Recovery of ombrotrophic *Sphagnum* mosses in relation to air pollution in the Southern Pennines

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Abstract

The influence of recent ambient air pollution on the recovery of *Sphagnum* and other mosses on ombrotrophic bogs in the Southern Pennines was examined by re-visiting in 2005-6: (a) a transplant experiment established around 1980, and (b) permanent, unmarked plots where the presence of *Sphagnum* and other bryophytes was recorded in the mid 1980s. Both surveys suggest that the environment for the successful growth of *Sphagnum* and other bryophtes on ombrotrophic bogs in the Southern Pennines has improved in the last two decades. However, the abundance of bryophytes on the bog surface is still low in comparison with other ombrotrophic bogs in other more remote areas of Britain. Chemical analysis of bog pool waters indicated high levels of other pollutants, such as nitrate, ammonium and certain metals, in the Southern Pennines. It is possible that these could currently limit the full recovery of ombrotrophic bog communities despite the substantial reductions in deposited sulphur pollution.

Introduction

The virtual absence of ombrotrophic *Sphagnum* species from the deep, largely *Sphagnum*-formed, peat of the southern Pennines during at least most of the 20th Century is one of the ecological wonders of European vegetation. The demise of *Sphagnum* species almost certainly is the result of the proximity of these extensive peatlands to major centres of the Industrial Revolution and their major emissions of atmospheric pollutants (Tallis 1987), notably sulphur dioxide and its solution products. Evidence for the inhibitory effects of SO_2 came from the experimental exposure in controlled environments of a range of *Sphagnum* mosses to high (131µg SO_2 m^{-3}) and low (9 µg SO_2 m^{-3}) (Ferguson *et al* 1978).

From the mid 1970's onwards, prompted by the observed decline in sulphur air pollution (Ferguson & Lee, 1983a), two re-introduction experiments were established at Holme Moss on an intact peat surface with a high water table (Ferguson & Lee, 1983b). The first experiment involving the re-introduction of 5 ombrotrophic *Sphagnum* species, *S. papillosum S. magellanicum S. capillifolium S. tenellum S. imbricatum, plus the mineretrophic species* S. *recurvum* failed, but a second resulted in several species surviving for several years at least from the early 1980's. The minerotrophic species *Sphagnum recurvum* (now known as *Sphagnum fallax*), which was locally fairly widespread on bog surfaces in the southern Pennines survived both experiments.

During the 1980's a series of studies was undertaken of southern Pennine bog pools and their vegetation. In particular, Dr Colin Studholme surveyed apparently permanent bog pools for the presence of the ombrotrophic species *S. cuspidatum* (Studholme, 1989). He also recorded the presence of all bryophytes within a 100 m radius of the pools. Studholme surveyed 17 sites from the Kinder massive northwards, and additionally Ringinglow bog. He found *S. cuspidatum* at only three localities: Holme moss, Alport moor and Ringinglow bog. The survey was carried out between 1983-1986, following a period of sharply declining sulphur dioxide concentrations in the surrounding industrial cities dating back to the 1940's (Figure 1a).

Since 1980s the fall in sulphur dioxide pollution has continued (Figure 1b) but other major air pollutants such as nitrogen compounds and ozone have not changed in the same way (NEGTAP, 2001, Fowler *et al*, 2005). Around twenty years on from the survey and from the last observation of the introduction experiments, it is timely to explore whether the sustained marked reduction in the sulphur pollution environment has resulted in significant recovery of ombrotrophic *Sphagnum* species, or whether other changes such as the marked increase in nitrogen deposition in the 20th Century (Fowler *et al*, 2004) have mitigated against such an improvement.

Objectives of the recent work were to:

1. Repeat Studholme's survey of the *Sphagnum* species of bog pools at Holme Moss, and Alport moor and to examine the result of the introduction experiments at Holme Moss.
2. Repeat the botanical survey of all bryophytes within 100 m radius of the central pool at these sites.
3. Analyse the pool water chemistry and plant tissue contents at Holme Moss and compare with data from cleaner sites.
4. Interpret results in relation to available air quality data over the past 20 years.

Methods and Materials

Site locations

The focus of research described here was in the Dark Peak SSSI in the Peak District National Park region of the southern Pennines of England. The main study site for the transplant experiment and the open moorland plots was Holme Moss (altitude: 524 m, approximate UK grid reference: SE096036), a site described in greater detail by Tallis (1987). The other open moorland site described here was Alport moor (altitude: 490 m, approximate UK grid reference: SK132929). Both are species-poor ombrotrophic blanket upland mires dominated by *Eriophorum* species, (cotton grass) and approximately match the National Vegetation Classification M20. Comparisons of nutrient and pollutant elements and ions were also made with plants and bog pool water sampled from Butterburn Flow, Cumbria (altitude 270 m, UK grid reference: NY666761) and the Migneint, Gwynedd (altitude 430 m, UK grid reference: SH779449). The Cumbrian and Welsh ombrotrophic mires, with species-rich bryophyte and higher plant communities, were regularly chosen in the original 1970-80s research as clean site comparisons.

Survey of changes in transplant plots

In April 2005 a survey was made of the *Sphagnum* moss within an exclosure plot near Holme Moss summit. This 10 x 10 m plot was established with fencing to exclude sheep in the 1970s (Ferguson and Lee, 1983b) when a range of *Sphagnum* species (Table 1) were transplanted, as 30 cm square sections, from the cleaner site near Butterburn Flow, Cumbria. The original transplant design comprised 6 replicates of 6 species, laid out in the form of a 6 x 6 Latin square; unfortunately no record exists of exactly where each species was placed in the original experiment. In the re-survey of 2005 the position of living *Sphagnum* were mapped, using tape measures, in order to compare with the original latin square design.

Survey of plots in open moorland 2005, 2006

Permanent, unmarked plots at Holme Moss and Alport moor, first surveyed by Colin Studholme and colleagues in 1983-5 (Studholme, 1989), were re-visited by Studholme and colleagues (authors of this report) during July 2005. Further visits later in 2005 and 2006 were made to both sites in order to confirm species identities with assistance of the bryologist Martha Newton. The presence of all bryophytes were recorded within an approximate 100 m radius of a central bog pool. Present latin names of liverworts follow the British Bryological Society checklist of British and Irish bryophytes (www.britishbryologicalsociety.org.uk) and moss names follow Smith (2004) but past names are also given in order to be consistent with the names used in the earlier, original papers from the southern Pennines.

Elemental analysis of Sphagnum moss and bog pool water

All analyses were conducted at Manchester Metropolitan University. Nutrient and other elements in *Sphagnum* sampled from Holme Moss and Butterburn flow in spring-summer of 2005 were analysed following a sulphuric acid-selenium digest (with lithium sulphate catalyst) at 350 degrees C. The resulting digest solution was diluted and analysed for nitrogen, as the ammonium ion, by ion chromatography and for lead by Inductively coupled plasma (ICP). Sulphur was measured in separate samples of dried sphagnum using an elemental analyser.

Bog water was sampled from 8 discrete pools at both the Migneint and Holme Moss in January 2005 and the chemistry of the water was quickly analysed on fresh, filtered (0.2 um) samples using ion chromatography and ICP.

Air Quality changes in the Southern Pennines

Air pollution features of the Dark Peak region were discussed by Caporn (1997). Recent changes in air quality in the Southern Pennines area were assessed using data from 1988 to the present gained at nearby rural monitoring stations and provided by AEA Technology (Warrington, Cheshire) through the UK Defra Air Quality Archive (www.airquality.co.uk). Data for gaseous pollutants, SO_2, NO_2, Ozone data came from the Ladybower station, while the rainfall sulphate, nitrate and ammonium data was from Wardlow monitoring station further south in the White Peak.

Results

1. Transplant experiment 1979-81 to 2005

Of the original six *Sphagnum* species brought to Holme Moss between 1979 and 1981, four of these were found in 2005 (Table 1). While *S. capillifolium, S. papillosum and S. fallax* were each present as several discrete patches of up to 0.3-0.8 m width, *S. magellanicum* was found only in one very small patch. Two other *Sphagnum* species, *S. cuspidatum*, which is commonly found within the area, and *S. palustre* were also found in the exclosure. The position of *Sphagnum* in 2005 was approximately mapped (Figure 2) and did not obviously resemble the original latin square design used in the original experiment.

Other vegetation in exclosure

In addition to the *Sphagnum*, several other bryophytes were observed in the exclosure area in 2005. These may have established naturally or have been inadvertently carried there with the original cores or in other research activity in following years. These were the mosses *Straminergon stramineum, Campylopus flexuosus, Campylopus pyriformis, Warnstrofia fluitans, Hypnum jutlandicum, Polytrichum commune, Pseudotaxiphyllum elegans, *Racomitrium lanuginosum,* and liverworts *Calypogeia muelleriana, Cephalozia bicuspidate, Cephaloziella hampeana, Gymnocolea inflata Mylia taylorii, Scapania gracilis.* A single piece of the lichen *Cladonia portentosa* was found as were the higher plants **Calluna vulgaris, *Narthecium ossifrage and Vaccinium oxycoccus.* Some of these species (denoted by an asterix) were known to have been brought into the exclosure as part of transplant experiments in the 1980s.

2. Observations in open, ombrotrophic un-marked plots

Sphagnum moss

Site visits in 2005 to Holme Moss and 2005-6 to Alport moor enabled identification of a large number of *Sphagnum* (Table 2), other mosses and liverworts (Table 3) in the open permanent plot areas previously visited in the 1980s. By far the most extensive of all bryophytes at both sites in 2005-6 was *S. cuspidatum*, forming extensive mats in several large pools and pool complexes. The most common species at both these sites in the 1980s and in 2005-6, *S. cuspidatum* was found in more pools and in larger amounts at the later date than twenty years earlier. There was also a large increase in the total number of *Sphagnum* species observed at both sites in comparison with those in 1983-5. *Sphagnum subnitens* and *S. fimbriatum* species were also observed forming hummocks around the pools. Away from the pools occasional hummocks were evident comprising *S.subnitens* and, less commonly, *S. palustre* and *S. papillosum*. At Holme Moss, the *Sphagnum* species/varieties increased from 2 to 6, while at Alport moor they rose from 1 to 5 species between 1983-5 and 2005-6.

Other bryophytes

Other non-*Sphagnum* moss species also showed substantial increases between 1983-5 and 2005-6. At both sites the moss *Warnstorfia fluitans,* growing on the edges or within the pools were observed in the 1980s and recently. Very little else was found in the 1980s (Table 3). However, by 2005-6 there was a very wide range of moss species, with most visible being the dark green cushions of *Campylopus flexuosus*.
The increase in liverworts was more striking as there were no records from the open plots in 1983-5, but several species found in 2005-6.

The general pattern of increase in all bryophyte groups examined was very similar at Holme Moss and Alport moor (Table 4 and Figure 3). While there was a marked increase in the total number of species and varieties observed at Holme Moss (from 5 to 16) and Alport moor (from 3 to 22) over this period (Table 4), the overall cover of bryophytes on the ombrotrophic bog surface in 2005-6 was still poor.

3. Changes in air quality

The main wet and dry forms of air pollution at nearby monitoring stations have been regularly recorded from the 1980s to the present (Figure 4). Since the late 1980s the mean annual SO_2 concentration has dropped from around 20-25 to about 3 ug m^{-3}. A decade earlier it was estimated at 40-50 ug m^{-3} at Holme Moss by Ferguson and Lee (1983a). A large reduction, though not as dramatic, also occurred in the mean annual NO_2 concentration which dropped from 27 to about 9 ug m^{-3}. In contrast to these strong downward trends, the mean annual concentration of the secondary pollutant ozone fluctuated around 50 ug m^{-3} with a hint of an upwards trend. Another important pollutant gas is ammonia, released largely from agricultural sources, but long term records of concentration in the region are not available, although national emissions data suggests a downward trend (Fowler *et al*. 2004).

The sulphur and nitrogen gases in air undergo chemical reactions in the atmosphere to produce nitrate, ammonium and sulphate in wet deposition (rain and cloud). The rainfall sulphate (non-marine) concentration has dropped significantly from around 2 to 1 mg l^{-1}, but the levels of nitrogen compounds nitrate and ammonium have fluctuated around 0.5-1 mg l^{-1}, and only a modest downward trend is apparent (Figure 4).

4. Elemental and ionic contents of plants and bog water

Nitrogen content of Sphagnum

The nitrogen content of various *Sphagnum* species collected from Holme Moss and the cleaner Cumbrian site near Butterburn was compared from both 1979 and 2005 (Figure 5). The average nitrogen content at Butterburn was very similar in 2005 to that in 1979 at around 8.1-8.6 mg g^{-1}, while the content of the Holme Moss samples had declined from an average of 20 mg g^{-1}in 1979-89 to 12.6 mg g^{-1} in 2005. The outcome being that the difference between Holme Moss and the cleaner site was much less in 2005 than two decades earlier. In 1979, of the different species sampled, the more minerotrophic species *S. fallax* contained the highest nitrogen levels, but by 2005 the only notable interspecific difference was the much greater nitrogen content of the bog pool species *S. cuspidatum* at Holme Moss in comparison with specimens from Butterburn.

Sulphur and metal contents of Sphagnum

In 2005, the sulphur contents of *Sphagnum* were much greater at Holme Moss than at Butterburn for *S. capillifolium* and *S. cuspidatum* but not significantly different for *S. fallax* (Figure 6). Comparisons with data from the 1980s are less reliable than for nitrogen due to changes in analytical methods for sulphur.

As a marker for industrial and traffic pollution, lead was analysed in *Sphagnum* tissue sampled in 2005 and compared with data from 1979 and 1985 (Table 5). The levels of lead were much higher in 1979/85 compared with twenty or more years later, even at the cleaner Butterburn site, but on both dates the *Sphagnum* lead content was far greater at Holme Moss compared with Butterburn.

Composition of bog pool water

The bog pool water sampled in 2006 from Holme Moss was enriched in several elements compared with the water from the Migneint (Table 6, Figure 7 and Figure 8). A list of elements and ions analysed (Table 6) reveals greater concentrations in the southern Pennines of many elements but particularly in nitrate, ammonium, zinc and aluminium. Holme Moss water was also more acidic (pH 4.2) compared with Migneint (pH 4.6). The strongly marine influenced elements sodium and chloride were found at similar concentrations at the two locations, while only two elements, potassium and manganese, were at lower levels in the Pennines pools than in Wales.

Discussion

Observations of both the transplants and the open, unmarked pots lead us to conclude that present day (2005-6) growth of *Sphagnum*, other moss and liverworts in the southern Pennines is better now than it was in the early 1980s.

Transplants

The lack of detailed monitoring in the Holme Moss exclosure since the detailed research in the early 1980s (Ferguson and Lee 1983b) makes it difficult to assess how the existing *Sphagnum* colonies are related to the original transplants After poor success in the 1979 transplant experiment another was initiated in 1981 using four (*S. fallax, S.magellanicum, S.papillosum, S. capillifolium*) of the six original species. This second attempt was no more successful than the first and according to Ferguson and Lee (1983b) “after more than three years, *Sphagnum recurvum (*now called *S. fallax)* alone survives of the original transplants in the southern Pennines”.

In 2005-6, the position of current *Sphagnum* in the same exclosure does not clearly resemble the original 6x6 latin square layout. However, the higher cover and diversity of *Sphagnum* inside the exclosure than outside strongly suggests that the current colonies are largely descendants of one or both of the transplants of 1979 or 1981. The impressive hummock of *S. papillosum* in the exclosure is much greater in size than any example of this species anywhere else in the Holme Moss area while another species in the plot, *S. magellanicum*, was not found by us anywhere in the locality.

The complete absence of surviving *S. austinii* and *tenellum* is of note since these were the two species most sensitive to SO_2 and bisulphite in controlled experiments (Ferguson *et al* 1978). Both also grew poorly in the initial stages following transplant to Holme Moss in 1979. Their lack of success after transplantation is unlikely to reflect poor response to being moved since both performed well after parallel transplantation to the cleaner site in the Berwyn hills of North Wales. Unfortunately we have no knowledge of the present day health of the transplants at the Welsh location. A major, important question is whether transplantation of these sensitive species into the southern Pennines would now be more successful than it was in 1979-81?

Open, permanent plots

There has been a significant increase in bryophytes (*Sphagna*, other moss and liverworts) on the ombrotrophic bog surface at Holme Moss and Alport moor since the mid 1980s. Bryophytes increased over this time from 5 to 16 at Holme Moss and 3 to 22 at Alport moor (Figure 3). The dominant bryophyte at both open plot sites was the bog pool *Sphagnum cuspidatum* and this species also increased in cover over the twenty year period. Two aspects of the work give us confidence that these changes are genuine indications of improvement and not artefacts resulting from our approach. Firstly, unlike the Holme Moss site, Alport moor was visited only occasionally and no transplant studies took place. The chances of accidental import of ‘alien’ specimens were much less than at Holme Moss where numerous experiments, including more transplant research with other vegetation, took place in the 1980s. Despite one of these sites being a much busier experimental site than the other, the increase in bryophytes was similar. Secondly, the observations and identification work in both the 1980s and recently, closely involved the same bryologists (J Lee, M Newton and C. Studholme).

Evidence from earlier times, using peat cores and macrofossil identification, indicates that *Sphagnum* was much more abundant prior to the Industrial revolution at Holme Moss (Tallis, 1987). At the present time, despite improvements since the 1980s, the bryophyte species cover and richness remains low amongst the dominant stands of monotonous *Eriophorum* sedges and occasional *Empetrum nigrum* (crowberry) and *Nardus stricta* (mat grass). This is typical of the ombrotrophic surfaces of the Dark Peak region of the southern Pennines where *Sphagnum* species are not rare but neither are they common. In contrast to the poverty of the present day ombrotrophic bog surfaces, the gullies and flushes draining off the moors are often much better endowed in *Sphagnum*, notably *S. fallax* and *S. denticulatum*, minerotrophic species suited to the better nutrient conditions found there.

Our observations indicate that on the ombrotrophic bog surfaces there is potential for recovery of the important hummock species of *Sphagnum* such as *S. papillosum* and *S. capillifolium*, but outside of the Holme Moss exclosure these species are not common, whilst species more typical of less pristine conditions such as *S. subnitens* and *S. fimbriatum* are more likely to be found.

It is important to understand why there has been an increase in *Sphagnum* and other bryophytes in the southern Pennines in recent decades. It seems likely that the steep decline in concentrations of sulphur dioxide in air and its solution products in rain (Figure 4) have allowed increased growth and propagation. The aerial deposition of some other gaseous pollutants such as NO_2 (Figure 4) and of metals (e.g. lead) have also fallen in recent decades so too have nitrogen compounds (nitrate and ammonim) in rain (Figure 4) that were shown to harm *Sphagnum* growth and physiology (Press *et al*. 1986).

In addition to air pollution there are no doubt other changes that may have positively influenced bryophyte recovery in the past twenty years. However, the only obvious ones are probably climate and grazing. Apart from during dry spells, the water table at both Holme Moss and Alport moor is close to the surface now as it was twenty years ago. The grazing pressure has fallen in recent years and this may have contributed to bryophyte change but less trampling damage and decreased removal of over-shading graminoid plants could have opposing effects on bryophytes. It is not clear, without experiments, which would be the most important at these sites. Alteration in grazing pressure was not an issue for the transplant experiment as it took place in a fenced exclosure.

Continuing constraints due to pollution?

Finally, there remains the question of why recovery of bryophytes, in particular of ombrotrophic *Sphagnum* species, is still poor in the southern Pennines? Twenty or more years ago Ferguson and Lee (1983b) concluded that despite the fall in sulphur pollution, this pollutant, along with nitrogen pollution, combined with the metals in the surface peat to negatively affect the success of the transplants. The conclusion today would be rather similar, except that sulphur dioxide has fallen to very low levels while the annual mean concentrations of ozone (O_3) are rising (Figure 4). There is little knowledge of the effects of current ozone levels on bryophytes (Potter *et al*, 1996), but on the basis of current understanding of effects in other vegetation (Negtap, 2001), some effects on bryophytes seem likely. The decline in concentrations of nitrogen pollutants in precipitation measured at Wardlow has been fairly modest compared to the drop in SO_2 and sulphate (Figure 4) and it is likely that nitrogen deposition and the resulting high concentrations of nitrate and ammonium in surface bog pool waters (Figure 7) are limiting for *Sphagnum* health based on the physiology and growth experiments of Press *et al* (1986). Even if the atmospheric inputs of nitrogen and sulphur compounds and metals in wet and dry deposition were to fall to negligible amounts in the future, the substantial residual store of these elements in the surface peat (reflected here in the concentrations in the bog pools water and the *Sphagnum* tissues) may remain a factor limiting the success of the bryophytes in the southern Pennines.

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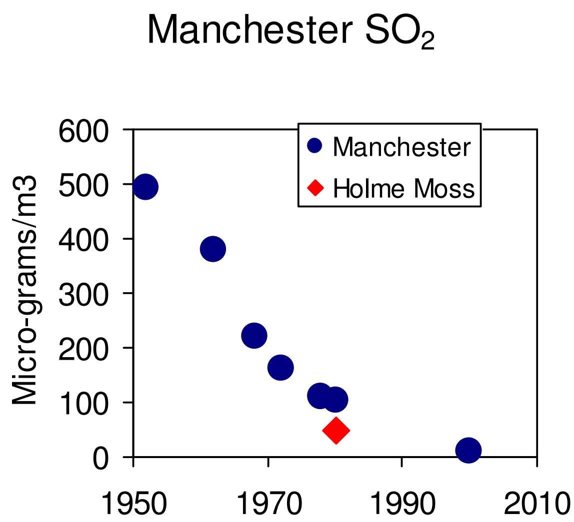


Figure 1a: Decline in atmospheric SO_2 mean annual concentration in Manchester; data also for Holme Moss (diamond symbol) in 1980 (after Ferguson & Lee, 1983a except for the most recent date from the UK Air Quality Archive)

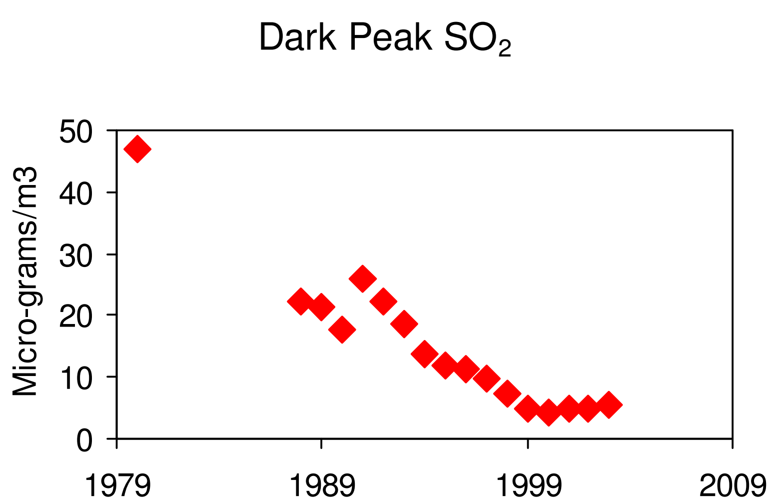


Figure 1b: Mean annual concentration of SO_2 at in the Dark Peak. Data from Ladybower monitoring station, except for the 1980 data from Ferguson and Lee (1983b) collected at Holme Moss.

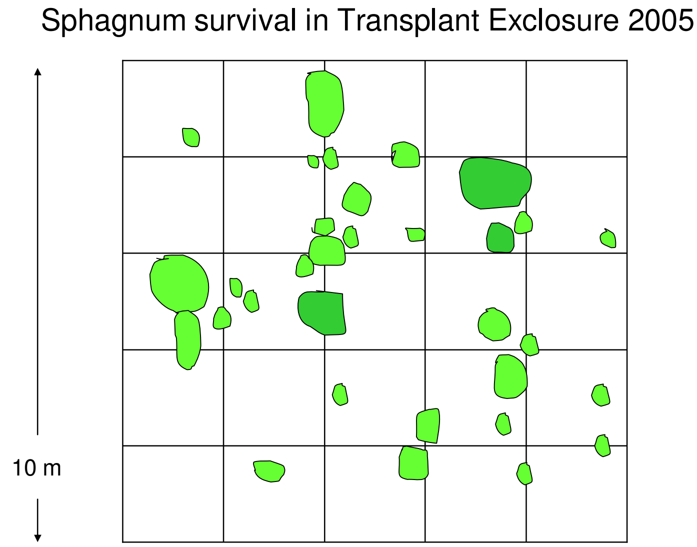
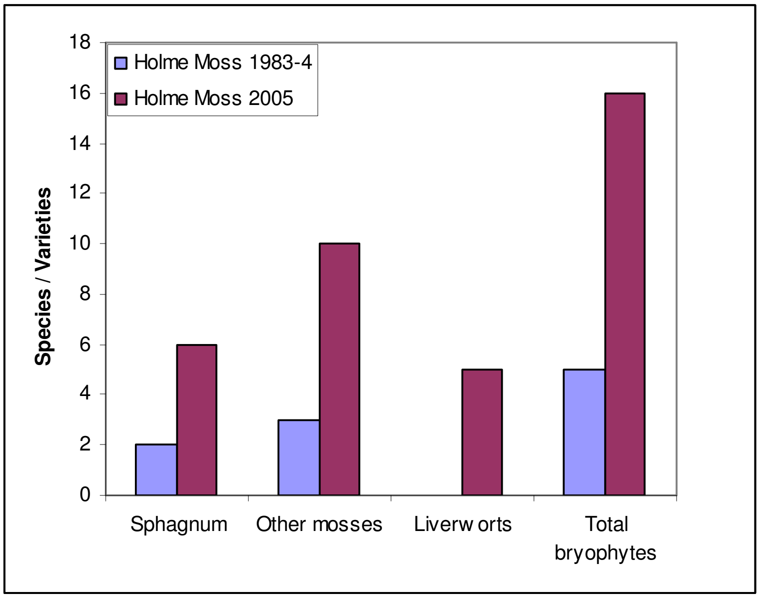


Figure 2: Spatial arrangement of *Sphagnum* in exclosure at Holme Moss as surveyed in April 2005. Originally the six replicates of different species had been transplanted into a 6 x 6 grid layout.



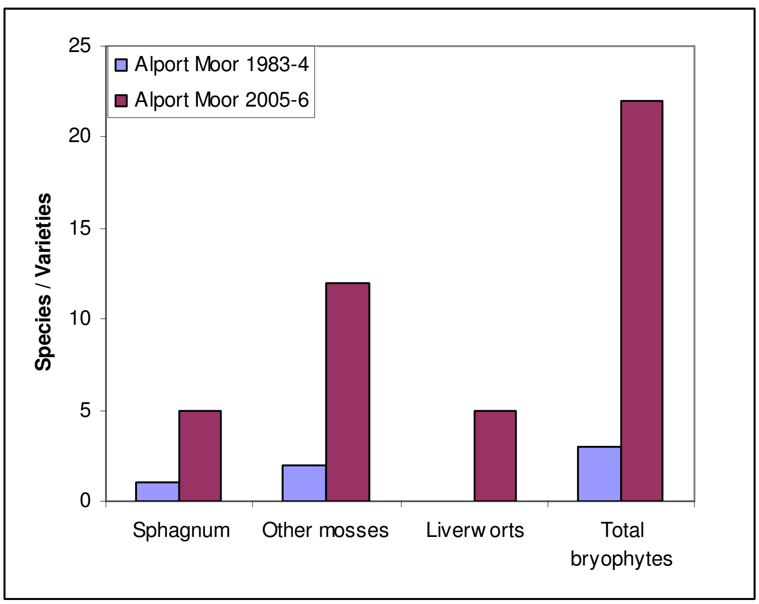
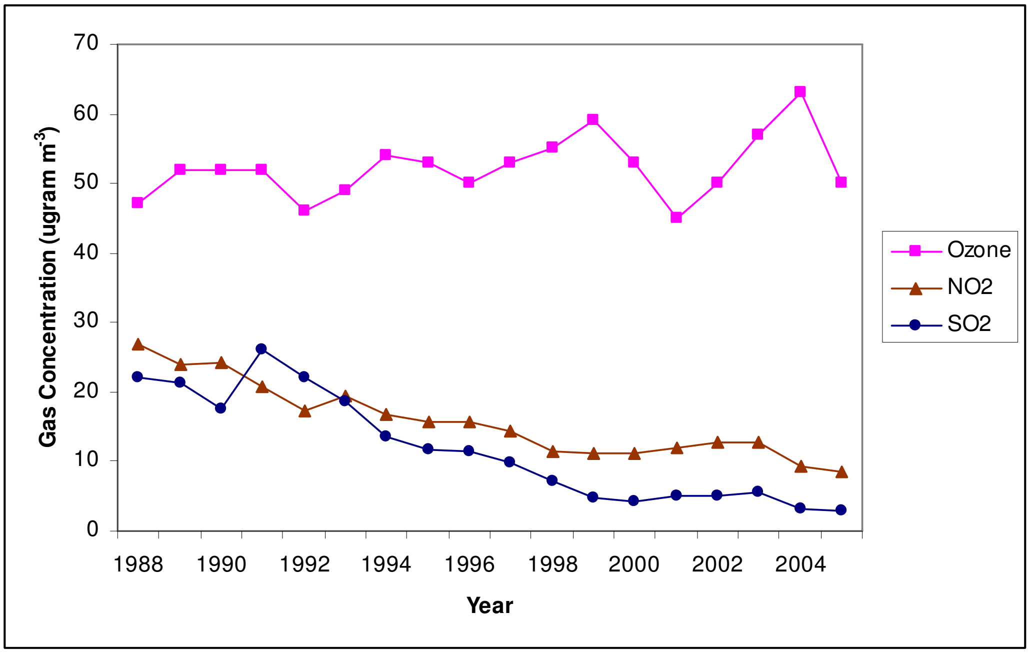


Figure 3: The increase between 1983-5 and 2005-6 in the number of species (or varieties) of *Sphagnum*, other mosses and liverworts in the open, unmarked plots at Holme Moss (above) and Alport moor (below). Species details given in the text and tables.



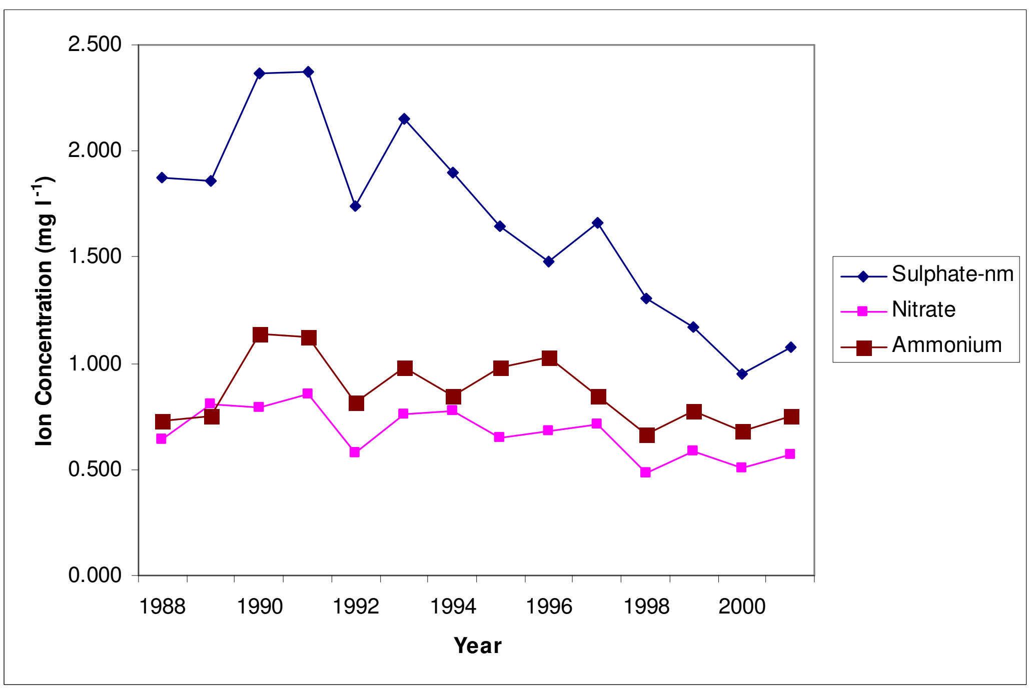


Figure 4: Changes in gaseous concentrations of major air pollutants at Ladybower (above) and in ionic concentrations of major solutes in wet deposition (below) at Wardlow. Data courtesy of the UK Air Quality Archive.

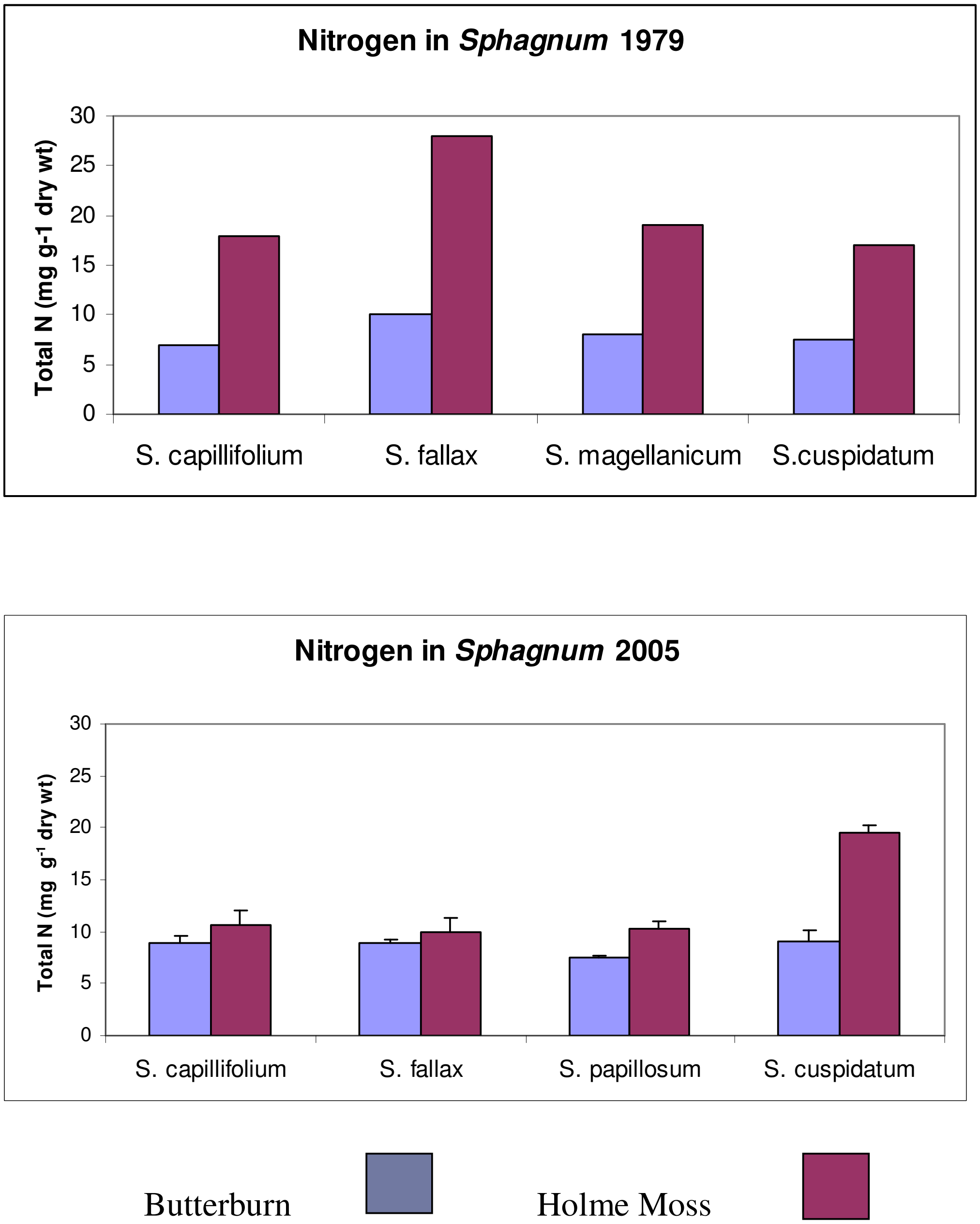


Figure 5: Total nitrogen concentration in *Sphagnum* (apical sections) of different species from the ‘clean’ site at Butterburn, Cumbria and from Holme Moss in 1979 (above) and 2005 (below). Data of 1979 from Ferguson *et al* (1984).

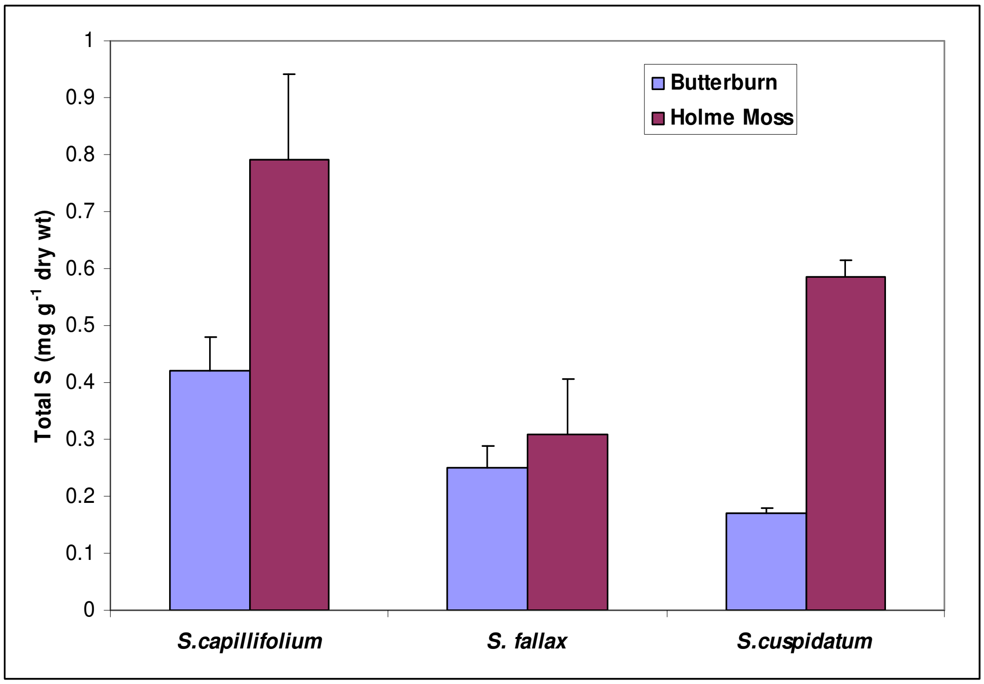


Figure 6: Total sulphur concentration measured in different species of *Sphagnum* sampled in 2005 from the ‘clean’ site at Butterburn, Cumbria and Holme Moss.

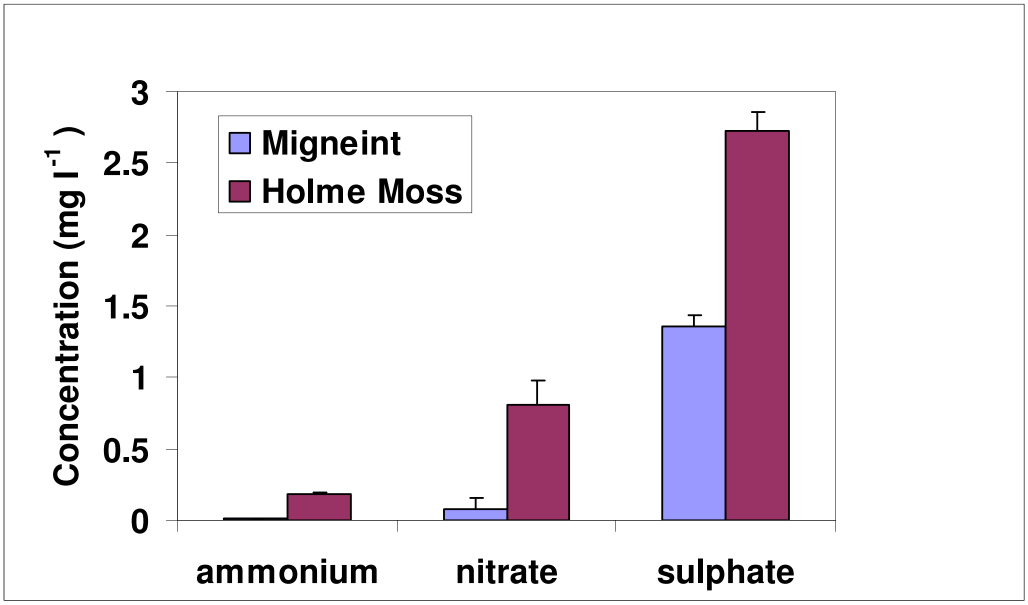


Figure 7: Major pollutant ions in bog pool water at the 'clean' site at the Migneint, North Wales and Holme Moss, sampled in January 2006.

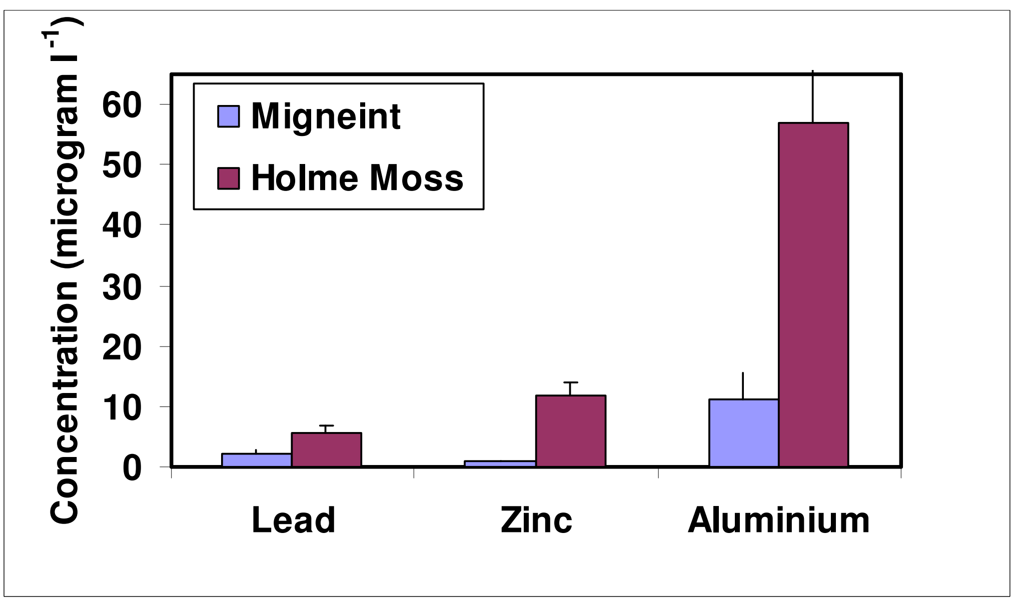


Figure 8: Major pollutant metals in bog pool water at the 'clean' site Migneint, North Wales and Holme Moss, sampled in January 2006.

Table 1: *Sphagnum* moss species originally planted in the experimental transplant study in 1979-81 (Ferguson and Lee, 1983) and found when re-surveyed in 2005.

Sphagnum transplanted in 1979-81	Found in 2005	Notes
S. austini	No	None
S. capillifolium ssp. rubellum	Yes	Found within and also spreading beyond exclosure
S. fallax	Yes	Extensive
S. magellanicum	Yes	Very small patch
S. papillosum	Yes	Some large hummocks
S. tenellum	No	None

Also found in exclosure was a moderate amount of S. *cuspidatum* and smaller quantity of *S. palustre.*
In Ferguson and Lee (1983) the species *S. imbricatum* was listed as being transplanted; in fact it was the hummock variety 'austinii' that was moved and this is now known as the distinct species *S. austinii*. *S. fallax* was previously known as *S. recurvum*.

Table 2: *Sphagnum* moss species found in ombrotrophic, un-marked plots at two sites in the Dark Peak SSSI in the period 1983-4 reported by Studholme (1989) and in 2005-6 in this study.

	1983-4		2005-6	
	Holme Moss	Alport Moor	Holme Moss	Alport Moor
S. cuspidatum	●	●	●	●
S. fallax ssp. fallax			●	
S. fallax ssp. isoviitae			●	
S. fimbriatum	●		●	●
S. palustre				●
S. papillosum			●	●
S. subnitens			●	●

Table 3: Moss species other than *Sphagnum* found in ombrotrophic, un-marked plots at two sites in the Dark Peak SSSI in the period 1983-4 reported by Studholme (1989) and in 2005-6 in this study.

	1983-4		2005-6	
	Holme Moss	Alport Moor	Holme Moss	Alport Moor
Mosses				
Brachythecium rutabulum			●	●
Campylopus flexuosus			●	●
Campylopus introflexus	●		●	●
Campylopus pyriformis			●	
Ceratodon purpureus			●	
Dicranella heteromalla				●
Dicranum polysetum				●
Dicranum scoparium				●
Kindbergia praelonga				●
Hypnum cupressiforme		●		
Hypnum jutlandicum			●	
Hypnum lacunosum				●
Orthodontium lineare			●	
Plagiothecium denticulatum				●
Plagiothecium undulatum			●	
Pohlia nutans				●
Polytrichum commune			●	
Rhytidadelphus squarrosus				●
Splachnum sphaericum	●			
Warnstorfia fluitans	●	●	●	●
Liverworts				
Calypogia azurea			●	
Calypogia muelleriana			●	●
Cephalozia bicuspidata			●	●
Diplophyllum albicans			●	
Gymnocolea inflata			●	●
Lophocolea bidentata				●
Lophozia ventricosa				●

Table 4: Total number of different groups of bryophytes found in ombrotrophic, un-marked plots at two sites in the Dark Peak SSSI in the period 1983-4 reported by Studholme (1989) and in 2005-6 in this study.

	Holme Moss		Alport Moor	
	1983-4	2005	1983-4	2005-6
Sphagnum	2	6	1	5
Other mosses	3	10	2	12
Liverworts	0	5	0	5
Total bryophytes	5	16	3	22

Table 5: Lead (µg g^{-1} dry wt) in *Sphagnum* tissue from Holme Moss and clean sites near Butterburn, Cumbria in 1979/85 (Studholm 1989 and Ferguson *et al* 1984) and 2005 (this study).

	1979/85		2005	
	Butterburn	Holme Moss	Butterburn	Holme Moss
S. cuspidatum	180	350	2.04 +/-0.3	80.3 +/- 1.4
S. fallax	50	600	0.01 +/- 0.001	3.12 +/- 0.3

Table 6: Concentrations of major soluble inorganic ions in bog pool water sampled from the Migneint, North Wales and Holme Moss in January 2006. Units are ppm (mg per litre) or ppb (micrograms per litre) of the compound or single element as appropriate; values are average of eight pools in each locality.

		Migneint	Holme Moss	Ratio HM/M
ppm	Ammonium	0.014	0.187	13.6
	Nitrate	0.083	0.811	9.8
	Phosphate	0.062	0.126	2.0
	Sulphate	1.385	2.724	2.0
	Iron	0.269	0.432	1.6
	Calcium	0.139	0.222	1.6
	Magnesium	0.253	0.322	1.3
	Chloride	3.675	4.589	1.2
	Sodium	2.682	2.827	1.1
	Potassium	0.228	0.132	0.6
ppb	Zinc	0.928	11.94	12.9
	Aluminium	11.35	56.9	5.0
	Lead	2.15	5.5	2.6
	Manganese	19.32	8.44	0.4