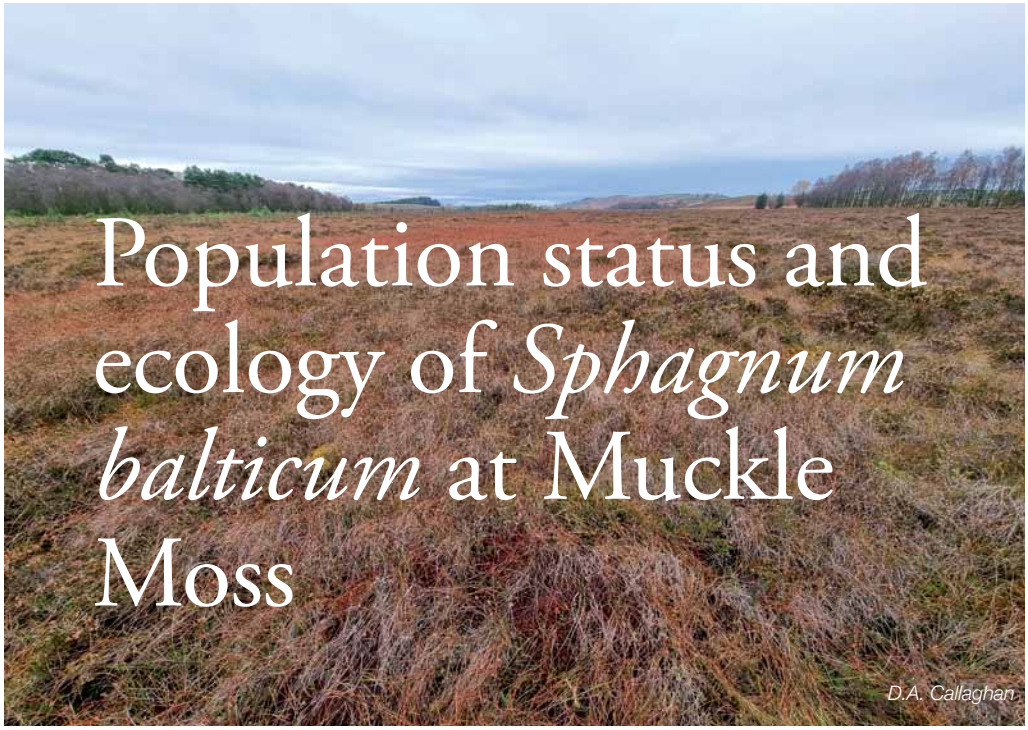


Population status and ecology of *Sphagnum balticum* at Muckle Moss

D.A. Callaghan

Des Callaghan reports on the best-known site for Britain's rarest *Sphagnum* species

Sphagnum balticum is the rarest of the 37 species of *Sphagnum* that presently occur in Britain, being confined to just three locations: a small mire at the edge of Abernethy Forest, Easterness, a mire at the head of Black Burn, South Aberdeenshire, and Muckle Moss, S. Northumberland (Callaghan *et al.*, 2023). It has been lost from at least four other sites as a result of habitat destruction and alteration, and is categorised as 'Vulnerable' on the new IUCN Red List of bryophytes in Britain (Callaghan, 2023). The species is specially protected under Schedule 8 of The Wildlife and Countryside Act 1981 (as amended) and has been the subject of a national conservation action plan (Porley, 2013).

Sphagnum balticum was first found at Muckle Moss by E.M. Lobley and D.A. Ratcliffe on 10 January 1961 (BBSUK) and this has become the best-known site for the species in Britain, having been recorded subsequently on many occasions. In 1984, the species became a designated interest feature of Muckle Moss Site of Special Scientific Interest (SSSI), which led to attempts to monitor the population (Hodgetts, 2006; O'Reilly, 2012, 2018; Turner, 2000, 2002), but surveyors encountered identification problems owing to confusion between *S. balticum* and very similar forms of *S. fallax*. For example, Hodgetts (2006) noted two types of *S. balticum* at the site, including a rare 'well-marked form' and a more frequent 'less well-marked form'. It is possible that the latter was in fact a form of *S. fallax*. These identification problems recently led to the typification of *S. balticum* (Callaghan & Brinda, 2022) and an integrated taxonomic study that has resolved its identification features (Callaghan *et al.*, 2023). Given this new understanding, the aim of this study is to investigate the population status and ecology of *S. balticum* at Muckle Moss.

Muckle Moss

Muckle Moss SSSI (Fig. 1) is an elongated valley mire of 149 ha located in a depression that is flanked on the north and south by Carboniferous sandstone ridges, partially concealed by drift. The mire surface slopes gradually from the western end (216 m alt.) to the eastern end (200 m). The peat layer is deep, with a maximum thickness of *c.*10.5 m, underlain by clay (Pearson, 1960). The site has features showing affinities with some Scandinavian mire types, in particular the pattern of crescentic pools with intervening ridges. These are thought to be the result of a slow, eastward movement of the peat, producing water-filled surface fissures. There are three main sections of the mire (Fig. 1). The western section was burned regularly until 1993, when the site was declared a National Nature Reserve (NNR). It is also grazed by sheep, but since 1993 the stocking density has been relatively low and the animals have tended to avoid grazing the mire itself, concentrating instead on the drier marginal ridges. The central section has been subject to significant degradation. Sometime before 1960, drains were excavated and the area was planted with conifers. After it was designated an NNR in 1993, the drains were blocked and the conifers were removed. No grazing by domestic stock has occurred on the central section. The eastern section was subject to drainage and intensive stock grazing, but most of it was fenced off from grazing in the 1990s and the drains were blocked. The climate is oceanic, with 144 raindays per year and average air temperatures of 13.8°C during the hottest month (July) and 2.1°C during the coldest month (February) for the period 1961–2002 (Met Office data supplied through the UK Climate Impact Programme).

▽ Figure 1. Location of Muckle Moss SSSI and the main sections of mire habitat. Satellite image © Google, DigitalGlobe.

△ Figure 2. *Sphagnum balticum* (left) and *S. fallax* (right) growing amongst *S. medium* at Muckle Moss, 15 November 2021. *D.A. Callaghan*

Identification of *Sphagnum balticum*

Identification of *S. balticum* follows the guidance provided by Callaghan *et al.* (2023). Some forms of *S. fallax* at Muckle Moss can be very similar to *S. balticum* (Fig. 2), including plants with fascicles composed of three branches, stem leaves that are spreading, and stem leaves that have fibrillose hyalocysts. Usually, however, it is possible in the field to observe the diagnostic cuspidate stem-leaf apex of *S. fallax* with the use of a ×20 hand-lens, though sometimes the stem-leaf margins of *S. balticum* can be loosely incurved, forming a point at the tip, which disappears when the leaf is flattened beneath a microscope coverslip. In cases of identification doubt in the field, a small sample was collected and determined by microscopy.

Distribution and abundance of *S. balticum* at Muckle Moss

Fieldwork was undertaken during 14–17 November 2021. A search was made for *Sphagnum balticum* across all parts of the site that contained favourable habitat. An OS grid reference waypoint was logged for each colony found with a hand-held GPS (Garmin GPSMAP 64s), which consistently reported accuracy of ≤5 m. Waypoints were not logged for colonies <1 m from a previously logged colony. Each logged colony is considered to be a separately occupied 1 m grid cell and, following Bergamini *et al.* (2019), each occupied 1 m grid cell is considered to be an 'individual-equivalent'. Once searching of the site was complete, a count was made of the number of individual-equivalents that were found and an overall population estimate for the site was made, informed by the frequency with which the species was detected along the survey route and the amount of favourable habitat present.

Following 22 hours of search effort, 83 occupied 1 m grid cells of *Sphagnum balticum*

were found, concentrated within the wetter parts of the central section of the mire and the adjacent wetter parts of the western section (Fig. 3). The west half of the western section and the entire eastern section of the mire contained no suitable habitat for *S. balticum*, being too dry. It is estimated that the total population comprises 100–250 occupied 1 m grid cells.

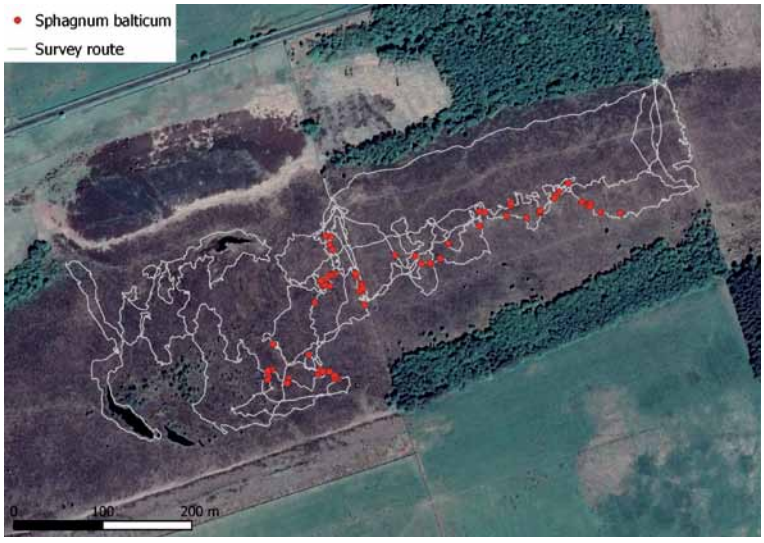
Habitat and community composition

Relevés were recorded to describe habitat conditions and community composition of locations occupied by *Sphagnum balticum*, generally following the method of Bates (2011). Sample locations were selected to represent the full range of conditions occupied by the moss. Relevés measured 50 × 25 cm, and within each, percentage cover of each species of bryophyte, lichen and vascular plant was estimated. Percentage cover of dead plant material ('litter') and bare ground was also recorded in each relevé. Shade was recorded according to the following index:

- 1, fully exposed to sunlight at all times;
- 2, shaded from direct sunlight for up to half the day;
- 3, receiving significant direct sunlight but for less than half the day (index values 2 and 3, and those for more shaded sites, were not required).

Slope was measured with a digital clinometer, recorded as the average angle (°) from horizontal in the direction of greatest slope. Aspect was recorded as the bearing (°) of the relevé using the above GPS unit. Water pH at each relevé was measured in the field with a calibrated Hanna HI-98130 meter.

Results from 10 relevés (Table 1) show that *Sphagnum balticum* typically occurs in low abundance at Muckle Moss and that *S. medium* is its most constant and abundant associate. Frequent vascular plant associates include *Andromeda polifolia, Erica tetralix, Eriophorum angustifolium, E. vaginatum* and *Vaccinium oxycoccos*. A small assemblage of bog liverworts also occurs. *Sphagnum balticum* is confined to the open mire, where locations are fully exposed to sunlight throughout the day. Water pH is strongly acidic (mean 5.1, range 4.4–5.7).



◁ Figure 3. Survey trail and locations where *Sphagnum balticum* was found at Muckle Moss during the present study. Satellite image © Google, DigitalGlobe.

Table 1. Percentage cover of plant species and environmental data from relevés occupied by ***Sphagnum balticum*** at Muckle Moss. Lichens are absent.

	Relevés (% cover)									
	1	2	3	4	5	6	7	8	9	10
Liverworts										
Calypogeia sphagnicola							0.1		0.1	
Cephalozia macrostachya var. macrostachya							0.1	0.1	1	
Cephaloziella hampeana								0.1	0.1	
Mylia anomala						0.5	1	1		
Odontoschisma sphagni								2		
Mosses										
Polytrichum commune						1	2	3		1
Polytrichum strictum				7				4		
Sphagnum balticum	1	1	3	2	0.5	1	2	1	1	0.5
Sphagnum rubellum		20	5	5		5	2	95		
Sphagnum cuspidatum		1			4					
Sphagnum fallax		4			2				5	3
Sphagnum medium	90	30	80	90	95	95	95		95	95
Sphagnum papillosum		5		1						1
Sphagnum tenellum	3									
Vascular plants										
Andromeda polifolia	0.5	0.1	1	1	0.5	0.5			0.5	0.1
Calluna vulgaris								3	5	15
Empetrum nigrum						2		4		
Erica tetralix	2	4	5	4	5	5	10	2	3	5
Eriophorum angustifolium	5	3	5	5	10	5	2		0.5	1
Eriophorum vaginatum	0.5	0.1	1	3	10	3	1	2	1	1
Vaccinium oxycoccos	0.5	3	2	2	1	0.5	3	2	0.1	0.1
Litter	5	5	3	4	4	5	5	3	3	2
Bare ground	0	0	0	0	0	0	0	0	0	0
Shade Index*	1	1	1	1	1	1	1	1	1	1
Water pH	5.6	5.3	5.7	5.4	4.4	5.3	5.7	4.4	5.1	4.5

* See text for definitions of scores.

Temperature regime

The temperature regime of the niche occupied by *S. balticum* was investigated using three TOMST TMS-4 data loggers (Wild *et al.*, 2019) installed beside representative colonies of the moss (Fig. 4). Each logger contained three sensors that recorded temperature at three different levels, including 8 cm below the moss surface ('T1'), level with the moss surface ('T2'), and 15 cm above the moss surface ('T3'). Temperature measurements were logged every 15 mins for a complete year, starting at 0:00 UCT on 1 January 2022.

The temperature regimes between the three locations where loggers were installed did not differ significantly. Monthly summary statistics are provided in Table 2. The warmest month, as recorded at the moss surface beside colonies of *Sphagnum balticum*, was July (mean 15.6, range 4.4–35.9°C) and the coldest month was December (mean 0.5, range -8.9–6.9°C). Fig. 5 shows a plot of the temperature data throughout

◁ Figure 4. Locations of temperature loggers installed beside colonies of *Sphagnum balticum* at Muckle Moss. Satellite image © Google, DigitalGlobe.

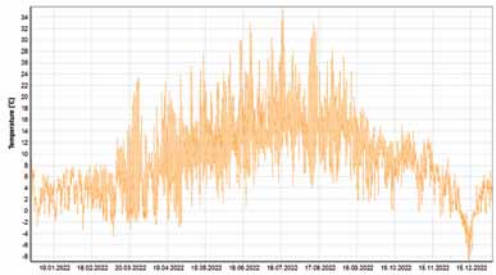
2022 from the moss surface, while Fig. 6 shows a plot for the hottest month and Fig. 7 shows a plot of the coldest month. Fig. 8 shows the total duration (hrs) by month of freezing conditions (≤0°C) at ground level. A total of 214 hours of sub-zero temperatures occurred in 2022 at the moss surface adjacent to colonies of *S. balticum*, restricted to the winter months and early spring, and mostly occurring in December.

Discussion

The present study shows that *Sphagnum balticum* is widely scattered in small quantity within the wetter parts of Muckle Moss, with an overall

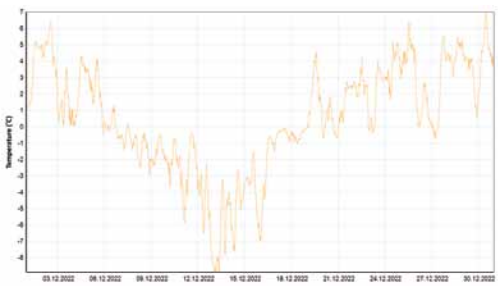
Table 2. Monthly summary statistics of temperature (°C) data from loggers located beside colonies of *Sphagnum balticum* at Muckle Moss for the year 2022. T1 = temperature at 8 cm below the moss surface; T2 = temperature level with the moss surface; T3 = temperature 15 cm above the moss surface.

Temperature sensor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T1												
Minimum	0.9	0.9	0.3	1.3	5.3	6.1	9.4	8.9	6.7	4.1	1.8	-2.1
Mean	3.9	4	4.4	6.5	9.6	11.6	13.6	13.6	11.6	9.2	6.8	1.5
Maximum	7.8	6.3	13.9	14.8	16.4	20.3	26.3	22.6	18.1	12.1	10.9	5.8
T2												
Minimum	-2.8	-3.4	-4.6	-2.9	0.6	0.7	4.4	4.1	1.6	0.1	-1.3	-8.9
Mean	3.1	3.6	4.4	7.1	10.8	13.5	15.6	14.6	11.6	8.9	5.9	0.5
Maximum	9.3	8.5	23.3	23.9	27.6	33.1	35.9	32.9	27.3	15.1	12.8	6.9
T3												
Minimum	-7.6	-9.5	-10.5	-8.1	-2.3	-3.2	0.5	0.5	-1.6	-4.4	-5.4	-13.8
Mean	3.3	3.8	4.8	7.1	11.2	13.9	16.3	15	11.6	9.4	6	0.5
Maximum	12.4	12.5	26.1	24.4	28.4	34.4	38.7	35.1	29.6	18.5	16.8	11.5



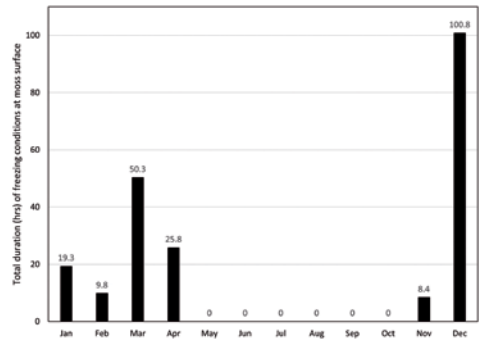
△ Figure 5. Plot of temperature (°C) at the moss surface beside a colony of *Sphagnum balticum* at Muckle Moss during 2022.

△ Figure 6. Plot of temperature (°C) at the moss surface beside a colony of *Sphagnum balticum* at Muckle Moss during the hottest month (July) of 2022.



△ Figure 7. Plot of temperature (°C) at the moss surface beside a colony of *Sphagnum balticum* at Muckle Moss during the coldest month (December) of 2022.

population estimated to comprise 100–250 individual-equivalents. This is broadly similar to the population at Abernethy Forest, while that at Black Burn appears to be smaller (Hodgetts, 2011; personal observation). Regarding the trend in the population at Muckle Moss, it is difficult to compare the results of the present study with



△ Figure 8. Monthly total duration (hrs) of freezing conditions (≤0°C) at the moss surface beside colonies of *Sphagnum balticum* at Muckle Moss during 2022.

previous surveys of the species (Hodgetts, 2006; O'Reilly, 2012, 2018; Turner, 2000, 2002) because of the confusion that occurred with forms of *S. fallax*. However, Maass (1965) knew *S. balticum* well and following a visit to Muckle Moss in August 1964, in the company of the *Sphagnum* expert E.M. Lobley, who first found the species at this site, he described *S. balticum* as 'filling a number of slight depressions especially where the minerotrophic nutrition is more pronounced'. This is similar to its normal growth pattern in the core of its range, where it typically forms mats in wet hollows and around the margins of pools in open boreal mires (Laine *et al.*, 2018). During the present study, no such colonies of *S. balticum* were found, with all occurrences of it comprising small numbers of thinly scattered shoots within dense colonies of other *Sphagnum* species, usually *S. medium* but also *S. rubellum*. This suggests there may have been a decline in *S. balticum* at Muckle Moss since the 1960s. Whether it is undergoing a continuing decline is unknown, and may only be determined by future monitoring. At Black Burn and Abernethy Forest, *S. balticum* similarly occurs only as scattered shoots amongst colonies of other *Sphagnum* species around the edge of wet hollows and pools (personal observation).

The frequent occurrence of *Sphagnum balticum* within the central section of Muckle Moss is notable. This area was substantially degraded, having been drained and planted with conifers, with habitat restoration beginning in the 1990s, including the blocking of drains and the removal of the conifers. The ability of *S. balticum*, which is not known to produce sporophytes in Britain, to recolonise this restored habitat is encouraging and is evidence of local dispersal via plant fragments. Roe Deer *Capreolus capreolus* are a possible dispersal vector, as their trails criss-cross the mire.

The results of this study show that the microclimate of Muckle Moss varies substantially across small spatial scales. The temperature regime at the moss surface is substantially different from that 8 cm below or 15 cm above the surface. For example, sub-zero conditions occurred during some night-time periods in May, June, September and October 2022 at 15 cm above colonies of *S. balticum*, but these did not occur at the moss surface inhabited by *S. balticum*. This is presumably a result of significant warming of the upper peat layer by solar radiation during the summer months, as recorded by the T1 sensors located 8 cm below the surface. During the winter and early spring months, however, 214 hours of sub-zero conditions were recorded in 2022 at the surface inhabited by *S. balticum*, concentrated within an unusually cold period in December, when the lowest temperature of -8.9°C occurred on 13 December. Being a boreal species of open habitat, it can be expected that *S. balticum* is relatively frost-tolerant. Indeed, utilising material collected from sites in the mid-taiga zone of Finland, Balagurova *et al.* (1996) showed experimentally that *S. balticum, S. subsecundum* and *S. teres* were more frost-tolerant than *S. fuscum* and *S. magellanicum*.

Given that *Sphagnum balticum* is located at the southern edge of its European range in Britain, a warming climate gives cause for concern for its future. The year of 2022 included periods of unusually hot weather at Muckle Moss. The summer heatwaves were exceptional and resulted in a peak temperature of 35.9°C on 19 July at the moss surface. Beside the possibility of causing heat stress to *S. balticum*, such conditions cause increased evaporation and, as a consequence, may lead to increases in the length and severity of desiccation events experienced by the species.

In Sweden, high temperatures have been shown to have a negative effect on *S. balticum* in both field and glasshouse experiments (Breeuwer *et al.*, 2009; Gunnarsson *et al.*, 2004), and there is a clear risk that future temperature regimes at Muckle Moss will affect the competitive ability of *S. balticum*, if they have not already done so. It is therefore important that monitoring of the population continues, ideally coupled with long-term monitoring of the temperature regime.

The principal vegetation type in which *Sphagnum balticum* occurs at Muckle Moss corresponds with the M18a *Erica tetralix-Sphagnum papillosum* raised and blanket mire *Sphagnum magellanicum-Andromeda polifolia* sub-community (Rodwell, 1991). This vegetation is confined to saturated peats and is widespread but local in Wales, northern England and Scotland. Searches for new sites for *S. balticum* could usefully target the best sites that support this vegetation, especially any sites where detailed bryophyte surveys have not been undertaken.

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