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The effects of cool burning on the vegetation at Howden and Bamford Moor in the Peak District

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Executive summary

1. Controlled burning is a traditional management technique used to maintain upland moors for a variety of reasons; specifically to maintain the productivity of the main plant species (heather – *Calluna vulgaris*) for grouse and sheep. To improve burning performance, in the Peak District a method of "cool burning" has been developed over the last 15 years, where the vegetation is burned at relatively wet stage, using a diesel kettle. This is a much less aggressive approach to controlled burning and produces a fire that is much easier to control. The aim of this study is to describe the response of vegetation to "cool" burning.

2. We surveyed two sites (Howden and Bamford Moors) in the North Peak ESA, Derbyshire, UK. On each moor all of the burnt areas were mapped and cross-referenced to information on burning history provided by the moorland managers.

3. Individual burnt patches were then identified (79 and on Bamford and 103 on Howden Moors) and 10 burns were selected randomly one each moor for survey. We surveyed 10 quadrats in each patch; all species present were assessed along with a range of environmental variables.

4. The vegetation data collected shows the species present are typical of acid heath. The dominant species was *Calluna* with *Empetrum nigrum, Eriophorum angustifolium. E. vaginatum, and Vaccinium myrtillus,* also present at high frequency. *Rubus chamaemorus and Erica tetralix* had an intermediate abundcance and *Agrostis capillaris, Galium saxatile, Deschampsia flexuosa* were present in lower amounts*.* *Campylopus introflexus* and *Hypnum jutlandicum* were the dominant bryophytes; *Dicranum scoparium* and *Polytricum spp* were also present in lower amounts. A few lichen species were present at low amounts, although *Cladonia squammules* were relatively common*.*

5. Species community composition appeared to be related to two environmental factors, age since burning and elevation; they appeared to be orthogonal. The interesting result was that *Calluna vulgaris* and *Deschampsia flexuosa* were increasing through time.

6. This survey has provided a baseline against which future change can be assessed.

Contents

1. Introduction

Controlled burning is a traditional management technique used to maintain upland moors; specifically to increase the productivity of the main plant species (heather – *Calluna vulgaris*) for grouse and sheep (Gimingham, 1972). The burning should be carried out at a stage in the heather's life cycle so that it regenerates quickly from stem bases, if the burning is carried out too late in the life-cycle or at too hot a temperature then the plants can be killed and regeneration has to occur from germinating seed, a much slower process (Miller & Miles, 1971).

Burning is regulated in England and Wales under the "*Heather and grass (burning) regulations 1986 (as amended 1987) and the heather and grass burning code"* and there is separate legislation for Scotland. There is, however, much confusion over the terminology, specifically because in people's minds there is no difference between controlled burning applied for management purposes and wildfires or vandalism fires. Controlled burning is restricted to winter and early spring by law and should be done on rotation at a relatively small scale, but the latter often take place in the summer when the burn temperatures are very high, the fires are much harder to control and the burned areas are large (Defra, 2005). Implicit within this discussion is that of fire hazard, and there is some suggestion that summer fire hazards can be reduced and the patchwork of burns allows better access for fire management. A further issue is the suggestion that burning causes impacts on water quality through sediment loss and chemical leaching into watercourses. This has economic consequences in water treatment, but the scale of treatment required will depend on the scale and timing of the burning (viz. small burns in a patchwork, little and often verses large, severe burns on an irregular basis).

To improve burning performance, in the Peak District a method of "cool burning" has been developed over the last 15 years (G. Eyres per, comm.), where the moorland vegetation is burned at relatively wet stage using a diesel kettle and others have or also have developed a method This is a much less aggressive approach to controlled burning and produces a fire that is much easier to control. Casual observations suggest that it has a very positive effect on the moorland vegetation. As cool burning can also be implemented under wetter conditions than the usual moor burning practice, its use effectively extends the potential burning season. However, there is no quantitative data to support this assertion and the aim of this project is to survey a series of patches of vegetation where the cool burn approach has been used, and then to assess vegetation change to burning using a chronosequence approach. The initial project plan was intended to use information derived from the GIS-database of moorland fires, which had been linked to burning history by Moors for the Future.

2. Methods

2.1. Study area

This study focussed on Bamford and Howden Moors in the North Peak ESA, Derbyshire, UK (National Grid Reference SK28 & SK19&29; Longitude1°41'W, Latitude 53º41'N) with elevations ranging from 340-420m and 420-548m respectively. Howden Moor is the highest moor in the Peak District. These moors were selected because high-quality, documented historical burning data and management reports were available.

2.2. Survey methods

All of the burnt areas on each moor were mapped using ArcGIS v.9. Photographic images taken in September 2005 by UK Perspectives with a resolution of 25cm. Four 1-km^2 squares were used for each site; reference numbers: Bamford = 1993, 1994, 2093, and 2094 Howden = 2184, 2185, 2284, and 2285. These maps were cross-referenced land burning management references and with maps provided by the land managers. The combined images were printed at A0 scale after ensuring no distortion by cross-referencing with Ordinance Survey Maps. Burnt patches were then identified individually.

This process identified 79 and 103 burn sites on Bamford and Howden Moors respectively. From these of available burns, 10 burns on Howden and 10 burns on Balmford were selected randomly. Digitised outlines of each of the sample sites were created by the drawing tool. Then a feature was created which then is converted to a raster feature to produce geo-referenced polygon. An example is shown in Fig.1.

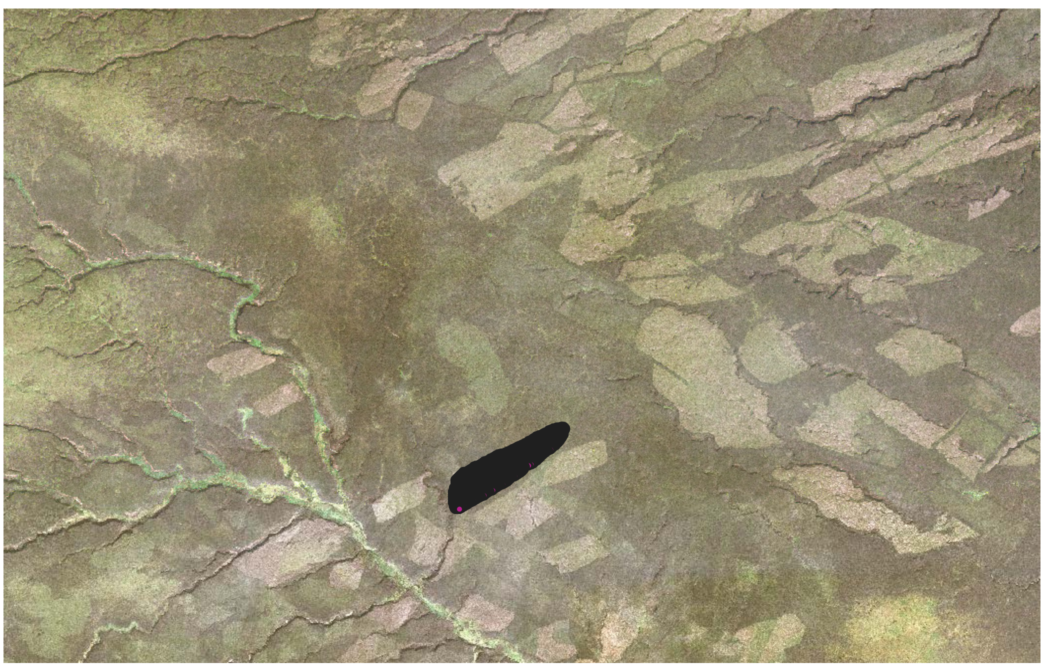


Fig 1. An example of a burn site as a geo-referenced polygon created using ArcGIS on Howden moor

The area of each burn site was calculated using the ArcGIS AREA procedure, and this was used to estimate the number of potential 1 m^2 quadrats within each burn site. The geographical position for each quadrat was then individually cross-checked by reference to estimated areas using grid overlays. A 1x1m geo-referenced grid was placed across the polygon enabling the x and y co-ordinates for all possible quadrat positions to be calculated. Within any individual burn there were between 1000-4500 1m^2 squares, and from these a random selection of 10 was chosen from each polygon for field sampling.

Separate individual identification site maps were produced for the field work to cross reference with the given GPS readings for the quadrat positioning to ensure accuracy (Appendix I). The ArcGIS Quadrat positions were checked against maps and a GPS datum measurement with an estimated quadrat position accuracy ± 1.0m. The GPS was checked every day before going into the field by using a given correction point from (Ordinance survey map OL1) to eliminate any error factors in the readings.

Vegetation was surveyed between late July and mid August. The quadrat positions were located using GPS and each quadrat was aligned from the pole so that one side of the quadrat aligned in a north direction and one side aligned east from the datum pole. Within the 1m^2 the cover of all species were recorded using a pre-designed recording sheet (Appendix II). In addition the state of *Calluna* after burning was also assessed in two categories "Stick" and "Bush", examples of each are shown in Fig 2a and 2b.

(a) (b)

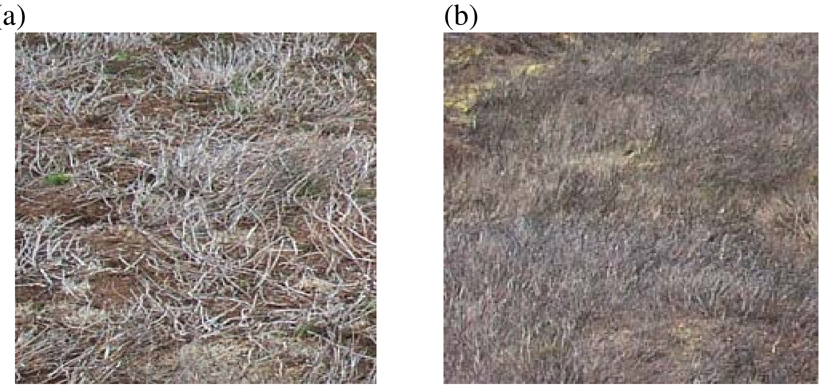


Fig 2. (a) Sticky *Callua* and (b) bushy *Calluna*

At each quadrat the aspect (^{o}), slope (^{o}) and vegetation height (cm) were recorded.Vegetation height was measured by placing the pressure disc surface area (0.30m) and mass (0.200kg) in the centre of every quadrat and measurements (cm) of the vegetation height (distance from the disc to the ground) being recorded. The pressure disk differs to the drop disk in respect in that it is not stanardisable and is carefully placed on the vegetation and not allowed to compress the vegetation on its descent (Stewart *et al.* 2001).

The name codes used throughout for species and environmental variables are shown in (Tables 1 and 2).

2.3. Soil analyses

A soil sample (6cm diameter, 20cm depth) was also collected from each burn patch, returned to the laboratory and stored at 4^{o}C. Soil pH was measured in 1:2 slurry of soil:

deionized water (Allen, 1989). Loss-on-ignition (%) was also measured as an estimate of soil organic matter using the technique of (Allen, 1989).

Table 1. Species detected their abbreviated codes and constancies (%) at Bamford & Howden Moors.

	Species constancy %	
Species code	Bamford	Howden
Calluna vulgaris ***Cv***	100	100
Eriophorum angustifolium ***Ea***	88	91
Eriophorum vaginatum ***Ev***	85	88
Campylopus pyriformis ***Cp***	81	86
Empetrum nigrum ***En***	80	80
Vacinium myrtilus ***Vm***	73	73
Campylopus introflexus ***Ci***	67	70
Cladonia squamules ***Csqu***	65	65
Hypnum jutlandicum ***Hj***	59	59
Rubus chamaemorus ***Rc***	38	38
Erica tetralix ***Et***	29	29
Dicranum scoparium ***Ds***	5	10
Polytrichum sp ***Ps***	4	9
Agrostis capillaries ***Ac***	3	8
Galium saxatile ***Gs***	3	4
Deschampsia flexuosa **Df**	2	2
Cladonia squamosa **Cs**	1	6
Cladonia coccifera ***Cc***	1	2
Cladonia chlorophaea ***Chl***	1	1

Table 2. Environmental variables measured or derived for the study at Bamford & Howden Moors.

Variable name	Description	Source
EASTING	National Grid (km)	Ordinance Survey Maps
NORTHING	National Grid (km)	Ordinance Survey Maps
ELEVATION	Height above mean sea level (m)	Ordinance Survey Maps
FASPECT	Functional transformation (F) of Aspect (a, degrees, the estimated site-wise mean), F=$\vert$ - sin (a/2) $\vert$	Magnetic compass(corrected for magnetic anomaly)
SLOPE	Mean gradient of survey site(degrees)	Clinometer
ELAPSED TIME SINCE LAST BURN (ET)	Elapsed time (year) since burning	Estate management
BURNT *Calluna* BUSHY	Cover (%)	
BURNT *Calluna* STICKY	Cover (%)	Estimated on site in 1m^2 quadrats
OTHELITT	Cover (%) of other litter	Estimated on site in 1m^2 quadrats
BAREGROU	Cover (%) of bare ground	Estimated on site in 1m^2 quadrats
ANIMEXCR	Cover (%) of animal excrement	Estimated on site in 1m^2 quadrats
pH	pH = -log$_{10}$ [H$^+$]	Measured in the laboratory Allen (1989)
LOI	Amount of organic matter present in the soil	Measured in the laboratory Ball (1964)
PD	Measurement (cm) of the height of Vegetation within the quadrat pressure disk surface area Pressure of disk on vegetation P = Force/Area – (m x g)/ (л xr^2) = 27.76 Pa	Measured on site with a pressure disk surface area 0.30m, mass 0.200kg

2.4. Statistical analysis

Summary data tables were calculated for the cover of all species and environmental variables; medians and ranges are presented (Appendices III, IV). NVC classes (Rodwell, 1991) were determined using TABLEFIT (Hill, 1989).

Multivariate analysis was then used to describe changes in the entire community dataset and link these to the environmental factors (ter Braak & Šmilauer 1998). All calculations were performed on transformed species data ($\log_e x+1$). The resultant dataset had 200 samples and 19species. Analyses were performed using the VEGAN package (Oksanen, 2005) implemented in the R-environment (Venables et al. 2005). Initially, a Detrended Correspondence Analysis (DCA) was performed; the eigenvalues were 0.1534, 0.1430, 0.1179 and the gradient lengths were 2.2, 2.1, 2.6 and 3.2 for the first four axes. The gradient lengths support the use of the linear Redundancy Analysis (RDA) constrained model (ter Braak & Šmilauer, 1998). The distribution of the two moors was assessed using bivariate standard-deviational 95%CL ellipses for axes 1 and 2 (Milligan *et al.*, 2004) calculated using the ORDIELLIPSE function in VEGAN. The relationship with environmental factors was initially explored using the ENVFIT function which fitted the environmental variables to the DCA and tested their significance using a Monte-Carlo test with 999 permutations.

Thereafter, a stepwise modelling approach was used constrained ordinations; this process used the STEP function in VEGAN, and the analysis started with a null RDA model and significant environmental variables were added one at a time using a forward selection approach until potentially all environmental factors were added. Significance was then assessed using the AIC statistic and variation partitioning was then used (Borcard *et al.* 1992; Marrs & Le Duc, 2000) to assess the relative importance of each variable.

HOF models, a series of five response models, were fitted using GRAVY and a gaussian error structure (Gradient Analysis of Vegetation software, version 0.0-21; Oksanen 2003), implemented within R (R Development Core Team 2004). The HOF protocol fits a hierarchical set of five increasingly complex response models (Model I, no trend; Model II, increasing or decreasing trend; Model III, increasing or decreasing trend below maximum attainable response; Model IV, symmetrical response curve; Model V, skewed response curve in which the most parsimonious model is selected using a least likelihood criteria. HOF-models thus provide a mathematical means of describing observed relationships, which may result both from environmental conditions and intra- and inter-specific interactions. This combined analysis of coenoclines with HOF-modelling of species behaviour, is one of the most robust methods for estimating niche characteristics of plant species (Lawesson & Oksanen, 2002). The AIC statistic was used to assess significance.

3. Results

3.1. Description of the vegetation and environment of the survey sites

The moors occur at slightly different elevations; Bamford between 370-430m and Howden between 490-530m. The moors also showed a difference in aspect, Bamford was predominantly south-east and Howden predominantly north-east. Bamford soils had a higher pH (4.4) relative to Howden (3.4). These physcio-climatic differences translate into greater species richness, sheep activity and taller vegetation at Bamford, and a greater litter cover at Howden. These overall data key out as NVC types M19 (*Calluna vulgaris-Eriophorum vaginatum* blanket mire) and M20 (*Eriophorum vaginatum* blanket and raised mire).

The species detected in the survey are all typical of upland moors in the UK (Table 1); the species detected being in similar amounts on both moors. The dominant species was *Calluna* with a constancy of 100% at each moor, and *Empetrum nigrum*, *Eriophorum angustifolium. E. vaginatum*, and *Vaccinium myrtillus*, all present at a constancy > 70% (Table 1). *Rubus chamaemorus* and *Erica tetralix* had an intermediate constancy and *Agrostis capillaris*, *Galium saxatile*, *Deschampsia flexuosa* was present in lower amounts. *Campylopus introflexus* was the dominant bryophyte (constancy = 67-70%) with *Hypnum jutlandicum* present at 60%; *Dicranum scoparium* and *Polytricum* spp. were also present in lower amounts. A few lichen species were present at low amounts, although *Cladonia* squammules were found in relatively high amounts.

3.2 Exploratory multivariate analysis

The distribution of species in the DCA analysis (Fig.3a) shows *Calluna* and *E. vaginatum* plotted around the origin. Axis 1 represents a gradient from predominantly bryophytes and *Rubus chamaemorus* at the negative end, through *Calluna*, towards *Vaccinium myrtillus*, *Agrostis capillaris*, *Galium saxatile* and *Erica tetralix* at the positive end. On Axis 2 *Hypnum jutlandicum*, *Erica tetrlix* and *Vacinnium myrtillus* are at the negative end and *Eriophorum angustifolium*, *Agrostis capillaris* at the positive end. The Moors were separated along Axis 1, Bamford being near the negative end and Howden the positive, although there was a large degree of overlap (Fig 3b).

Relating the species and plot data to environmental factors (Fig 3, Table 3) indicates the over-riding importance of geographical factors, which are all significant $P < 0.001$, and lie along an axis moving from the upper left hand quadrant through to the lower right hand one. Some of these variables are obvious correlated with each other as a result of geographical location, thus, Moor, Elevation and Aspect lie along the easting, northing gradient as a result of the sampling positions on the respective moors. Soil pH was also significant $P < 0.001$, and this vector was in a negative direction towards the Bamford moor but was lower than the Moor vector. Elapsed time since burning was significant ($P < 0.01$); it was orthogonal to axis 1, and almost to the geographical axis, being positioned negatively along axis 2. Vegetation (PD, $P<0.01$) and cover of bare ground ($P<0.05$) and bushy *Calluna* ($P<0.05$) were also significant; bare ground and vegetation height being greater on Bamford and lower on Howden, and bushy *Calluna* being greater on Howden.

(a)

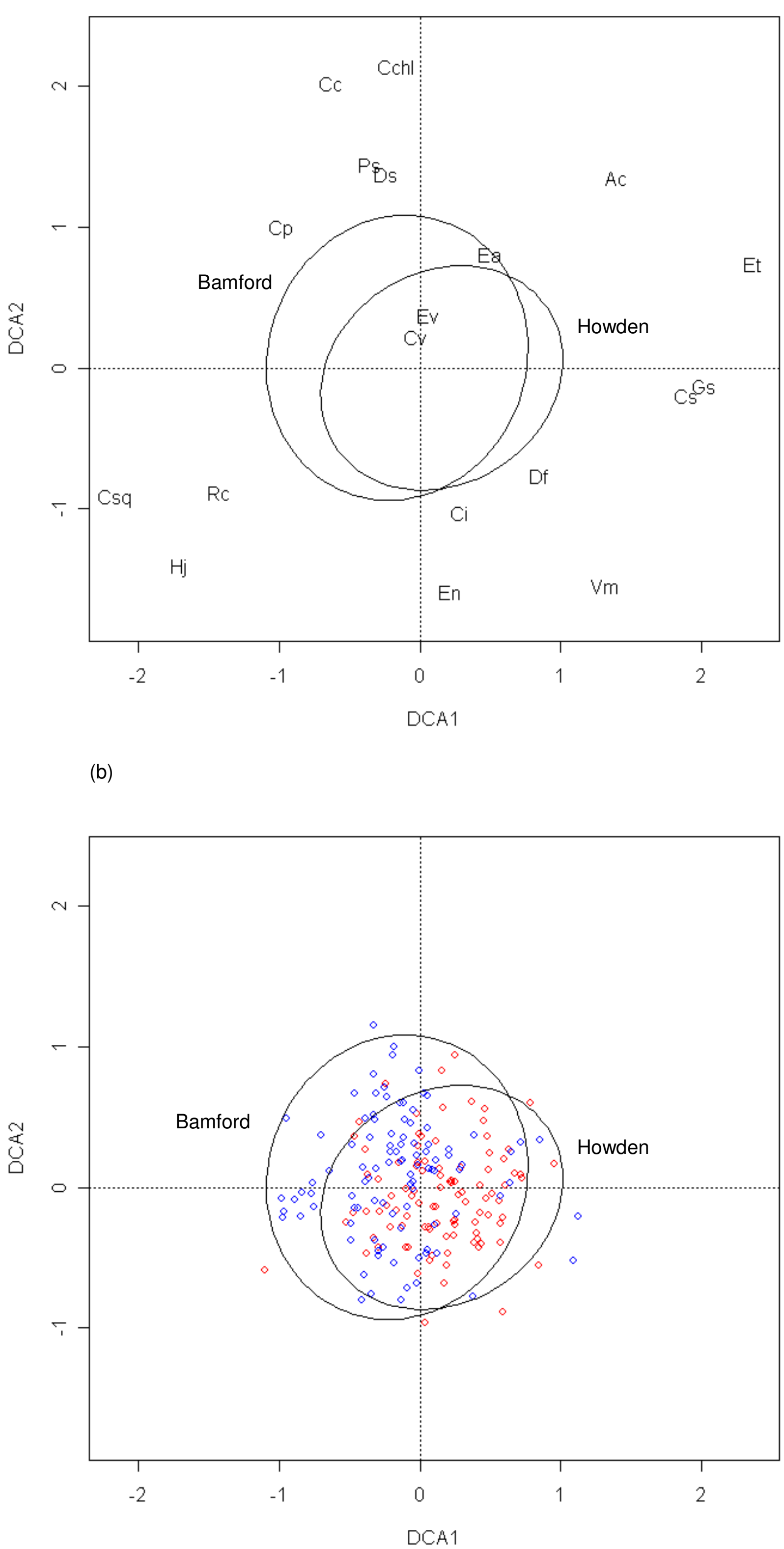
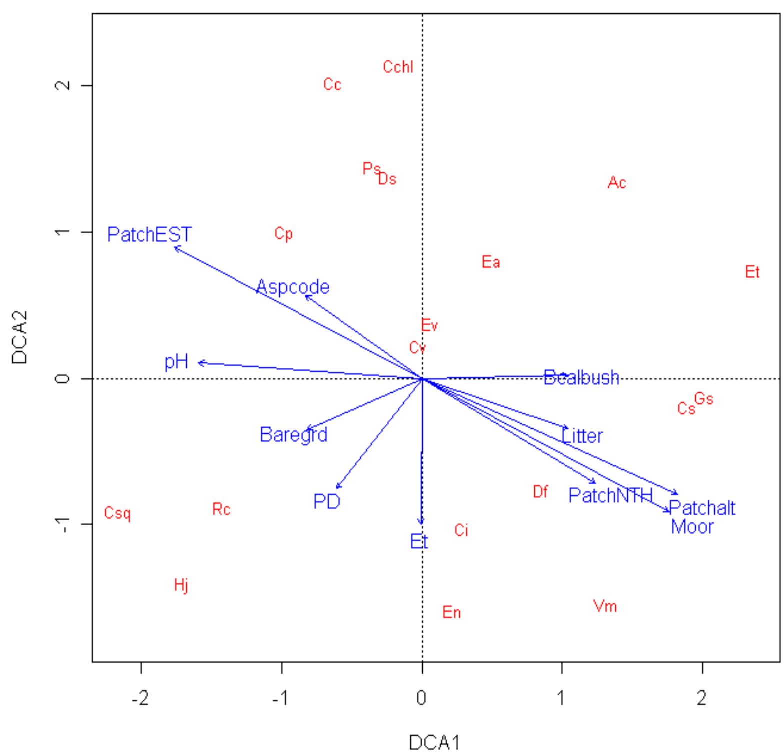


Fig 3. DCA plots of (a) species, (b) quadrats, each with the moor distributions indicated using 95% CL ellipses. Species codes are as in Table 1; Bamford = Blue; Howden = Red.

(a)



(b)

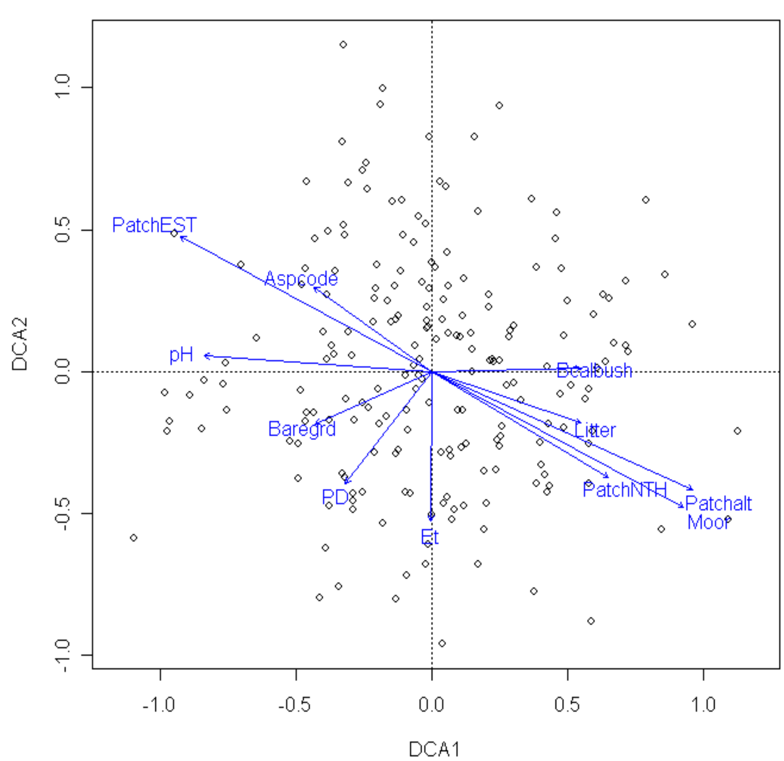


Fig 4. DCA plots of (a) species and (b) quadrats regressed against significant (P, 0.05) environmental variables.

Table 3. Significance of the regressions of the environmental factors against the axis scores for the DCA shown in (Figs 3 & 4).

Var	DCA1	DCA2	r^2	*P*	Sig
Moor	0.888569	-0.45874	0.1986	< 0.001	***
PatchEST	-0.89003	0.455907	0.1981	< 0.001	***
PatchNTH	0.865838	-0.50032	0.1032	< 0.001	***
Patchalt	0.917212	-0.3984	0.1997	< 0.001	***
pH	-0.99776	0.066857	0.1288	< 0.001	***
Et	-0.00867	-0.99996	0.0507	0.007007	**
Litter	0.949269	-0.31447	0.0612	0.002002	**
PD	-0.62841	-0.77788	0.0475	0.007007	**
Aspcode	-0.82563	0.564206	0.0509	0.006006	**
Bcalbush	0.999823	0.018799	0.0547	0.01001	*
Baregrd	-0.91985	-0.39226	0.0403	0.019019	*

3.3 Relating species community composition to environmental factors

The constrained RDA analysis using the selection procedure identified four significant environmental variables, which collectively reduced the AIC statistic from 524.7 in the null model to 515.8; the variables included were the geographical factors (elevation, northing), elapsed time (ET), and litter cover, bushy *Calluna* cover. The analysis was run again with just the selected variables and it was significant (PF=0.38. P<0.001).

As the main factors of interest in controlling vegetation development through time were likely to be elevation reflecting both elevation on its own and Moor and elapsed time (ET), further constrained RDA models were tested. Model 1 considered elevation and elapsed time with the effects of litter and bushy *Calluna* removed as covariables. Models 2 and 3 then tested elevation and elapsed time independently as constrained variables with elapsed time or elevation added to the covariable list as appropriate. The aim was to assess the role of elevation and elapsed time (ET) independent of all other significant variables.

The total variation (inertia) in all models was 13.715. The variation accounted for by all for elevation and elapsed time together (model 1) was 0.4668 (3.4%) and for elevation and elapsed time the variation was 0.2647 (1.9%) and 0.218 (1.5%) respectively. That the variation accounted for both elevation and elapsed time is additive suggests an orthogonal relationship with no interaction, i.e. they are acting independently. This is borne out by inspection of the species-environment biplot (Fig. 6).

The species-environment biplots for models 2 and 3 indicate the weak effects of both elevation and elapsed time; or rather the environmental variables associated with the unconstrained axis 2 have a much greater influence on species composition than the constrained variable (Fig. 7). HOF models relating species response to elapsed time (ET) and elevation are shown (Figs 7, 8), in both HOF analyses the X-axis gradient was derived from the constrained axis 1 of (Figs 4, 5). The significant responses of species to each gradient were separated into those that either decreased or increased with elapsed time and elevation; the species groups are shown in Table 4.

Table 4. Species groupings based on responses to elevation and elapsed times, derived from scores on the constrained axes of (Figs. 7 & 8).

Elapsed time (Fig.7)		Elevation (Fig. 8)	
Response type	Species	Response type	Species
Species reducing through time	*Campylopus pyriformis* *Cladonia squamosa* *Eriophorum vaginatum* *Hypnum jutlandicum*	Species decreasing with elevation	*Vacinium myrtillus* *Eriophorum angustifolium* *Empetrum nigrum* *Erica tetralix* *Galium saxatile* *Campylopus introflexus* *Cladonia squamosa*
Species increasing through time	*Calluna vulgaris* *Deschampsia flexuosa*	Species increasing with elevation	*Campylopus pyriformis* *Cladonia squamules* *Rubus chamaemorus*

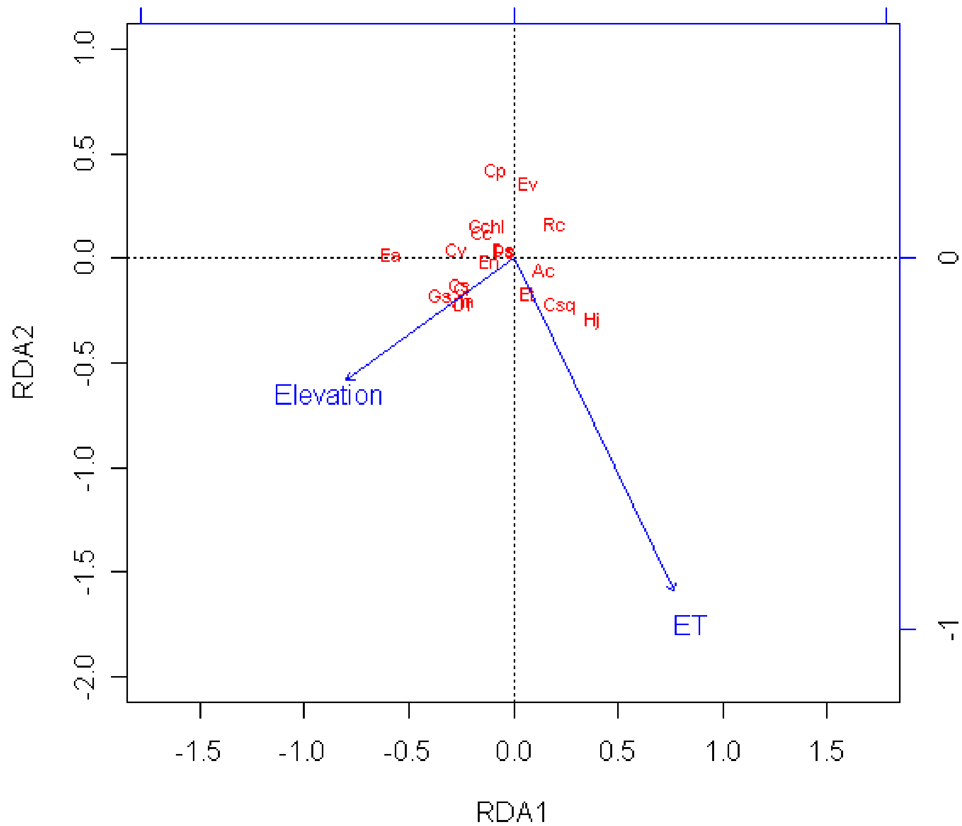
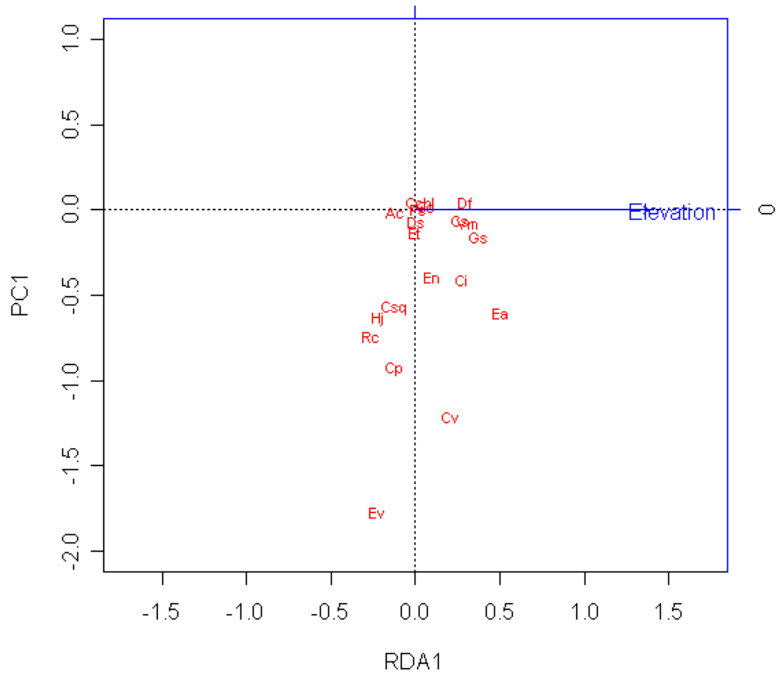


Fig 5. RDA plot of species constrained against elevation and elapsed time since burning (ET), with all other significant variables removed as covariables.

(a)



(b)

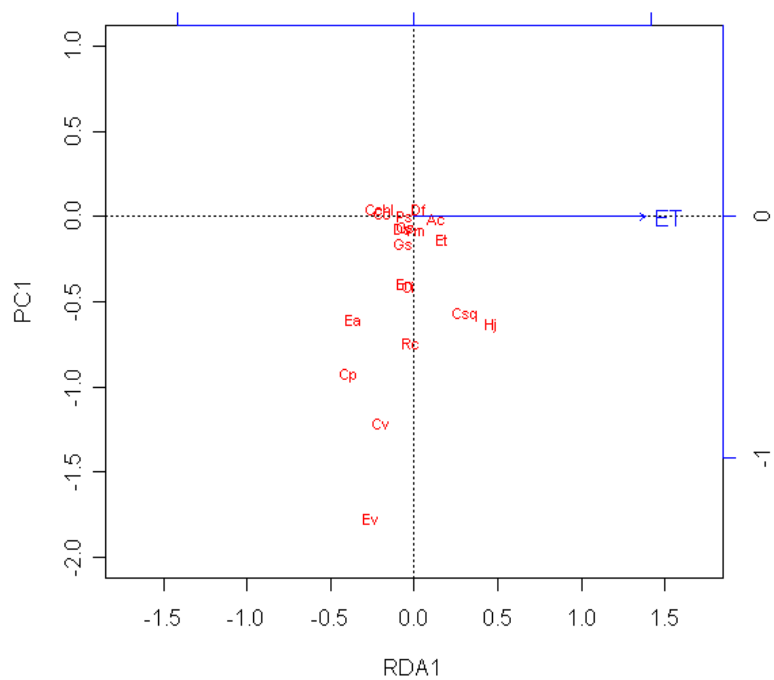


Fig 6. RDA plots of species constrained against (a) elevation, and (b) elapsed time since burning (ET), with all other significant variables removed as covariables.

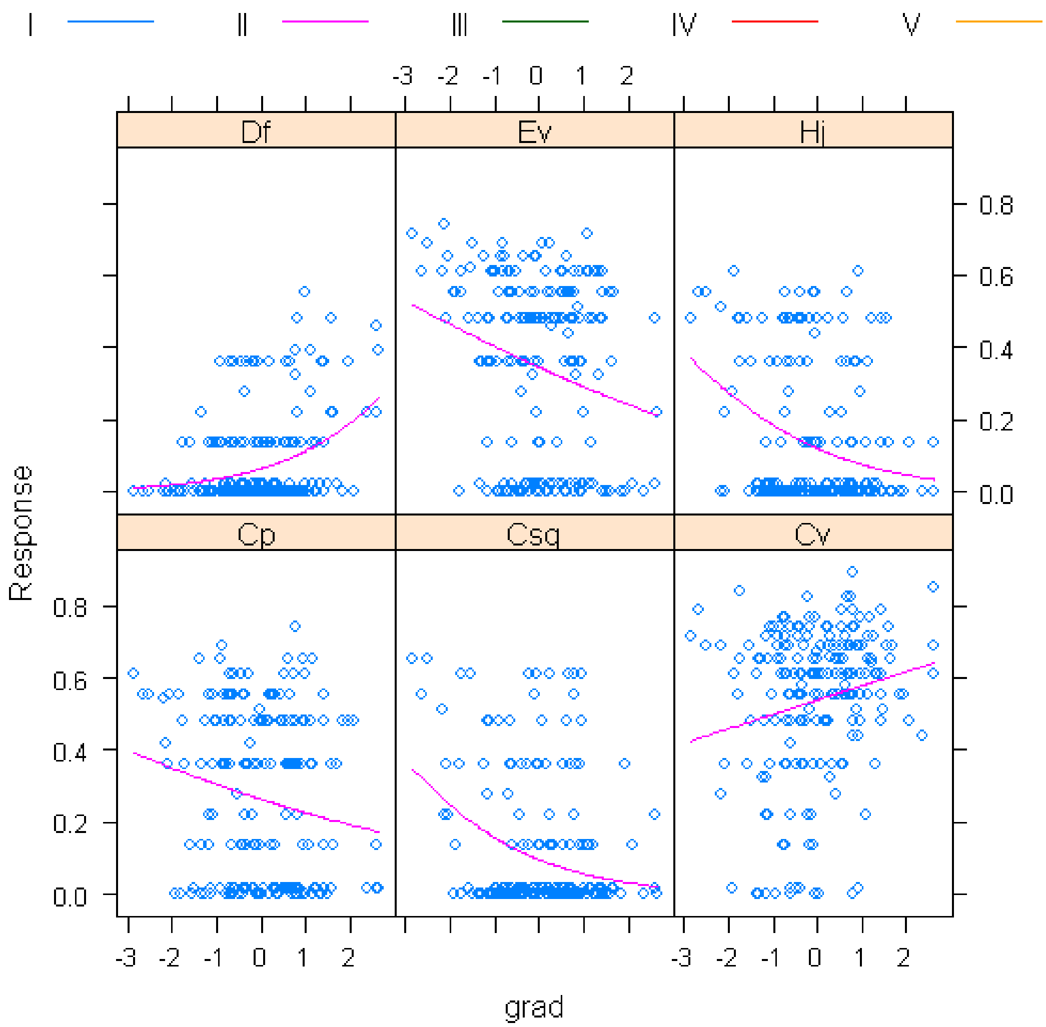


Fig 7. Fitted HOF model of species responses to elapsed time (ET), derived from the constrained axis 1 of Fig 6a.

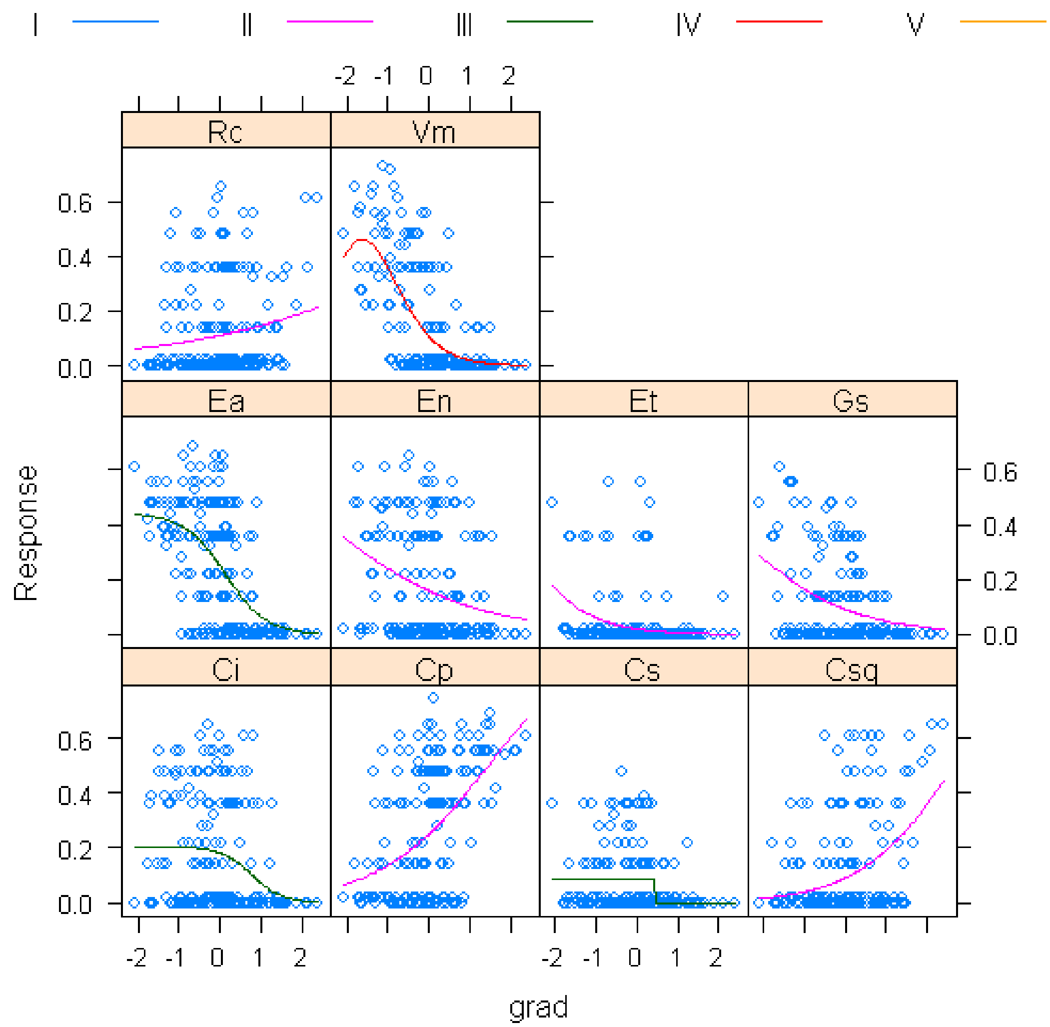


Fig 8. Fitted HOF model of species responses to elevation, derived from the constrained axis 1 of Fig 6b.

4. Discussion

Burning as a management practice within the uplands is predominantly executed in habitats with a significant frequency of dwarf shrubs. Grassland burning, which may be locally important, is a much less significant feature of the landscape nationally, although this is partly because of the short duration of burn signatures on grassland. In 2000 a measure of area of the newest burns (Class 1) of DSH (Dwarf Shrub Heathland)-*Calluna*, of current activity was 114km^2 of the English uplands being burnt annually. This figure is not just for areas of dry heath but includes all forms of wet heath and bog with visible presence of dwarf shrubs (Defra, 2002).

Controversy exists regarding the correct burning management protocol for the English uplands (Tucker, 2003, Glaves & Haycock, 2005, Costigan *et al*. 2005). This controversy is driven by both lack of scientific evidence and the different aims of various groups (principally grouse rearing and nature conservation). Indeed, Costigan *et al*. (2005) states: "It is important that the various parties involved can reach a common science based understanding of the impacts of burning on moorland". One problem is our imprecise knowledge of the interaction of burning with other ecological processes, particularly grazing, which is the subject of much current research (Freckleton, 2004, Vandvik *et al*. 2005).

The effect of local environmental variation on the results of such interactions may be complex (Palmer & Hester, 2000, Hulme *et al*. 2002, Pakeman *et al*. 2003, Fuhlendorf & Engle, 2004) and the spatial effect of burning management may influence the behaviour of important herbivores, so that it is difficult to predict the outcome of burning regimes without detailed study (Palmer & Hester, 2000, Fuhlendorf & Engle, 2004). It has been widely stated in the literature that too frequent burning of dwarf shrubs heath leads to an increase in Graminea and Cyperaceae at the expense of dwarf shrubs, principally *Calluna* (Hobbs & Gimingham, 1984, Miles, 1988, Shaw *et al*. 1996, Marrs *et al*. 2004), although other processes may be important, particularly in bogs, for example overgrazing (Anderson & Yaalden, 1981, Pakeman *et al*, 2003), nitrogen deposition (Tomassen *et al*. 2004) and draining (Stewart & Lance, 1991). Similarly, too infrequent burning of moorland may lead to Graminae becoming dominant (Hester & Sydes, 1992) via the poor regeneration of over-mature *Calluna*. Such changes are difficult to reverse (Pakeman *et al*. 2003, Marrs *et al*. 2004). Miles (1988) indicated that burning at 3-6 year intervals favours the grasses *Deschampsia flexuosa* and 10-year rotation favours cotton grass *Eriophorum vaginatum* over *Calluna* (Rawes & Hobbs, 1979). The most severe damage occurs when uncontrolled fires occur at long intervals (Imeson, 1971, Tallis, 1987, Maltby *et al*. 1990), which some sort of burning regime might prevent (Mackay & Tallis, 1996).

The rationale being burning to prevent burning seems a contradiction in terms. However, it is important to take into account both the scale and timing of the burning and the type of burning used. The objectives of good heathland burning is to use prescribed management burning, where individual fires are of small scale, on a variable rotation and carried out according to the burning code. If this is done properly then fires will not be too intense and the *Calluna* in each patch will regenerate from stem bases, making regeneration relatively rapid. One advantage of consistent management is that the overall fuel load on the moor will be reduced. Where burning has not been carried out for some time, the stands will be older, the fuel load will be greater, fires will be hotter, there will be almost no resprouting from stem bases and regeneration will be very slow (Miles, 1988)

The response to wildfire and vandalism fires will also be affected by the burning pattern on the moorland, especially if such fires occur in summer. Where good burning management has been implemented, the fuel loads will be small and heathland regeneration should be rapid (or at least the probability of rapid regeneration will be increased). On unburnt moors, the fuel loads will be very high and regeneration is likely to be very poor, as for example the recovery after the summer fires in the hot, dry summer of 1976 (Legg, C.J. & Malby, E.)

The technique of cool burning was developed in the Peak District to aid burning management; it can be used in damper weather – hence effectively extending the burning season, it allows greater control of burning, and anecdotal evidence suggests that the vegetation recovers relatively quickly. Nevertheless, this is the first study to monitor the recovery of vegetation from hot and cool burning in Peak District.

4.1 Limitations of this study

At the outset of this project it was planned to use the maps of both Howden and Bamford moors held in GIS format, linked to a database of burning history, both held by Moors for the Future. Unfortunately both the GIS maps and database were not available in time so a modified sampling strategy needed to be developed. This modified design entailed transferring aerial photographs from Moors for Future into a GIS system, collecting burning history data from moorland managers, and then developing a rigorous sampling protocol to locate the sample quadrats on the ground. This development took a considerable time and meant that field sampling time was reduced accordingly.

Nevertheless, the sampling protocol has considerable advantages for both this baseline survey and subsequent monitoring work. First, sampling of the individual patches on both moors, and the sampling locations within each patch, has all been done randomly. This means that the data are independent and hence are suitable for rigorous statistical analysis. Second, individual sampled quadrats have been located accurately so that they can be resampled in the future, and because the exact sampling positions are known can be analyzed using geostatistical techniques. Thus, the sampling methodology developed here can be used in future studies of burning in the Peaks to:

(a) assess the time since burning on species composition and other environmental measurements at moorland, between-patch and within-patch scales;
(b) assess change in the patches sampled here through time using these data as a baseline.

Another limitation is that in order to assess the efficiency of cool burning relative to the more usual, standard approach of hot burning, there needs to be a comparison of the two methods in the same moorland area. After the cool burning approach was developed approximately 15 years ago, it has been adopted universally by moorland managers in the Peak District. Thus, there is no available hot burn comparator, and we can only describe the response to cool burns. It is also difficult to compare our results directly with those using hot burns from other areas (e.g. the north Pennines, Rawes & Hobbs, 1979), because, as we have seen here response is affected by local conditions, elapsed time (ET) and elevation. To ensure a true comparison in the same moorland area, it would be necessary to run controlled experiments in the same area testing cool *versus* hot burns.

The final limitation is, of course, a chronosequence, or space-for-time substitution approach has been used here, and it suffers from all the problems inherent with this approach. Clearly a better approach is to follow individual vegetation patches through time; this is of course possible using the methodology developed here, but will take a long time to show significant responses.

4.2 Vegetation change after cool burning on Bamford and Howden Moors

The moors reflect two examples of moors in Derbyshire reflecting a gradient of elevation and soil pH and exposed to different aspects. Bamford has a lower elevation (370-430 m) a higher soil pH (pH=4.4) and has a predominantly south-east aspect, whereas Howden is higher (490-530 m) is more acidic (pH=3.4) and has a north-easterly aspect. The Bamford site has greater species richness and sheep activity also the vegetation is taller than at Howden, but litter cover is greater at Howden, presumably as a result of a colder-wetter climate. The vegetation on the burned patches were classified as either *Calluna vulgaris-Eriophorum vaginatum* (NVC, M19), or *Eriophorum vaginatum* blanket bog and raised mire (NVC, M20).

The number of species detected was relatively low, but all were typical upland moors in the UK the species detected being in similar amounts on both moors. The dominant species was *Calluna* with a constancy of 100% at each moor, and *Empetrum nigrum*, *Eriophorum angustifolium*. *E. vaginatum*, and *Vaccinium myrtillus*, all present at a constancy > 70% (Table 1). *Rubus chamaemorus* and *Erica tetralix* had an intermediate constancy and *Agrostis capillaris*, *Galium saxatile*, *Deschampsia flexuosa* was present in lower amounts. *Campylopus introflexus* was the dominant bryophyte (constancy = 67-70%) with *Hypnum jutlandicum* present at 60%; *Dicranum scoparium* and *Polytricum* spp. were also present in lower amounts. A few lichen species were present at low amounts, although *Cladonia* squammules were found in relatively high amounts.

4.3 Factors affecting species composition

The initial analysis of species community composition using an unconstrained analysis yielded significant relationships with almost all the environmental factors studied, geographical/management (moor, easting, northing, elevation, aspect) elapsed time since burning, and site factors (soil pH, litter cover, vegetation height, type of *Calluna* present. However, analysis using a linear RDA model using constrained analysis showed only significant relationships between overall species composition and elevation and elapsed time (ET), which showed an additive response, ie there was almost no shared variation between these two variables. The HOF modelling then identified those species which increased or decreased with respect to each of these two variables.

The change through time indicated that *Eriophorum vaginatum*, two bryophyte and one lichen species reduced with time since burning, and two species *Calluna vulgaris* and *Deschampsia flexuosa* increased. The rapid response of *E. vaginatum* after burning is well know (Rawes & Hobbs, 1979), with *Calluna vulgaris* taking longer to re-establish.

Similarly, generalized responses to altitude were found with most of the heathland species decreasing in cover at higher elevations. The only species which were increasing with elevation were *Rubus chamaemorus Cladonia pyriformis* and *Cladonia* squamules. The response of *R. chamaemorus* is expected as it tends to be found in greater amounts in the higher moors (Taylor *et al*. 1994). The lichens perhaps are responding to the slower vegetation recover at high elevation.

4.3 General Conclusions

The results from this study suggest that there is a temporal response to cool burning but that the response is affected by both elevation and unknown factors. The relationships between time since burning and *Calluna vulgaris* cover are pleasing and suggest that the cool burning is achieving its intended management objectives. However, the response is relatively slow, and our results provide only a brief insight into the role of cool burning in moorland management, and there is an obvious need for further data on the extent and distribution of burning management in respect to the cool burning and hot burning methods.

5. Acknowledgements

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Appendix I: Field site map for a specimen burn site on Howden Moor.

1

Site: MC1

Sample	Easting (m) SK	Northing (m) SK	Adjusted GPS Correction Easting (m) SK	Adjusted GPS Correction Northing (m) SK
1*	19635	94325	19635	94327
2	19646	94337	19646	94339
3	19645	94341	19645	94343
4	19655	94341	19655	94343
5	19667	94347	19667	94349
6	19673	94348	19673	94350
7	19685	94349	19685	94351
8	19685	94350	19685	94352
9	19660	94351	19660	94353
10	19683	94351	19683	94353

* = Datum Point

419152 35846 5

Map Datum for GPS Correction:	SK19152	86465
GPS Reading 1	SK19151	86468
GPS Reading 2	SK19151	86469
Average GPS Reading	19151	86468
Diff (GPS – Map)	−1	+3

0 +2

Altitudinal influences rationalisation.

2086
2085
2054 21 22

Appendix II. Specimen field recording sheets.

Heather burn survey

Moor: Howdon	**Date:** 21/7/06	**Quadrat 1 grid ref:**	
Site: MC1	**Recorders:** Mike/mike McDon	SK19635, 94325.	

Item code	Item	Quadrat number: 1	2	3	4	5	6	7	8	9	10
SPECIES % COVER:											
7	*Calluna vulgaris*	3	17	+	4	20	20	15	15	5	30
45	*Erica tetralix*										
44	*Empetrum nigrum*	1	8	+	+	+					10
9	*Vaccinium myrtillus*			+		10		10	35		25
385	*Rubus chamaemorus*										
17	*Deschampsia flexuosa*										
158	*Eriophorum angustifolium*	1	4	1	1		2	4	1	1	7
291	*Eriophorum vaginatum*	30	25	30	10	45	20	+	+	25	+
26	Campylopus pyriformis	5	2	+	1	10	3			1	1
51	*Campylopus introflexus*	1	1	2	1	1		1	+	2	1
29	*Dicranum scoparium*										
36	*Hypnum jutlandicum*	1		5		1					
70	*Pohlia nutans*										
76	*Cladonia* squamules							+	+		2

UNIDENTIFIED SPECIES % COVER: (specimens retained for identification)

	Description										

NON-LIVING ITEMS % COVER:

509	Burnt Calluna - bushy		5	3		+					
510	Burnt Calluna - sticky	30	5	15	20	15	2	15	5	15	1
502	Litter	50	30	35	80	20	25	50	30	55	30
503	Bare ground						1				2
505	Rock										
506	Water										
507	Animal dung	4	3	4	1	2	1	2	2	2	3

OTHER ITEMS:

	Pressure disk height (cm)	15	10.5	14.5	11.5	14.2	9.5	8.5	10.5	8	6.5
	Slope (°)	0	3	0	10	0	0	4	4	2	4
	Aspect (°)	/	120	/	240	/	/	52	50	182	58
	Soil sample taken	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

v2 20/07/06

Appendix III. Species composition estimated in burned patched on (a) Bamford and (b) Howden Moors: median values are presented with ranges in parentheses. Species codes are in Table 1.

(a) Bamford

Overall 25 5 7 7.5 10 5 5 5 1 0.1 0.1

Cv (%)	En (%)	Vm (%)	Ea (%)	Ev (%)	Cp (%)	Ci (%)	Hj (%)	Csq (%)	Rc (%)	Ds (%)	Ps (%)	Ac (%)	Et (%)	Gs (%)	Df (%)
20	0.1	0.1	5	10	10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	0.1
[illegible]-35)	(0.1-10)	(0.1-5)	(0.1-25)	(0.1-20)	(0.1-20)	(0.1-1)	(0.1-1)	(0.1-1)	(0.1-1)	(0-1)	(0-0.1)	(0-1)	(0-1)	(0.1-10)	(0.1-1)
15	1	1	10	10	10	1	1	0.1		1	0	0	0.1	1	0.1
[illegible]-40)	(0.1-10)	(0.1-5)	(0.1-10)	(0.1-24)	(0.1-20)	(0.1-1)	(0-1)	(0-1)	(0-1)	(0-2)	(0-1)	(0-1)	(0-1)	(0-10)	(0-1)
15	0.1	5	0.1	10	5	5	5	0	0	0.1	0	0.1	0.1	5	0.1
[illegible]-30)	(0.1-10)	(0.1-5)	(0.1-10)	(0.1-15)	(0.1-25)	(0-15)	(0-10)	(0-1)	(0-1)	(0-1)	(0-0.1)	(0-1)	(0-0.1)	(0-15)	(0-0.1)
15	0.1	0.1	0.1	5	5	1	5	0.1	0.1	0.1	0.1	0.1	0.1	5	0.1
[illegible]-35)	(0-10)	(0-15)	(0-5)	(0-25)	(0-15)	(0-15)	(0-10)	(0-0.1)	(0-1)	(0-5)	(0-1)	(0-1)	(0-1)	(0-20)	(0-0.1)
5	5	5	0.1	5	0.1	1	1	0.1	0	0	0	0.1	0.1	0.1	1
[illegible]-60)	(0.1-25)	(0.1-10)	(0.1-10)	(0.1-30)	(0.1-15)	(0.1-10)	(0.1-10)	(0.1-2)	(0.1-1)	(0.1-1)	(0.1-1)	(0.1-1)	(0.1-1)	(0.15)	(0.1-10)
5	0.1	0.1	0.1	15	5	0.1	5	1.5	1	0.1	0.1	0.1	0.1	10	1
[illegible]-50)	(0.1-1)	(0.1-.1)	(0.1-1)	(0.1-40)	(0.1-20)	(0.1-1)	(0.1-20)	(0.1-5)	(0.1-1)	(0-0.1)	(0-1)	(0-1)	(0-5)	(0.1-25)	(0.1-5)
20	0.1	0.1	5	15	10	0.1	0.1	0.1	1	0.1	0.1	0	0.1	5	0.1
[illegible]-40)	(0-1)	(0-2)	(0.1-25)	(0.1-25)	(0-15)	(0-1)	(0-10)	(0-1)	(0-1)	(0-5)	(0-1)	(0-0.1)	(0-1)	(0-15)	(0-1)
20	5	0.1	0.1	20	5	0.1	5	1	0	0.5	0.1	0.1	0.1	10	0.1
[illegible]-65)	(0-15)	(0-15)	(0-10)	(0-30)	(0-40)	(0-20)	(0-15)	(0-1	(0-0.1)	(0-5)	(0-1)	(0-1)	(0-0.1)	(0-25)	(0-1)
15	0.1	0.1	0.1	2	5	1	5	0.1	0.1	0.1	0	0.1	0.1	10	1
[illegible]-45)	(0-20)	(0-5)	(0-15)	(0-15)	(0-30)	(0-25)	(0-20)	(0-1	(0-1)	(0-5)	(0-1)	(0-1)	(0-5)	(0-20)	(0-5)
20	0.1	0.1	0.1	0.1	5	10	0.1	0.1	0.1	0.1	0	0	0.1	5	0.1
[illegible]-40)	(0.1-5)	(0.1-10)	(0-10)	(0-10)	(0.1-20)	(0.1-20)	(0-15)	(0.1-1	(0-1)	(0-2)	(0-0.1)	(0-0.1)	(0-0.1)	(0.1-20)	(0-1)

0.1 0.1 0.1 10 0.1 0.1 0.1 0.1

Bamford (0-65) (0-25) (0-15) (0-25) (0-40) (0-40) (0-25) (0-20) (0-5) (0-1) (0-1)

(0-1) (0-1) (0-1) (0-25) (0-1) (0-2) (0-5) (0-1)

(b) Howden

Patchno	Age (Yrs)	Cv (%)	En (%)	Vm (%)	Ea (%)	Ev (%)	Cp (%)	Ci (%)	Hj (%)	Csq (%)	Rc (%)	Ds (%)	Ps (%)	Ac (%)
PB27	12	35	5	1	5	10	5	5	5	2	1	0.1	0.1	0.1
		(5-80)	(0-10)	(0-10)	(0-10)	(0-35)	(0-15)	(0-15)	(0-10)	(0- 5)	(0- 5)	(0-0.1)	(0-0.1)	(0- 0.1)
PB29	13	5	1	1	2	5	0.1	0.5	5	0.1	0.1	0.1	0.1	0.1
		(0.1-29)	(0-5)	(0-25)	(0-15)	(0-25)	(0-2)	(0-10)	(0-15)	(0- 5)	(0- 0.1)	(0- 0.1)	(0- 0.1)	(0- 0.1)
MC5	2	16	0.1	0.1	10	1	5	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		(1- 27)	(0- 0.1)	(0- 17)	(0.1- 25)	(0- 20)	(0- 10)	(0- 15)	(0- 10)	(0- 6)	(0- 5)	(0- 0.1)	(0-0.1)	(0- 0.1)
PB32A	15	25	5	4	5	10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	5
		(0.1-40)	(0.1-10)	(0.1-15)	(0.1-20)	(0.1-35)	(0-1)	(0-1)	(0-1)	(0- 5)	(0- 0.1)	(0- 5)	(0- 0.1)	(0.1- 10)
PB19	3	35	5	0.1	5	1	5	1	0.1	0.1	0.1	0.1	0.1	0.1
		(1- 35)	(0.1- 10)	(0- 0.1)	(0- 5)	(0- 10)	(0- 15)	(0-6)	(0-0.1)	(0-0.1)	(0-0.1)	(0-0.1)	(0-1)	(0-0.1)
MC19B	4	10	2	10	6	5	1	5	0.1	2	0.1	0.1	0.1	0.1
		(1-19)	(0-9)	(0-35)	(0-10)	(0-15)	(0-15)	(0-9)	(0-3)	(0-6)	(0-2)	(0-4)	(0-0.1)	(0-0.1)
Overall Howden		26	5	4	6	10	5	5	5	2	0.1	0.1	0.1	0.1
		(0-80)	(0-20)	(0-35)	(0-25)	(0-35)	(0-15)	(0-20)	(0-15)	(0-10)	(0-5)	(0-5)	(0-1)	(0-10)
MC1	5	16	5	5	1	20	1	1	0.1	0.1	0.1	0.1	0.1	0.1
		(5-26)	(0-10)	(0-35)	(0-5)	(0-30)	(0-10)	(0-2)	(0-5)	(0- 2)	(0- 0.1)	(0- 0.1)	(0- 1)	(0- 0.1)
PB74	8	35	5	5	5	10	3.5	0.1	1	0.1	0.1	0.1	0.1	5
		(1-25)	(0-20)	(0-15)	(0.1-20)	(0-20)	(0-15)	(0-6)	(0-10)	(0- 6)	(0- 3)	(0- 1)	(0- 1)	(0- 10)
PB28	11	15	1	1	2	5	3	5	0.1	0.1	0.1	0.1	0.1	0.1
		(5-68)	(0-5)	(0-10)	(0.1-15)	(0.1-20)	(0-10)	(0-10)	(0-5)	(0- 2)	(0- 1)	(0- 0.1)	(0- 0.1)	(0- 1)
PB51	11	5	5	0.1	1	5	0.1	5	5	3	1	0.1	0.1	0.1
		(0.1-40)	(0-20)	(0-15)	(0.1-10)	(0.1-10)	(0-5)	(0-20)	(0-10)	(0- 10)	(0- 5)	(0- 1)	(0-0.1)	(0-0.1)

Combined Bamford & Howden	25 (0-80)	5 (0-25)	5 (0-35)	5 (0-25)	15 (0-40)	10 (0-40)	5 (0-25)	2 (0-20)	2 (0-10)	1 (0-5)	0.1 (0-5)	0.1 (0-1)	0.1 (0-1)	1 (0-25)	1 (0-1)	0.1 (0-1)	0.1 (0-2)	1 (0-5)	0.1 (0-1)

Appendix IV. Environmental variables measured in burned patches on (a) Bamford and (b) Howden Moors: median values are presented with ranges in parentheses. Species codes are in Table 1.

(a)

Patchno	ET (Yrs)	Elevation (Metres)	BurntCalbush (%)	BurntCalstick (%)	Litter (%)	BareGround (%)	Animalmdung (%	Slope (˚)	pH	LOI (%)	PD (cm)	Faspect (˚)
PB18	2	410	1	15	5	5	1	2	4.16	49.7	8	0.36
			(1-20)	(1-20)	(0-20)	(0-10)	(0-4)	(0-5)			(0-14)	(0-0.76)
PB19	3	420	15	18.5	0.25	1	0.1	5	4.35	52.6	3	0.37
			(0-25)	(0-30)	(0-10)	(1-10)	(0-5)	(0-12)			(0-9)	(0-0.76)
PB16	4	380	10	15	10	5	0.1	4	4.23	52.6	10	0.43
			(0-20)	(1-20)	(0-25)	(0-10)	(0-2)	(0-9)			(0-16)	(0-0.75)
PB110	5	390	1	25	10	0.1	1.5	4	4.24	51.2	9	0.63
			(1-10)	(0-20)	(0-20)	(0-20)	(0-5)	(0-9)			(0-12)	(0-0.9)
PB85	7	400	5	15	15	0.1	5	5	4.35	54.2	12	0.62
			(0-25)	(0-25)	(0-30)	(0-10)	(0-10)	(0-9)			(0-18)	(0-0.8)
PB89	8	370	1	5	20	5	2	4	4.02	51.7	14	0.34
			(0-10)	(1-40)	(0-30)	(0-40)	(0-3)	(0-8)			(0-35)	(0-0.67)
PB38	10	400	1	15	10	5	0.1	3	4.16	51.7	8	0.36
			(1-10)	(0-25)	(0-15)	(0-10)	(0-2)	(0-8)			(0-11)	(0-0.76)
PB82	12	424	5	15	5	5	0.1	5	4.26	53.7	7	0.42
			(5-25)	(0-30)	(0-35)	(0.1-20)	(0-10)	(0-10)			(0-20)	(0-0.69)
PB114	13	410	5	12.5	10	5	0.1	6	4.16	50.7	10	0.59
			(0-15)	(0-25)	(0-30)	(0-5)	(0-5)	(0-10)			(0-25)	(0-0.7)
PB122	14	426	5	25	10	5	1.5	4	4.24	51.2	9	0.64
			(0-10)	(0-20)	(0-20)	(0.1-20)	(0-5)	(0-9)			(0-12)	(0-0.9)
Overall Bamford			5	1	15	10	1	7	4.45	51.15	2	0.76
			(1-25)	(0-40)	(0-35)	(0-40)	(0-10)	(0-10)			(0-35)	(0-0.9)

(b)

Patchno	ET (Yrs)	Elevation (Metres)	BurntCalBush (%)	BurntCalStick (%)	Litter (%)	Bareground (%)	Animaldung (%)	Slope (˚)	pH	LOI (%)	PD (cm)	Faspect (˚)
MC5	2	530	1	25	25	0.1	1	4	3.71	53.73	8	0.56
			(0-5)	(0-60)	(0-55)	(0-5)	(0-1)	(0-7)			(0-15)	(0-0.76)
PB19	3	520	4	10	15	5	1	3	3.71	52.33	12	0.62
			(0-10)	(0-30)	(0-30)	(0-25)	(0-2)	(0-7)			(0-13)	(0-0.8)
MC19B	4	520	4	45	35	0.1	1	4	3.58	52.58	11	0.37
			(0.1-15)	(0-52)	(5-45)	(0-10)	(0-2)	(0-11)			(0-15)	(0-0.76)
MC1	5	500	1	15	35	1	2	5	3.73	47.34	10	0.58
			(0-5)	(0-30)	(5-60)	(0-2)	(0-3)	(0-10)			(0-12)	(0-0.68)
PB74	8	470	15	15	5	0.1	0.1	7	3.76	49.82	11	0.39
			(0-25)	(0-30)	(1-10)	(0-10)	(0-5)	(0-9)			(0-20)	(0-0.7)
PB51	11	510	10	15	25	1	0.1	10	3.78	52.95	13	0.40
			(0.1-30)	(0-25)	(5-35)	(0-40)	(0-0.1)	(0-8)			(0-19)	(0-0.8)
PB28	11	490	0.1	25	4	1	0.1	9	3.86	49.44	4	0.54
			(0-6)	(0-50)	(0-20)	(0-0.1)	(0-1)	(0-24)			(0-14)	(0-0.75)
PB27	12	490	1	20	5	1	1	5	3.65	52.71	11	0.78
			(0-10)	(0-40)	(0-20)	(0-5)	(0-2)	(0-13)			(0-18)	(0-0.93)
PB29	13	500	5	40	35	0.1	0.1	5	3.35	53.73	11	0.29
			(0.1-13)	(0-55)	(0-45)	(0-5)	(0-1)	(0-17)			(0-14)	(0-0.8)
PB32A	15	530	20	11	35	0.1	0.1	3	3.49	52.58	3	0.57
			(0-25)	(0-30)	(0-40)	(0-5)	(0-5)	(0-10)			(0-9)	(0-0.79)
Overall Howden			8	30	35	1	1.45	7	3.45	50.15	12	0.46
			(0-30)	(0-50)	(0-60)	(0-40)	(0-5)	(0-24)			(0-16)	(0-0.63)
Combined Bamford			10	25	20	0.1	1	7	3.65	51.54	11	0.56
& Howden			(0.1-30)	(0-60)	(0-60)	(0-40)	(0-10)	(0-24)			(0-32)	(0-0.65)