* (Dusén) R.H.Zander
- \**Tayloria dubyi* Broth.
- \*\**Tayloria magellanica* (Brid.) Mitt.
- \*\**Tayloria stenophysata* (Herzog) A.K.Kop.
- \**Tetraplodon fuegianus* Besch. (Figure 3E)
- \*\**Tortella knightii* (Mitt.) Broth.
- \*\**Tortula atrovirens* (Sm.) Lindb.
- Ulotia billbuckii* Garilleti, Mazimpaka & F.Lara
- \*\**Ulotia carinata* Mitt.
- \**Ulotia fuegiana* Mitt.
- \**Ulotia germana* (Mont.) Mitt.
- Ulotia larrainii* Garilleti, Mazimpaka & F.Lara
- \**Ulotia luteola* (Hook.f. & Wilson) Wijk & Marg.
- \*\**Ulotia macrocalycina* Mitt.
- \**Ulotia macrodontia* Dixon & Malta
- \**Ulotia magellanica* (Mont.) A.Jaeger
- \*\**Ulotia phyllantha* Brid.
- \*\**Ulotia pusilla* Malta
- \*\**Ulotia pycnophylla* Dusén ex Malta
- \**Ulotia pygmaeothecia* (Müll.Hal.) Kindb.
- \**Ulotia rufula* (Mitt.) A.Jaeger

*Ulota streptodon* Garilleti, Mazimpaka & F.Lara

\**Vittia pachyloma* (Mont.) Ochyra

\**Warnstorfia exannulata* (Schimp.) Loeske

\*\**Warnstorfia fluitans* (Hedw.) Loeske

\**Warnstorfia fontinalopsis* (Müll.Hal.) Ochyra

\**Weymouthia cochlearifolia* (Schwägr.) Dixon

\**Weymouthia mollis* (Hedw.) Broth.

\*\**Zygodon hookeri* Hampe var. *hookeri*

\**Zygodon hookeri* var. *leptobolax* (Müll.Hal.) Calabrese

\**Zygodon magellanicus* Dusén ex Malta

\**Zygodon papillatus* Mont.

\**Zygodon pentastichus* (Mont.) Müll.Hal.

\**Zygodon pichinchensis* (Taylor) Mitt.

*Zygodon reinwardtii* (Hornsch.) A.Braun

From the analysis of the five simplified distribution patterns, 38.08% (n=99) of the taxa are actually endemics of southern South America, followed by the “austral” taxa with 30.77% (n=80). The rest of the taxa were found to be either of “wide distribution” (13.85%, n=36), “bipolar” (9.62%, n=25), or “Andean” (7.69%, n=20).

## Discussion

The known diversity of Capitán Prat Province was incremented from 49 to 260 taxa, representing a 531% increment. This is remarkable and demonstrates the very little attention this area has historically received in terms of its bryophyte diversity. The current number of species reported for the province makes sense with the numbers known from the adjacent provinces of Aisén (311) and Última Esperanza (250). The number of moss taxa known from adjacent General Carrera province [27 in Müller's (2009a) checklist] is still very low and certainly needs further study, although General Carrera province lacks the most humid habitats found in the coastal lowland rainforests, that in this study yielded a large number of taxa not found anywhere else.

Three taxa were described as new based on the collections gathered during this study in Capitán Prat (*Ulota billbuckii*, *U. larraini* and *U. streptodon*), and four others were found to be new records for Chile (*Hedwigia ciliata* var. *nivalis*, *Philonotis esquelensis*, *Pohlia longicollis* and *Rigodium toxarion* var. *robustum*), the latter previously known to be an endemic of the Juan Fernández Islands. The number of new species and new records for Chile might increment even more after study of the material that still remains unidentified.

The high level of endemic taxa in southern South America temperate rainforests has already been reported in the literature for neighboring areas (i.e., Seki 1974, Villagrán et al. 2003, Larraín 2005). This is also the principal distribution pattern in Capitán Prat Province, with almost 40% of all the taxa known for the area being endemics.

It is also interesting that the moss flora of these Austral forests is way more related to distant Austral lands as New Zealand, Australia, or some remote subantarctic islands rather than to neighboring Neotropical countries like Perú or Bolivia: only 7.69% of the taxa studied has a continuous distribution along the Andes into the northern Tropics. This is explained by the condition of “biogeographic island” of southern Chile forests, isolated from the rest of the continent by the very high peaks of central and northern Chile, and extremely arid deserts both to the north (Atacama) and to the east (Patagonian steppe).

Several species were found farther south from their previously known distribution ranges. This is interesting as it would appear to suggest that many of these taxa are apparently not able to disperse south of the Southern Patagonia Ice Field. This ice field would act as a natural barrier to the dispersion of Valdivian rainforest endemics such as *Ancistrodes genuflexa*, *Cryphaea consimilis*, *Cryphaeophilum molle*, *Eriodon conostomus*, *Eurhynchiella acanthophylla*, *Rhaphidorrhynchium dendrologotrichum*, *Rigodium tamarix*, and *Weymouthia cochlearifolia*, among others, preventing their colonization of Magallanes Region. This might be due also to less collecting effort in the more wet areas of Magallanes, because of the logistical difficulties to access the most western islands, where rainfall is similar to what can be found in the wettest areas of Capitán Prat.

It is important to mention that not a single locality above 700 m was visited. Although most of the area above this altitude is covered in ice and snow all year round, it would be interesting to visit higher altitude spots and glaciers, since several of the species found by Donat around the glaciers of Lago O’Higgins were not found during this expedition. Covering these sites would maybe increase even more the number of moss taxa known from Capitán Prat Province.

## Acknowledgements

This work was made as a consultancy for Hidroaysén hydroelectric project within the framework of the baseline study prior to the environmental-impact study as required by the Chilean authority. I am specially acknowledged to the staff at the botany department of Universidad de Concepción, and to the many colleagues that helped with the determination of difficult groups of mosses: María Jesús Cano, Mayte Gallego, Ricardo Garilleti, Paco Lara, Lars Hedenäs, John Spence, Barbara Murray, Guille Suárez, Sol Jimenez and Barbara Andreas. Reinaldo Vargas and Götz Palfner are acknowledged for company during the fieldwork. Thanks also to Alicia Marticorena, Alejandra Jiménez, Ernesto Teneb and Roberto Rodríguez for making their collections from the area available for my study. I acknowledge the staff at CONAF office in Cochrane for allowing me to collect inside Tamango National Reserve. Finally I would like to thank the staff at CONC, F and NY herbaria for providing working space and full access to their bryophyte collections.

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## **Supplementary material I**

### **Systematic list of taxa and additional information**

Authors: Juan Larraín

Data type: specimens data

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# *Alysicarpus poklianus* (Fabaceae, Desmodieae), a new species from India

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Academic editor: P. Herendeen | Received 22 July 2016 | Accepted 26 July 2016 | Published 16 August 2016

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**Citation:** Gholami A, Pandey AK (2016) *Alysicarpus poklianus* (Fabaceae, Desmodieae), a new species from India. PhytoKeys 68: 117–124. doi: 10.3897/phytokeys.68.9975

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## Abstract

A new species, *Alysicarpus poklianus* Gholami & Pandey from Sinharath, Maharashtra, India is described. It is morphologically most similar to *A. hamosus* but differs in having ovate leaves, rounded-ovate bracts, larger size of calyx, pods comprising 5–7 longer than broad joints with easily separable septa. In this study, a comprehensive description, and identification key of *A. poklianus* are provided.

## Keywords

*Alysicarpus*, endemic new taxon, taxonomy, India

## Introduction

The genus *Alysicarpus* Necker ex Desvaux, a member of tribe Desmodieae, family Fabaceae, comprises approximately 30 species distributed in tropical and subtropical regions of the old world (Lewis et al. 2005). The major centers of diversity of the genus are Africa (10 spp.), India, Indo-China, Malaysia and Japan (20 spp.) (Lewis et al. 2005, Mabberley 2009). In India, the genus is represented by approximately 18 species, (Sanjappa 1992, Pokle 2002, Gholami and Pandey 2016).

The genus *Alysicarpus* is characterized by its calyx with reticulate or striate venation, and turgid indehiscent pods. The leaves are generally unifoliate or rarely pinnately 3-foliate (Pedley 2001, Pokle 2002).

During the taxonomic revision of the genus *Alysicarpus*, field trips were made to different parts of India and several specimens were collected. We compared our collected specimens with all the voucher specimens of *Alysicarpus* species deposited in different herbaria (BAMU, BSD, BSI, CAL, DD, DUH, LWG, MH, PAN). A critical examination of the collected specimens and literature indicated that the collected material represented an undescribed species. Hence, the objective of the present study was to undertake morphological and molecular analyses to test whether these specimens represent a new taxon. Our unpublished preliminary molecular sequence data analysis supports the recognition of new species. In the present communication, the new species is described based on morphological data supplemented with identification key for all Indian species of *Alysicarpus*.

## Materials and methods

### Morphology

The overall morphology of the new species was examined by stereobinocular microscope (SMZ 1000). For morphological comparisons, we consulted herbarium specimens kept in different herbaria in India (BAMU, BSD, BSI, CAL, DD, DUH, LWG, MH, PAN). The Flora of India and floras of different states in India and neighboring regions including China, Bhutan, Nepal, Pakistan, Bangladesh were also consulted. The diagnostic traits of the new species and morphologically most similar species viz., *Alysicarpus hamosus* and *A. ovalifolius* are presented in Table 1. In addition, an identification key is provided to distinguish new species and other taxa.

### SEM study

For SEM study, mature seeds were mounted on aluminum stubs with double adhesive tape and sputter-coated with gold palladium in a JFC-1600 Autofine coater, JEOL, Japan sputter coating unit. Samples were examined using a Scanning Electron Microscope JSM-6610LV, JEOL, Japan, at the Department of Botany, University of Delhi, India.

## Results

### Morphology

*Alysicarpus poklianus* is distinct from *A. hamosus* in having ovate leaves, longer pods with easily separable septa and foveo-regulate pattern of spermoderm. Table 1 gives an overview of the differences between *A. poklianus* (the new species proposed here), *A. hamosus* and *Alysicarpus ovalifolius*.

**Table 1.** Differences between *Alysicarpus poklianus*, *A. hamosus* and *A. ovalifolius*.

Characters	<i>A. poklianus</i> sp. nov.	<i>A. hamosus</i>	<i>A. ovalifolius</i>
Stem	Densely covered with long hairs	Densely covered with long hairs	Glabrous or sparsely covered with short hairs
Leaves	Unifoliolate	Unifoliolate mixed with trifoliolate	Unifoliolate
Leaflet shape	Ovate to orbicular	Orbicular	Ovate at base, lanceolate in the upper part
Leaflet size	10–50 × 5–40 mm	5–20 × 5–20 mm	20–60 × 10–20 mm
Inflorescence	50–150 mm long	30–40 mm long	50–150 mm long
Pedicel	2–5 mm long, filiform	1–3 mm long, thick	1–2 mm long, thick
Calyx	3–5 mm long	1–3 mm long	4–6 mm long
Pod size	15–20 × 2–3 mm	10–15 × 2–3 mm	15–20 × 2–3 mm
Pod joints	5–7 joints, longer than broad	3–5 joints, broader than long	5–8 joints, longer than broad
Pod septa	Present, easily separable	Present, not easily separable	Septa absent
Spermoderm	Rugulate	Rugulate	Foveo-rugulate

## Taxonomic treatment

### *Alysicarpus poklianus* A. Gholami & A. K. Pandey, sp. nov.

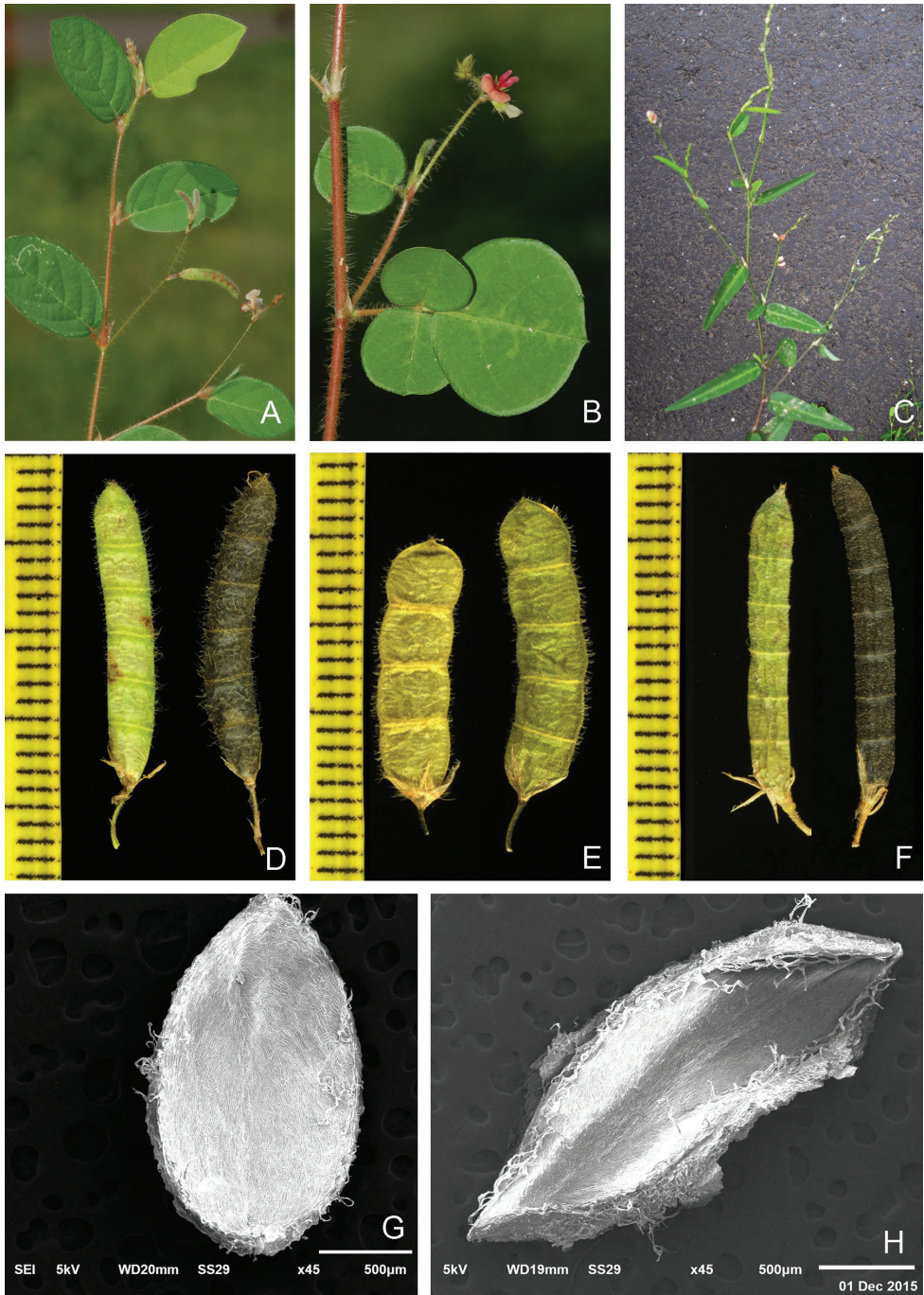
urn:lsid:ipni.org:names:60472842-2

Fig. 1, 2

**Note.** Diagnostic characters for *Alysicarpus poklianus* include ovate leaves, 5–7 joint pods, easily separable septa and foveo-regulate spermoderm.

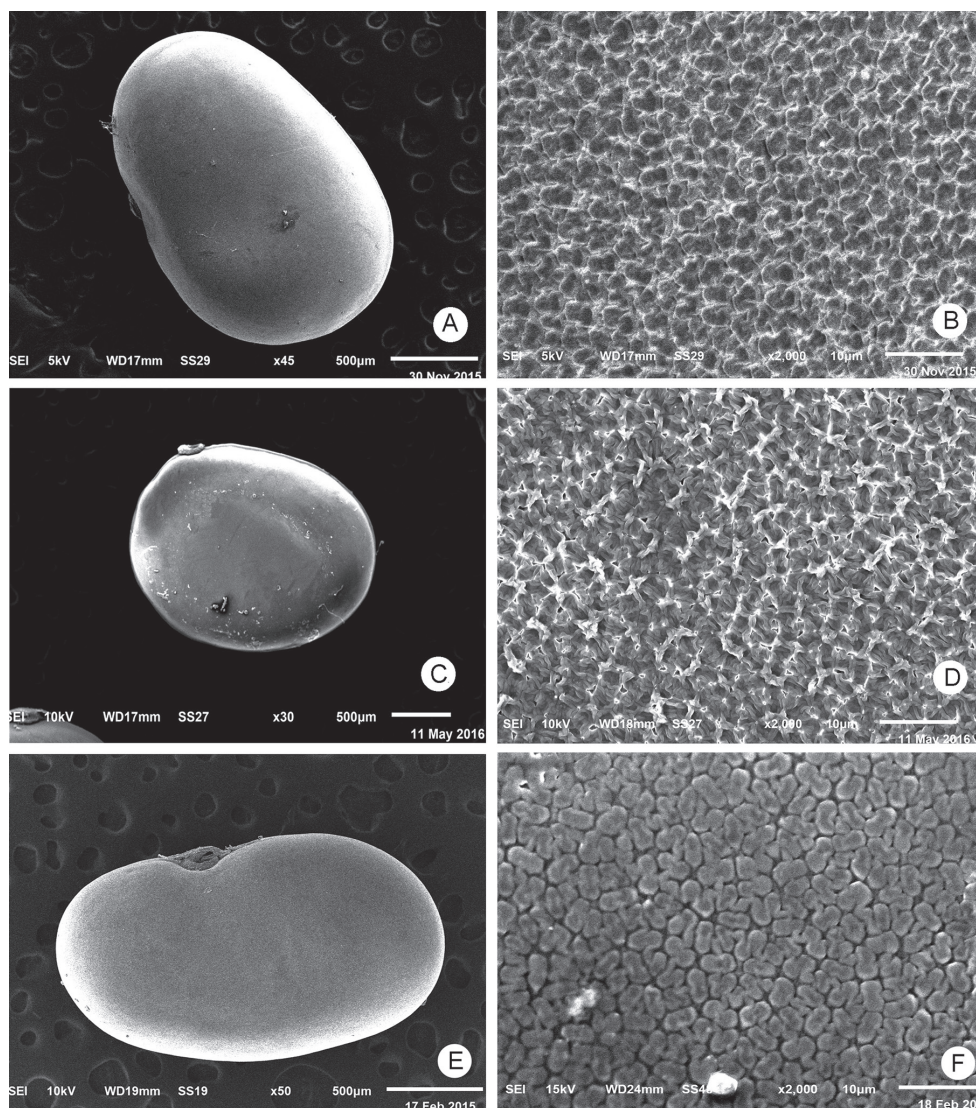
**Type.** INDIA. Maharashtra: Sinhgarh, 18°21'56.39"N, 73°45'18.97"E, 587 m, 19 October 2014, *Gholami & Pandey 4642* (holotype DUH!, isotype BSD!, CAL!).

**Description.** Annual, prostrate to procumbent, profusely branched, slender, 30–50 cm long, stem densely covered with long hairs. Stipules triangular to linear, scarious, acute striate, 3–7 mm long, glabrous with ciliate margins. Petiole 5–6 mm, hairy. Leaflets ovate to oval, 15–35 × 5–20 mm, apex rounded to mucronulate, both surfaces hairy though the density of hair on lower surface is more. Inflorescence axillary or terminal, 50–150 mm long, lax with stiff hairs. Flowers in pairs, 2–3 pairs along each rachis, subtended by deciduous bract and secondary bracts; pedicels 3–5 mm long. Bracts rounded to ovate, 3–4 mm long, acute, ciliate at margins with long hairs; secondary bracts 1–3 mm long, lanceolate to triangular, ciliate at margins with long hairs. Calyx much shorter than the first joint of the pod; 2–3 mm long, tube very short, c. 1 mm long, lobes acute, not imbricated, ciliate all over. Standard petal light pink, 2–3 mm long, emarginated at apex; wing petals dark pink, 3–3.5 mm long; keel petal boat-shaped, bent and folded, c. 3 mm long. Stamens diadelphous, 2–3 mm long. Ovary 1.5–3 mm long, pubescent. Pods cylindrical, 15–20 mm long, 1.5–2 mm broad, compressed, 5–7 jointed, clothed with straight and hooked hairs, septa between two joints of pod boat-shaped, easily separable. Seeds light to dark brown, 2 × 1 mm, oval, smooth, spermoderm rugulate.



**Figure 1.** *Alysicarpus*. **A** *A. poklianus* **B** *A. hamosus* **C** *A. ovalifolius* **D** Pod of *A. poklianus* **E** pod of *A. hamosus* **F** Pod of *A. ovalifolius* **G, H** Pod septa of *A. poklianus* and *A. hamosus* respectively.





**Figure 2.** Seed and spermoderm pattern. **A, B** *Alysicarpus poklianus* **C, D** *Alysicarpus hamosus* **E, F** *A. ovalifolius*.

**Etymology.** The species is named in honor of Prof. D.S. Pokle who has done extensive work on the taxonomy of the genus *Alysicarpus* in India.

**Distribution and habitat.** Maharashtra (Fig. 3), India, growing on gravelly slopes along roadsides at 500–600 m elevation.

**Phenology.** Flowering from August to October; fruiting from September to November.





**Figure 3.** Distribution of *Alysicarpus poklianus* in Maharashtra, India

#### Key for identification of *Alysicarpus* species in India

- |   |  |                     |
|---|--|---------------------|
| 1 | Joints of pods strongly transversely rugose, never tetragonal.....   | 2                   |
| – | Joints of pods tetragonal, rugose, reticulated or smooth .....   | 5                   |
| 2 | Inflorescence short dense, calyx and bract conspicuously ciliated, pod not exerted from calyx .....          | <i>A. scarious</i>  |
| – | Inflorescence long dens or lax, calyx and bract less ciliated or glabrous, pod exerted from calyx .....      | 3                   |
| 3 | Secondary bract present .....  | <i>A. rugosus</i>   |
| – | Secondary bract absent .....   | 4                   |
| 4 | Stem densely pubescent, calyx and bract slightly ciliate, leave ovate....                                    | <i>A. heyneanus</i> |
| – | Stem glabrous or with a line of hair, calyx and bract glabrous, leaves usually linear-lanceolate.....        | <i>A. ludens</i>    |
| 5 | Joints of pods reticulated or tetragonal rugose, calyx and bract densely covered with silky white hairs..... | 6                   |
| – | Joints of pods slightly reticulate or smooth, hairs in calyx and bract not silky white .....                 | 8                   |
| 6 | Leaflets 3-nerved at base, inflorescence long, pods included in the calyx .....                              | <i>A. pubescens</i> |

- Leaflets 1-nerved at base, inflorescence short, pod exserted from calyx ..... 7
- 7 Joint of pod tetragonal, as long as broad, conspicuously reticulate ..... *A. tetragonolobus*
- Joint of pod 4-winged, longer than broad, obscurely reticulate ..... *A. luteovexillatus*
- 8 Calyx reticulate-veined, shorter than first joint of pod ..... 9
- Calyx striate-veined, longer than first joint of pod ..... 13
- 9 Pod moniliform ..... *A. monilifer*
- Pod cylindric not moniliform ..... 10
- 10 Pod not pubescent or hairs are short ..... 11
- Pod conspicuously pubescent with long hair ..... 12
- 11 Infructescence lax, leaflets dimorphic ..... *A. ovalifolius*
- Infructescence dense, leaflets uniform ..... *A. vaginalis*
- 12 Pod 3–5 joint, joints of pod broader than long, pod septa not easily separable, leaflets orbicular, mix one and three foliolate ..... *A. hamosus*
- Pod 5–7 joint, joints of pod longer than broad, pod septa easily separable, leaflets ovate, one foliolate ..... *A. poklianus*
- 13 Pod puberulous, calyx and bract densely pubescent, secondary bract absent ... *A. longifolius*
- Pod glossy, glabrous, calyx and bract slightly ciliate at the margin, secondary bract present ..... 14
- 14 Pedicel 3–4 mm long filiform, pod drooping ..... *A. gamblei*
- Pedicel 1–2 mm long, pod straight ..... 15
- 15 Pod moniliform, branches glabrous, leaflets elliptic oblong ..... *A. gautalensis*
- Pod cylindrical, branches covered with appressed hairs ..... 16
- 16 Leaflets linear lanceolate, calyx and bract almost glabrous ... *A. bupleurifolius*
- Leaflets usually ovate-obovate, calyx and bract more ciliate ..... *A. naikianus*

### Additional specimens examined

INDIA, Maharashtra, Nanded, Bodhadi, 14.12.1997, *A. S. Dhabe*, 913 (BAMU); Aurangabad, 13.10.1998, *A. S. Dhabe*, 948 (BAMU); Satara, 20.09.1998, *Ravi Patil*, 236 (BAMU); Poona, 2.8.1960, *John Cheria*n 63517 (CAL).

### Acknowledgements

We thank Prof. S.R. Yadav, Shivaji University, Kolhapur, for help in field trips. We would like to thank Dr Paramjit Singh, Director, Botanical Survey of India and In-charge of different herbaria (BAMU, BSD, BSI, CAL, DD, DUH, LWG, MH, PAN) for permission to consult herbaria. Authors are thankful to Dr L.B. Chaudhary, NBRI, Lucknow for critically going through the manuscript.

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