Lindbergia 39: 12–19, 2016
ISSN 2001-5909
Accepted 8 April 2016

Scopelophila ligulata recorded for the first time in northern Europe

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Scopelophila ligulata (Spruce) Spruce is reported for the first time from Europe north of the Alps. The moss was discovered in crevices in south facing cliff walls of felsic volcanic rock on the island Varaldsøy in Hordaland County, southwest Norway, in September 2015.

The island Varaldsøy in Kvinnherad Municipality, Hordaland County, southwest Norway, was visited on 10 September 2015, during a field meeting arranged by the Norwegian bryological society (Moseklubben), the Swedish bryological society (Mossornas Vänner) and the project 'Liverworts of Western Norway', funded by the Norwegian Species Initiative (Artsprosjektet). The large group of bryologists attending the meeting was split into small groups, in order to cover as much of the island as possible. The authors and Arne Pedersen† investigated an area of rich deciduous forest covering a steep slope facing the sea close to Åkre on the southeastern side of Varaldsøy (Fig. 1).

A portion of a vertical cliff wall inside the forest attracted our attention because of its different yellowish-brown colour. The rock was mostly smooth and dry and housed a limited amount of bryophytes, most of which were growing in small cracks or crevices. A medium-sized acrocarpous moss unfamiliar to all of us grew as patches and cushions in cracks, crevices and on layers of soil associated with the yellowish-brown rock. Its upper leaves had a fresh green colour, whereas the lower part of the shoots was blackish. The leaves were narrowly lingulate–elliptic with an obtuse apex, broadest above the middle, curved and erect when dry and widely spreading when moist (Fig. 2–5). They had an indistinct border, which was visible under a hand lens, appearing lighter than the rest of the lamina on young leaves and darker on older leaves. Many leaves had a cover of clear-white crystals on their tips (Fig. 6). The moss occurred along a few meters of the cliff wall, between 0.5 and 2 m above the cliff base. No sporophytes were observed in the field, or on the collected material. Once back in the lab the moss was identified as *Scopelophila ligulata* (Spruce) Spruce. The only bryophyte growing close together with *S. ligulata* was *Gymnocolea inflata* subsp. *acutiloba* (Schiffn.) R.M. Schust. & Damsh. ex L. Söderstr. & Váňa. Among bryophytes found on adjacent parts of the cliff wall were *Cephalozia bicuspidata* (L.) Dumort., *Conocephalum salebrosum* Szweyk., Buczk. & Odrzyk., *Pseudotaxiphyllum elegans* (Brid.) Z. Iwats., *Ptychomitrium polyphyllum* (Sw.) Bruch & Schimp., *Tortella tortuosa* (Schrad. ex Hedw.) Limpr., and *Trichostomum brachydontium* Bruch. The site is located at 60°6'14.7"N, 6°1'24.1"E (WGS-84), ca 50 m a.s.l.

Just over 100 m northeast of the first site, *S. ligulata* grew in a second site on a rock surface exposed by blasting by the side of a small brook at the roadside (Fig. 7–8). The rock had the same yellowish-brown colour, but the habitat was more exposed, and *S. ligulata* occurred abundantly within approximately 1 m^2. It was partly surrounded by extensive patches of protonemata (Fig. 9). Bryophytes

In memory of Arne Pedersen, who sadly passed away only one week after our visit to Varaldsøy.

Figure 1. The steep slope with deciduous forest in which *Scopelophila ligulata* was first found. Photo: L. Appelgren.

Figure 2. Dry plants of *Scopelophila ligulata.* Photo: K. Homble.

Figure 3. A moist patch of *Scopelophila ligulata.* Photo: L. Appelgren.

Figure 4. Moist plants of *Scopelophila ligulata.* Photo: K. Homble.

Figure 5. One young and one older leaf of *Scopelophila ligulata.* Note the indistinct border comprised of more thick-walled cells. Photo: L. Appelgren.

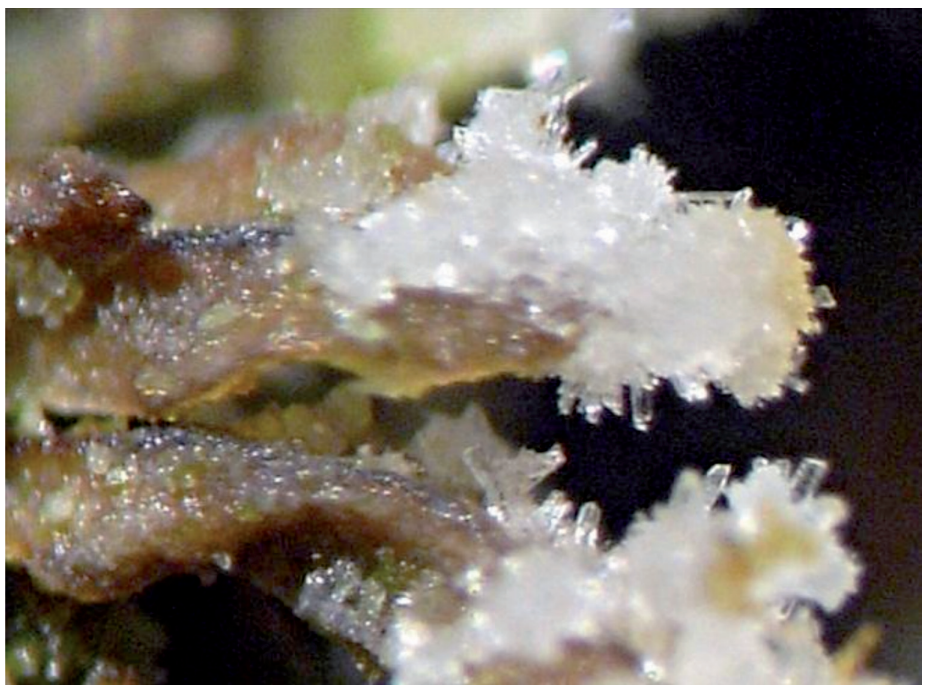

Figure 6. Crystals covering leaf tips of *Scopelophila ligulata.* Photo: K. Homble.

Figure 7. The yellowish-brown rock at the second site for *Scopelophila ligulata* on Varaldsøy. Photo: L. Appelgren.

Figure 8. *Scopelophila ligulata* growing in cracks at the second site. Photo: K. Homble.

Figure 9. Mats of protonemata surrounding *Scopelophila ligulata* at the second site. Photo: K. Homble.

growing on this rock wall and by the brook close to *S. ligulata* were *Brachythecium rivulare* Schimp., *Bryum pseudotriquetrum* (Hedw.) G. Gaertn., B. Mey. & Scherb., *Cratoneuron filicinum* (Hedw.) Spruce, *Dichodontium flavescens* (Dicks. ex With.) Lindb., *Ditrichum* sp., *Oxystegus tenuirostris* (Hook. & Taylor) A.J.E. Sm., *Palustriella commutata* (Hedw.) Ochyra, *Philonotis* sp., *Platyhypnidium riparioides* (Hedw.) Dixon, *Pohlia cruda* (Hedw.) Lindb., *Pohlia wahlenbergii* (F. Weber & D. Mohr) A.L. Andrews, *Scapania undulata* (L.) Dumort., and *Trichodon cylindricus* (Hedw.) Schimp. This site is located at 60°06'17.6"N, 6°01'28.5"E (WGS-84), ca 30 m a.s.l.

The locality

Varaldsøy island is situated in the Hardangerfjord, ca 40 km southeast of the city of Bergen. The area belongs to the boreonemoral zone and is clearly oceanic (Moen 1999). It has a mean annual temperature of 6–8°C and a precipitation between 2000 and 3000 mm per year (normal 1971–2000, Norges vassdrags- og energidirektorat (Norwegian Water Resources and Energy Directorate) <www.senorge.no> accessed 25 Jan 2016.) The southeastern side of the island is characterised by steep slopes mixed with vertical rock walls reaching from ca 25 to 200 m or more above sea level. Deciduous forests, with e.g. *Fraxinus excelsior* L., *Tilia cordata* Mill., *Corylus avellana* L. and *Ilex aquifolium* L., cover much of the slopes on this part of the island. At some places, like Åkre, narrow strips of gently sloping farmland extend between the hills and the seashore.

The geology of Varaldsøy is complex and diverse; narrow strips of rock with different mineral composition alternate and create significant local variation in the conditions for the flora. At the sites of *S. ligulata*, the bedrock consists of felsic volcanic rocks. According to the geological map of the area (Geological Survey of Norway (NGU) <http://geo.ngu.no/kart/berggrunn/> accessed 27 Jan 2016) it is most probably rhyolite, but there is also dacite in the area (Arne Solli, NGU, pers. comm. 27 Jan 2016). Rhyolite regularly contains considerable amounts of sulphides. Abandoned mines and quarries further north on Varaldsøy are reminders of the extraction of pyrite, or iron sulphide, in the 19th and early 20th centuries. Sulphides are readily oxidised to sulphates, which leads to acidification of surface water and mobilisation of metal ions. Oxidation of ferrous iron results in deposits of ochre, a clayey mineral rich in ferric oxide that varies in colour from light yellow to red, or brown. This probably explains the colour of the rock surface at the sites with *S. ligulata*. Since other areas of Varaldsøy have a similar bedrock, the species may well be found in additional localities.

Scopelophila ligulata

Scopelophila ligulata was first described by Richard Spruce from the Pyrenees in 1847, as *Encalypta ligulata*. It is dioicous and sexual reproduction is unknown in Europe and North America, but sporophytes are present in collections from Asia and South America (Shaw and Anderson 1988). The spores are small, 8–13 µm (Zander 1993), which should make the species suitable for long distance dispersal.

The distribution of *S. ligulata* is almost worldwide, but highly disjunct (Fig. 10). In Europe, it has been recorded mainly in the Alps and the Pyrenees. It is known from Spain, France, Switzerland, Austria, Italy and Slovenia. Outside the European mainland there are records from the Canary Islands and the Azores; Africa (Rwanda, Uganda); North, Central and South America (USA, Mexico, Guatemala, Costa Rica, Venezuela, Colombia, Ecuador, Peru, Bolivia) and Asia (Georgia, Russia, India, Nepal, Bhutan, China, Taiwan, Japan, Thailand, Indonesia, the Philippines, Papua New Guinea, the Solomon Islands) (Bardunov and Cherdantseva 1982, Schumacker et al. 1989, Sollman 1993, Porley et al. 1999, Ignatov et al. 2006, Zander 2007, Sabovljević et al. 2008, Moosflora der Schweiz 2011, Ros et al. 2013, Hodgetts 2015, see also Tropicos.org. Missouri Botanical Garden <www.tropicos.org> accessed 1 Feb 2016 and GBIF (Global Biodiversity Information Facility) <www.gbif.org/> accessed 1 Feb 2016).

The Norwegian record is the most northerly so far known in Europe as well as worldwide, with the previously northernmost collection from south–central Siberia, not far from the Mongolian border (Bardunov 2008). The distance from the closest European localities (in Switzerland and Austria) to the Norwegian locality is ca 1500 km, almost due north. The discovery of *S. ligulata* in Norway was unexpected, but not totally surprising considering its wide, disjunct distribution.

Scopelophila ligulata belongs to a group of bryophytes loosely referred to as 'copper mosses', characterised by a preference for substrates rich in metal sulphides, which are toxic to many bryophyte species. Copper mosses are generally rare and have a disjunct, but often wide, distribution. In Norway, they are represented by *Grimmia atrata* Miel. ex Hornsch., *Mielichhoferia elongata* (Hoppe & Hornsch.) Nees & Hornsch., *M. mielichhoferiana* (Funck) Loeske, *Cephaloziella massalongi* (Spruce) Müll.Frib. and *Gymnocolea inflata* subsp. *acutiloba*. *Grimmia atrata, C. massalongi* and *Gymnocolea inflata* subsp. *acutiloba* are known from a few localities in the south, while *M. elongata* and *M. mielichhoferiana* have scattered occurrences all over the country. *Grimmia atrata* was collected in the northern parts of Varaldsøy by other groups of bryologists on 10 and 12 September 2015.

Copper mosses have traditionally been considered to be more or less restricted to substrates with high concentrations of copper and/or other heavy metals. The substrates of several species have been analysed (Mårtensson and Berggren 1954, Shacklette 1967, Shaw and Anderson 1988), but the results are inconsistent and the relationships between plants and substrates have not been fully resolved. It has been proposed that the acidity of the substrate, rather than the metal ion content, is the abiotic factor that favours the occurrence of copper mosses (Hegi 1927, Persson 1948). A low pH is indeed common for the majority of analysed substrates, presumably caused by oxidation of reduced sulphur to sulphuric acid. Schatz (1955) suggested that sulphur might be the determinant factor for the occurrence of copper mosses, and that it would

Figure 10. World distribution of *Scopelophila ligulata*.

be more accurate to refer to them as "sulphur mosses". *Scopelophila ligulata*, for example, grows next to sulphurous hot springs in Java and the Azores (Persson 1948). Schatz (1955) also proposed that "sulphur mosses" would have thrived during the Tertiary, when volcanic activity was more widespread, and that they may in that sense be regarded as "living fossils".

Substrates of *Scopelophila ligulata* have been analysed in North America (Shaw and Anderson 1988) and Japan (Aikawa et al. 1999, 2000, Nagano et al. 1999). They all exhibited a low pH and a low to moderate concentration of copper. Two of the Japanese studies compared substrates of *S. ligulata* to those of non-copper mosses growing at the same sites (Nagano et al. 1999, Aikawa et al. 2000), while the third study analysed substrates of *S. ligulata* and two other copper mosses: *S. cataractae* (Mitt.) Broth. and *Mielichhoferia japonica* Besch. (Aikawa et al. 1999). All three Japanese studies showed substrates of *S. ligulata* to be more acidic and to contain significantly higher concentrations of water-soluble iron and sulphates than those of the other species. The concentration of copper in the moss tissue was lower for *S. ligulata* than for *S. cataractae* and *M. japonica*, while the concentration of iron was higher. Judging from these analyses, *S. ligulata* appears to thrive on acidic substrates with high concentration of water-soluble iron and sulphate. In contrast to *S. cataractae*, it does not appear to be confined to substrates rich in copper or zinc.

The concept of 'copper mosses' thus encompasses taxa with overlapping, yet distinct substrate specificities, not all of which include a high concentration of copper. Instead, different species within this group may have different requirements or preferences. It is likely that the ability to tolerate these unfriendly habitats provides a selective advantage in biotopes where few other species can compete, and it is possible that these adaptations evolved during periods in the Earth's history when such biotopes and conditions were more widespread.

Specimens of *S. ligulata* collected at the two sites on Varaldsøy are kept at TRH, accession numbers: B9335 and B13588.

Acknowledgements – Thanks to David G. Long for checking the language.

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