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New bryophyte species for Saudi Arabia and the Arabian Peninsula from AlUla County

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With 9 figures

Abstract: This paper represents the first results of an intensive bryological survey of AlUla County (northwest Saudi Arabia). *Riella affinis*, *Acaulon triquetrum*, *Microbryum rectum* and *Syntrichia rigescens* are newly reported species for the Arabian Peninsula whereas *Clevea spathysii*, *Ptychostomum cellulare*, *Funaria hygrometrica*, *Gymnostomiella vernicosa*, *Molendoa handelii* and *Pterygoneurum ovatum* are new records for Saudi Arabia. The details of new localities are presented in association with taxonomic and ecological notes.

Keywords: Bryodiversity; ecology; floristics; liverworts; mosses

Introduction

The Kingdom of Saudi Arabia (KSA) is the largest country in southwest Asia, covering approximately 2,150,000 km^2 of land, and around three-quarters of the Arabian Peninsula (Chaudhary 2001). It is an environmentally diverse landscape. The central and eastern parts of Saudi Arabia consist of rocky and sandy desert environments, whereas large mountain ranges, reaching 3700 m above sea level, dominate the southwestern areas, near the Yemen border. The country's close proximity between Africa, Asia, and Europe significantly influences its flora and bryoflora. Taking into consideration the few endemics, the bryoflora is composed of six floristic elements (Kürschner & Ghazanfar 1998). Cosmopolitan or Northern taxa are rather few, whereas there are many drought-adapted taxa (Xerotherm-Pangean or Circum-Tethyan elements). The occurrence of several interesting tropical species exhibiting a southeast Asian-Arabian, African-Arabian, Pantropical or Paleotropical ranges has been repeatedly demonstrated (Kürschner 2000).

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Scientific recording of bryophytes in Saudi Arabia began relatively recently (Frey & Kürschner 1982), but has increased steadily since the pioneer phase. The first bryological checklist of the Arabian Peninsula (including Saudi Arabia) was published in 2000 (Kürschner 2000). A second comprehensive checklist, encompassing entire southwest Asia was published in 2011 (Kürschner & Frey 2011). Taha (2019) published the first country checklist for mosses of Saudi Arabia. A number of species have been added to the list since (Kürschner & Frey 2020; Taha & Abou-Salama 2020; Jiménez et al. 2022; Al-Khulaidi et al. 2024). The bryoflora of Saudi Arabia is now considered to include 125 mosses and 29 liverworts. Presently, there are no hornwort recorded from Saudi Arabia.

It is a well-established fact that most of bryological diversity of Saudi Arabia is confined to the mountainous monsoon-influenced South-Hejaz region (Kürschner & Ghazanfar 1998) and that, by contrast, only few species are recorded from other more arid regions. At the extreme, the hyper-arid Empty Quarter (Al-Rubi Al-Khale desert, located in south-eastern part of the country) harbour no recorded bryophyte species to date. Logically, most of the previous surveys were conducted in more likely environments for bryophyte species, such as the humid southwestern regions of the country, which has resulted in large expanses of Saudi Arabia being neglected in bryophyte research.

AlUla County is located in the northwestern part of Saudi Arabia, south of Tabuk, approximately 200 km east of the Red Sea. This county, covering an area of 22561 km^2, has not been the subject of any bryological surveys or research. During the winter of 2024, the authors (VH, FP) had the opportunity to conduct intensive field trips through the entire region, focussing on the Nature Reserves. Here we publish the new bryophyte species records for the Arabian Peninsula and the Kingdom of Saudi Arabia. A separate publication will present the bryophyte checklist of AlUla county and bryosociological descriptions of communities.

Study site

AlUla County is located in the northwest part of the Arabian Peninsula (Fig. 1.1), and belongs to the Saharo-Sindian regional zone (Zohary 1973; Kürschner 1998) which is generally characterised by an arid to hyper-arid climate with annual rainfall of less than 50 mm per year.

For a relatively small area within the Arabian Peninsula, AlUla has an incredibly rich geodiversity. The county is a part of the Arabian Shield, which includes a large variety of Precambrian igneous and metamorphic rocks, as well as Cambrian and Early Ordovician sandstones (Hadley 1987). The sandstones, which dominated the central and northern part of AlUla, are the older Siq and younger Saq Sandstones, both composed of fine-grained to medium-grained quartz (Hadley 1987). Tectonic activity as a result of the rifting of the Red Sea created several extensive basaltic lava fields (locally known as harrats) during the Tertiary dating from around 10 million years ago to around 500,000 years ago

(Hadley 1987; Rasul et al. 2015; Altherr et al. 2019). More recent alluvium deposits can be found across the region, especially in valleys (wadis), ranging from large water-travelled boulders to fine-grained wind-blown sand (Al-Bassam 2014).

A rich and varied geodiversity in an area will result in a range of habitats, and subsequently, increased biodiversity (Comer et al. 2015; Lawler et al. 2015; Alahuhta et al. 2018). The erosion of the different rock types, particularly with the lack of vegetation cover and the low annual rainfall, has created a large number of different habitats across AlUla. The crystalline igneous and metamorphic rocks in the south erode very differently than the sandstones in the north, creating different landscapes and different types of soils. The geodiversity of AlUla is a contributing factor to the fact that five Nature Reserves were established, aimed at protecting over 50% of the county. Harrat Uwayrid, Harrat AlZabin, Wadi Nakhlah, Sharaan and AlGharameel Nature Reserves, are each very different from each other: environments created by the underlying geology.

The climate of most parts of North Arabia is characterised by very hot, dry, summers and cool to warm winters. Rain-bearing cyclonic depressions during winter and spring that originate in the Atlantic or Mediterranean is the main source of precipitation. Throughout the area, rainfall is erratic and unpredictable in time, quantity, and space and often falls as heavy local showers. In some years, certain areas may receive almost no rain. The data

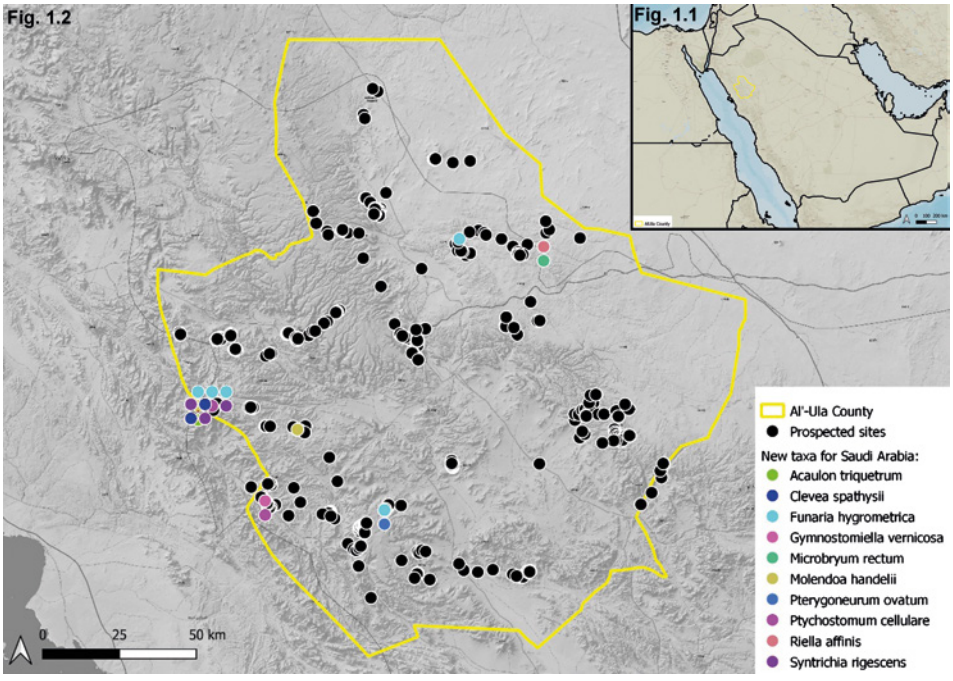

Fig. 1. 1: Location of AlUla county within the Arabian Peninsula; 2: surveyed sites in AlUla county: coloured dots indicate location of new species for Saudi Arabia.

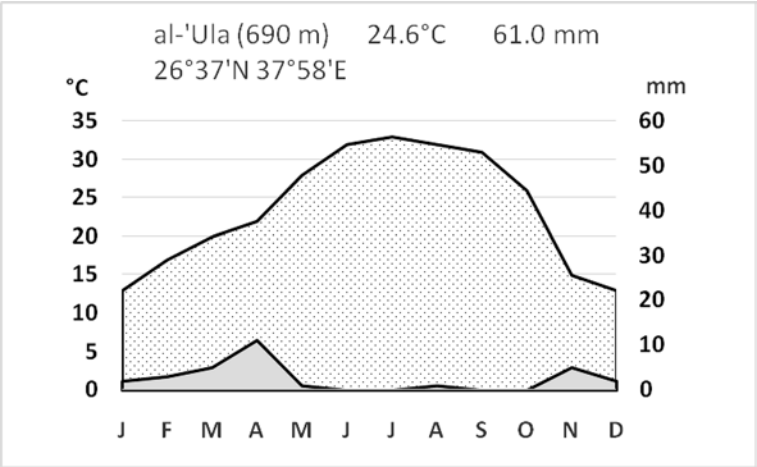

Fig. 2. Climagram for AlUla meteorological station (Data: 1991–2021)

obtained for the AlUla meteorological station give a good picture of the regional climate (Fig. 2). The mean annual rainfall is 61 mm and the mean annual temperature is 24.6 °C.

Materials and methods

The surveys were carried out from January 13 to February 27, 2024, with 488 sites surveyed (Fig. 1.2). The selection of sites was guided by the examination of geological and topographical maps and the existence of moisture sources (wadis, springs, wetlands). Additionally, the accessibility of the sites was analysed considering the presence of trails allowing an approach within a walking distance of less than 5 km. Finally, advice was obtained from local rangers regarding the difficulties of prospecting and the presence of potential habitats for bryophytes. All the sites meeting these selection criteria were visited during the field session.

A total of 150 bryosociological relevés were taken systematically, using Frey & Kürschner (1995) adapted scale. Hence, the associated species cited in the present work are species sharing the same microhabitat, and not species growing nearby within distinct communities. Additionally, classic ecological parameters were sampled (e.g., exposure, inclination, cover of bryophytes, depth of the soil when relevant etc.). Bryosociological results will be published separately.

The definition of the Arabian Peninsula follows Kürschner (2000), and therefore excludes Iraq and Jordan. The taxonomy and nomenclature of the bryophytes mainly follow Kürschner & Frey (2020) except for *Athalamia spathysii* (here *Clevea spathysii*), *Plagiobryoides cellularis* (here *Ptychostomum cellulare*) and *Anoectangium handelii* (here *Mo-*

lendoa handelii). For the *Bryaceae*, the nomenclature of Holyoak (2021) is followed. For vascular plants, we use Kürschner & Neef (2018). The vouchers are currently kept in the private herbarium of Vincent Hugonnot and Florine Pépin, and will be transferred to the Royal Commission for AlUla's (RCU) collection in early 2025.

The vegetation description is largely taken from the Inventory and Vegetation of AlUla Flora Project (Royal Commission for AlUla 2023) and from Kürschner & Neef (2018). Associated vascular plants are systematically noted. A distinction is made between vascular plants growing in the same microhabitat (e.g. a wet fissure, under an overhang etc.) and those growing in the vicinity, under distinct ecological conditions.

Results

Ten species are new for Saudi Arabia, from which four turned out to be new records for the entire Arabian Peninsula. Aside from *Funaria hygrometrica*, *Microbryum rectum* and *Riella affinis* which were observed once each within Sharan Nature Reserve (North East of the county), all other localities are in the western part of the county, with a strong concentration of new records in the small area in the vicinity of Jabal Alwared, which is also the most elevated mountain range in the county.

Cleveaceae

***Clevea spathysii (*Lindenb.) Müll. Frib.**

[**Syn**. *Athalamia spathysii* (Lindenb.) S. Hatt.]

Saudi Arabia: Medina Province, Jabal Alwared,1660 m, 26° 25' 45.2" N, 37° 12' 10.18" E, wadi with dripping rocky steps, on soil under large blocks 25/02/2024, V. Hugonnot & F. Pépin; 1679 m, 26° 25' 42.42" N, 37° 12' 6.17" E, habitat idem, 25/02/2024, V. Hugonnot & F. Pépin

Clevea spathysii is a Circum-Tethyan taxon, widespread in the Mediterranean and subtropical regions of both hemispheres (Rubasinghe 2011; Gradstein 2017). In southwestern Asia it is recorded in Afghanistan, Turkey, Israel, Jordan, Lebanon, and, in the Arabian Peninsula, in Oman and Yemen (Kürschner & Frey 2020). This is a new species for Saudi Arabia.

Together with *Targionia hypophylla* and *Plagiochasma rupestre*, this is the third Marchantioïd species in AlUla County. It is easily recognized by the spongy, reticulate and crystalline thallus, showing striking black-purple marginal colour and the dorsal female receptacle. The thallus of this species does not show xeromorphic features and this is in contrast with most Arabian complex thalloid liverworts. This may explain why it occupies strongly protected micro-niches, where isolation and temperatures are less extreme than in exposed environments.

In AlUla county, *Clevea spathysii* was observed growing in the minor bed of a small rocky wadi (with few vascular plants, mainly *Ferula sinaica*, *Lycium shawii*, *Retama raetam* and *Senecio glaucus*), where it occupies the bottom of some small crevices facing north. In this microhabitat, protection and exposure guarantee a minimum quantity of moisture throughout the year. Associated bryophyte species are scarce and poorly developed. They are small colonies of a sterile *Entosthodon*, *Fissidens* cf. *arnoldii* and *Weissia condensa*. Vascular plants in close proximity are *Hemionitis pteridioides*, *Parietaria alsinifolia* and *Umbilicus horizontalis*.

Riellaceae

Riella affinis M. Howe & Underw.

Saudi Arabia: Medina Province, AlUla, Sharaan Nature Reserve, 988 m, 26° 53' 55.6" N 38° 19' 30.43" E, semi-permanent pools, 11/02/2024, V. Hugonnot & F. Pépin

Riella affinis is a very rare species worldwide, being known from only 10 populations (Segarra-Moragues et al. 2014), most of them being recently unconfirmed records. It is a broadly distributed, old-world amphitropical species, being recorded in Africa, Asia and southern Europe (Iberian Peninsula and Macaronesia). In southwestern Asia, the unique record is that of Lipkin & Proctor (1975) which is considered to require verification (Segarra-Moragues et al. 2014). Hence, the genus is a new record for Saudi Arabia and the Arabian Peninsula. The new population appears very isolated and very far from the Indian population (Patel 1977) and the South Algerian, Sahara population (Puche & Boisset 2009).

Riella affinis belongs to a taxonomically difficult genus that is additionally challenging to spot in the field, due to the ephemeral nature of the populations and the aquatic habitat (Segarra-Moragues et al. 2014), which may account for its rarity in records. *Riella affinis* is characterized by the occurrence of longitudinal wings on the involucres and its monoecy, both characters, which are easy to demonstrate, even in the field. The antheridia are easily seen as small orange dots on the margin of the wing. The spores are densely echinulate, without discernible membrane uniting spines. Panduriform vegetative caducous scales were abundantly produced locally.

The described habitat of the Algerian population is very similar to that of Arabian Peninsula. In the Sahara, the species was growing in a seasonal rock pool (guelta) of approximately 10 m^2 located in a canyon. Elsewhere, it is also mentioned in artificial habitats, like dams or reservoirs (Segarra-Moragues et al. 2014). In AlUla County, the species was observed in two ponds, one natural and one of artificial origin (Fig. 3). The natural basin is only a few m^2 large (approximately 50 cm deep at the period of observation), at the base of a Saq sandstone canyon, along a water drainage channel. The artificial one is much larger (approximately 220 m^2), and results from the construction of a small dam in 1970, which is 1 m deep, with sandy ledges. Whereas only a few thallus were observed in the natural pond, thousands were developing in the artificial basin.

Fig. 3. Habitat of *Riella affinis* in Sharaan Nature Reserve (26° 53' 55.6" N 38° 19' 30.43" E)

The only associated species in the artificial pond is *Phragmites australis*, which is apparently very dynamic here, and may outcompete the *Riella* in the near future with increased sand accumulation. The conservation of the Arabian population raises specific issues. Insufficient precipitation could lead to an impoverishment of the diaspore bank. In fact, the completion of the entire cycle (from spore to spore), demands probably several months of complete immersion. A detailed study of habitat conditions and monitoring of the population should be very useful to uncover tendencies and evaluate the relevancy of carrying active management actions.

Bryaceae

Ptychostomum cellulare (Hook.) D. Bell & Holyoak

[Syn. *Bryum cellulare* Hook.; *Plagiobryoides cellularis* (Hook.) J.R. Spence]

Saudi Arabia: Medina Province, Bir Jaydah, 807 m, 26° 9' 9.89" N 37° 25' 58.8" E, rocky wadi, seepage, 26/01/2024, V. Hugonnot & F. Pépin; East Jabal Alwared, 1444 m, 26° 26' 41.06" N 37° 16' 10.87" E, rocky wadi, along dripping fissures, 03/02/2024, V. Hugonnot & F. Pépin; 1398 m, 26° 26' 46.63" N 37° 16' 6.22" E, habitat idem, 03/02/2024, V. Hugonnot & F. Pépin

This is a tropical species widely spread on all the continents (Holyoak 2021), and recorded from Oman and Yemen in the Arabian Peninsula (Kürschner & Frey 2020). It is a new record for Saudi Arabia.

The Saudi specimens are mostly small but very homogeneous, combining reddish coloration, concave and imbricate leaves, lax mid-leaf cells, no border, and a costa ceasing just below the apex.

It is often observed in mixed-sands with *Bryum dichotomum*. In such cases, it remains perfectly constant in its morphological characters and clearly distinct from this species. *Bryum dichotomum* has long excurrent nerve, much less concave leaves, and is often green. Associated vascular species are scant (mainly *Hemionitis pteridioides* and *Parietaria alsinifolia*).

It grows in the minor bed of small wadis, on 1–2 m high rock-steps, with approximately 2 cm deep tufa deposits. *Ptychostomum cellulare* belongs to a remarkable small assemblage of tropical species (*Gymnostomiella vernicosa*, *Hymenostylium hildebrandtii*), growing in flowing water in desert environment in AlUla county. Other species frequently associated are *Bryum dichotomum*, *Riccia cavernosa*, *Geheebia tophacea*, *Timmiella barbuloides*.

Funariaceae

Funaria hygrometrica Hedw.

Saudi Arabia: Medina Province, 60 km West Fadhla, 1435 m, 26° 26’ 24.97” N 37° 15’ 2.64” E, Seepage on a dam, 15/01/2024, V. Hugonnot & F. Pépin; 1445 m, 26° 26’ 31.34” N 37° 15’ 5.44” E, sandy depressions in a wadi, 17/01/2024, V. Hugonnot & F. Pépin; 61 km West Fadhla, 702 m, 26° 26’ 22.13” N 37° 14’ 51.32” E, sandy depressions in a wadi, 15/01/2024, V. Hugonnot & F. Pépin; AlUla, Sharaan Nature Reserve, 853 m, 26° 55’ 15.93” N 38° 3’ 6.17” E, grassland at the base of a sandstone cliff, 11/02/2024, V. Hugonnot & F. Pépin; AlUla, Harrat AlZabin, 21km West Masader, 897 m, 26° 8’ 8.69” N 37° 48’ 31.64” E, sandy banks of a wadi, 21/01/2024, V. Hugonnot & F. Pépin

This is a sub-cosmopolitan species widely spread in southwestern Asia, but is only recorded from Kuwait in the Arabian Peninsula (Kürschner & Frey 2020). This is even more surprising that the species turned out to be very widespread and abundant in suitable habitats in AlUla county.

It is distributed mostly in banks of sandy wadis, together with *Microbryum starckeanum*, *Bryum dichotomum*, *Riccia cavernosa*, either on sandy deposits or in more argillaceous small depressions. It is also recorded in human-made habitats such as around small leaks in damns, with *Bryum dichotomum* and *Geheebia tophacea*. Associated vascular species are either hygrophilous (*Juncus rigidus*, *Mentha longifolia* and *Veronica anagalloides*) or ruderal species benefiting from regular disturbance (*Bromus tectorum*, *Calendula tripterocarpa*, *Lepidium aucheri*, *Malva parviflora*, *Matricaria aurea*, *Senecio flavus*).

The species has obviously been underestimated. Perhaps this is related to the date of the observations, *Funaria hygrometrica* being only visible very early in the year (January–February) in AlUla County and to the fact that it is often sterile. It is probable that sterile colonies, observed in January–February, are not able to complete their biological cycle and do not produce sporophytes before drying out.

Pottiaceae

Acaulon triquetrum (Spruce) Müll. Hal.

Saudi Arabia: Medina Province, 61 km West Fadhla, 702 m, 26° 26’ 22.13” N 37° 14’ 51.32” E, small depressions in a wadi, 15/01/2024, V. Hugonnot & F. Pépin

This is a xerothermic Pangean species, widespread in the Mediterranean region and Macaronesia, reaching south Ural to the East and Tajikistan in Central Asia (Ignatov et al. 2006). It is also recorded in North America (Zander 2007) and Australia (Stone 1989). In Southwest Asia, it is recorded in Turkey, Israel and Iraq (Kürschner & Frey 2020). The genus *Acaulon* is newly recorded for Arabian Peninsula.

The Tunisian type of *Sphaerangium triquetrum* var. *desertorum* Besch. (*Acaulon triquetrum* var. *desertorum* (Besch.) Jelenc) has been examined by Cano et al. (2000) and found to be identical with Southern Spain material, by the non-triangular habit of the shoots, the long excurrent nerve and smooth lamina cells. This set of characters is also present in the Arabian population observed, notably the long excurrent and flexuose nerve (reaching 0.5 mm in upper leaves). Whether var. *desertorum* belong to the normal variability of the species or deserves taxonomic recognition (as Cano et al. (2000) argued) remains to be demonstrated.

This is an ephemeral species growing on fine-textured soil. In temperate regions, it requires opening of the vegetation, which is mostly achieved by grazing and trampling. In arid and hyper-arid environments, natural erosion due to extreme summer drought likely regenerate available micro-sites. Locally, it grows in small sandy depressions along the course of a wadi, on fresh 5 cm deep soil, together with *Bryum dichotomum* and *Funaria hygrometrica*. Associated vascular species are sparse and mostly ruderal species (*Asphodelus tenuifolius*, *Isatis lusitanica* and *Malva parviflora*).

Ahrens (2003) demonstrated the persistence of a subterranean rhizoid system producing new gametophores at favourable time intervals. This is likely an important mode of propagation in arid environments since sporophytes are only produced under favourable weather conditions (sufficient moisture).

Gymnostomiella vernicosa (Hook. ex Harv.) M. Fleisch.

Saudi Arabia: Medina Province, 4 km NNW Bir Jaydah 769 m, 26° 10’ 19.23” N 37° 24’ 45.71” E, wadi, on small rocky dripping steps, 25/01/2024, V. Hugonnot & F. Pépin

This is a tropical species, widely spread in tropical and subtropical regions on all continents except Europe. In the Arabian Peninsula, it is recorded in Yemen (including Socotra), Kuwait and Oman, mainly in Dhofar (Kürschner & Frey 2020). It is a new record for Saudi Arabia.

Splachnobryum has sometimes been linked with *Gymnostomiella* Fleisch. The two genera share similar growth habits, flaccid textures, leaf shapes, areolation, and they both lack perigonial paraphyses. When well developed, *Gymnostomiella* differs from *Splachnobryum* in having papillose leaf-cells, whereas they are smooth in *Splachnobryum*. Kürschner & Frey (2020) mentions that var. *tenerum* may have smooth cells, which resembles a *Splachnobryum* species. The local specimens appear to be very juvenile and depauperate, with very short, spatulate to suborbicular leaves, and almost smooth leaf-cells, that corresponds well to *Gymnostomiella vernicosa* var. *tenerum* (Müll. Hal. ex Dusén) T. Arts which is now considered to fit within the morphological variability of var. *vernicosa* by Gonzalez-Mancebo et al. (2010).

However, Saudi specimens clearly differ from *Splachnobryum* in having moniliform axillary hairs (they are clavate or filiform in *Splachnobryum*) and by the presence of caducous clavate and multiseriate axillary brood bodies that are mostly grouped in a form of apical cup (Fig. 4). Those are filiform and uniseriate in *Splachnobryum*, and absent in the only species recorded in Arabian Peninsula, *S. aquaticum* Müll. Hal. (Arts 2001). They additionally differ by KOH colour reaction of the leaf lamina (blackish patches of cells in *Gymnostomiella* against yellow throughout in *Splachnobryum*) (Zander 1993; Arts 1998).

Ecologically, the observed populations grow in the minor bed of temporary rivulets (wadis), on dripping rock walls that are often incrusted with lime deposits (1–2 cm deep), within tufa bryophytic communities (Fig. 5). Associated species are *Bryum dichotomum*, *Entosthodon attenuatus*, *Geheebia tophacea* and only *Parietaria alsinifolia* for vascular plants. This appears to be most similar to the reported habitat conditions for *Splachnobryum* species.

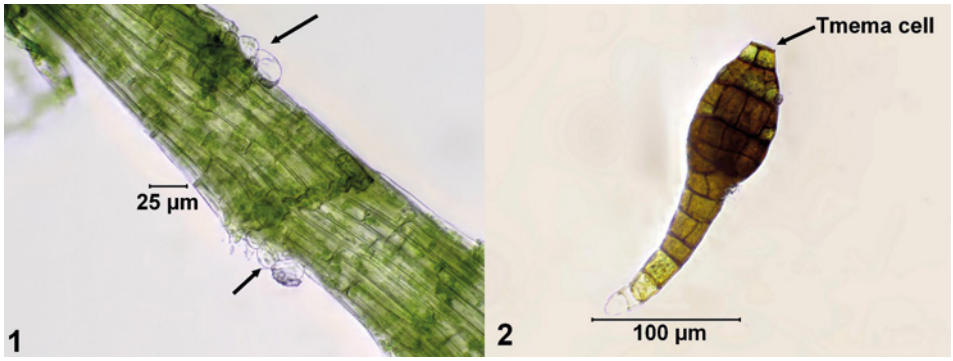

Fig. 4. *Gymnostomiella vernicosa* (Hook. ex Harv.) M. Fleisch.: 1: two axillary hairs indicated by arrows; 2: axillary gemmae.

Fig. 5. Habitat of *Gymnostomiella vernicosa* near Bir Jaydah (26° 10’ 19.23” N 37° 24’ 45.71” E)

Microbryum rectum (With.) R.H. Zander

[Syn. *Pottia recta* (With.) Mitt.]

Saudi Arabia: Medina Province, AlUla, Sharaan Nature Reserve, 853 m, 26° 55’ 15.93” N 38° 3’ 6.17” E, grassland at the base of a sandstone cliff, 11/02/2024, V. Hugonnot & F. Pépin

This is a Circum-Tethyan taxon, widely spread in Mediterranean region. In southwestern Asia it is recorded in Iran, Iraq, Turkey and Israel (Kürschner & Frey 2020). This is a new record for the Arabian Peninsula.

It is characterized by short stem, single and thin nerve stereid layer, short seta, exothecium with irregular and anastomosing streaks, and a rudimentary annulus of 2–3 cell rows.

It was recorded growing in a dense herbaceous ruderal plant community (with a rich assemblage: *Blumea bovei, Bromus tectorum, Calendula tripterocarpa, Gastridium phleoides, Lepidium aucheri, Malva parviflora, Matricaria aurea, Parietaria alsinifolia,*

Fig. 6. Habitat of *Microbryum rectum* in Sharaan Nature Reserve (26° 55' 15.93" N 38° 3' 6.17" E)

Rumex vesicarius, *Senecio flavus*, *Spergularia marina*) together with abundant *Microbyum starkeanum*, and sparse *Bryum dichotomum* and *Funaria hygrometrica*, at the base of a gigantic cliff of Saq sandstone of northwest exposure, providing almost permanent shade (Fig. 6). Most probably, the lush bryophytic assemblage benefits from being well protected from direct sunlight.

Molendoa handelii (Schiffn.) Brinda & R.H. Zander

[Syn. *Anoectangium handelii* Schiffn.]

Saudi Arabia: Medina Province, 32 km West Fadhla, 988 m, 26° 22' 11.23" N 37° 31' 40.29" E, boulder with *Lycium shawii–Ephedra foliata* shrubland, 28/01/2024, V. Hugonnot & F. Pépin; Jabal Alwared, 1766 m, 26° 24' 59.35" N 37° 12' 28.82" E, wadi, on soil, under rocks in a *Retama raetam–Artemisia sieberi* shrubland of the high Hijaz mountains, 25/02/2024, V. Hugonnot & F. Pépin

This is a Circum-Tethyan species, recorded in North America (Zander & Weber 2005; Brinda & Zander 2020), very locally in Europe (Crimea in Ukraine, cf Ignatova 2009) as well as southwestern and central Asia (Ignatova 2009). In southwestern Asia it is known in Afghanistan, Iran, Iraq, Turkey, Syria and Israel. In Arabian Peninsula, it was recorded in United Arab Emirates and Oman (Kürschner & Frey 2020). This is a new record for Saudi Arabia.

Molendoa handelii bears a strikingly similar overall morphological appearance to *Gymnostomum*, notably *G. mosis*, a widespread species in Arabian Peninsula. In *M. handelii*, the leaves are keeled, and appear deeply grooved along costa (best visible in transverse section), but care should be taken because some morphs of *G. mosis* may also have relatively keeled leaves in the upper part. Both species are best distinguished by the observation of the adaxial side of the costa (upper 1/3): the smooth and translucent guide cells are exposed in *M. handelii*, whereas they are covered by a layer of chlorophyllose and papillose cells in *G. mosis*, and this gives a compact appearance to the tissue (Fig. 7). The species is locally totally sterile (no gametangia nor sporophytes observed). Ovoid, long

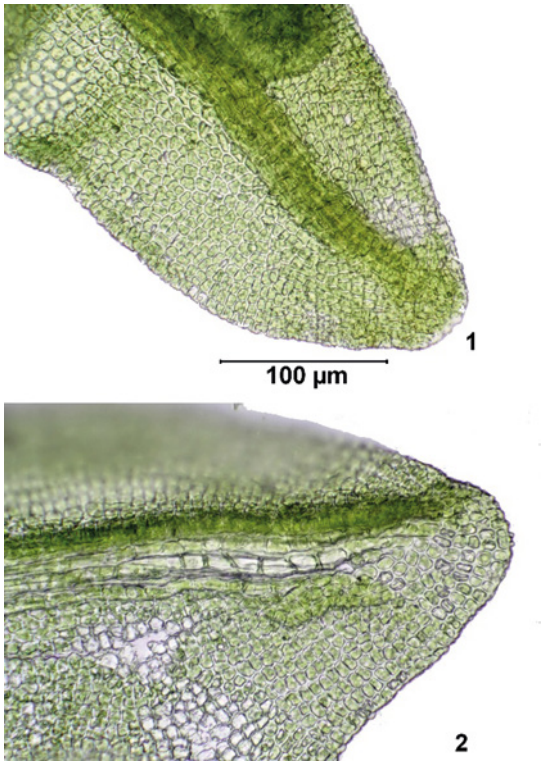

Fig. 7. 1: Leaf apex of *Gymnostomum mosis* (Lorentz) Jur.; 2: leaf apex of *Molendoa handelii* (Schiffn.) Brinda & R.H.Zander.

Fig. 8. Habitat of *Molendoa handelii*, West Fadhla (26° 22' 11.23" N 37° 31' 40.29" E)

apiculate propagule are few and difficult to find but were seen after targeted search. The stems are fragile which are identified as a means of asexual multiplication by Zander & Weber (2005). Yet, *M. handelii* remains a poorly known species that would benefit from a molecular study.

The affinity of the species toward xeric environments has been repeatedly emphasized (Ignatova 2009; Zander & Weber 2005). In Saudi Arabia, it typically inhabits large dry sloping boulders dominated by *Lycium shawii–Ephedra foliata* or *Retama raetam–Artemisia sieberi* shrubland. *Abutilon fruticosum*, *Artemisia sieberi*, *Ballota undulata*, *Colchicum ritchiei*, *Ephedra foliata*, *Euryops jaberiana*, *Hibiscus micranthus*, *Lavandula coronopifolia*, *Stachys aegyptiaca* or *Tanacetum sinaicum* are often noted with this species (Fig. 8). Locally it occupies small niches protected from direct sunlight where it is associated with other small Pottiaceous mosses often with aborted sporophytes. *Tortula inermis*, *Trichostomopsis australasiae*, *Tortula atrovirens*, *Crossidium squamiferum* are the most frequent associated species.

Pottiaceous communities are very sensitive to disturbance. Camel, goat and donkey grazing on the rocky slopes may lead to overturning and movement of stone assemblages, which in turn cause excessive erosion and the disappearance of pioneer mosses.

***Pterygoneurum ovatum* (Hedw.) Dixon**

Saudi Arabia: Medina Province, AlUla, Harrat AlZabin, 21km West Masader 897 m, 26° 8’ 8.69” N 37° 48’ 31.64” E, small sandy depression in a wadi, 21/01/2024, V. Hugonnot & F. Pépin

This is a Pangean species recorded in xeric areas on all continents, known from southwestern Asia in Iran, Iraq, Turkey, Syria, Jordan, and only in Kuwait in the Arabian Peninsula (Kürschner & Frey 2020). The species is a new record for Saudi Arabia.

From a morphological point of view, the Saudi specimen is typical for the species albeit rather diminutive, the shoots not exceeding 4 mm high, whereas it generally attains 5–6 mm high in more favourable conditions (Herrnstadt & Heyn 2004; Cano 2006).

It was observed in the course of an open sandy wadi, in small drying depressions, on clay-sandy material, together with *Riccia cavernosa*, *Funaria hygrometrica* and *Bryum dichotomum* and only very few vascular plants (*Asphodelus tenuifolius* and *Zilla spinosa*) (Fig. 9). The population was very small, composed of only several scattered individuals.

Fig. 9. Habitat of *Pterygoneurum ovatum* in Harrat AlZabin Nature Reserve (26° 8’ 8.69” N 37° 48’ 31.64” E)

***Syntrichia rigescens* (Broth. & Geh.) Ochyra**

Saudi Arabia: Medina Province, Jabal Alwared, 2040 m, 26° 24' 56.86" N 37° 13' 4" E, granitic boulder, on soil under large blocks in a *Retama raetam–Artemisia sieberi* shrubland of the high Hijaz mountains, 25/02/2024, V. Hugonnot & F. Pépin

Syntrichia rigescens is a Circum-Tethyan species, known in Europe, North Africa (Gallego et al. 2002) and south-western Asia, where it is recorded from Israel, Jordan and Syria (El-Oqlah et al. 1988; Kürschner & Frey 2020). This is a new record for the Arabian Peninsula.

The characteristic brood bodies that are considered as diagnostic are very scantly present in the local material. They can nevertheless be observed in old leaves, where they are confined to adaxial upper third of costa. Gallego (2005) notes that gemmae production could be the response of the plant to stress, which is substantiated by our observation. Yet, the species is relatively easy to differentiate from related ones, by the medially constricted leaves, the partially bistratose leaf lamina and the dorsal side of costa adorned with high stellate papillae.

It was observed under a large granitic boulder with mega-blocks (3–4 m large) colonized by the *Retama raetam–Artemisia sieberi* shrubland typical of the high Hijaz mountains with *Artemisia sieberi*, *Ballota undulata*, *Colchicum ritchiei*, *Diplotaxis harra*, *Euryops jaberiana*, *Stachys aegyptiaca* and *Tanacetum sinaicum*. *Syntrichia rigescens* was colonizing small compacted soil deposits under prominent blocks, together with *Tortula inermis* and *Vinealobryum vineale*.

Discussion

Two liverworts and eight mosses are new records for Saudi Arabia, of which four species are also new records for the Arabian Peninsula. The newly recorded species belong mostly to the *Pottiaceae* family, which comprises many drought-adapted species, typical of the xeropottioid life syndrome (Frey & Kürschner 1988; 1998; Kürschner 2004), hence reflecting the overall aridity of the AlUla county.

With the additions provided herein, the bryophyte flora of Saudi Arabia now counts 164 species (133 mosses and 31 liverworts). The results of this inventory demonstrate that many new bryophytes records are yet to be discovered, even in the arid regions of the Arabian Peninsula. Ephemeral and winter annuals that only appear after sufficient rainfall in springtime (particularly in run-off areas, episodic water pools) are certainly underrepresented in the flora at present, due to the lack of collection activities and surveys.

The new species were found either in arid habitats or along temporary watercourses or in episodic water pools. Nonetheless, in AlUla County, probably as in the entirety of the arid Arabian Peninsula, bryophytes appear very restricted in space and always confined to protected niches. Even the most drought tolerant species tend to occur under protected granitic mega boulders, or at the base of huge northern exposed cliffs. The critical feature

of the microhabitats is the "available" moisture allowing the completion of the biological cycle of the bryophytes. Aborted sporophytes are often observed in mosses or in liverworts, which shows that efficient production of spores may not occur every year, which in turn render the population more vulnerable to ecological hazards.

Some globally very widespread species are abundant and largely distributed in the Mediterranean region (*Acaulon triquetrum*, *Microbryum rectum*), but are probably rare and localized species in the Arabian Peninsula. They are recorded from many sites in nearby Israel, Jordan etc. and it is difficult to conceive that they have passed unnoticed in the many previously surveyed areas of Saudi Arabia.

Other species have a high conservation value, and some of them are rare worldwide, regionally Red Listed, as it is the case of *Riella affinis.* For example, this species was considered Vulnerable in Algeria and Endangered in the Canary Islands. *Molendoa handelii* is a rare drought-tolerant species (Ignatova 2009) as is probably *Syntrichia rigescens*.

The occurrence of several species of tropical affinities so far North, at a latitude far exceeding the one generally considered to be limit (South to 18th parallel North), means that an Afrotropical bryofloristic penetration occurs along the Red Sea, in particular in the western mountain range of Northern Hijaz. Remarkably, Kürschner & Frey (2020) recently underlined the occurrence of monsoon influence (summer rainfall) far to the north, in Makkah province. Summer monsoon events combined to prevalence of fog may account for the presence of such species, but the dependence towards hydrological network of such species should not be underestimated. *Gymnostomiella vernicosa*, *Ptychostomum cellulare*, *Hymenostylium hildebrandtii* (a rare species of paleotropical, afro-montane affinities, which is also quite widespread in AlUla county) etc. are all hygrophytic species growing in protected micro-sites, like recesses in the minor beds of temporary rivulets, or small waterfalls. They are all sterile species locally (never being recorded with sporophytes) that probably have a relictual character (Kürschner 2000).

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