Annex 1

Vegetation trajectories on bare peat stabilisation sites

Prepared by

MOORS FOR THE FUTURE PARTNERSHIP

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1 SUMMARY

The aim of this annex report is to analyse survey data collected by Moors for the Future Partnership (MFFP) from once degraded and now restored blanket bog sites in the context of showing improvement in condition, especially with regards to Favourable Condition.

Bare peat sites

A total of twenty individual bare peat sites, including non-treated control sites and intact (vegetated) reference sites were treated with the MFFP restoration 'prescription', including heather brash, lime, seed and fertiliser, moorland plant plugs and gully blocking. The sites were located in four main geographical areas spread across the South Pennines Special Area of Conservation (Bleaklow, Black Hill & Holme Moss, Kinder Scout and Turley Holes & Rishworth.

Cover of Bare peat

The cover of bare peat decreased over time in all of the different geographical areas. Relatively long-running areas with more than about five years monitoring history, such as Black Hill & Holme Moss (specifically the Black Hill site, section 6.1.1) and Bleaklow (specifically the Joseph Patch site and the two Shelf Moor sites, section 6.2.1), appeared to reach minimal values of about 20% and 10%, respectively, after about four growing seasons following seeding, thereafter remaining at an equilibrium value. These and other variations between all four individual areas were nevertheless resolved into a strong and significant curvilinear function. Simple linear relationships for each of the four areas were derived by truncating the data and then resolved into a strong and significant linear function. The slope of the linear equation suggested that with a starting value between 95 and 100% bare peat cover, the predicted rate of decline as a mean of all areas was approximately 25 percentage points per growing season over three growing seasons, thereafter beginning to enter an equilibrium phase.

Favourable condition: At least 90% of quadrats with cover of bare peat less than 10%

The proportion of quadrats with less than 10% bare peat cover increased over time in all of the four geographical areas indicating a widening spatial distribution of areas fulfilling the attribute target. Maximal values were reached at Black Hill & Holme Moss (60%, specifically at the Black Hill site, section 6.1.5) and Bleaklow (90%, specifically at the Joseph Patch site and also especially at the sites on Shelf Moor, section 6.2.5), after about four and seven growing seasons respectively, thereafter entering an equilibrium phase. These variations were resolved into a single strong and significant quadratic function. Variations found in derived linear relationships (using truncated data) were also resolved into a single strong and significant linear function which predicted a rate of increase of 15.6 percentage points per growing season over seven growing seasons, thereafter beginning to enter equilibrium.

Cover of indicator species

The cover of indicator species increased over time in all of the different geographical areas. The trajectory of increase for relatively long-running areas such as Bleaklow (specifically the Joseph Patch and Shelf Moor sites) and Black Hill & Holme Moss (specifically the Black Hill site) suggested that an equilibrium phase was reached, with maximum values varying from 100% to 70%, respectively. These variations were resolved into a strong and significant quadratic function which nevertheless showed an almost linear increase, even over 12 years. Simple linear relationships for the areas were derived without the need for truncating the dataset, but there were variations in slope, in particular the Kinder Scout area indicated a relatively slow rate of increase at least for the most recent time period. However, these variations were resolved into a strong and significant linear function when summarised over all areas which predicted a rate of increase of approximately 12 percentage points per growing season for at least 10 growing seasons.

Favourable condition: At least 90% of quadrats with at least 50% vegetative cover composed of at least three indicator species

The proportion of quadrats with at least 50% of the cover composed of at least three indicator species increased over time in most of the areas, but there was wide variation between areas (and constituent sites). Variations between areas were nevertheless resolved into a single, strong and significant quadratic function which was almost linear, even after 12 years. Simple linear relationships were derived and resulting variations were resolved into a single, strong and significant linear function which predicted a rate of increase of 5.9 percentage points per growing season, over at least 12 growing seasons.

Count of indicator species

The number of indicator species increased over time in all of the different areas, suggesting a maximal number of between four and five indicator species attained after approximately seven years, thereafter entering an equilibrium phase with negligible further gains. There were some area-specific variations in rate of increase, some of which could be explained by management and quadrat placement (Kinder Scout). Variations were resolved into a strong and significant cubic function. Variations in derived linear relationships (by truncating the dataset) were resolved into a strong and significant linear relationship which suggested a mean of 0.7 indicator species per quadrat already present at time zero – subsequently increasing at a rate of 0.6 indicator species per growing season over seven growing seasons, which with the intercept, predicted a maximum value of 4.7. After this time the trajectory entered an equilibrium phase beyond which no further increases have yet been shown.

Favourable condition: At least 90% of quadrats with at least six indicator species

The proportion of quadrats with at least six indicator species appeared to increase relatively slowly over time in most of the different areas. Outlying values were again found for the Kinder Scout area. Variations were resolved to give a strong and significant quadratic function which was almost linear over 12 years. Variations between derived linear relationships were resolved into a strong and significant linear relationship predicting a rate of increase of about 1.4 percentage points per growing season, over at least twelve years.

However, all of the above predictions are based on mean values over all areas, and both area-and site-specific differences were found.

2 INTRODUCTION

More than half of England's SSSIs (53%) are found in the uplands. They are designated as such for their outstanding wildlife habitats, species or geology. Almost 90% of these upland SSSIs form part of the Natura 2000 series; sites regarded as having special significance in a European context. The European-legislated South Pennines Moors Special Area of Conservation (SPM SAC) is an internationally-recognised SAC, overlapping with many of the Peak District National Park and South Pennines SSSIs. It is particularly notable for containing one-third of the UK's blanket bog habitat; a habitat that is both globally rare (Britain holds between 10 and 20 % of the entire global resource) and also endowed with an assemblage of vegetation types that is internationally our most important (Lindsay et al 1988; Tallis 1995).

Blanket bog areas within the SPM SAC suffered from a high level of degradation mainly through the loss of peat-forming *Sphagnum* mosses which followed from historical and sometimes ongoing effects of pollution, in addition to wildfire, overgrazing and localised trampling. As a result these areas became characterised by extensive bare patches, while also being intersected by erosion gullies (reviewed in Buckler et al, 2013).

Building on the approach put forward in the Natural Environment White Paper (June 2011) and the England Biodiversity Strategy (August 2011), 'Biodiversity 2020' seeks to halt overall biodiversity loss, with targets to improve the condition of SSSIs by achieving 50% in <u>favourable</u> condition and 95% in <u>favourable or recovering</u> condition by 2020, and for non SSSI priority habitats, such as blanket bog, 90% to be in <u>favourable or recovering</u> condition (Natural England 2013)

Working alongside these targets, the principal aim of the Moors for the Future Partnership's (MFFP) conservation work is to 'conserve and reverse the degradation of blanket bog habitat in the Dark Peak and South Pennines, working towards the re-creation of active blanket bog, with an active *Sphagnum*-based acrotelm, and dominant surface vegetation based on the NVC community M19 *Calluna vulgaris-Eriophorum vaginatum* blanket mire *Empetrum nigrum* ssp. *nigrum sub-community*' (Buckler et al, 2013)

However, current assessment of condition status in SSSIs may not of a sufficient detail or temporal resolution to show the effect of conservation actions and management in making progress towards <u>favourable condition</u>. In response, Natural England commissioned MFFP to provide: 'An inventory of published and unpublished examples which provide evidence of responses to land management and restoration interventions which indicate change (positive or negative change) with an assessment of timescales for delivery for each example. The aim is to produce a trajectory matrix which estimates the timescales required to deliver favourable condition. The specific output required was 'A report on monitoring to recommend: (a) The use of simple proxies for recording change and (b) The use of remote surveillance techniques for monitoring change at a landscape scale'.

In addition the above, specific actions required to deliver the output were listed as follows:

- Set up scoping meeting/project board to agree outputs and lines of communication for the project
- Collaborate with the other major peatland restoration partnerships to collate unpublished data (where available) which provides evidence of recovery rates
- Use this and published evidence (PAA reports and other sources) to develop a set of milestones to demonstrate change in condition in different circumstances and under different interventions
- Capture the evidence using the format set out in 3.2 in the brief
- Use this evidence to develop trajectory approaches for the range of situations set out in the above examples. This should be done separately for blanket bog and dry heath but taking into account that some of the interventions may be similar for both habitat types

• Using knowledge and understanding of current monitoring programmes develop a simple monitoring process to assess change. In particular consider what proxies might allow rapid and repeatable assessment of changes in key indicators for example biodiversity, carbon and water.
• Identify remote sensing / surveillance techniques that would be suitable for countrywide monitoring of the change in condition of blanket bog and upland dry heath.

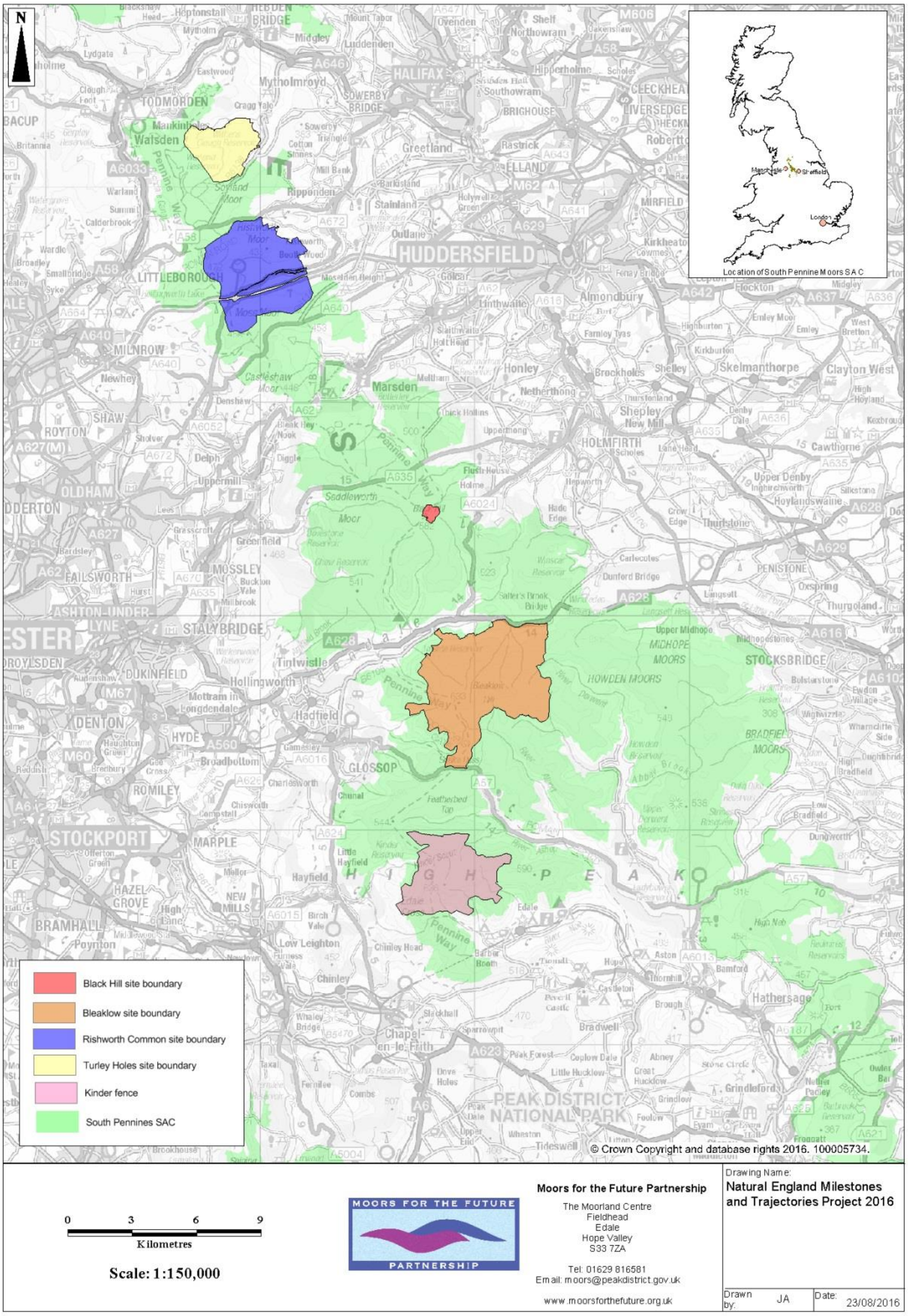

Fig. 1. Geographical areas containing the experimental sites

3 GENERAL METHODS

3.1 Conservation work

Conservation work was carried out using a 'prescription' which involved combinations of the following: fencing to exclude grazing; a suspension of managed burning; application of heather brash or, on steeper parts, cover with geojute; treatments of grass seed (Table 1), lime and fertiliser; plug planting of moorland plants and *Sphagnum*; Gully blocking. These techniques are extensively reviewed in Buckler et al (2013). Conservation work was concentrated in four main geographical areas - Bleaklow, Black Hill & Holme Moss, Kinder Scout and Turley Holes & Rishworth (Fig. 1). Specific conservation activities and temporal details for the individual sites is detailed in section 4, below.

Table 1. Species composition of a typical seed mix treatment
Exact composition may vary depending on availability

Seed mix plant species		Application rate (kg/ha)
Browntop Bentgrass	*Agrostis castellana*	4.0
Sheep's Fescue	*Festuca ovina*	14.0
Fine-leaved Sheep's Fescue	*Festuca longifolia*	10.0
Wavy Hair-grass	*Deschampsia flexuosa*	1.0
Perennial Rye Grass	*Lolium perenne*	6.0
Perennial Rye Grass	*Lolium perenne*	7.0
Perennial Rye Grass	*Lolium perenne*	8.0
Heathers	*Calluna vulgaris*	0.65
	Erica tetralix (90:10)	

Taken from Buckler et al (2013)

3.2 Monitoring

Monitoring the success of conservation work areas was carried out using a mixture of random and stratified placement of fixed 2 m x 2 m quadrats (details for individual sites are given in section 4, below), and surveys were initiated either before, or at the same time as the application of nurse crop seed. The time of the nurse crop seeding application was considered to be 'time zero' for the emerging trajectory of change, being the main contributor to changes in cover. However, in some cases the pre-seeding 'stabilisation' phase, involving the spreading of heather brash, was carried out more than one growing season prior to nurse crop seeding and the emerging cover (mainly of heather) originating from the passive application of seeds contained in the brash, will have contributed to varying degrees of cover prior to time zero, and thus may have been a factor involved in variability of trajectory data between sites.

Trajectories representing the geographical areas are presented in the first part of the results section. Trajectories representing the individual sites are presented in the second part of the results section.

Other surveys, again involving fixed quadrats on bare peat patches, were conducted on areas that were excluded from any type of treatment, the 'control' sites, in order to provide a visual comparison and a justification that no statistical trajectory was found in these sites. A third category involved surveys using fixed quadrats on so-called 'intact reference' sites which were placed on areas of remnant vegetation and which may have experienced varying degrees of treatment. Specific monitoring activities and temporal details for the individual sites is detailed in section 4, below.

3.3 Data processing and analysis

For each site, bare peat cover and individual plant species cover data were entered into Excel spreadsheets and the mean cover per quadrat of each species and groups of species (such as 'grasses' or 'indicator species') calculated. Cover was estimated visually as a percentage of the 2 x 2 m quadrat. Bare peat and plant species frequency data were derived from cover data according to presence/absence per quadrat. From these latter data, key variables required in Common Standards Monitoring (CSM) were calculated, e.g. the proportion of quadrats with less than 10% bare peat, etc.

Individual survey sites were grouped within four main geographical areas; Black Hill & Holme Moss, Bleaklow, Kinder Scout and Turley Holes & Rishworth (Fig. 1).

Analysis was undertaken on three key variables: (i) bare peat cover, (ii) indicator species cover and (iii) indicator species count. The data were also analysed in terms of the percentage of quadrats satisfying the conditions for three key equivalent 'attribute targets' required for Favourable Condition (90% of quadrats being the minimum): (iv) at most 10% cover of bare peat; (v) at least 50% vegetative cover to be composed to at least three indicator species; (vi) at least six indicator species. These latter three attributes were singled out because either one or a combination of these was most often the reason for failure to achieve Favourable Condition.

The analysis involved four main steps:

(i) Trajectories for each variable took the form of curvilinear regression relationships with time. The time of treatment and the duration of monitoring varied between sites, and so the x-axis was standardised using the number of growing seasons after the seeding treatment – the latter assumed to be the main contributor to change.

(ii) The data were then combined to give a single curvilinear trajectory.

(iii) Trajectories for relatively long-term sites/areas often appeared to extend into a plateau or equilibrium phase, showing no further changes in the variable in question. In this step, the data making up the equilibrium phase was then omitted, so that only a linear section remained for comparison and combination with other site/area trajectories that did not extend into equilibrium phase.

(iv) The data contributing to these individual linear site trajectories were then combined to give a single linear trajectory for each of the four geographical areas. Confidence and Prediction limits were appended to the trajectory and linear equation values were noted, so that, often by interpolation, an estimate of time required to reach the maximum limit of variables (i), (ii) and (iii), or, often by extrapolation, the estimate of time required to reach Favourable Condition (for variables (iv), (v) and (vi)).

4 INDIVIDUAL SITE DETAILS

4.1 Black Hill

Black Hill forms a large dome situated between the Longdendale valley and the Saddleworth - Holmfirth road. It is one of the three major peat and gritstone plateaux of the Dark Peak region, but smaller in area and lower in maximum height than either Kinder or Bleaklow, never reaching 600m.

4.1.1 Black Hill (long-term re-vegetated)

Surveyed using twenty five 2 m x 2 m randomly located fixed quadrats annually from 2006 up to 2015 (Table 2). Black Hill was a long-term revegetated site, having undergone initial stabilisation treatments with brash in 2005/6, followed by lime, seed and fertiliser in June 2006 and a further treatment with lime in 2008. Black Hill was the first MoorLife site to receive applications of *Sphagnum* propagules (beads) in September 2012. No other treatments were applied.

4.1.2 Issues Edge

This site was surveyed using thirty 2 m x 2 m randomly located fixed quadrats in 2010 (Table 2). There was uncertainty concerning the placement of quadrats which were variously on 'treated, intact or unknown' areas. Quadrats placed on treated areas received brash, others did not. Application of lime, seed and fertiliser was uncertain.

4.1.3 National Grid

Surveyed using twenty five 2 m x 2 m randomly located fixed quadrats in 2010 and 2011 (Table 2). There was uncertainty concerning the placement of quadrats which were variously on 'treated, intact or unknown' areas. Quadrats placed on treated areas received brash, others did not. Application of lime, seed and fertiliser was uncertain.

Table 2. Number of growing seasons post-seeding for vegetation surveys on Black Hill

Year	Black Hill	Issues Edge	National Grid
2006	0		
2007	1		
2008	2		
2009	3		
2010	4	1	2
2011	5		3
2012	6		
2013	7		
2014	8		
2015	9		

4.2 Bleaklow

Over time, the Bleaklow massif has been the location of a relatively large number of vegetation monitoring projects including some relatively long-running ones. As a result, there is a relatively wide range of years in which seeding took place as part of the re-vegetation treatments (Table 3).

4.2.1 Joseph Patch and Shelf-Moor (long-term re-vegetated)

The main projects that have been active in these sites are: Bleaklow Massif Restoration Monitoring and NE Bleaklow Monitoring (2003-12); MoorLife (2010 – 2015; Making Space for Water (2009 – 2015).

Treatments included stabilisation with brash and applications of lime, seeds and fertiliser in 2003, followed by further applications of lime and fertiliser in 2004 and 2005.

From 2003 to 2006 there is some uncertainty around quadrat size used, due to incomplete metadata records, but most likely the dimensions were either 0.5 x 0.5m or 0.25 x 0.25m. They were located randomly, and stratified by slope and aspect: hagg top, hagg bottom, north-facing slope and south-facing slope. In this dataset, only quadrats from hagg tops have been included, as they describe the most equivalent conditions to the locations selected from 2008 onwards. In 2007, these smaller sized quadrats were replaced with 2 x 2m quadrats on previous hagg top locations. Additionally, new randomly located fixed 2 x 2m quadrats surveyed, in 'hard to win' locations. From 2008 onwards, there were approximately thirty five (Joseph Patch) or fifteen (Shelf-Moor) fixed 2 x 2m quadrats, randomly located with an emphasis on 'hard to win' areas such as drier, dome-top locations.

Early data are taken from NE Bleaklow Monitoring Report 2003-12; data from 2010 onwards are taken from MoorLIFE.

4.2.2 Woodhead and Woodhead 26

Treatments included stabilisation with the use of geotextile on gully sides (2011) and brash (2012/13), followed by applications of lime, seed and fertiliser in 2012, with further applications of lime and fertiliser in 2013, 2014 and 2015. These sites included several different subset sites that were not always treated simultaneously, potentially contributing to lack of temporal resolution in the data. Surveys were carried out using randomly located, fixed 2 m x 2 m quadrats at Woodhead (thirty eight quadrats) and Woodhead 26 (eight quadrats). Surveys were carried out between 2010 and 2015 (Table 3).

4.2.3 Trenches (bare peat control)

Surveys were carried out using randomly located, fixed 2 m x 2 m quadrats (ten quadrats) positioned within a control area from which treatments had been excluded. Surveys were carried out between 2007 and 2014 (Table 3).

4.2.4 Trenches (bare peat reference)

Surveys were carried out using randomly located, fixed 2 m x 2 m quadrats (thirteen quadrats) positioned on vegetated Hagg tops within the bare peat control site of the same name. Surveys were carried out between 2008 and 2014 (Table 3)

4.2.5 BB1, BB5 and BB6

These sites were situated in three estates in North Longdendale (Ashway Gap, Arnfield and Quiet Shepherd), where most of the bare peat re-vegetation works in SCaMP was carried out. They are dominated by blanket bog merging into heather-dominated heathland or acid grasslands. All three sites were excluded from grazing and also received lime, seed and fertiliser in 2007/8, with BB6 also receiving brash and geojute. Gully blocking using stone (deeper gullies) or heather bales (shallower areas) was carried out in 2010. Surveys were carried out in 2007 with repeats in 2008, 2009, 2010 and 2012 (Table 3).

Table 3. Number of growing seasons post-seeding for vegetation surveys in the Bleaklow sites

Year	Jo Pa	Shelf 1,3	Shelf 2	WH 26	Trenches (Con)	Trenches (Ref)	WH	BB1	BB5	BB6
2003	0		0							
2004	1		1							
2005	2	0	2							
2006	3	2	3							
2007	4				0			0	0	0
2008	5	4	5		1	0		1	1	1
2009	6	5	6		2			2	2	2
2010	7	6	7		3	2		3	3	3
2011	8	7	8	0	4	3	0			4
2012	9				5	4		5		5
2013	10	9		2	6	5	2			
2014	11	10		3	7	6	3			
2015	12			4			4			

Jo Pa = Joseph Patch, Shelf 1, 3 = sites on Shelf Moor, WH26 = ‘Woodhead 26’ site, Trenches (Con) = bare peat control site, Trenches (Ref) = intact reference site, WH = ‘Woodhead’ site.

4.3 Kinder Scout

Kinder Scout plateau is the highest peak (average height of 600m) in the Peak District National Park and the South Pennines Special Area of Conservation (SAC). The plateau has suffered from a high level of degradation through pollution, wildfire and overgrazing. The deep peat here is intersected by a high density of erosion gullies, and had extensive areas of bare peat. Several projects involving conservation works and associated with Moors for the Future Partnership are or have been located here.

The Kinder Catchment project (KCP) area was located on the south west of the Kinder Scout plateau, mainly involving re-vegetation and gully blocking treatments. Five sites were set up to monitor vegetation; three on treatment sites (Biffa, Budgies and Fred), one on an intact reference site (Gates), and one on the MS4W bare peat control site (Firmin) – details of the latter below.

The Making Space for Water (MS4W) project area was located on the north edge of Kinder Scout, within the upper Ashop catchment, a headwater catchment of the Upper Derwent valley. The aim was to provide evidence that restoration treatments involving re-vegetation and gully blocking contributed to a reduced risk of flooding downstream, while also providing multiple additional benefits ranging from reduced erosion, improved water quality, increased biodiversity ansx many others. The 84 ha project area was in a severely degraded blanket bog habitat. In 2009, the area contained approx. 34% (28 ha) severely gullied and bare peat areas. The experimental design included thee micro-catchments of less than 1 ha, one of which would remain as an untreated bare peat control (Firmin), one would be re-vegetated (Olaf) and one both re-vegetated and its gullies blocked (Nogson). Two additional reference micro-catchments on the neighbouring Bleaklow plateau were located on a late stage (2003) restored site (Joseph Patch) and a site considered to be representative of an intact Blanket bog.

The Catchment Restoration Fund's (CRF) was located on Seal Edge to the south-west of the M4SW project area on Kinder Scout. At this site, the Peatland Restoration project re-vegetated bare peat patches, installed stone dams in gully systems; and introduced moorland species in the form of plug plants. A further site (Ashop Head) was set up as an intact reference site.

4.3.1 Biffa

Surveys were carried out in ten 2 m x 2 m fixed quadrats located at approximately Grid Reference Northing 408469 Easting 387944 as part of the Kinder Catchment project. Surveys were carried out in April of 2011, and July/August of 2012, 2014. Seeds were applied in summer of 2013 (Table 4).

4.3.2 Budgies

Surveys were carried out in ten 2 m x 2 m fixed quadrats located at approximately grid reference Northing 408600, Easting 388549 as part of the Kinder Catchment project. Surveys were carried out in April of 2011, and July/August of 2012, 2014. Seeds were applied in summer of 2013 (Table 4).

4.3.3 Fred

Surveys were carried out in ten 2 m x 2 m fixed quadrats located at approximately grid reference Northing 408521, Easting 388598 as part of the Kinder Catchment project. Surveys were carried out in April of 2011, and July/August of 2012, 2014. Seeds were applied in summer of 2013 (Table 4).

4.3.4 Gates (intact control)

Surveys were carried out in ten 2 m x 2 m fixed quadrats located at approximately Grid Reference Northing 408996 Easting 388208 as part of the Kinder Catchment project. Surveys were carried out in April of 2011, and July/August of 2012, 2014 (Table 4).

4.3.5 Firmin (bare peat control)

Surveys were carried out in nine 2 m x 2 m fixed quadrats located at approximately Grid Reference Northing 409023 Easting 389429 as part of the Making Space for Water Project. These quadrats were set up and surveyed in February 2011. This control site received no seed, although application of seed in the nearby treatment sites of Nogson and Olaf took place in spring 2011. Post-seeding surveys took place in August of 2012, 2013, 2014, 2015 (Table 4).

4.3.6 Nogson/Olaf

Surveys were carried out in ten 2 m x 2 m fixed quadrats located at approximately grid reference Northing 408203, Easting 389452 as part of the Making Space for Water Project. These quadrats were set up and surveyed in February 2011. Application of seed took place in spring 2011. Post-seeding surveys took place in August of 2012, 2013, 2014, 2015. These quadrats were positioned mainly in the Olaf mini-catchment, to show the effects of re-vegetation (Table 4).

In 2015, ten new quadrats were set up and located solely within the Nogson mini-catchment, at approximately Grid Reference Northing 408237 Easting 389367, mainly to show the effects of re-vegetation in addition to intense *Sphagnum* plug inoculation and also gully-blocking on water flow.

4.3.7 CRF Ashop Head (intact reference)

Surveys were carried out in twenty seven 2 m x 2 m fixed quadrats, arranged into sets of five quadrats within a plot. There are five of these plots at this site, plus one additional quadrat at each of two dipwells. A survey was undertaken in 2014 as part of the Catchment Restoration Fund project (Table 4).

4.3.8 CRF Seal Edge

One hundred and twenty five fixed quadrats were involved as part of the Catchment Restoration Fund project: seventy five 2 m x 2 m fixed quadrats were set up in three bare peat locations, each containing five sets of five quadrats; fifty 2 m x 2 m fixed quadrats were set up in two vegetated locations, each containing five sets of five quadrats. All of these quadrats were set up between December 2012 and April 2013. Application of seed took place in spring 2013. Post-seeding surveys took place in June 2013, and July 2014 (Table 4).

Table 4. Number of growing seasons post-seeding for vegetation surveys on Kinder Scout

Year	Biffa	Budgies	Fred	Gates	Firmin (con)	Nogson	Olaf	CRF AH (ref)	CRF SE
2010						0	0		
2011	0					1	1		
2012	0.5	0	0	0		2	2		
2013	2					3	3		0
2014		2	2	2		4	4	1	1
2015						5	5		

4.4 Rishworth and Turley Holes in the South Pennines

4.4.1 Turley Holes

Surveys were carried out in twenty five 2 m x 2 m randomly located fixed quadrats in 2011, 2013 and 2014 (Table 5). Treatments included brash and geotextile in 2011 – 2013, seeds in April 2012 and fertiliser/lime in 2012, 2013 and 2014. *Sphagnum* propagules were applied in 2013 – 2015.

4.4.2 Rishworth

Surveys were carried out in twenty five 2 m x 2 m randomly located fixed quadrats in 2011, 2013 and 2014 (Table 5). Treatments included brash and geotextile in 2011 – 2013, seeds in April 2012 and fertiliser/lime in 2012, 2013 and 2014. *Sphagnum* propagules were applied in 2013 – 2015.

Table 5. Number of growing seasons post-seeding for vegetation surveys on Rishworth and Turley Holes

Year	Turley Holes	Rishworth
2011	0	0
2012		
2013	2	2
2014	3	3
2015		

5 RESULTS – TRAJECTORIES FROM GEOGRAPHICAL AREAS

5.1 Cover of bare peat

The cover of bare peat decreased over time in all of the different geographical areas (Fig. 1, top left). For the areas with more than about five years monitoring history, such as Black Hill & Holme Moss and Bleaklow, the decrease appeared to have reached minimal values between 0 and 20% after about five growing seasons following seeding, thereafter remaining at an apparent equilibrium value. Cover of bare peat appeared to have reached a lower equilibrium value on Bleaklow than on Black Hill & Holme Moss.

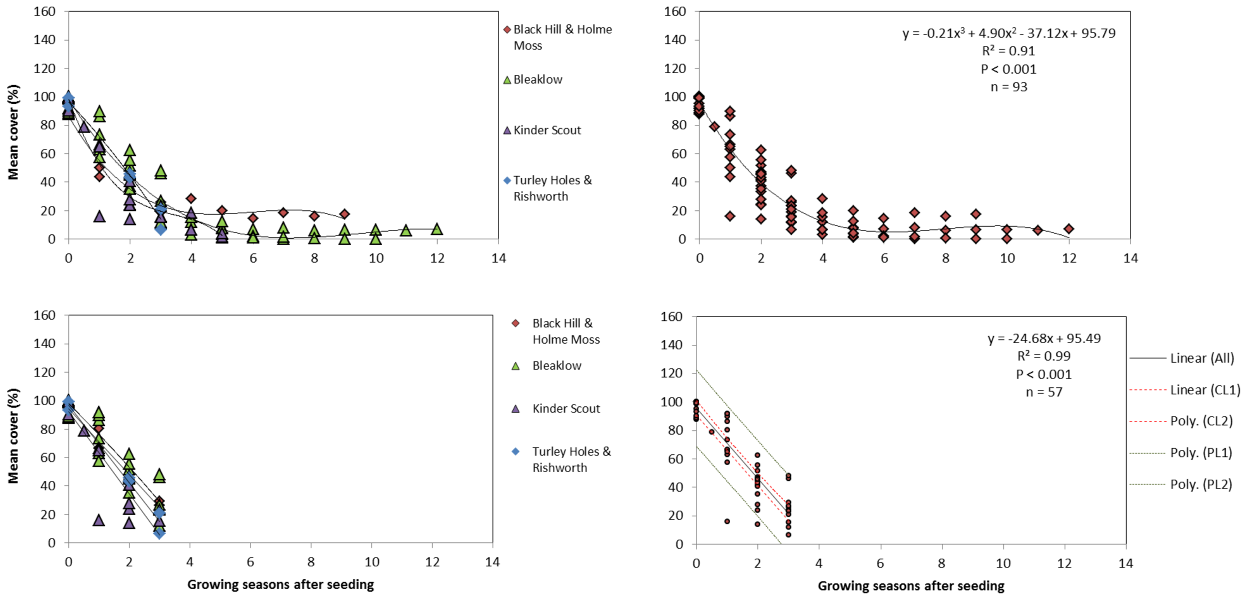

Fig. 2. Relationships between time and bare peat cover over all areas

Curvilinear relationships (top) are described by quadratic or cubic functions of time. Linear relationships (bottom) are derived by the removal of equilibrium values. Relationships are shown for individual areas (left side) or as a mean of all areas (right side) with details including equations, regression coefficients (R^2), p-values (P) and number of replicates (n). Confidence limits (95%) for the mean are given (CL) as well as the prediction limits (95%) for data points (PL); Cover is expressed as a mean value per 4 m^2 quadrat; Area information is given in Methods section.

Variations between individual areas for the relationships between time and bare peat cover were resolved into a strong and significant cubic function when summarised over all areas, showing an initial strong decline and a later equilibrium stage after about five growing seasons (Fig. 2, top right). Simple linear relationships for the areas were derived by truncating the data set so that bare peat cover values that were approaching equilibrium were removed (Fig. 2, bottom left). Data were mainly removed from the longer-running areas. Variations between areas for the linear relationships between time and bare peat cover were resolved into a strong and significant linear function when summarised over all areas (Fig. 2, bottom right). The slope of the line suggested that with a starting value between 95 and 100% bare peat cover, the predicted rate of decline as a mean of all areas was approximately 25 percentage points per growing season over three growing seasons, thereafter beginning to slow.

5.2 Cover of indicator species

The cover of indicator species increased over time in all of the different geographical areas (Fig. 3, top left). For all the areas and especially those with more than about five years monitoring history, such as Black Hill & Holme Moss and Bleaklow, the trajectory of increase was relatively variable in nature, appearing to reach maximal equilibrium values around 100% cover for Bleaklow, as opposed to 70% for Black Hill & Holme Moss (values above 100% signifying a more complex and multi-layered canopy).

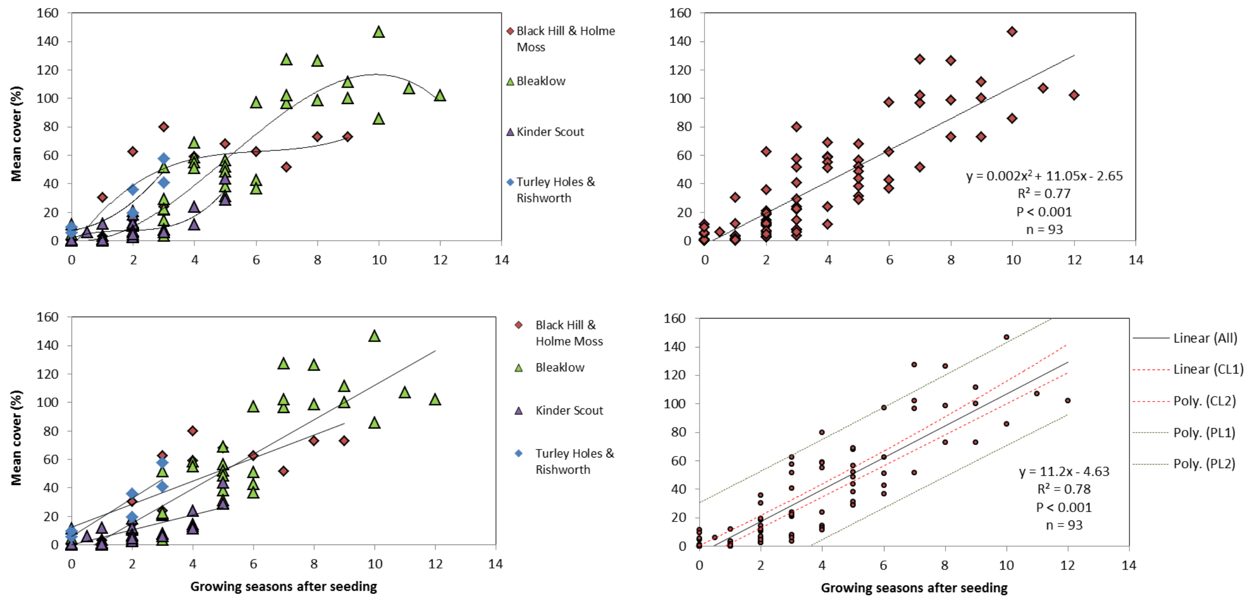

Fig. 3. Relationships between time and indicator species cover over all areas
Details and explanations as in Fig. 2

Variations between individual areas for the relationships between time and indicator species cover were resolved into a strong and significant quadratic function when summarised over all areas showing an almost linear increase, with no indication of a deceleration of rate even after 12 years (Fig. 3, top right). Simple linear relationships for the areas were derived without the need for truncating the dataset, but there were variations in slope, in particular that describing the relationship for the Kinder Scout area which appeared relatively shallow in comparison to the others (Fig. 3, bottom left), indicating a slower increase here. However, it is possible that this might change with the addition of further data points. Variations between individual areas for the linear relationships between time and indicator species cover were resolved into a strong and significant linear function when summarised over all areas (Fig. 3, bottom right). The equation of the line predicted a short delay after which the predicted rate of increase as a mean of all areas was approximately 11 percentage points per growing season for at least 12 growing seasons.

5.3 Count of indicator species

The number of indicator species increased over time in all of the different geographical areas (Fig. 4, top left). For almost all areas, the trajectory of increase suggested that there would be between four and five indicator species after approximately seven years thereafter achieving negligible further gains. On Kinder Scout, one of the replicate sample measurements reached a mean count of 5.9 after only five years; however, this can be explained by the presence within some of these quadrats of densely planted *Sphagnum* plugs as part of a separate trial (see section6.3.3).

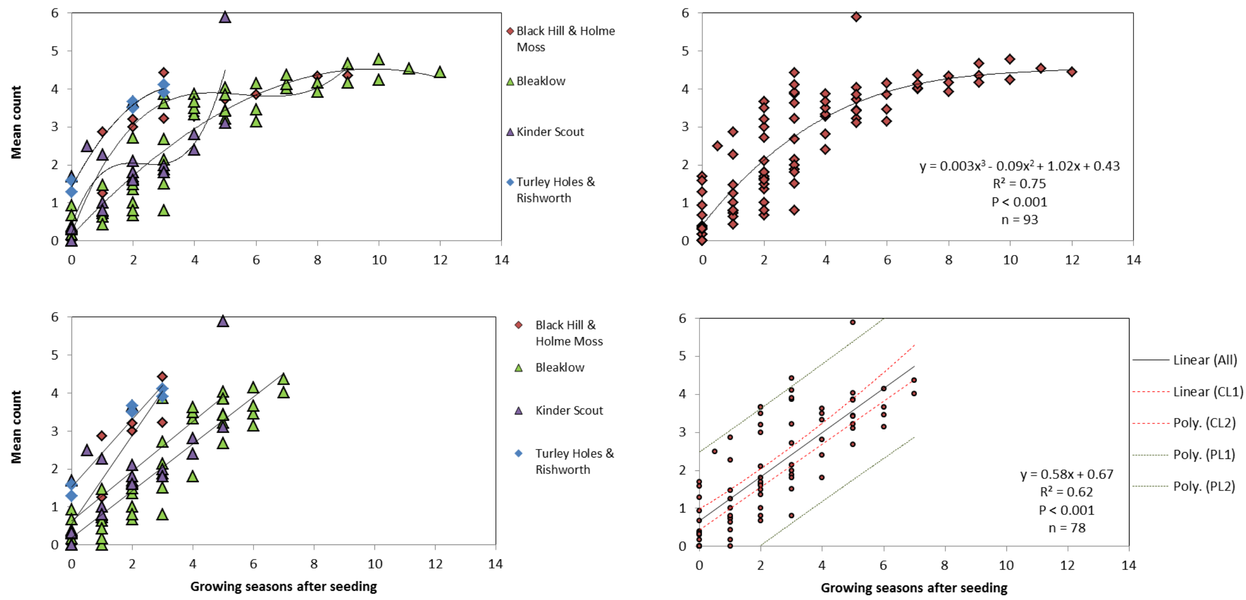

Fig. 4. Relationships between time and indicator species count over all areas
Details and explanations as in Fig. 2

Variations between individual areas for the relationships between time and indicator species count were resolved into a strong and significant cubic function when summarised over all areas (Fig. 4, top right). This trajectory suggested an initial steady linear increase followed by a gradual slowing and an eventual equilibrium phase of about 4.5 indicator species per quadrat. Simple linear relationships for the different areas were derived by truncating the relevant datasets so that the equilibrium phase was removed (Fig. 4, bottom left). Note that in the Turley Holes & Rishworth and the Black Hill & Holme Moss areas, there are relatively faster rates of increase and also variations in the y-intercept. As discussed below (section 6), these latter variations were likely to be the result partly of natural variations in the number of indicator species at the start of the trajectory but partly also due limitations associated with the linear function itself. Variations between individual areas for the linear relationships were resolved into a strong and significant linear relationship (Fig. 4, bottom right). The intercept suggested that on average there was a mean of 0.67 indicator species per quadrat already present at time zero – either just before or at the time of seeding. The slope predicted a gain of 0.58 indicator species per growing season over seven growing seasons, which with the intercept comes to a mean of 4.73. After this time the trajectory enters an equilibrium phase after which no further increases have yet been shown.

5.4 Species dominance

Averaging over all geographical areas and over the spectrum of survey durations of the relevant sites, species cover was mainly dominated by grasses (mostly *Deschampsia flexuosa*) and mosses with relatively strong cover of *Calluna vulgaris* and notable presence of the Cotton grasses (Table 6).

Table 6. Average cover of species/groups over all areas

Species/Group	Average cover (%)
Grasses	31
Acrocarpous mosses	20
Pleurocarpous mosses	17
Calluna vulgaris	12
Eriophorum vaginatum	7
Eriophorum angustifolium	6
Vaccinium myrtillus	3
Empetrum nigrum	1
Rubus chamaemorus	0

Grasses were dominated by *Deschampsia flexuosa; Calluna vulgaris was the dominant dwarf shrub*

In terms of trajectory of species dominance, there was an early dominance of grasses, overtaken in time, or at least rivalled, by that of mosses, first pleurocarpous and then acrocarpous in habit (Fig. 5, left). There was also a relatively slow, consistent and growing dominance of *Calluna vulgaris*. However, there was relatively high variability in the temporal duration of monitoring at sites available for contributing data). There was also a substantial decline in the number of sites contributing data with increasing time after seeding (Fig. 5, right), and thus a substanital decline of confidence in the data as an indication of general patterns. Only one site had been restored 11 and 12 years previously.

The early dominance of grasses was mainly due to extensive cover of *Deschampsia flexuosa*, this speceis being represented in the seed mix (see Buckler et al 2013). *Calluna vulgaris* is also present in the brashing treatment - its relatively slow but growing dominance is likley to be the result of the relatively slow growing habit of this species. Species cover within each of the four geographical areas is described in detail within the relevant paragraphs of section 6.

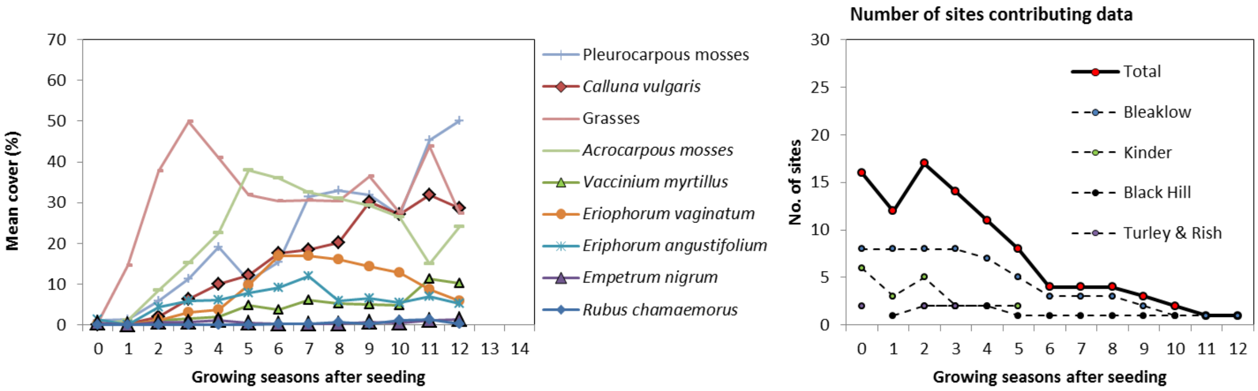

Fig. 5. Relationships between time and cover of species (left) and number of sites (right)
Relationships are described by direct line-plots, summarised over all areas. Grasses were defined as belonging to the Gramineae, excluding the cotton grasses. The order of species/types in the legend reflects dominance in the most recent year of data acquisition (left). There was strong site-specific variation and with increasing time after seeding, fewer sites were available to contribute data (right).

5.5 Control (bare peat) and reference (intact) areas

Re-vegetation treatments were excluded from control sites in which quadrats were positioned on bare peat patches. Reference sites were also used, with quadrats positioned on remnant or 'intact' vegetative cover. However, these latter sites may have received all or part of the re-vegetation treatments that were aimed at the adjacent bare peat areas. Both of these control and reference sites were set up on the geographical areas of Kinder Scout, Bleaklow and Turley Holes & Rishworth (reference only in the latter). Data for key variables were presented as a summary within individual areas and as a summary of all areas (Fig. 6, top and bottom, respectively).

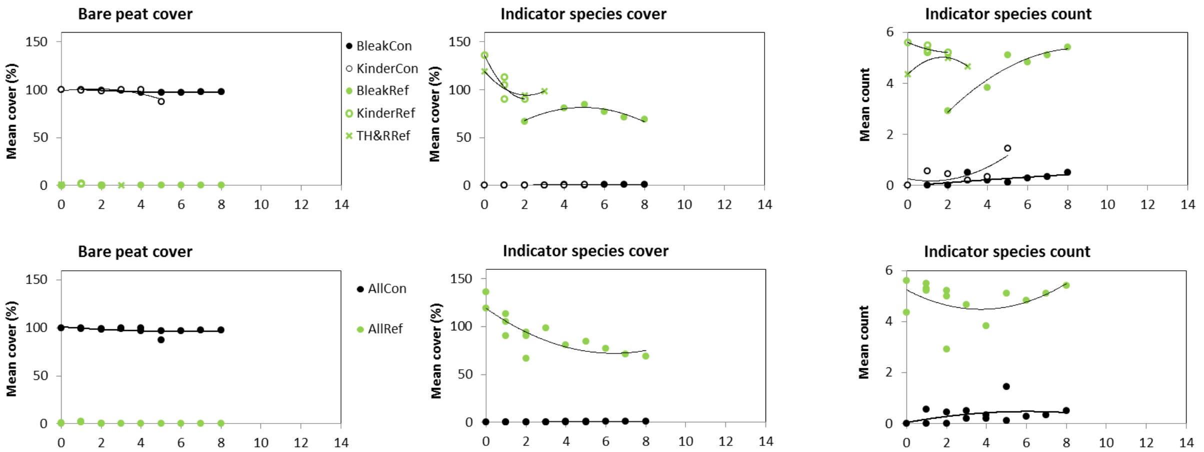

Fig. 6. Relationships between time and key variables in control and reference over all areas
Data are presented as a summary individual areas (top) and as a summary of all areas (bottom). BleakCon = Bleaklow control; KinderCon = Kinder Scout control ('Firmin); BleakRef = Bleaklow reference; KinderRef = Kinder Scout reference; TH&RRef = Turley Holes & Rishworth reference. Trajectories are presented as quadratic best-fit lines.

Data summarised over all of these sites/areas showed that bare peat cover remained at approximately 100% in the control sites and 0% in the reference sites (Fig. 5, left). Similarly, the cover of indicator species remained at 0% in the control sites while appearing to decline from 120% to about 70% in the reference sites (Fig. 5, middle).

Finally, counts of indicator species remained relatively low in the control sites and relatively high in the reference sites (Fig. 5, right)Fluctuations of indicator species cover/number in the reference sites are likely to be due to burgeoning cover of grasses and heather originating from the treatment and ensuing interspecific competition pressures. It is also likely that treatments of fertiliser and lime may have disrupted competitive balance.

5.6 Favourable Condition

Favourable condition status requires that the above measures of cover (bare peat and indicator species) and number of indicator species fulfil certain minimum standards within a framework known as Common Standard Monitoring (CSM). The CSM ‘targets’ for these measures, or ‘attributes’ must fulfil two thresholds: one that is specific for the attribute, e.g. a minimum ‘target’ of 6 indicator species; and one that is general for all attributes, requiring that the individual targets should be met in over 90% of survey quadrat samples – usually 20 per survey. This study considers three key attributes targets – (i) less than 10% bare peat cover, (ii) 50% indicator species cover consisting of at least three indicator species and (iii) presence of at least six indicator species.

5.6.1 Key attribute 1: Bare peat cover less than 10%

The proportion of quadrats with less than 10% bare peat cover increased over time in all of the four geographical areas (Fig. 7, top left), indicating that the spatial distribution of areas fulfilling the attribute target was broadening out over time. Maximal values were reached at Black Hill & Holme Moss (60%) and Bleaklow (90%), after about four and seven growing seasons respectively. Variations between areas in the shape of the trajectory for the proportion of quadrats achieving this attribute are likely to be a result of differences in the longevity of survey history, as much as differences between site- and area-specific environmental and floristic variables.

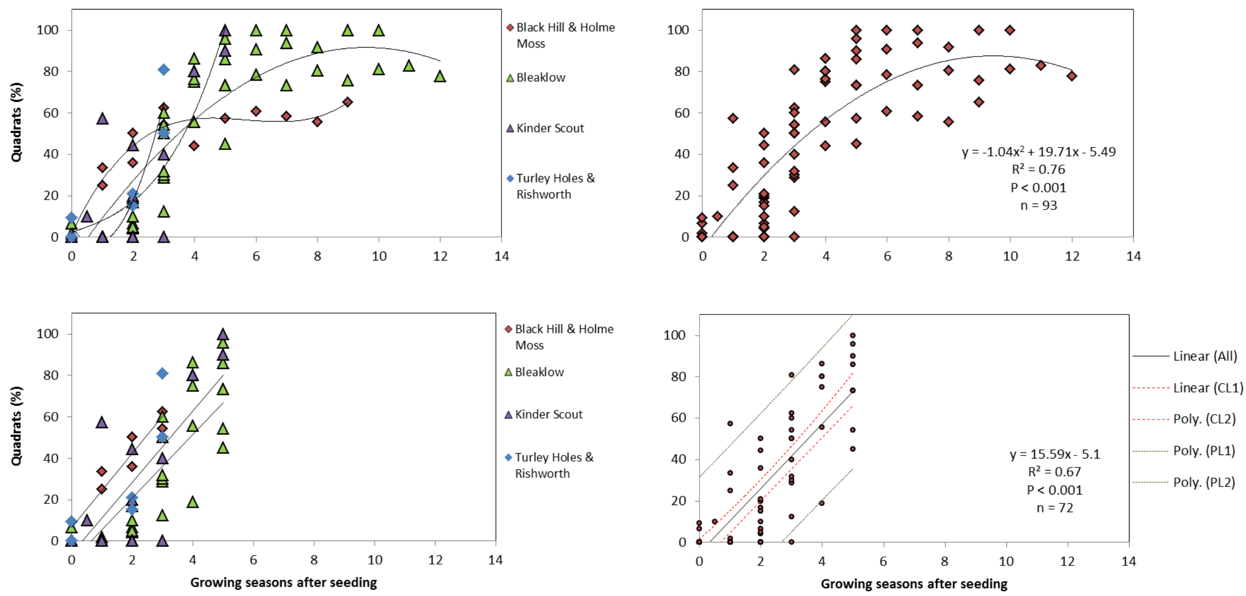

Fig. 7. Relationships between time and the proportion of quadrats with less than 10% bare peat cover, over all areas

Curvilinear relationships (top) are described by quadratic or cubic functions of time. Linear relationships (bottom) are derived by the removal of equilibrium values. Relationships are shown for individual areas (left side) or as a mean of all areas (right side) with details including equations, regression coefficients (R^2), p-values (P) and number of replicates (n). Confidence limits (95%) for the mean are given (CL) as well as the prediction limits (95%) for data points (PL); Cover is expressed as a mean value per 4 m^2 quadrat; Area information is given in Methods section.

These variations between individual areas were resolved into a strong and significant quadratic function when summarised over all areas, showing an initial strong increase and a later equilibrium stage after about seven growing seasons (Fig. 7, top right). Simple linear relationships were derived by truncating the dataset so that equilibrium values were removed (Fig. 7, bottom left). Data were mainly removed from the later stages of the longer-running areas. Variations between individual areas for the truncated linear relationships were resolved into a strong and significant linear function when summarised over all areas (Fig. 7, bottom right). The slope of the line suggested that with a starting value of approximately 0 %, the predicted rate of increase as a mean of all areas was 15.6 percentage points per growing season over seven growing seasons, thereafter beginning to slow.

5.6.2 Key attribute 2: At least 50% cover composed of at least three indicator species

The proportion of quadrats with at least 50% of the cover composed of at least three indicator species increased over time in most of the individual geographical areas (Fig. 8, top left). Wide variation between areas in the shape of the trajectories is a reflection of wide variation between individual sites, discussed in section 6, below.

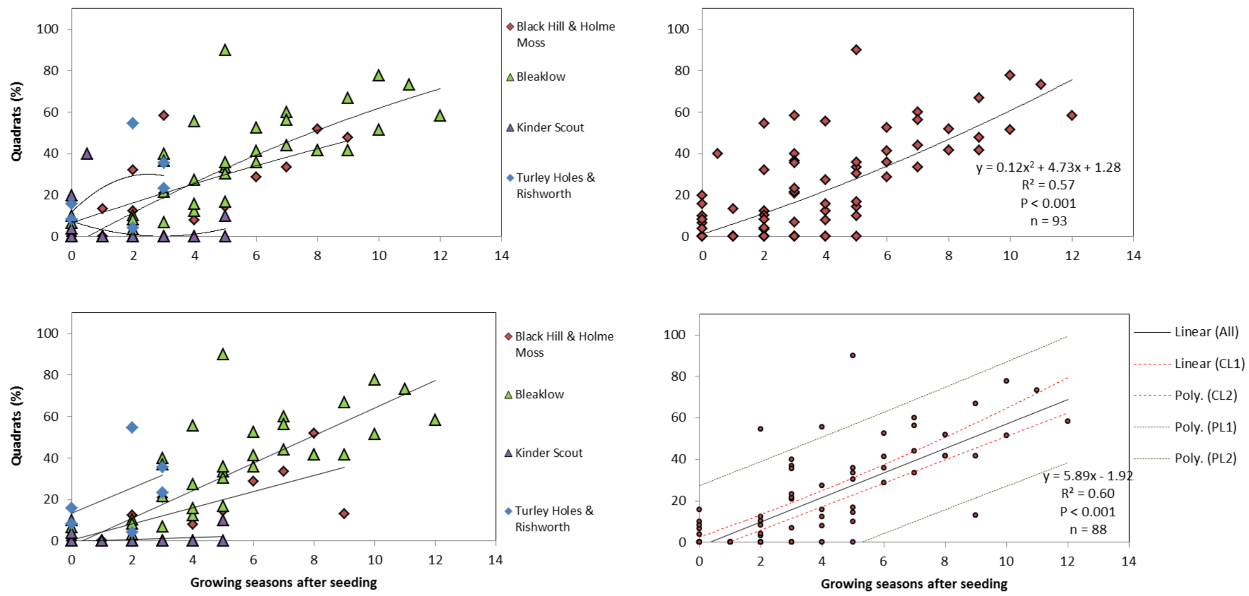

Fig. 8. Relationships between time and the proportion of quadrats with at least 50% cover composed of at least three indicator species, over all areas
Details and explanations as in Fig. 7

Nevertheless, the relationship derived from summarising individual area relationships was both strong and significant (Fig. 8, top right). There was no suggestion of a slowing in the rate of increase towards an equilibrium phase, even after 12 years. Simple linear relationships were derived without the need for truncating the dataset (Fig. 8, bottom left), but there was considerable variation in slope. Nevertheless, these variations were resolved into a strong and significant linear function when summarised over all areas (Fig. 8, bottom right). The equation of the line predicted a short delay after which the predicted rate of increase as a mean of all areas was 5.9 percentage points per growing season, over at least 12 growing seasons.

5.6.3 Key attribute 3: At least six species indicator species

The proportion of quadrats with at least six indicator species appeared to increase relatively slowly over time in most of the different geographical areas (Fig. 9, top left). Data for the Kinder Scout area showed a relatively large value after five growing seasons and this can be attributed to a trial concerning densely planted *Sphagnum* plugs at this time (see section 6.3.3).

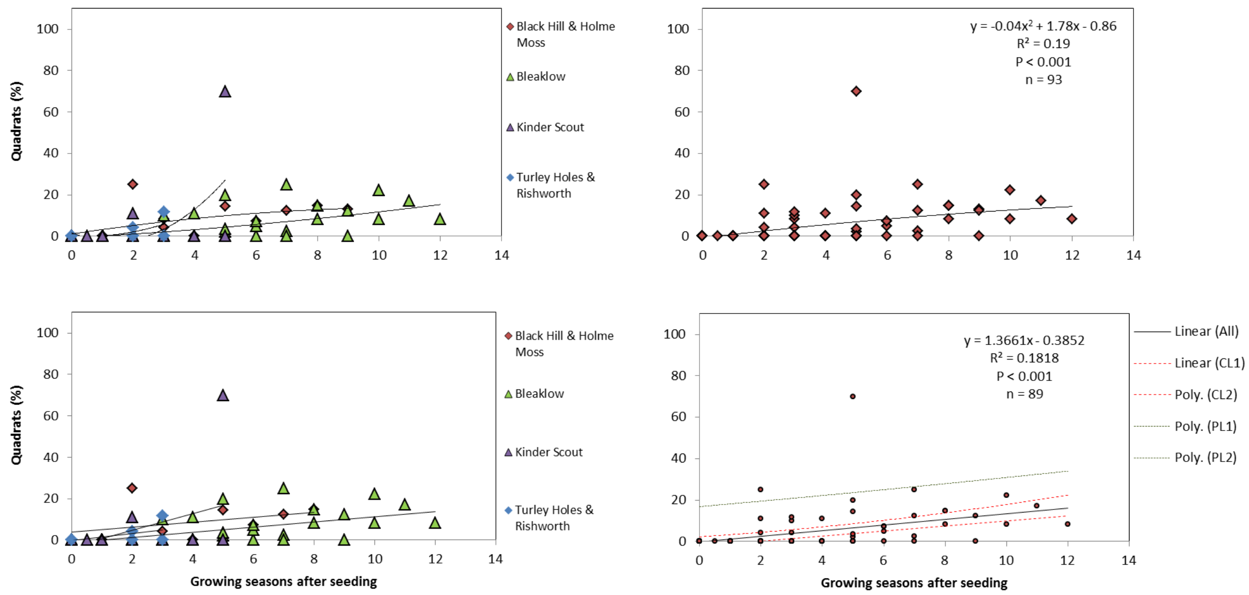

Fig. 9. Relationships between time and the proportion of quadrats with at least six indicator species, over all areas

Details and explanations as in Fig. 7

Area trajectories were summarised to give a strong and significant quadratic function which was almost linear in nature, predicting a relatively slow rate of increase over 12 years with no indication of a change in rate (Fig. 9, top right). Simple linear relationships for the different areas were derived without the need for truncating the data (Fig. 9, bottom left). Variations between individual areas for the linear relationships were resolved into a strong and significant linear relationship (Fig. 9, bottom right). The resulting slope predicted a rate of increase of about 1.4 percentage points per growing season, over at least twelve years.

6 SUPPORTING RESULTS – TRAJECTORIES FROM INDIVIDUAL SITES

6.1 Black Hill and Holme Moss

6.1.1 Cover of bare peat

In the Black Hill and Holme Moss geographical area, the cover of bare peat decreased over time, although only one site 'Black Hill' had more than two years of data (Fig. 10, top left). This site appeared to have reached minimal values between 0 and 20% after about six growing seasons following seeding, thereafter remaining at these values. Bare peat cover at the site known as Issues Edge, for which only one data point was available, appeared to be relatively high – this is likely to be due to the inclusion of quadrats placed on vegetated parts of the bog, although quadrats for the National Grid site were similarly placed.

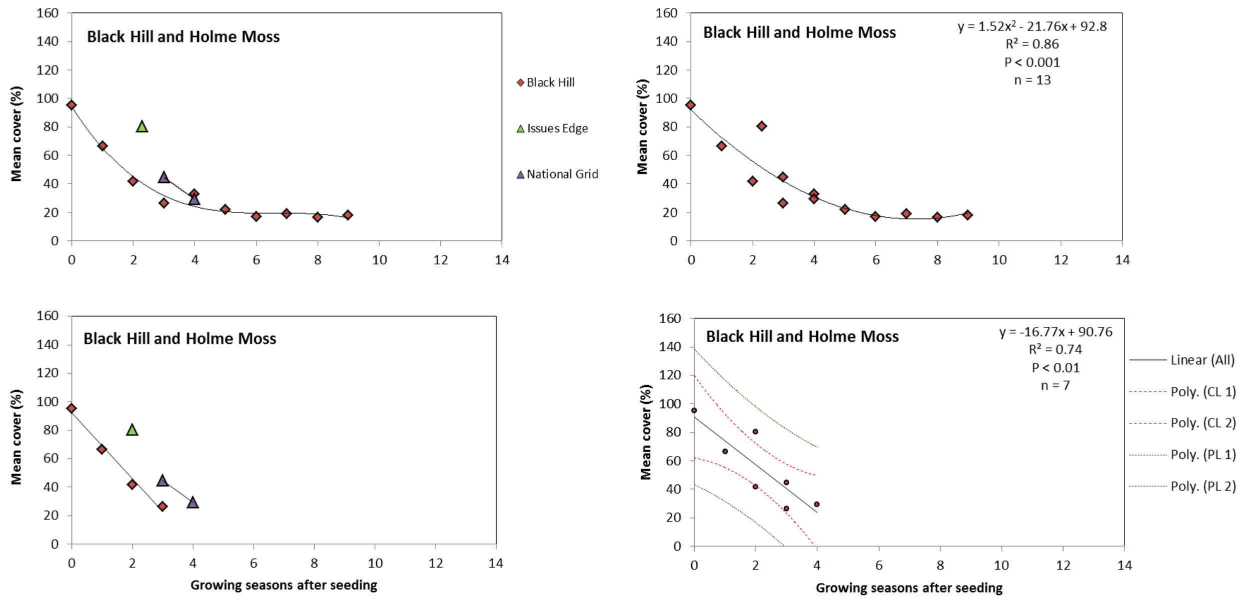

Fig. 10. Relationships between time and bare peat cover
Curvilinear relationships (top) are described by quadratic or cubic functions of time. Linear relationships (bottom) are derived, where necessary, by the removal of equilibrium values. Relationships are shown for individual sites (left side) or as a mean of all sites (right side) with details including equations, regression coefficients (R^2), p-values (P) and number of replicates (n). Confidence limits (95%) for the mean are given (CL) as well as the prediction limits (95%) for data points (PL); Cover is expressed as a mean value per 4 m^2 quadrat; Site information is given in Methods section.

Variations between individual sites for the relationships between time and bare peat cover were resolved into a strong and significant quadratic function when summarised over sites, showing an initial strong decline and a later equilibrium stage after about four growing seasons (Fig. 10, top right). Simple linear relationships were derived by truncating the data set of the longer-running site so that bare peat cover values that had achieved equilibrium were removed (Fig. 10, bottom left). Variations between sites for the linear relationships were then resolved into a significant linear function when summarised over all sites (Fig. 10, bottom right). The slope of the line suggested that with a starting value between 95 and 100% bare peat cover, the predicted rate of decline as a mean of all sites was approximately 17 percentage points per growing season over three growing seasons, thereafter beginning to slow.

6.1.2 Cover of indicator species

The cover of indicator species increased over time (Fig. 11, top left). For the longer-running site on Black Hill, the trajectory of increase appeared to reach maximal equilibrium values of approximately 70% cover. Data points for Issues Edge and National Grid appeared to have values on the outer range of variability of those at Black Hill.

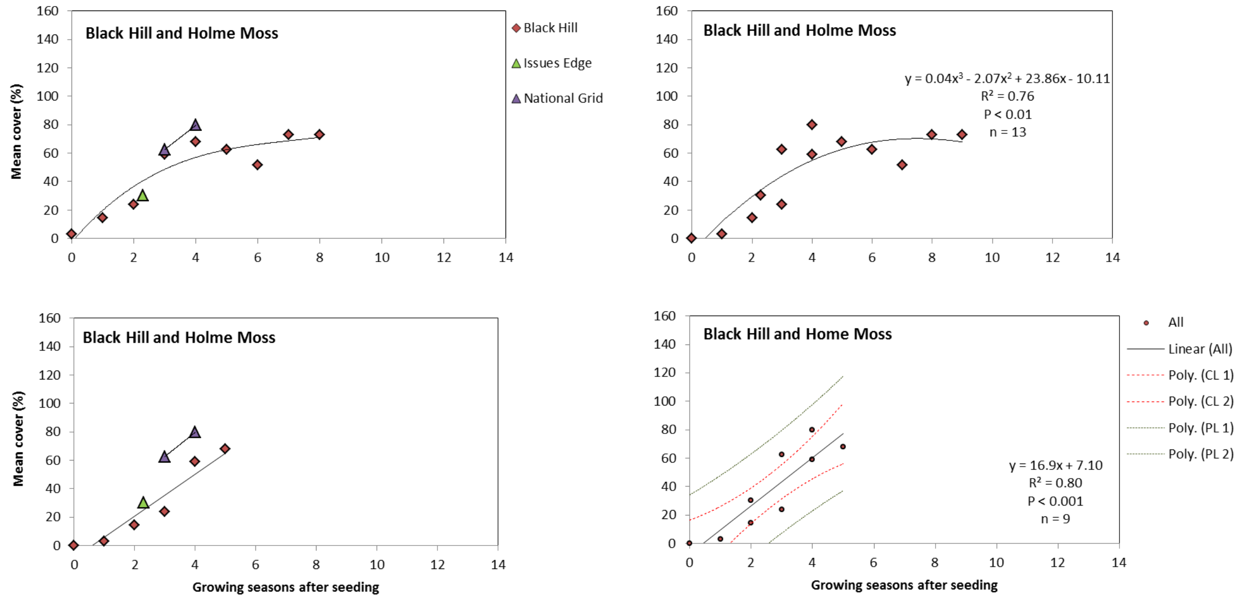

Fig. 11. Relationships between time and indicator species cover
Details and explanations as in Fig. 10

Variations between individual sites for the relationships between time and indicator species cover were resolved into a significant cubic function when summarised over all sites, showing a relatively high rate of increase initially, later slowing towards an equilibrium stage after about four growing seasons (Fig. 11, top right). Simple linear relationships were derived by truncating the data set of the longer-running site so that indicator species cover values that had achieved equilibrium were removed (Fig. 11, bottom left). Variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 11, bottom right). The slope of the line suggested that, after a short delay, from a starting value of 0% bare peat cover, the predicted rate of increase as a mean of all sites was approximately 17 percentage points per growing season over five growing seasons, thereafter beginning to slow.

6.1.3 Count of indicator species

The number of indicator species increased over time (Fig. 12, top left). For the longer-running site on Black Hill, the trajectory of increase appeared to reach maximal equilibrium values of approximately 4.3. Data points for Issues Edge and National Grid appeared to be on the margin for the range of data points for Black Hill.

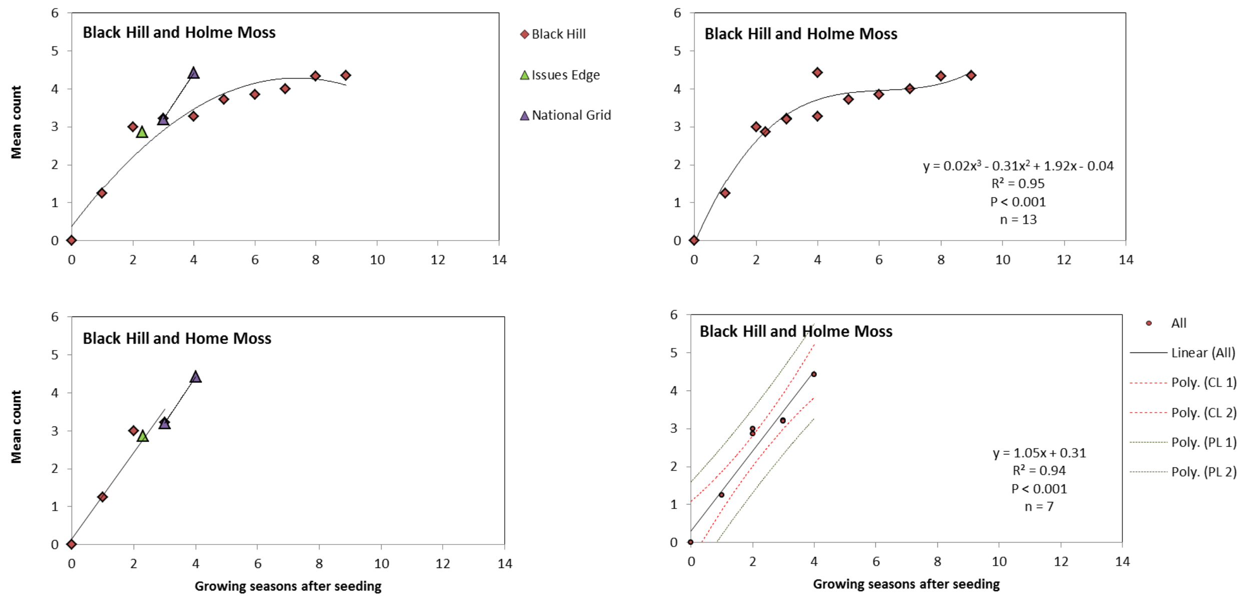

Fig. 12. Relationships between time and indicator species count
Details and explanations as in Fig. 10

Variations between individual sites for the relationships between time and indicator species cover were resolved into a significant cubic function when summarised over all sites, showing a relatively high rate of increase initially, later slowing towards an equilibrium stage after about four growing seasons (Fig. 12, top right). Simple linear relationships were derived by truncating the data set of the longer-running site so that indicator species cover values that had achieved equilibrium were removed (Fig. 12, bottom left). Variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 12, bottom right). The slope of the line suggested that, from a starting value of no indicator species, the predicted rate of increase as a mean of all sites was approximately 1 per growing season over four growing seasons, thereafter beginning to slow.

6.1.4 Species dominance

Averaging over the three sites in this geographical area and over the spectrum of available survey durations, species cover was dominated by *Acrocarpous* mosses with relatively strong cover of grasses (mainly *Deschampsia flexuosa*), *Eriophorum vaginatum, Calluna vulgaris* and *Pleurocarpous* mosses and notable presence of *Eriophorum angustifolium* (Table 7).

Table 7. Average cover of species/groups (Black Hill and Holme Moss)

Species/Group	Average cover (%)
Acrocarpous mosses	32
Grasses	20
Eriophorum vaginatum	14
Calluna vulgaris	13
Pleurocarpous mosses	13
Eriophorum angustifolium	7
Vaccinium myrtillus	2
Empetrum nigrum	1
Rubus chamaemorus	0

Grasses were dominated by *Deschampsia flexuosa; Calluna vulgaris was the dominant dwarf shrub*

In terms of trajectory, there was an early dominance of grasses, overtaken in time by that of acrocarpous mosses, (Fig. 13, left). There was also a relatively slow, consistent and growing dominance of *Calluna vulgaris*. However, there was relatively high variability in the temporal duration of monitoring at sites available for contributing data. Although both of the contributing sites contained at least 25 quadrats, confidence in the trajectory as an indication of general patterns is necessarily limited. Only one site had been restored 11 and 12 years previously (Fig. 13, right).

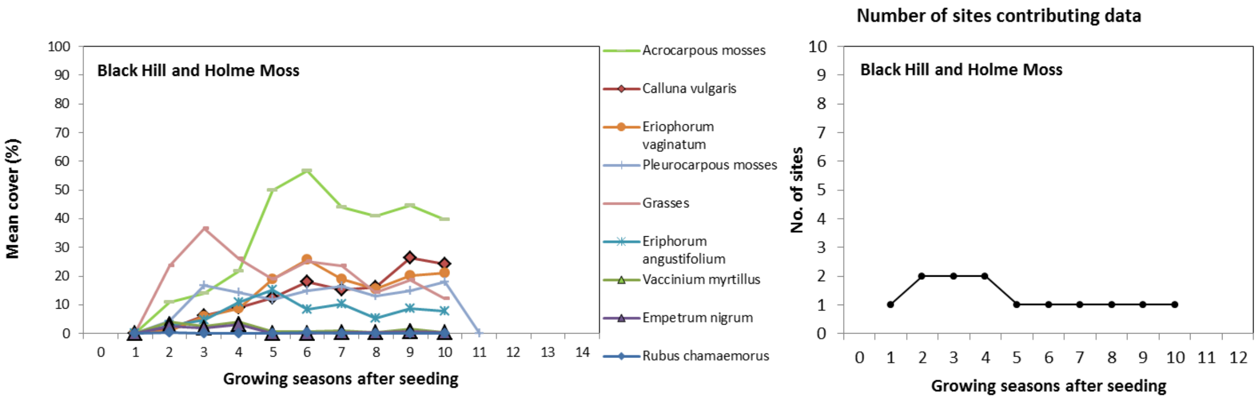

Fig. 13. Relationships between time and cover of species (left) and number of sites (right)
Details and explanation as in Fig. 5

6.1.5 Favourable Condition

For an explanation of Favourable Condition attributes and targets, see section 5.6

Key attribute 1: Bare peat cover less than 10%

The proportion of quadrats with less than 10% bare peat cover increased over time (Fig. 14, top left). For the longest running site (Black Hill), the increase appeared to have reached maximal values of approximately 60% after about four growing seasons following seeding. At the site known as Issues Edge, for which only one data point was available, and at the National Grid site, for which two data points were available, values appeared to be appeared to be within the range of variability for the Black Hill site – in spite of the inclusion of quadrats placed on vegetated parts of the bog.

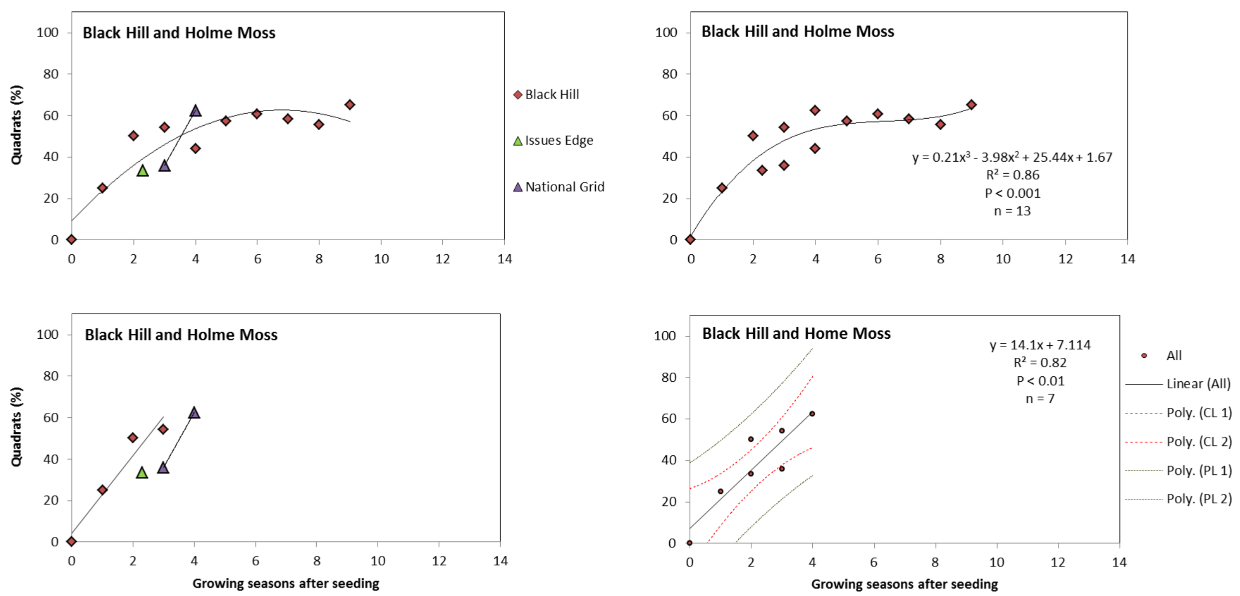

Fig. 14. Relationships between time and the proportion of quadrats with bare peat cover less than 10%

Details and explanations as in Fig. 10

Variations between individual sites for the relationships between time and the proportion of quadrats with less than 10% bare peat cover were resolved into a significant cubic function when summarised over all sites, showing a relatively high rate of increase initially, later slowing towards an equilibrium stage after about four growing seasons (Fig. 14, top right). Simple linear relationships were derived by truncating the data set of the longer-running site so that indicator species cover values that had achieved equilibrium were removed (Fig. 14, bottom left). Variations between sites for the linear relationships were then resolved into a significant linear function when summarised over all sites (Fig. 14, bottom right). The slope of the line suggested that, from a starting value of less than 10%, the predicted rate of increase as a mean of all sites was approximately 14 percentage points per growing season over four growing seasons, thereafter beginning to slow.

Key attribute 2: At least 50% cover composed of at least three indicator species

The proportion of quadrats with at least 50% of the cover composed of at least three indicator species increased over time (Fig. 15, top left). For the longest running site at Black Hill, the increase over time appeared to be continuing, with no indication of an equilibrium phase, although further monitoring will confirm. The two data points from the National Grid site appeared to have relatively higher values than expected from temporal variation of values in the Black Hill site. This was expected as National Grid quadrats were located on a mixture of both bare peat and vegetative parts of the bog.

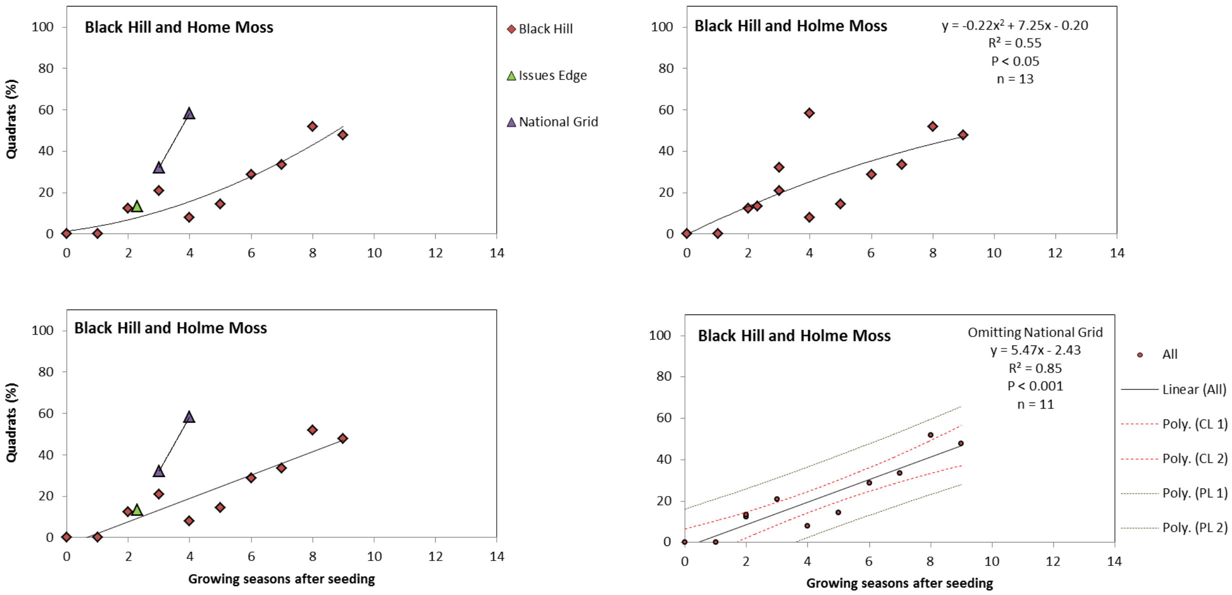

Fig. 15. Relationships between time and the proportion of quadrats with at least 50% cover composed of at least three indicator species
Details and explanations as in Fig. 10

Variations between individual sites were resolved into a significant quadratic function when summarised over all sites, showing an approximately linear relationship with some indication of a later slowing towards an equilibrium stage (Fig. 15, top right), although the data for the National Grid site detracted from the strength of the relationship. Simple linear relationships (Fig. 15, bottom left) were resolved into a strong and significant linear function (Fig. 13, bottom right) when data from the National Grid site were removed. The slope of the line suggested that, after a short delay, and from a starting value of 0%, the predicted rate of increase as a mean of all sites was approximately 5.5 percentage points per growing season over nine growing seasons. Inclusion of the National Grid site altered the function of the line very slightly; giving an earlier start (intercept = 3.2) and a shallower slope (5.2), but arriving at the same point and at the same time. The main difference involved the range of confidence and prediction limits which were narrower in the absence of the NG site.

Key attribute 3: At least six species indicator species per 4 m2 quadrat

The proportion of quadrats with at least six indicator species appeared to show relatively slight increases over time (Fig. 16, top left). For the longest running site at Black Hill, the rate of increase appeared to be relatively slow.

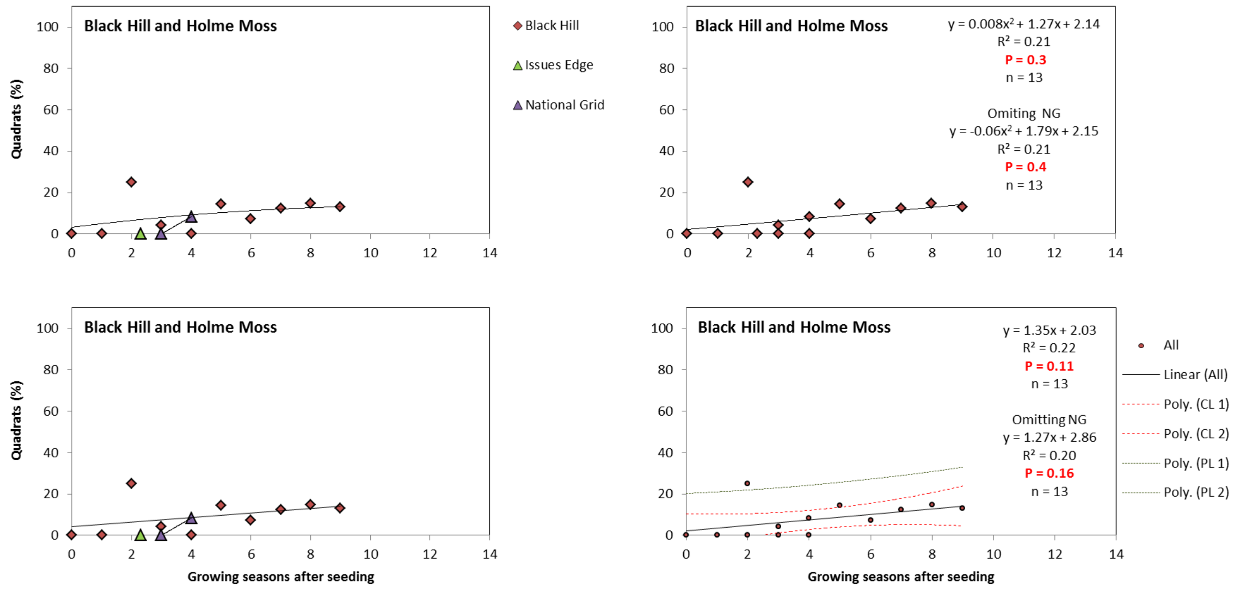

Fig. 16. Relationships between time and the proportion of quadrats with at least six indicator species
Details and explanations as in Fig. 10

Resolving the data points from the three sites into a single quadratic regression line did not provide a statistically significant fit (Fig. 16, top right), even after omitting the data for the National Grid site.

Simple linear trajectories were achieved for individual sites using complete datasets without the need for truncating the data (Fig. 16, bottom left). These were resolved into a single linear regression, with a slope suggesting a rate of increase of 1.4 percentage points per growing season, but again the linear regression lacked statistical significance, either with or without the National Grid data (Fig. 16, bottom right).

6.2 Bleaklow

6.2.1 Cover of bare peat

In the Bleaklow geographical area, the cover of bare peat decreased over time, with all relevant sites following the same approximate trajectory, although with increasing number of growing seasons after seeding, especially more than six, the number of sites with relevant data became increasingly scarce (Fig. 9, top left). Bare peat cover was reduced to below 10% in all relevant sites.

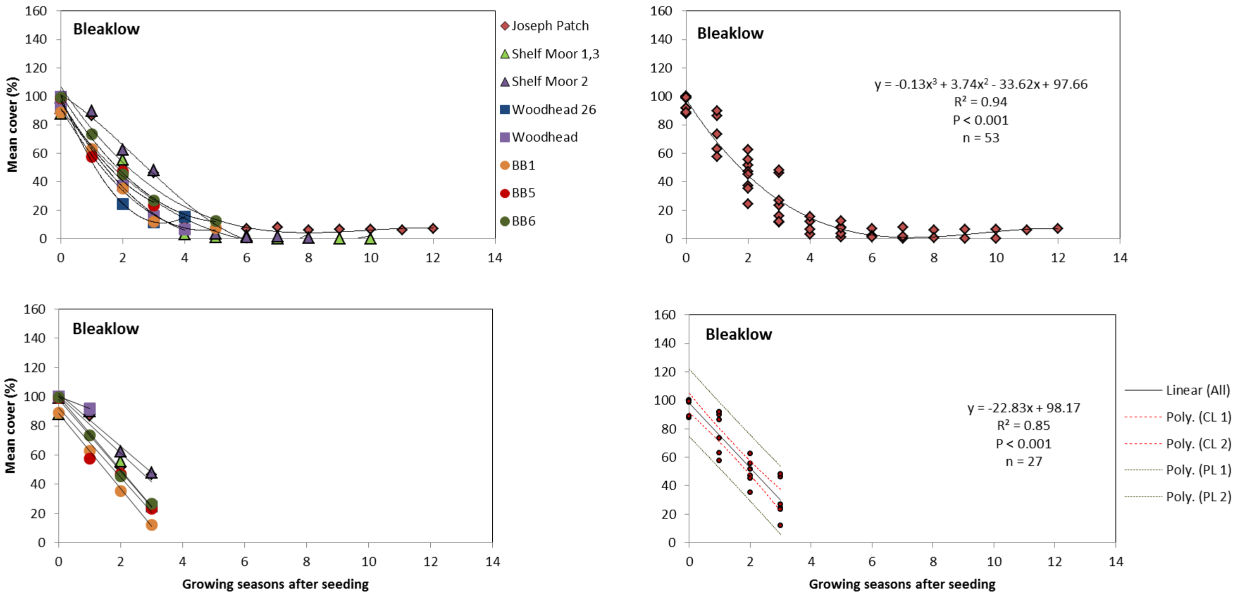

Fig. 17. Relationships between time and bare peat cover

Curvilinear relationships (top) are described by quadratic or cubic functions of time. Linear relationships (bottom) are derived, where necessary, by the removal of equilibrium values. Relationships are shown for individual sites (left side) or as a mean of all sites (right side) with details including equations, regression coefficients (R^2), p-values (P) and number of replicates (n). Confidence limits (95%) for the mean are given (CL) as well as the prediction limits (95%) for data points (PL); Cover is expressed as a mean value per 4 m^2 quadrat; Site information is given in Methods section.

Variations between individual sites for the relationships between time and bare peat cover were resolved into a strong and significant cubic function when summarised over all sites, showing an initial strong decline and a later equilibrium stage after about four growing seasons (Fig. 17, top right). Simple linear relationships were derived by truncating the data set of the longer-running sites so that bare peat cover values that had achieved equilibrium were removed (Fig. 17, bottom left). Variations between sites for the linear relationships were then resolved into a significant linear function when summarised over all sites (Fig. 17, bottom right). The slope of the line suggested that with a starting value of 100% bare peat cover, the predicted rate of decline as a mean of all sites was approximately 23 percentage points per growing season over three growing seasons, thereafter beginning to slow.

6.2.2 *Cover of indicator species*

In the Bleaklow area, the cover of indicator species increased over time, however there were considerable variations between sites in the precise trajectory taken, with one site appearing to show a most recent decrease (Fig. 9, top left). Maximum cover varied between approximately 100% (Joseph Patch) up to about 150% (Shelf Moor 1, 3), although equilibrium values may not have been reached in the latter case.

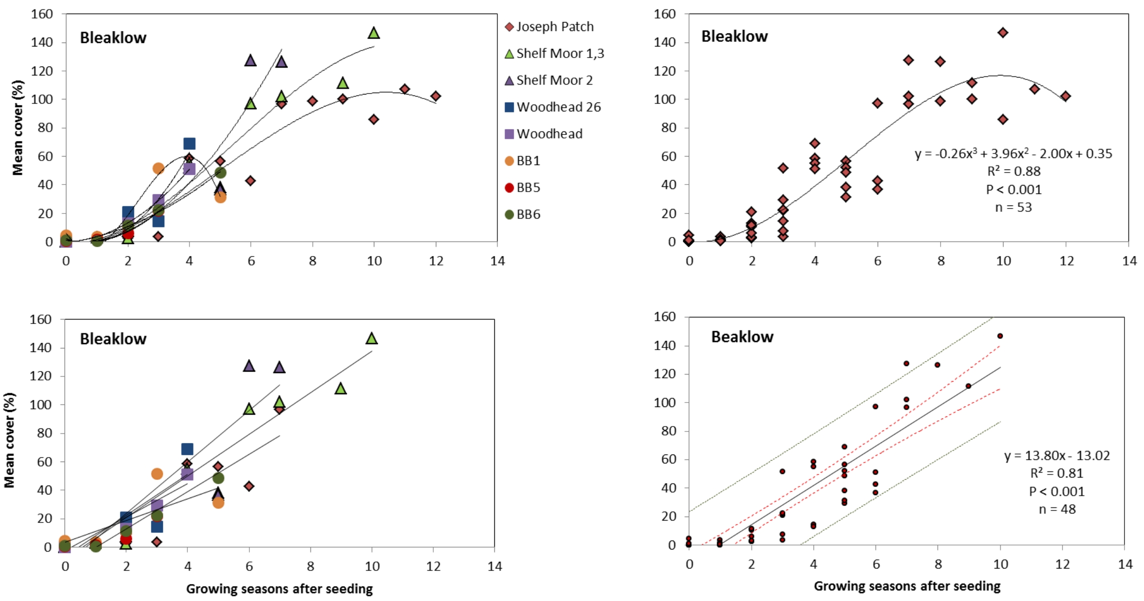

Fig. 18. Relationships between time and indicator species cover
Details and explanations as in Fig. 17

Variations between individual sites for the relationships between time and indicator species cover were resolved into a strong and significant cubic function when summarised over all sites, showing a relatively slow start accelerating to a relatively high rate of increase, later slowing towards an equilibrium stage after about nine growing seasons (Fig. 18, top right). The appearance of a decline in cover after about ten growing seasons is due to a lack of data available at this time. Simple linear relationships were derived by truncating the data set of the longer-running sites so that indicator species cover values that had achieved equilibrium were removed (Fig. 18, bottom left). Variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 18, bottom right). The slope of the line suggested that, after a short delay of about one growing season, and from a starting value of 0% bare peat cover, the predicted rate of increase as a mean of all sites was 13.8 percentage points per growing season over ten growing seasons, thereafter beginning to slow.

6.2.3 *Count of indicator species*

The number of indicator species increased over time in all of the individual sites (Fig. 19, top left), although there were some variations between the individual site trajectories. Maximum values of between 4.5 and 5.0 were achieved after about eight years in the longer running sites.

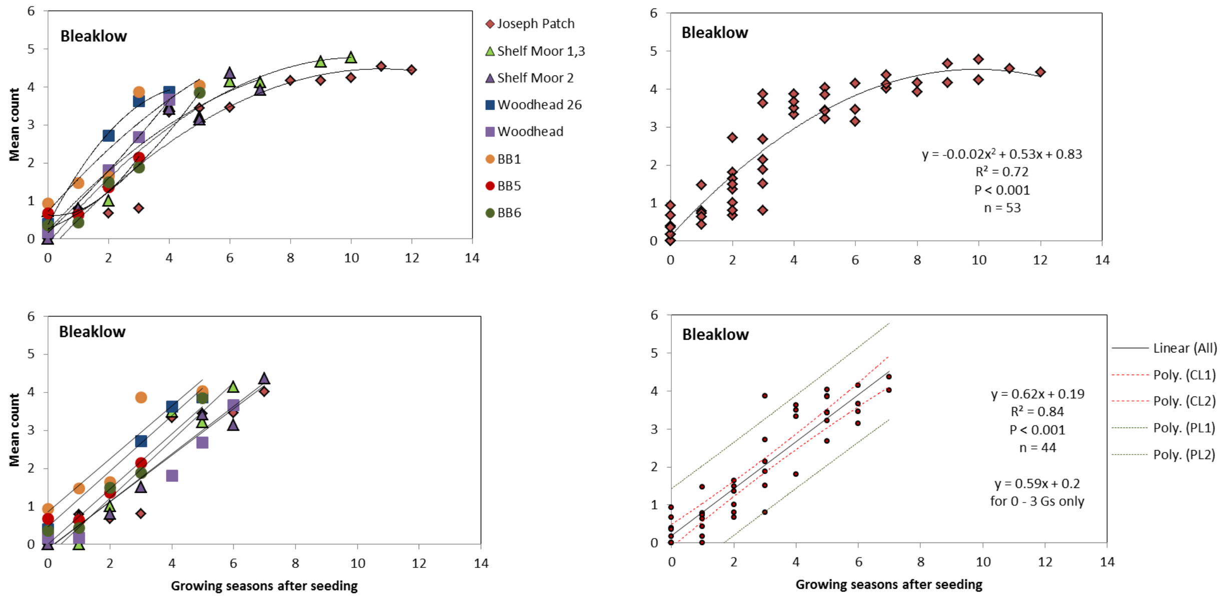

Fig. 19. Relationships between time and indicator species count
Details and explanations as in Fig. 17

Variations between individual sites were resolved into a strong and significant quadratic function when summarised over all sites, showing a relatively high rate of increase initially, later slowing towards an equilibrium stage after about seven growing seasons (Fig. 19, top right). The appearance of a decline in cover after about ten growing seasons is due to a lack of data available at this time. Simple linear relationships were derived by truncating the data set of the longer-running sites so that indicator species cover values that had achieved equilibrium were removed (Fig. 19, bottom left). Variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 19, bottom right). The slope of the line suggested that, from a starting value of just over zero indicator species, the predicted rate of increase as a mean of all sites was 0.6 per growing season over seven growing seasons, thereafter beginning to slow.

6.2.4 Species dominance

Averaging over all sites in this geographical area and over the spectrum of available survey durations, species cover was dominated by grasses (mainly Deschampsia flexuosa) with relatively strong cover of *Pleurocarpous* mosses, *Calluna vulgaris* and *Acrocarpous* mosses. There was notable presence of *Eriophorum vaginatum*, *Vaccinium myrtillus* and *Eriophorum angustifolium* (

Table **8**).

Table 8. Average cover of species/groups (Bleaklow)

Species/Group	Average cover (%)
Grasses	39
Pleurocarpous mosses	27
Calluna vulgaris	17
Acrocarpous mosses	14
Eriophorum vaginatum	6
Vaccinium myrtillus	6
Eriophorum angustifolium	5
Rubus chamaemorus	1
Empetrum nigrum	0

Grasses were dominated by *Deschampsia flexuosa; Calluna vulgaris was the dominant dwarf shrub*

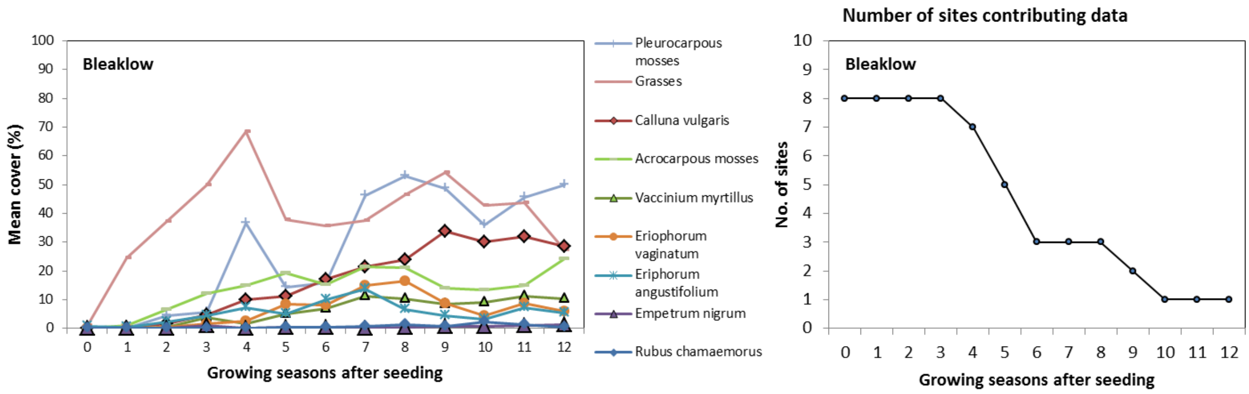

Fig. 20. Relationships between time and cover of species (left) and number of sites (right)
Details and explanations as in Fig. 5

6.2.5 Favourable Condition

For an explanation of Favourable Condition attributes and targets, see section 5.6.

Key attribute 1: Bare peat cover less than 10%

The proportion of quadrats with less than 10% bare peat cover increased over time in all the individual sites (Fig. 13, top left), although with increasing number of growing seasons after seeding, especially more than six, the number of sites with relevant data became increasingly scarce (Fig. 9, top left). For the longest running sites on Joseph Patch and those on Shelf Moor, the increase appeared to have reached maximal values between about 80% and 100%, respectively and after about six growing seasons following seeding.

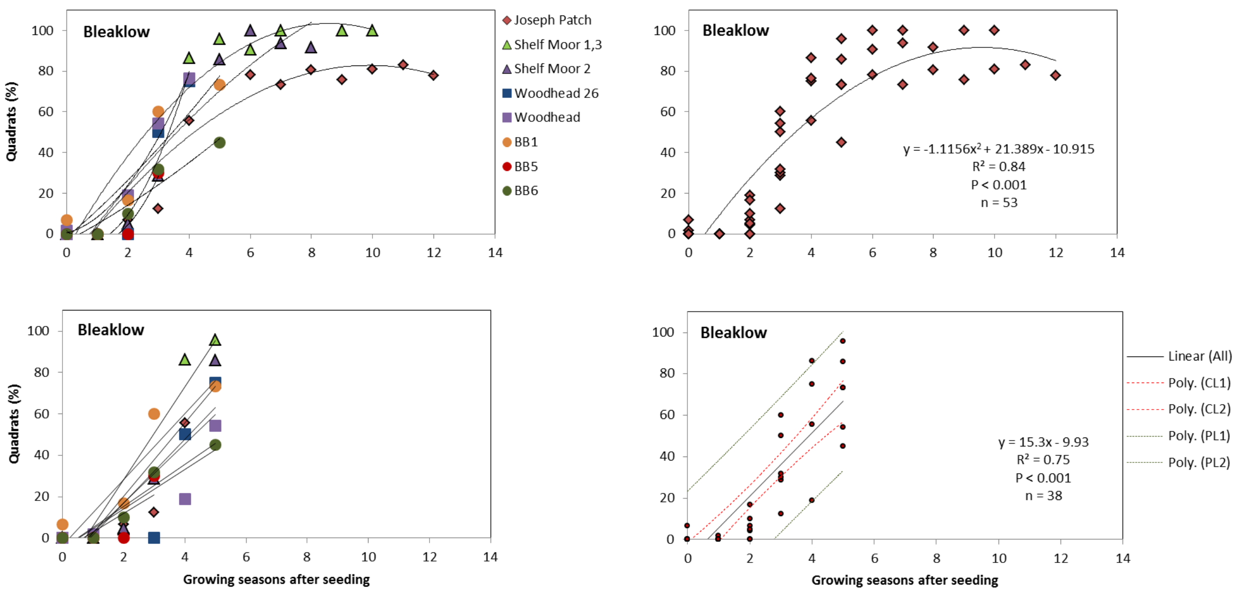

Fig. 21. Relationships between time and the proportion of quadrats with bare peat cover less than 10%

Details and explanations as in Fig. 17

Variations between individual sites for the relationships between time and the proportion of quadrats with less than 10% bare peat cover were resolved into a strong and significant quadratic function when summarised over all sites, showing a relatively high rate of increase initially, later slowing towards an equilibrium stage after about eight growing seasons (Fig. 21, top right). Simple linear relationships were derived by truncating the data sets of the longer-running sites so that indicator species cover values that had achieved equilibrium were removed (Fig. 21, bottom left). Variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 21, bottom right). The slope of the line suggested that, after an initial delay of less than one growing season, and from a starting value of 0%, the predicted rate of increase as a mean of all sites was approximately 15 percentage points per growing season over five growing seasons, thereafter beginning to slow.

Key attribute 2: At least 50% cover composed of at least three indicator species

The proportion of quadrats with at least 50% of the cover composed of at least three indicator species increased over time in all of the individual sites (Fig. 22, top left). For the longest running site at Joseph Patch, there was some indication of an equilibrium phase, although further monitoring will confirm. There was relatively high variation in the shape of the trajectories between sites.

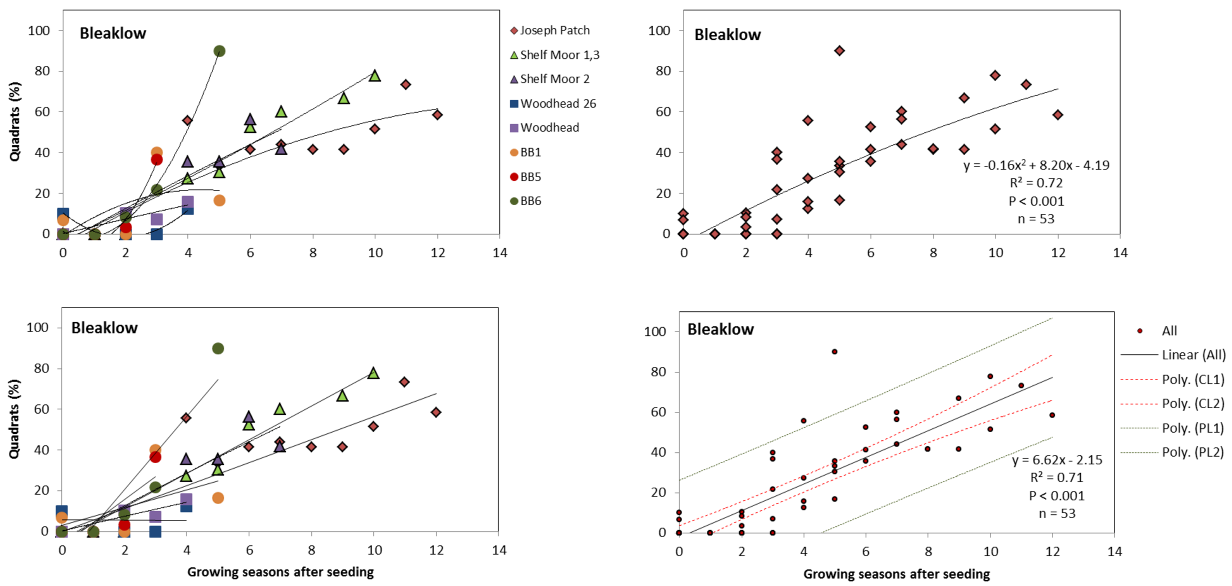

Fig. 22. Relationships between time and the proportion of quadrats with at least 50% cover composed of at least three indicator species
Details and explanations as in Fig. 17

Variations between individual sites were resolved into a strong and significant quadratic function when summarised over all sites, showing an almost linear trajectory with a relatively consistent rate of increase, up to 12 growing season after seeding (Fig. 22, top right). Simple linear relationships were imposed, showing that the rate of increase at the BB sites appeared unusually high (Fig. 22, bottom left). Nevertheless, variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 22, bottom right). The slope of the line suggested that, after an initial delay of less than one growing season, and from a starting value of 0%, the predicted rate of increase as a mean of all sites was approximately 6.6 percentage points per growing season over twelve growing seasons. Omitting the BB sites improved the strength of the relationships but made little real difference ($y = 6.61x - 3.86$, $R^2 = 0.81$, $P < 0.001$, $n = 39$).

Key attribute 3: At least six species indicator species per 4 m² quadrat

The proportion of quadrats with at least six indicator species appeared to show relatively slight increases over time (Fig. 23, top left). However, there were considerable variations between sites in this slight rate of increase.

Variations between individual sites were resolved into a strong and significant quadratic function when summarised over all sites, showing an almost linear trajectory with a relatively consistent rate of increase, for up to 12 growing seasons after seeding (Fig. 23, top right). Simple linear trajectories were achieved for individual sites using complete datasets without the need for truncating the data (Fig. 23, bottom left).

Variations between sites for these linear relationships were then resolved into a single strong and significant linear function when summarised over all sites (Fig. 23, bottom right). The slope of the line suggested a rate of increase of 1.2 percentage points per growing season.

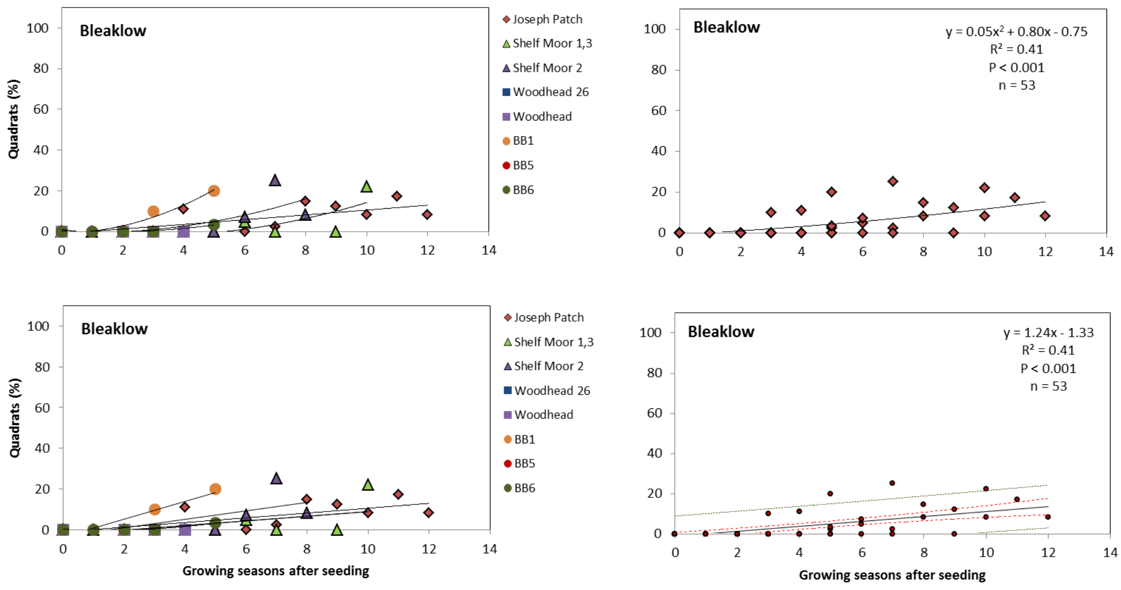

Fig. 23. Relationships between time and the proportion of quadrats with at least six indicator species

Details and explanations as in Fig. 17

6.3 Kinder Scout

6.3.1 Cover of bare peat

In the Kinder Scout geographical area, the cover of bare peat decreased over time, with most sites following the same approximate trajectory, although the CRF site appeared to show a relatively faster rate (Fig. 9, top left). Bare peat cover was reduced to below 10% in all relevant sites.

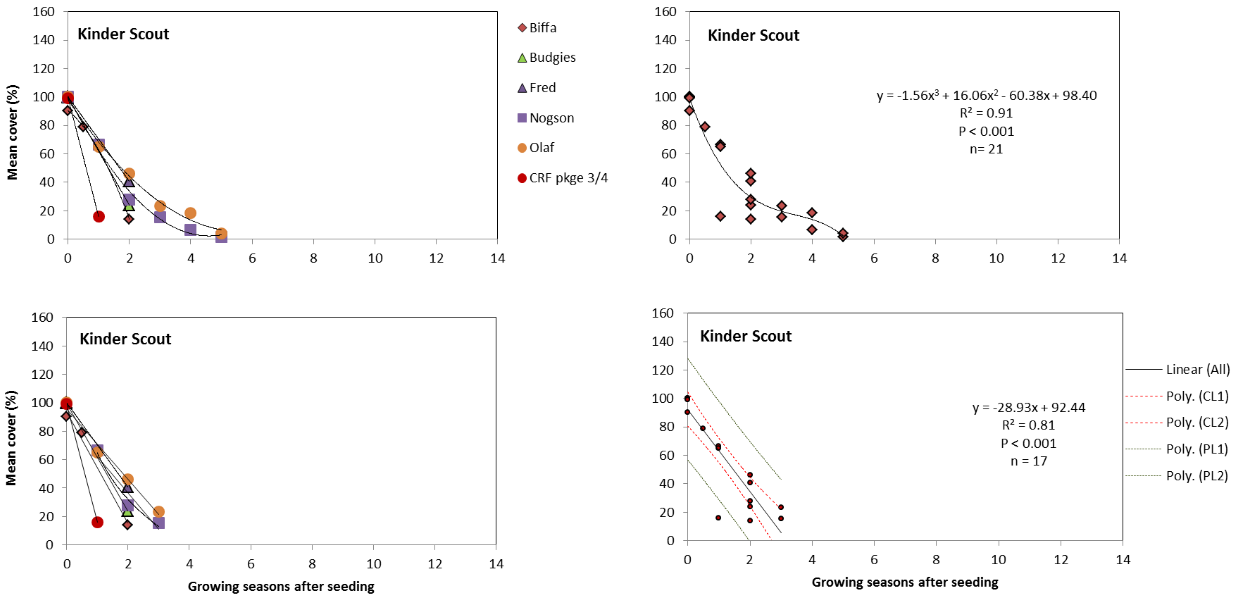

Fig. 24. Relationships between time and bare peat cover

Curvilinear relationships (top) are described by quadratic or cubic functions of time. Linear relationships (bottom) are derived, where necessary, by the removal of equilibrium values. Relationships are shown for individual sites (left side) or as a mean of all sites (right side) with details including equations, regression coefficients (R^2), p-values (P) and number of replicates (n). Confidence limits (95%) for the mean are given (CL) as well as the prediction limits (95%) for data points (PL); Cover is expressed as a mean value per 4 m^2 quadrat; Site information is given in Methods section.

Variations between individual sites for the relationships between time and bare peat cover were resolved into a strong and significant cubic function when summarised over sites, showing an initial steep decline and a later slowing in rate after about two growing seasons (Fig. 24, top right). Simple linear relationships were derived by truncating the data sets of the longer-running sites so that bare peat cover values that had achieved equilibrium were removed (Fig. 24, bottom left). Variations between sites for the linear relationships were then resolved into a significant linear function when summarised over all sites (Fig. 24, bottom right). The slope of the line suggested that with a starting value between 95 and 100% bare peat cover, the predicted rate of decline as a mean of all sites was approximately 29 percentage points per growing season over three growing seasons, thereafter beginning to slow.

6.3.2 *Cover of indicator species*

In the Kinder Scout area, the cover of indicator species increased over time, with considerable variations between sites in the precise trajectory taken (Fig. 25, top left). Maximum cover varied between approximately 30% (Olaf) and 40% (Nogson) after five years, although equilibrium values did not appear to have been reached in the either case.

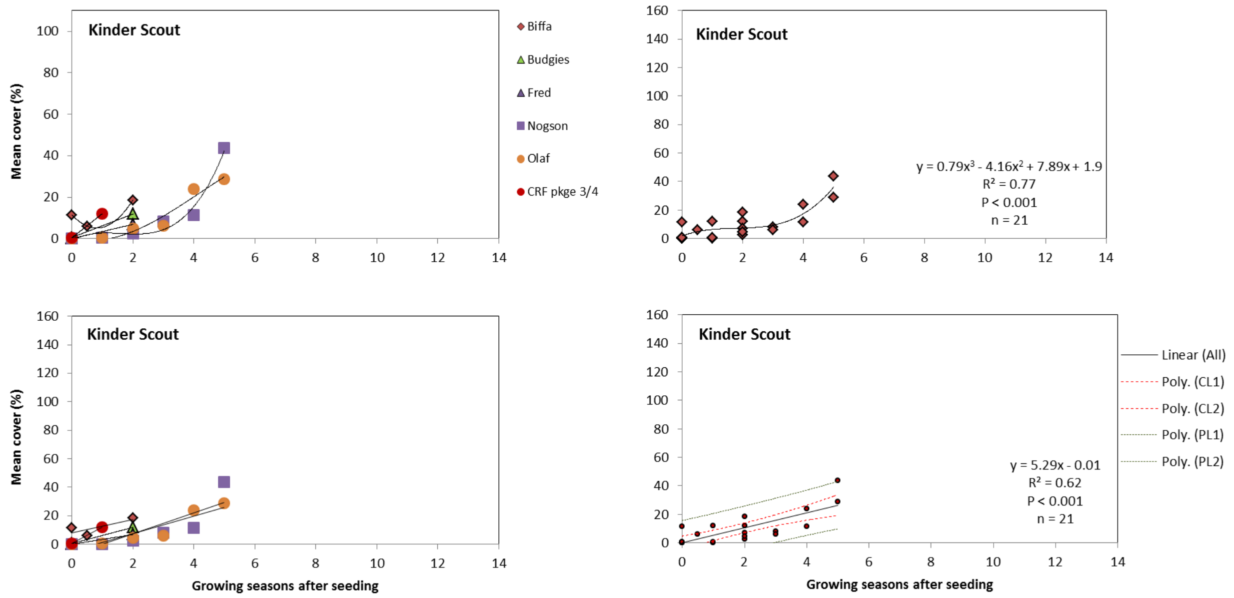

Fig. 25. Relationships between time and indicator species cover
Details and explanations as in Fig. 24

Variations between individual sites were resolved into a strong and significant cubic function when summarised over all sites, showing a relatively slow start accelerating to a relatively high rate of increase, after about three growing seasons (Fig. 25, top right). There was no suggestion of an approaching equilibrium phase. Simple linear relationships were derived (Fig. 25, bottom left) and variations between sites for these linear relationships were resolved into a strong and significant linear function when summarised over all sites (Fig. 25, bottom right). The slope of the line suggested that, from a starting value (intercept) of 0% indicator species cover, the predicted rate of increase as a mean of all sites was 5.3 percentage points per growing season over five growing seasons.

6.3.3 *Count of indicator species*

In the Kinder Scout area, the number of indicator species increased over time, with relatively large variations between sites in the precise trajectory taken (Fig. 26, top left). In particular, the Biffa data appeared to have an unusually high starting value. Maximum counts varied between approximately 3.1 (Olaf), 3.7 (Biffa) and 5.9 (Nogson) after two, five and five years, respectively, although equilibrium values did not appear to have been reached at any of the sites. For Nogson, the planting of *Sphagnum* propagules (as part of separate trial) between the fourth and fifth growing seasons after seeding was the cause of one additional indicator species. Although each different *Sphagnum* species is considered to be a separate indicator species for Common Standards Monitoring (there are conditions in the case of *S. fallax*), the propagules were not distinguished by species at this early stage of development, so were conservatively considered to be a single species. However, even after subtracting one indicator species at T = 5, this still leaves a relatively higher number than its counterpart site of Olaf. Another contributing factor may have been the result of local conditions following the targeted re-siting of the Nogson quadrats relevant to the aims of the separate trial.

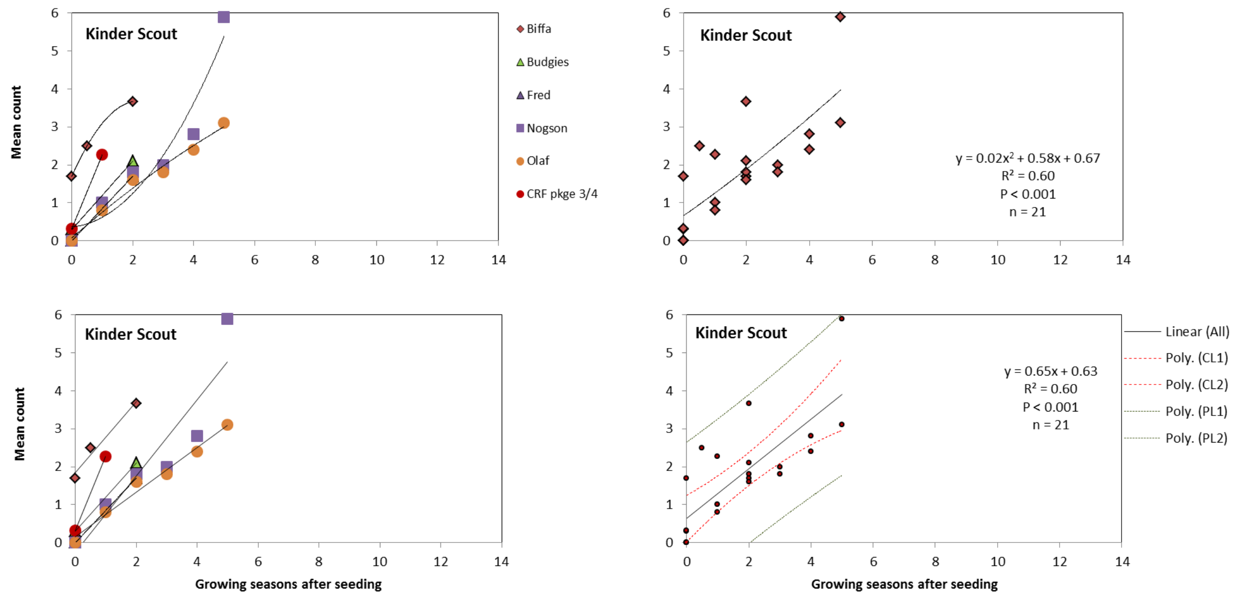

Fig. 26. Relationships between time and indicator species count
Details and explanations as in Fig. 24

Variations between individual sites were resolved into a strong and significant quadratic function when summarised over all sites, showing an approximately linear and relatively high rate of increase with no indication of an approaching equilibrium stage (Fig. 26, top right). However, the omission of the Nogson data point at the time of the fifth growing season led to a visibly different trajectory, with a clear equilibrium phase of about 2.8 indicator species appearing, after four growing seasons. Simple linear relationships were derived (Fig. 26, bottom left) and variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 26, bottom right). The slope of the line suggested that, from a starting value of about 0.6 indicator species, the predicted rate of increase as a mean of all sites was 0.7 indicator species per growing season over five growing seasons. However, omitting the high Nogson data point provided only a slightly slower rate of 0.5 indicator species per growing season.

6.3.4 Species dominance

Averaging over all sites in this geographical area and over the spectrum of available survey durations, species cover was dominated by grasses (mainly *Deschampsia flexuosa*) with relatively strong cover *of Acrocarpous* mosses. There was also notable presence of *Calluna vulgaris* and *Pleurocarpous* mosses (Table 9).

Table 9. Average cover of species/groups (Kinder)

Species/Group	Average cover (%)
Grasses	35
Acrocarpous mosses	16
Calluna vulgaris	5
Pleurocarpous mosses	4
Vaccinium myrtillus	2
Eriophorum angustifolium	1
Eriophorum vaginatum	1
Empetrum nigrum	0
Rubus chamaemorus	0

Grasses were dominated by *Deschampsia flexuosa; Calluna vulgaris was the dominant dwarf shrub*

In terms of trajectory, there was an early dominance of grasses, overtaken in time by that of acrocarpous mosses, (Fig. 27, left). There was also a relatively slow, consistent and growing dominance of *Calluna vulgaris*. However, there was relatively high variability in the temporal duration of monitoring at sites available for contributing data and a decline in the number of contributing sites with time since seeding, therefore confidence in the trajectory as an indication of general patterns also declined with time (Fig. 27, right).

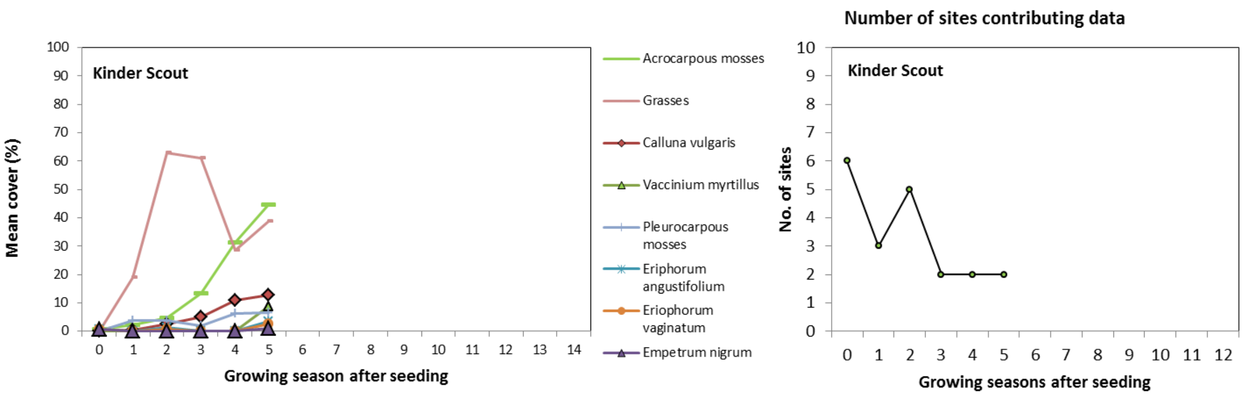

Fig. 27. Relationships between time and cover of species (left) and number of sites (right)
Details and explanations as in Fig. 5

6.3.5 Favourable Condition

For an explanation of Favourable Condition attributes and targets, see section 5.6.

Key attribute 1: Bare peat cover less than 10%

The proportion of quadrats with less than 10% bare peat cover increased over time with most sites following the same approximate trajectory, although some sites showed a relatively early start while the CRF site appeared to also show a relatively faster rate (Fig. 28, top left), For the longest running sites at Olaf and Nogson, the increase reached maximal values between about 90% and 100%, respectively and after about five growing seasons following seeding.

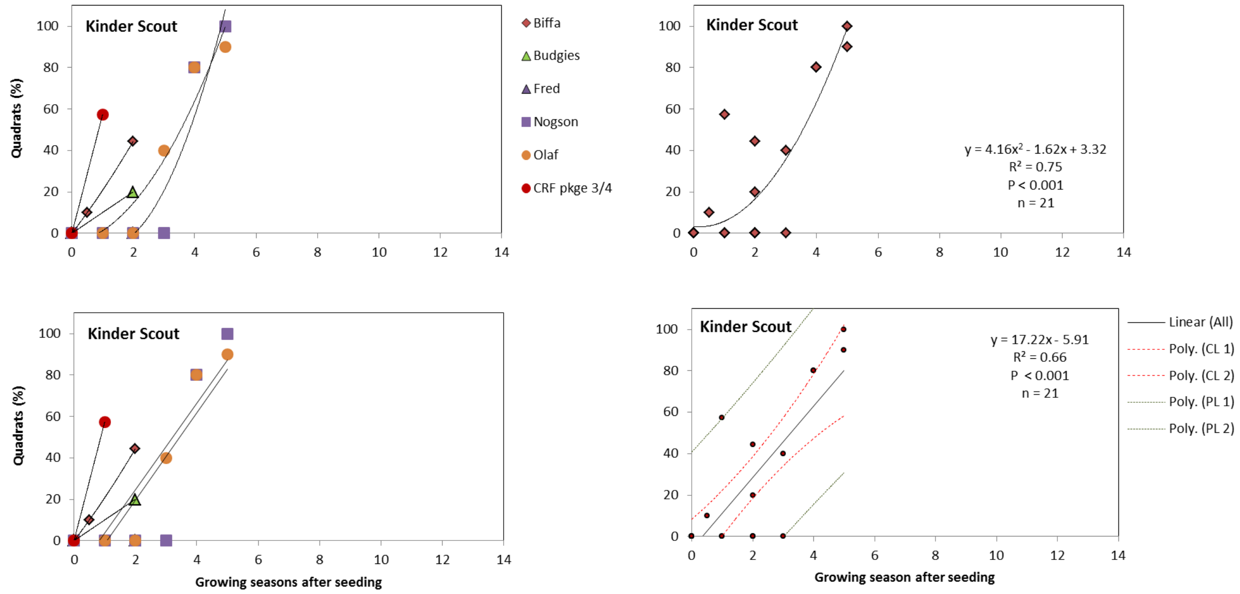

Fig. 28. Relationships between time and the proportion of quadrats with bare peat cover less than 10%

Details and explanations as in Fig. 24

Variations between individual sites for the relationships between time and the proportion of quadrats with less than 10% bare peat cover were resolved into a strong and significant quadratic function when summarised over all sites, showing a relatively low rate of increase initially, but after about two growing seasons accelerating into an almost linear constant rate phase (Fig. 28, top right). Simple linear relationships were derived (Fig. 28, bottom left). Variations between sites for the linear relationships were then resolved into a strong and significant linear function when summarised over all sites (Fig. 28, bottom right). The slope of the line suggested that, after an initial delay of less than one growing season, and from a starting value of 0%, the predicted rate of increase as a mean of all sites was approximately 17 percentage points per growing season over five growing seasons.

Key attribute 2: At least 50% cover composed of at least three indicator species

The proportion of quadrats with at least 50% of the cover composed of at least three indicator species showed relatively weak increases over time in the individual sites (Fig. 29, top left). For one site, Biffa, an unusually steep increase over the first two growing seasons following seeding was followed by a steep decline in the third.

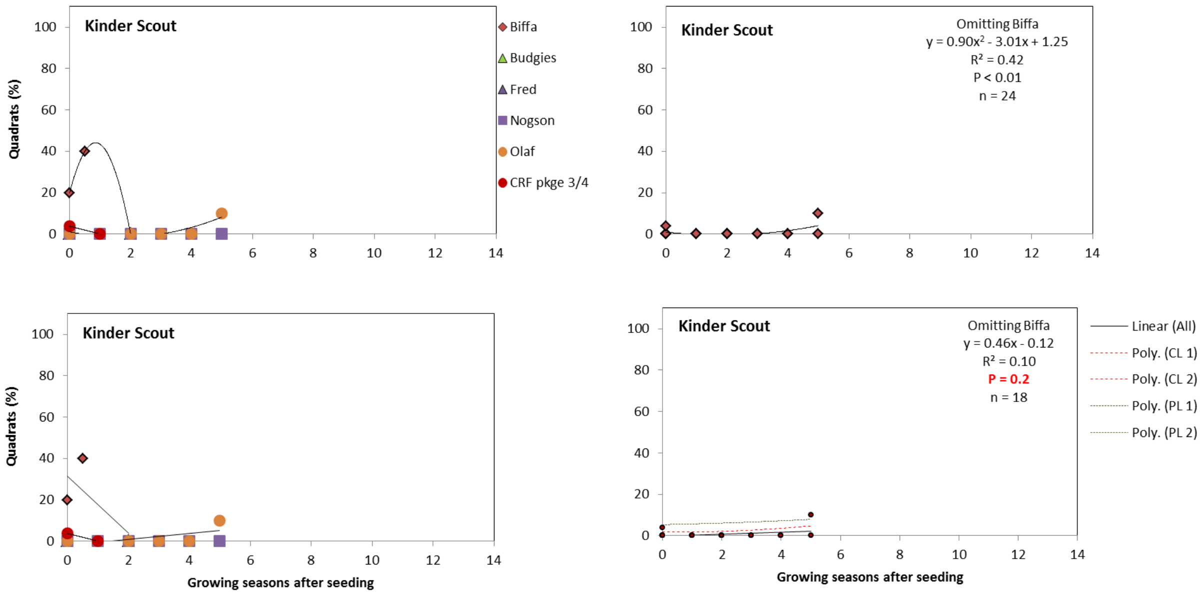

Fig. 29. Relationships between time and the proportion of quadrats with at least 50% cover composed of at least three indicator species
Details and explanations as in Fig. 24

Nevertheless, with the anomalies of Biffa removed, variations between the remaining sites were resolved into a significant quadratic function when summarised over all sites, showing a weakly increasing trajectory (Fig. 29, top right). When linear relationships were imposed on the individual sites, the Biffa site again showed anomalous behavior (Fig. 29, bottom left). Resolving the data points for all sites into a single linear function predicted a rate of increase of approximately 0.5 percentage points per growing season over five growing seasons, *but the trajectory lacked statistical significance*, even after the Biffa data points were removed (Fig. 29, bottom right).

Key attribute 3: At least six species indicator species per 4 m^2 quadrat

The proportion of quadrats with at least six indicator species appeared to be zero for most of the sites and at most of the time (Fig. 30, top left). However at two of the sites, Biffa and Nogson, there were increases at the time of the final survey, reaching 11% and 70%, after 2 and 5 growing seasons, respectively. As already mentioned there may be underlying explanations for the relatively high increase in the case of Nogson (see section 6.3.3).

These wide variations between individual sites were resolved into a weak and non-significant quadratic function when summarised over all sites (Fig. 30, top right). Simple linear relationships were derived (Fig. 30, bottom left) and variations between sites for the linear relationships were then resolved into a significant linear function when summarised over all sites (Fig. 30, bottom right). The slope of the line suggested that, after a delay of about one growing season, and from a starting value of 0 indicator species, the predicted rate of increase as a mean of all sites was 4 indicator species per growing season over five growing seasons.

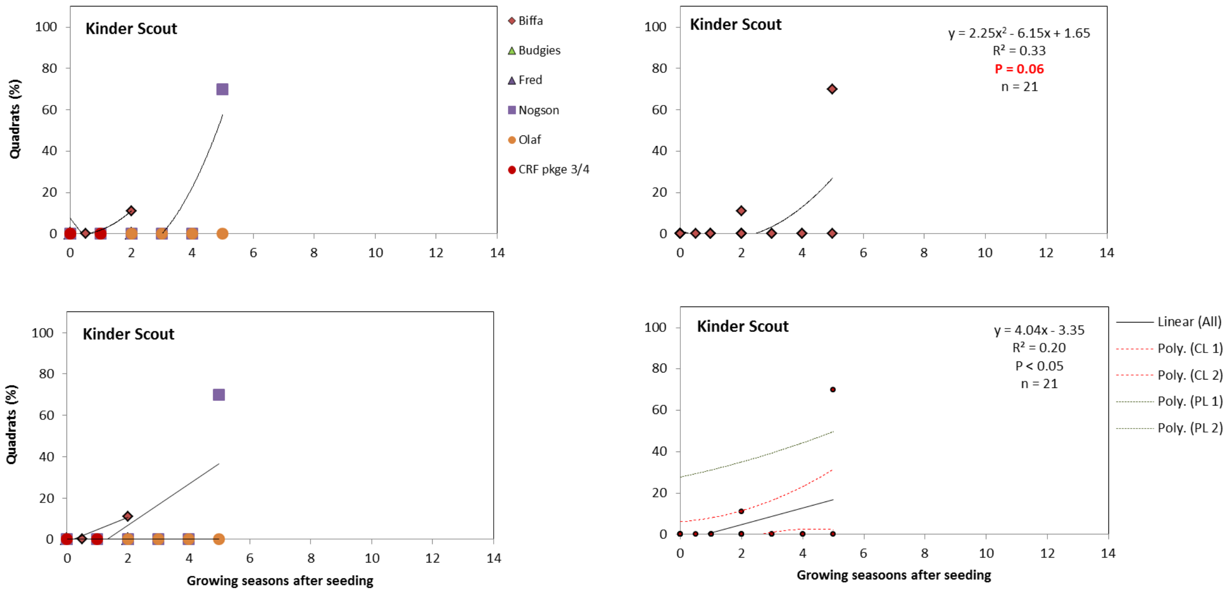

Fig. 30. Relationships between time and the proportion of quadrats with at least six indicator species

Details and explanations as in Fig. 24

6.4 Turley Holes and Rishworth

6.4.1 Cover of bare peat

In the Turley Holes and Rishworth geographical area, the cover of bare peat decreased over time, with the two constituent sites following the same trajectory (Fig. 31, top left). Bare peat cover was reduced to 20.9% at Rishworth and 6.6% at Turley Holes after three growing seasons.

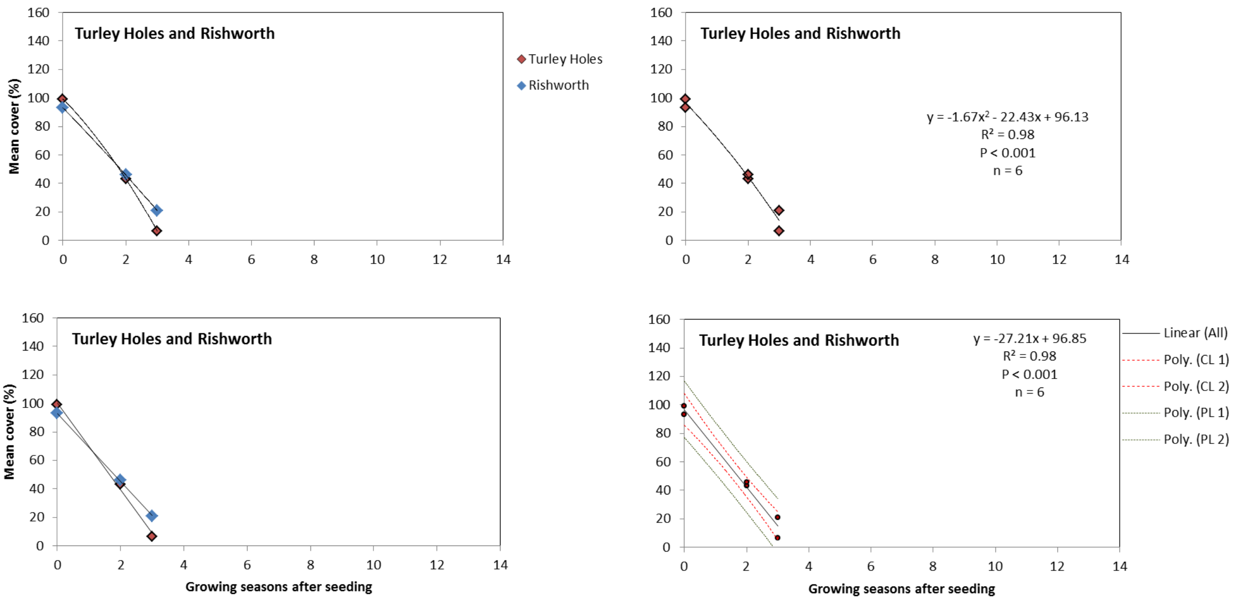

Fig. 31. Relationships between time and bare peat cover

Curvilinear relationships (top) are described by quadratic functions of time. Linear relationships (bottom) are derived, where necessary, by the removal of equilibrium values. Relationships are shown for individual sites (left side) or as a mean of all sites (right side) with details including equations, regression coefficients (R^2), p-values (P) and number of replicates (n). Confidence limits (95%) for the mean are given (CL) as well as the prediction limits (95%) for data points (PL); Cover is expressed as a mean value per 4 m^2 quadrat; Site information is given in Methods section.

Variations between individual sites for the relationships between time and bare peat cover were resolved into a strong and significant quadratic function when summarised over all sites, showing an almost linear decline with no indication of an equilibrium stage after three growing seasons (Fig. 31, top right). Simple linear relationships were derived for individual sites (Fig. 31, bottom left) and when these were resolved into a single significant linear function (Fig. 31, bottom right), the slope of the line suggested that with a starting value of 100% bare peat cover, the predicted rate of decline as a mean of all sites was approximately 27 percentage points per growing season over three growing seasons.

6.4.2 Cover of indicator species

In the Turley Holes and Rishworth area, the cover of indicator species increased over time, with the two constituent sites following the same approximate trajectory (Fig. 29, top left). Indicator species cover was increased to 41% at Rishworth and 58% at Turley Holes after three growing seasons.

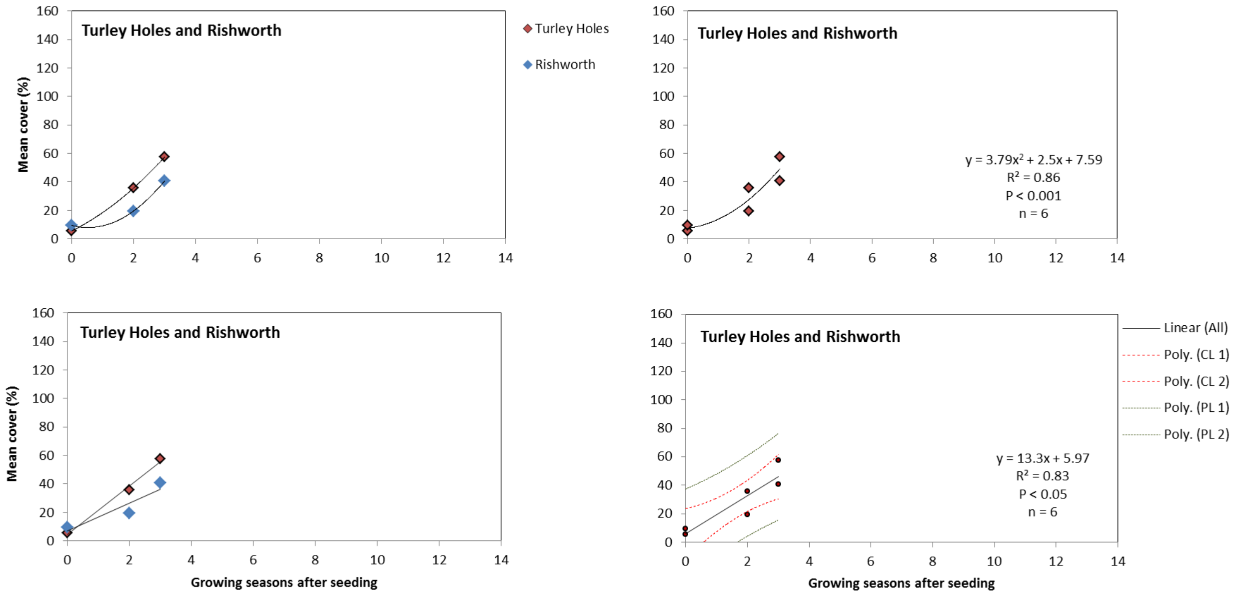

Fig. 32. Relationships between time and indicator species cover
Details and explanations as in Fig. 31

Variations between the two individual sites for the relationships between time and indicator species cover were resolved into a strong and significant quadratic function when summarised over all sites, showing an almost linear increase over three growing seasons (Fig. 32, top right). Simple linear relationships were derived for the two sites (Fig. 32, bottom left) and when these were resolved into a single significant linear function (Fig. 32, bottom right), the slope of the line suggested that with a starting value between 0 and 10% indicator species cover, the predicted rate of increase as a mean of all sites was approximately 13 percentage points per growing season over three growing seasons.

6.4.3 Count of indicator species

In the Turley Holes and Rishworth area, the number of indicator species increased over time, with the two constituent sites following the same approximate trajectory (Fig. 29, top left). Indicator species count was increased to 4.1 at Rishworth and 3.9 at Turley Holes after three growing seasons.

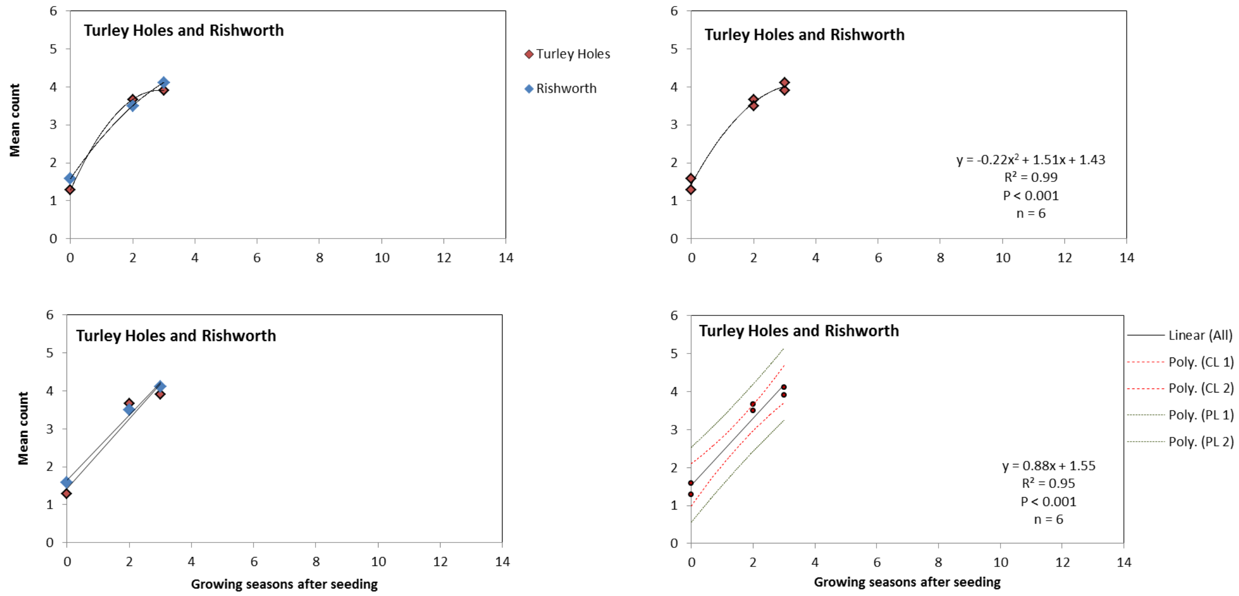

Fig. 33. Relationships between time and indicator species count
Details and explanations as in Fig. 31

Variations between the two individual sites for the relationships between time and indicator species count were resolved into a strong and significant quadratic function when summarised over all sites, showing an almost linear increase over three growing seasons (Fig. 33, top right). Simple linear relationships were derived for the two sites (Fig. 33, bottom left) and when these were resolved into a single significant linear function (Fig. 33, bottom right), the slope of the line suggested that with a starting value of about 1.5 indicator species, the predicted rate of increase as a mean of all sites was approximately 0.9 per growing season over three growing seasons.

6.4.4 Species dominance

Averaging over the two sites in this geographical area and over the spectrum of available survey durations (three growing seasons), species cover was dominated by grasses (mainly *Deschampsia flexuosa*) with relatively strong cover of *Pleurocarpous* and *Acrocarpous* mosses and also *Eriophorum angustifolium* (Table 10).

Table 10. Average cover of species/groups (Turley Holes and Rishworth)

Species/Group	Average cover (%)
Grasses	26
Pleurocarpous mosses	12
Acrocarpous mosses	11
Eriophorum angustifolium	10
Calluna vulgaris	4
Eriophorum vaginatum	2
Empetrum nigrum	0
Vaccinium myrtillus	0
Rubus chamaemorus	0

Grasses were dominated by *Deschampsia flexuosa; Calluna vulgaris* was the dominant dwarf shrub

In terms of trajectory, the two sites representing this area (each with 25 quadrats) suggested an early dominance of grasses, and growing cover of both acrocarpous and pleurocarpous mosses, (Fig. 34, left). However, the low number of sites and a paucity of temporal duration of data limited the emergence of a clear trajectory (Fig. 34, right).

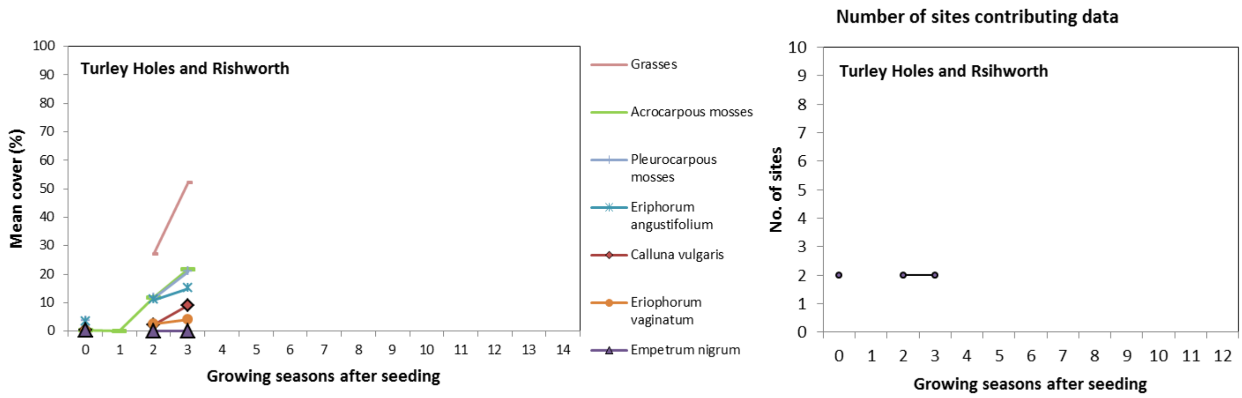

Fig. 34. Relationships between time and the cover of species (left) and number of sites (right)
Details and explanations as in Fig. 5

6.4.5 Favourable Condition

For an explanation of Favourable Condition attributes and targets, see section 5.6.

Key attribute 1: Bare peat cover less than 10%

The proportion of quadrats with less than 10% bare peat cover increased over time with the two constituent sites following the same approximate trajectory (Fig. 35, top left). The proportion of quadrats reached 50% at Rishworth and 81% at Turley Holes after about five growing seasons following seeding.

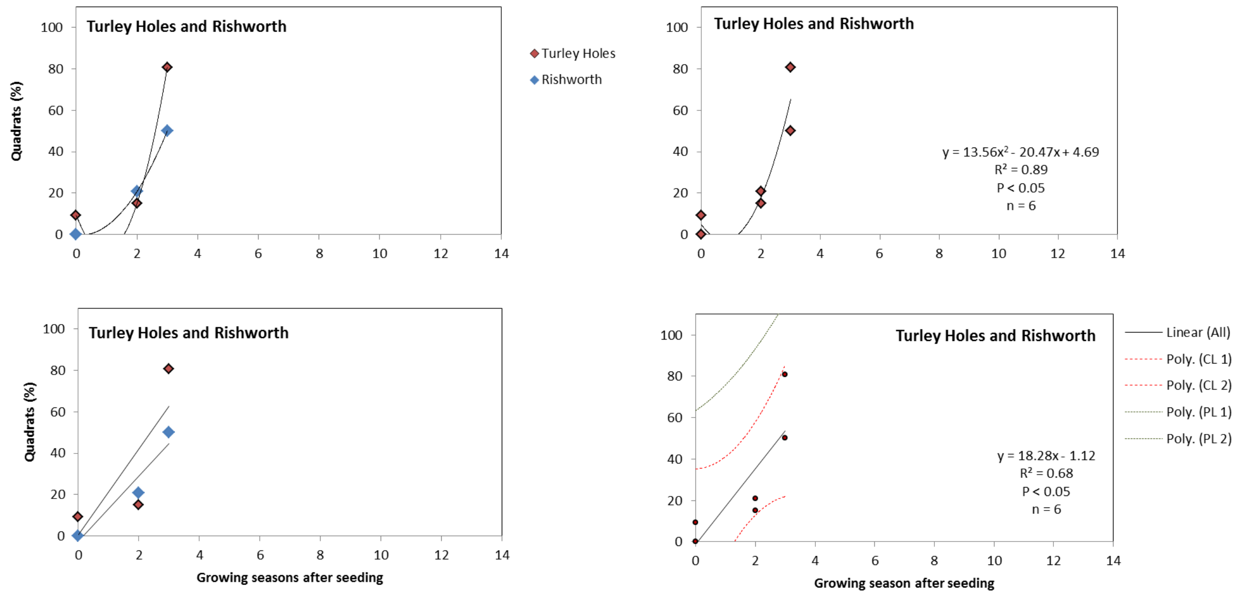

Fig. 35. Relationships between time and the proportion of quadrats with bare peat cover less than 10%

Details and explanations as in Fig. 31

Variations between individual sites for the relationships were resolved into a significant quadratic function when summarised over all sites, showing a relatively low rate of increase initially, but after about one growing season accelerating into an almost linear constant rate phase (Fig. 35, top right). Simple linear relationships were derived (Fig. 35, bottom left). Variations between sites for the linear relationships were then resolved into a significant linear function when summarised over all sites (Fig. 27, bottom right). The slope of the line suggested that, from a starting value of 0%, the predicted rate of increase as a mean of all sites was approximately 18 percentage points per growing season over three growing seasons.

Key attribute 2: At least 50% cover composed of at least three indicator species

The proportion of quadrats with at least 50% of the cover composed of at least three indicator species varied widely between the two constituent sites (Fig. 36, top left). The proportion at Turley Holes reached a maximum of 55% after two growing seasons, at the same time as that at Rishworth reached a minimum of 4%.

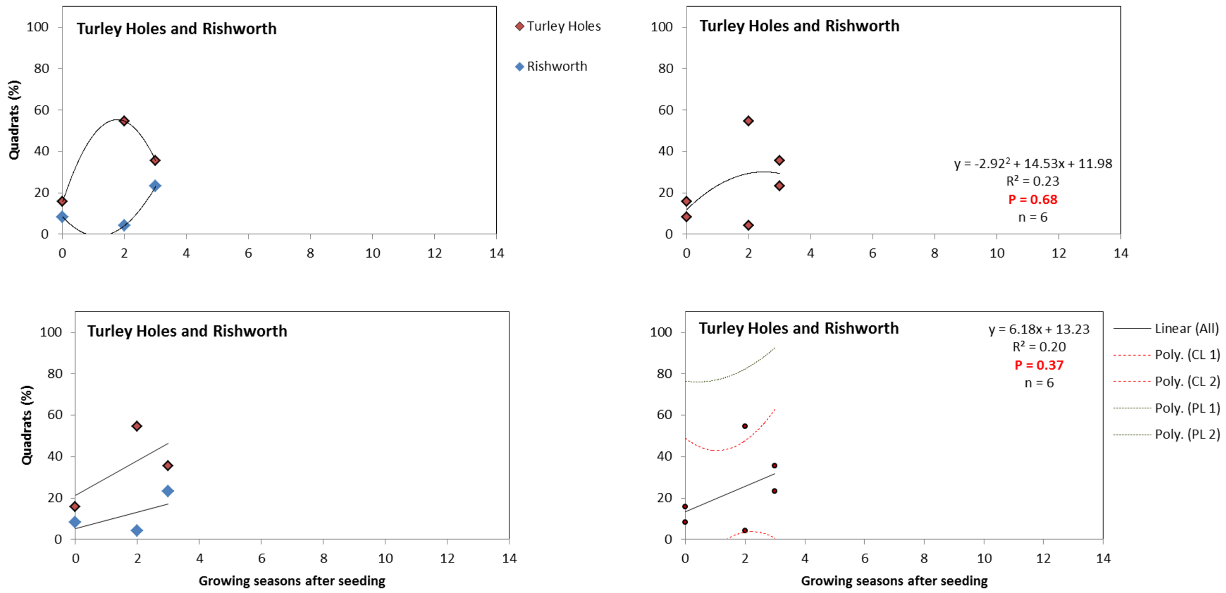

Fig. 36. Relationships between time and the proportion of quadrats with at least 50% cover composed of at least three indicator species

Details and explanations as in Fig. 31

These wide variations in data led to a relatively weak and statistically non-significant relationship with time when the data points from both sites were combined into a single quadratic function (Fig. 36, top right). When linear relationships were imposed on the individual sites, these wide variations were again apparent (Fig. 36, bottom left). Resolving the data points from the two sites into a single linear function predicted a rate of increase of approximately 6 percentage points per growing season over three growing seasons, *but again the trajectory was weak and lacked statistical significance* (Fig. 36, bottom right).

Key attribute 3: At least six species indicator species per 4 m^2 quadrat

The proportion of quadrats with at least six indicator species increased over time in only one of the two constituent sites, Rishworth, with a maximum of 11.5% after three growing seasons) but there was no increase at Turley Holes (Fig. 37, top left).

Variations between the two individual sites for these relationships were resolved into a weak and statistically non-significant quadratic function when summarised over all sites (Fig. 37, top right). Simple linear relationships were derived for the two sites (Fig. 37, bottom left) and when these were resolved into a single linear function (Fig. 37, bottom right), the slope of the line suggested that with a starting value of about 0%, the predicted rate of increase as a mean of all sites was approximately 1.8 percentage points per growing season over three growing seasons, but the relationship was weak and lacked statistical significance.

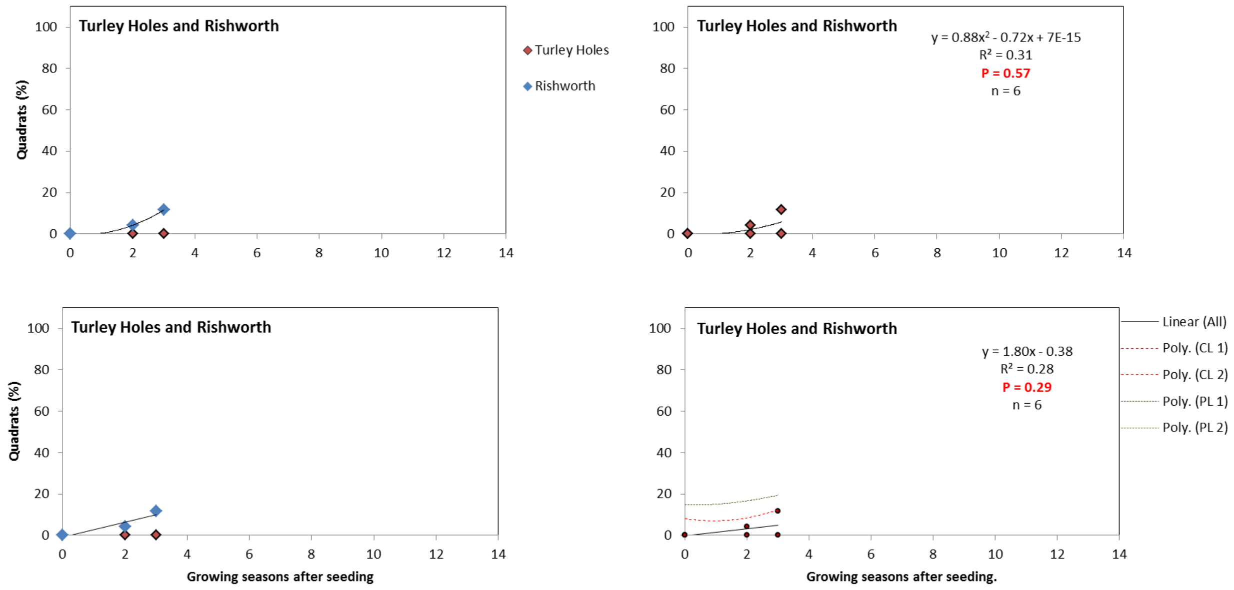

Fig. 37. Relationships between time and the proportion of quadrats with at least six indicator species

Details and explanations as in Fig. 31

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