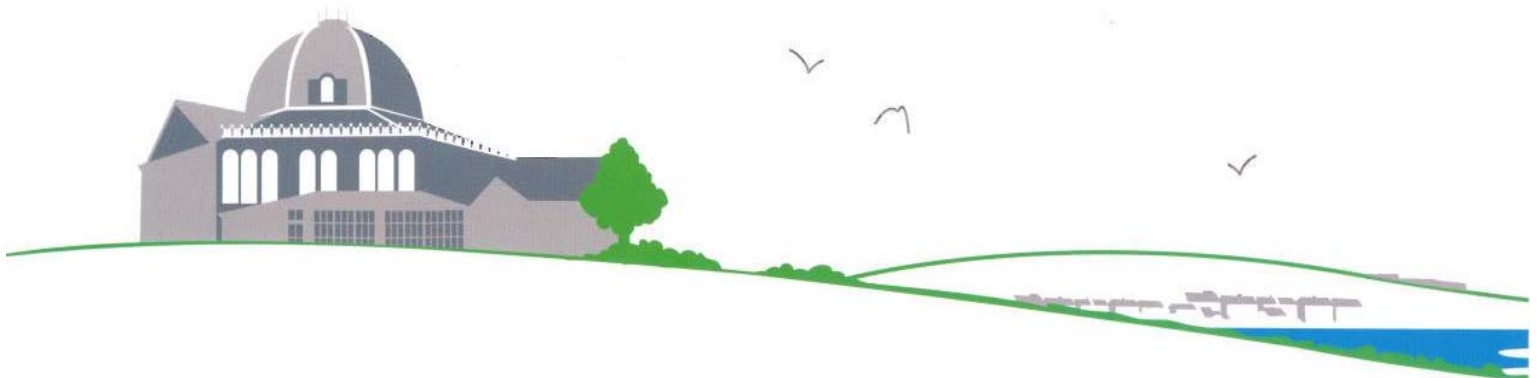




THE HEATHER TRUST
PEAK DISTRICT HEATHER BEETLE PROJECT
RESULTS OF JULY 2018 MONITORING



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Penny Anderson Associates Limited
'Park Lea'
60 Park Road
Buxton
Derbyshire
SK17 6SN

Project Manager and Author
Kath Longden BSc (Hons), MSc, MCIEEM, CEnv

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This project has been undertaken in accordance with PAA policies and procedures on quality assurance.

Signed:  _____

CONTENTS

	Page
1. INTRODUCTION AND BACKGROUND.....	1
2. EXPERIMENTAL DESIGN, METHODOLOGY AND TREATMENTS.....	2
Crag Estate.....	2
Combs Moss.....	2
Data Collection	3
Data Handling and Analysis	4
3. RESULTS AND DISCUSSION	6
Crag Estate.....	6
Dwarf Shrubs	6
Other Vascular Plants	8
Bryophytes	11
Bare Ground and Heather Litter Cover	14
Conclusions for Crag Estate.....	15
Combs Moss.....	16
Area 1.....	17
Dwarf Shrubs.....	17
Other Vascular Plants.....	19
Bryophytes.....	21
Bare Ground and Heather Litter Cover	23
Conclusions for Combs Moss Area 1.....	24
Area 3.....	24
Dwarf Shrubs.....	25
Other Vascular Plants.....	26
Bryophytes.....	28
Bare Ground, Open Water and Heather Litter Cover	29
Conclusions for Combs Moss Area 3.....	30
Area 4.....	31
Dwarf Shrubs.....	31
Other Vascular Plants.....	32
Bryophytes.....	34
Bare Ground and Heather Litter Cover	35
Conclusions for Combs Moss Area 4.....	36

Occurrence of Heather Seedlings	36
Crag Estate	37
Combs Moss	38
Conclusions for Heather Seedlings.....	40
Heather Beetle Damage	41
Crag Estate	41
Combs Moss	43
Area 1	43
Area 3	44
Area 4	45
Conclusions for Heather Beetle Damage	46
4. OVERALL DISCUSSION AND CONCLUSIONS	48
Overall Discussion.....	48
Heather Regeneration and Cover.....	48
The Effect of Burning Young Heather Beetle Damaged Heather	49
Addition of Heather Seed to a Cottongrass-dominated Vegetation.....	49
Conclusions	50
5. REFERENCES	52
 TABLES	
1 Overview of the Treatment Plots on the Crag Estate	
2 Overview of the Treatment Plots on Combs Moss	
3 Overview of the Treatment Plots and Monitoring at Combs Moss Area 1	3
4 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots at Crag Estate	
5 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots in Area 1 at Combs Moss	
6 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots in Area 3 at Combs Moss	
7 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots in Area 4 at Combs Moss	
 FIGURES	
1 Crag Estate Plot and Quadrat Locations	
2 Combs Moss Plot and Quadrat Locations	
3 The Cover of Heather in the Plots	6
4 The Cover of Regenerating Heather in the Plots	7
5 The Cover of Common Cottongrass in the Plots.....	8

6	The Cover of Hare's-tail Cottongrass in the Plots	9
7	The Cover of Wavy Hair-grass in the Plots	10
8	The Cover of Cross-leaved Heath in the Plots	10
9	The Total Cover of Vascular Plants in the Plots.....	11
10	The Cover of <i>Campylopus introflexus</i> in the Plots	12
11	The Cover of All Other <i>Campylopus</i> Species in the Plots.....	12
12	The Total Cover of Bryophytes in the Plots.....	13
13	The Total Cover of <i>Sphagnum</i> in the Plots	13
14	The Bare Ground Recorded in the Plots	14
15	The Heather Litter Recorded in the Plots	14
16	The Cover of Heather in Area 1	17
17	The Cover of Heather Regeneration in Area 1.....	18
18	The Cover of Common Cottongrass in Area 1	19
19	The Total Cover of Cottongrass in Area 1.....	20
20	The Cover of Wavy Hair-grass in Area 1.....	20
21	The Total Cover of Vascular Plants in Area 1	21
22	The Cover of <i>Hypnum jutlandicum</i> in Area 1.....	22
23	The Cover of <i>Campylopus introflexus</i> in Area 1.....	22
24	The Cover of Bare Ground in Area 1.....	23
25	The Cover of Heather in Area 3	25
26	The Cover of Regenerating Heather in Area 3.....	26
27	The Cover of Total Cottongrass in Area 3.....	27
28	The Cover of Wavy Hair-Grass in Area 3.....	27
29	The Total Cover of Vascular Plants in Area 3	28
30	The Total Cover of Bryophytes in Area 3	29
31	The Cover Heather Litter in Area 3	30
32	The Cover of Heather in the Four Plots in Area 4	32
33	The Total Cover of Cottongrass in Area 4.....	33
34	The Cover of Wavy Hair-Grass in Area 4.....	33
35	The Total Cover of Vascular Plants in Area 4	34
36	The Cover of <i>Campylopus</i> Species in Area 4	34
37	The Cover of <i>Hypnum jutlandicum</i> in Area 4.....	35
38	The Cover of Bare Ground in Area 4.....	35
39	The Cover of Heather Litter in Area 4	36
40	The Distribution of Heather Seedlings Within the Plots on Crag Estate	37

41	The Distribution of Heather Seedlings Within the Plots on Crag Estate	38
42	The Distribution of Heather Seedlings Within Area 1 on Combs Moss.....	39
43	The Distribution of Heather Seedlings Within Area 4 on Combs Moss.....	40
44	The Impact of Heather Beetle Damage in the Three Treatments on Crag Estate	42
45	The Impact of Heather Beetle Damage on Area 1 on Combs Moss.....	43
46	The Impact of Heather Beetle Damage on Area 3 on Combs Moss.....	45
47	The Impact of Heather Beetle Damage on Area 4 on Combs Moss.....	46

APPENDIX

1	Fixed Point Photographs for Both Sites	
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1. INTRODUCTION AND BACKGROUND

- 1.1 Penny Anderson Associates Limited (PAA) was commissioned to design a monitoring experiment to assess the effectiveness of different management methods in restoring a heather-dominated community after a severe infestation of heather beetle.
- 1.2 The project is lead by The Heather Trust with the support of Natural England (NE) and the two estates (Combs Moss and Crag Estate located in the Derbyshire Peak District) where the experimental plots are located.
- 1.3 The main aim of this project is to assess the effectiveness of different management methods after a heather beetle attack in order to restore the functionality of the moor. A full description of the background to the project and monitoring protocol is presented in the Baseline Report (PAA March 2013).
- 1.4 This report is one of a series which have been produced reporting on changes in cover of the different elements of the vegetation following management. The monitoring was initially proposed for the first two seasons following management treatment, and thereafter every two years unless the results suggested this was inappropriate.
- 1.5 Post-management surveys were undertaken in July 2013 and 2014 on both estates following cutting and spring burning management on Crag Estate, and cutting of heather (*Calluna vulgaris*¹) and addition of heather seed on Combs Moss in spring 2013. Burning management also occurred on two areas at Combs in December 2013 as it had not been possible to undertake this in the spring of 2013.
- 1.6 Because of the delay in burning at Combs Moss, (undertaken in December 2013), monitoring of plots in Areas 1 and 3 was also required in July 2015 to fulfil the original plan of monitoring annually for the first two years following management. This means that the monitoring of the plots on the Crag Estate and Area 4 at Combs Moss were out of synchrony with Areas 1 and 3 at Combs from 2015.
- 1.7 Following the initial annual monitoring for the first two years after treatment, the monitoring interval was continued every two years and this lead to a continuation of the lack of synchronicity between the sites and within the plots at Combs Moss during 2016 and 2017.
- 1.8 A heather beetle outbreak in 2017 in Areas 1 and 3 at Combs Moss provided the opportunity to study all sites again in 2018 and to record the immediate post-beetle attack vegetation in 2018. The extent of the heather beetle infestation on the plots at Crag and Area 4 at Combs in 2017 is unclear.
- 1.9 All plots which had undergone any treatment (and the controls) at both sites were re-surveyed in July 2018. This report relates to the monitoring of all plots on the Crag Estate and at Combs Moss.

¹ Nomenclature for plant species follows Stace, 2010.

2. EXPERIMENTAL DESIGN, METHODOLOGY AND TREATMENTS

2.1 The project design and methodology have been provided in previous reports (PAA March 2013, PAA December 2013, PAA January 2015, PAA May 2017 and PAA November 2017). Below is an analysis of all the trial plots on both sites surveyed in July 2018.

Crag Estate

2.2 The main areas of beetle damage on this site at the outset of the project were adjacent to the road. This, combined with an underlying history of larger burns (during the previous keeper's management), had resulted in more uniform vegetation with even-aged heather developing prior to the beetle infestation. Plot selection and layout was therefore relatively simple.

2.3 The areas and plots were all located in heather-dominated swards containing at least 50% of building or mature heather that had been damaged by beetle. There were to be four treatments for this site:

- cut;
- autumn burn;
- spring burn; and
- untreated control.

2.4 The scheme was designed to have three areas with four treatments on each area effectively giving three replicates for each treatment. This gave the total of 12 treated plots (four treatments x three replicate plots) for this estate.

2.5 At Crag Estate the good vehicle access to the plots allowed the completion of the cutting treatment and spring burns on the trial plots as planned during the winter/spring of 2012/13. However, the autumn burns at Crag Estate (scheduled for winter 2013) were not undertaken because of a lack of suitable burning days on days when the equipment and personnel were available. These plots were excluded from the July 2014 and subsequent monitoring events as to delay the autumn burn for a further year would have caused further complications in the analysis of the data. Other variables, predominantly variations in the weather and possible beetle attacks, would inevitably complicate the interpretation of results in respect to the rates of re-growth of the vegetation in the plots.

2.6 Table 1 presents a list of the plot codes, locations, broad habitat descriptions and treatments to help explain the codes used throughout the results section of the report. Those plots highlighted in grey have been excluded from monitoring after July 2013 because of lack of management within the appropriate timescale, and are not referred to again.

Combs Moss

2.7 This is a more complex site because of the high pre-beetle level of grouse moor management and the widespread beetle damage across the site, coupled with the burning of infected/dead heather and re-infestation of the new heather re-growth. It is also a much harder site to access as the track to the moor is only accessible by 4WD vehicles.

2.8 The final experimental design resulted in the monitoring of four areas with slightly different vegetation types and/or environmental conditions to which slightly different treatments were applied as described in previous reports (PAA December 2013).

- 2.9 During the 2013 spring, the weather was poor and the difficult access to the site for equipment combined with the unfavourable weather meant that there was an insufficient window to allow all the works to be completed.
- 2.10 Cutting took place on one plot in Area 1 in March 2013 as planned, but no burning occurred. The cutter was attached to a large tractor to enable access across the moor, which has several gullies and valleys. The height and level of the cutter was less adjustable than on the equipment used at Crag Estate, resulting in a more uneven cut with occasional areas being scalped and the tractor itself causing minor damage by occasionally exposing peat where it turned.
- 2.11 The over-seeding of heather seed in Area 4 was undertaken on 20th April 2013 using seed mixed with brash obtained from Geoff Eyre (a local supplier). Area 4 was an area of cottongrass- dominated (*Eriophorum* sp.) vegetation where the heather had been burnt (in the last five years – at the start of the experiment), the re-growth had been severely affected by beetle (>90%) and there were significant pockets of un-vegetated peat (>10%) at the start of the project. The treatment applied was over-seeding with heather seed at an even rate (three plots) and an untreated control.
- 2.12 Heather burning was undertaken in December 2013 on the plots in Areas 1 and 3 but not in Area 2, again insufficient time and resources was the reason. A decision was then taken to exclude Area 2 from the trials as neither the cutting or burning treatment had been undertaken in the time available.
- 2.13 Table 2 presents a list of the plot codes, locations, broad habitat descriptions and treatments to help explain the codes used throughout the results section of the report. Those plots excluded from monitoring after July 2013 because of lack of management within the appropriate timescale are highlighted in grey and are not referred to again.
- 2.14 The delay in burning the heather in Areas 1 and 3 resulted in the plots at Combs being recorded in the first two years following the burning treatment (2014 and 2015) whereas on Area 4 the first two years after treatment (heather seed addition) were 2013 and 2014. This means that the recording periods for the different areas are not the same.
- 2.15 On Area 1 the cutting and burning treatments were separated by a growing season and therefore the same monitoring period does not relate to an equal time after treatment. To simplify the results in Area 1, the monitoring periods have been given a code (A-E) to indicate which are equivalent in time after treatment, this is summarised in Table 3 below.

Table 3 Overview of the Treatment Plots and Monitoring at Combs Moss Area 1

Site and Area	February 2013	July 2013	July 2014	July 2015	August 2017	July 2018
Combs Area 1 Burn	Baseline	Baseline	Monitoring survey A	Monitoring survey B	Monitoring survey C	Monitoring survey D
Combs Area 1 Cut	Baseline	Monitoring survey A	Monitoring survey B	Monitoring survey C	Monitoring survey D	Monitoring survey E

Data Collection

- 2.16 Monitoring was scheduled for years 1 and 2 after treatment and thereafter every two years. All post-treatment monitoring has been undertaken within the same two-week period in July. The dates of the 2018 monitoring were 17th - 19th July at Crag Estate and 24th - 25th July for the plots on Combs Moss.

- 2.17 The features recorded in the 2x2m quadrats were consistent with the previous monitoring and included:
- the percentage cover for all vascular species recorded;
 - the percentage cover for all bryophytes (some were identified to species, others to family as in the previous monitoring);
 - vascular plant height;
 - percent bare ground;
 - percent open water;
 - percent heather litter cover;
 - type and frequency of any dung; and
 - numbers of heather seedlings in a 0.1m² quadrat located in the north-west corner of the larger quadrat or the percentage cover of heather when the plants were no longer seedlings.
- 2.18 Heather has been recorded in a number of ways during the monitoring. In the baseline survey it was recorded as 'heather'. After the treatments (cutting, burning or seed addition) the heather was differentiated into 'old' i.e. areas un-cut or un-burnt and 'regenerating heather'. The 'regenerating heather' class was used mainly in areas where treatments occurred, but occasionally in control areas where damaged heather has re-grown from seed or stems. By 2018 the difference between 'old' and 'regenerating' heather was indistinct so all heather was classed as 'heather'.
- 2.19 Fixed point photographs were taken at the north-west and north-east corners of each plot, looking south-east and south-west respectively. Photographs were also re-taken of three quadrats in each plot, these normally being quadrats 1, 4 and 8, again taken from the north-west corner. A selection of photographs for both sites is given in Appendix 1.
- 2.20 In addition to these data, the 'Beetle Index' designed in the previous monitoring periods to record the damage to the heather in each quadrat, was again applied to the heather. The categories are listed below.
- Category 1 = >75% heather dead, grey and brittle;
 - Category 2 = >75% heather dead, grey but stem still green;
 - Category 3 = 75-50% heather dead, grey;
 - Category 4 = 50-25% heather dead, grey;
 - Category 5 = <25% heather dead, grey; and
 - Category 6 = <5% heather dead, grey.

Data Handling and Analysis

- 2.21 All data are held within Excel spreadsheets allowing data to be readily analysed. The data for each Estate are analysed separately and on Combs Moss the three different areas were also analysed separately.
- 2.22 All analyses were undertaken in Systat 13. Differences in percent cover of individual plant species (or species groups) and in the measured environmental variables were assessed for the two estates using basic descriptive statistical analysis (means and standard errors).

- 2.23 The 4 datasets were tested for normal distribution to understand which statistical tests could be used. This was undertaken by using a Kolmogorov-Smirnov One-Sample Test. The data were found not to follow a normal distribution. Therefore, a nonparametric Kruskal-Wallis Test and a Dwass-Steel-Christlow-Fligner Test for all pairwise comparisons has been applied to the raw unmodified percentage cover data, to test differences between species distribution in the plots over the three monitoring periods to show where the inter-plot differences occurred.
- 2.24 In an earlier report (PAA January 2015) the analysis showed that the data for the different areas on the Crag Estate can be amalgamated by treatment, i.e. a replicated plot analysis, whilst the areas on Combs Moss are known to be different and, therefore, each area is analysed separately. The results of the analyses are given in Table 4 for Crag Estate and Tables 5 -7 for Combs Moss. The tables give the Kruskal-Wallis test statistic and the overall 'p-value' (i.e. the probability that the effect was a result of chance alone and not the treatment applied). There is also a column providing information on whether there are any pairwise statistically significant results (Dwass-Steel-Critchlow-Fligner (DSCF) Test p-values). The results for the Kruskal-Wallis test may be significant but may not have any significant pairwise results, or the significant pairwise results may not be related to treatments and are not ecologically significant. Only pairwise interactions that can be interpreted in an ecologically meaningful way are reported in the results section.
- 2.25 Resulting probability values (p-values) from each statistical test were assessed as follows:
- P value at 0.05 or lower = test is statistically significant at the 5% level (i.e. a 5% probability that the results have occurred by chance alone). Notation on Figures = a single asterisk (*);
 - P value at 0.01 or lower = test is statistically significant at the 1% level (i.e. a 1% probability that the results have occurred by chance alone). Notation on Figures = two asterisks (**); and
 - P value at 0.001 or lower = test is highly statistically significant at the 0.1% level (i.e. a 0.1% probability that the results have occurred by chance alone). Notation on Figures = three asterisks (***)

3. RESULTS AND DISCUSSION

3.1 The two sites, Crag Estate and Combs Moss are treated separately in this report as they are very different from each other in terms of species composition, terrain and exposure and also in the treatments applied.

Crag Estate

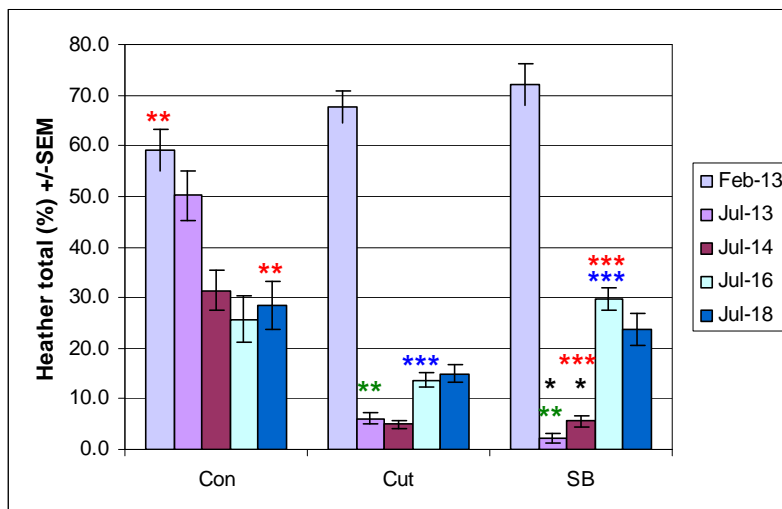
3.2 As described above, Areas 1, 2 and 3 had the same treatments applied and the previous analysis has shown that the areas can be treated as replicate plots. There are three treatment plots - control, cut and spring burn plots - with 24 quadrats in each. All results for the Kruskal-Wallis analysis are shown in Table 4 and are discussed below.

Dwarf Shrubs

3.3 The cutting and burning treatments in March 2013 drastically reduced the heather cover in these plots (as expected), resulting in statistically significant differences over time ($H = 243.73$, d.f. = 14, $p < 0.001$) as shown on Figure 3.

3.4 There are several pairwise significant differences between plots within a specific treatment over time. Within the two treated plots - cut or spring burn - there are obvious declines from the pre-treatment cover (67-72%) to the post treatment cover (15-24% respectively in 2018) and, in all post treatment years, these differences are statistically significant ($p < 0.001$, not shown on Figure 3). The heather cover has also reduced significantly in the control plot over the same monitoring period (February 2013 to July 2018) ($p < 0.01$). This is thought to be because the heather, previously damaged by the beetle, has died and collapsed during this period, illustrated by a slow decline over time contrasting with a sudden reduction due to a treatment.

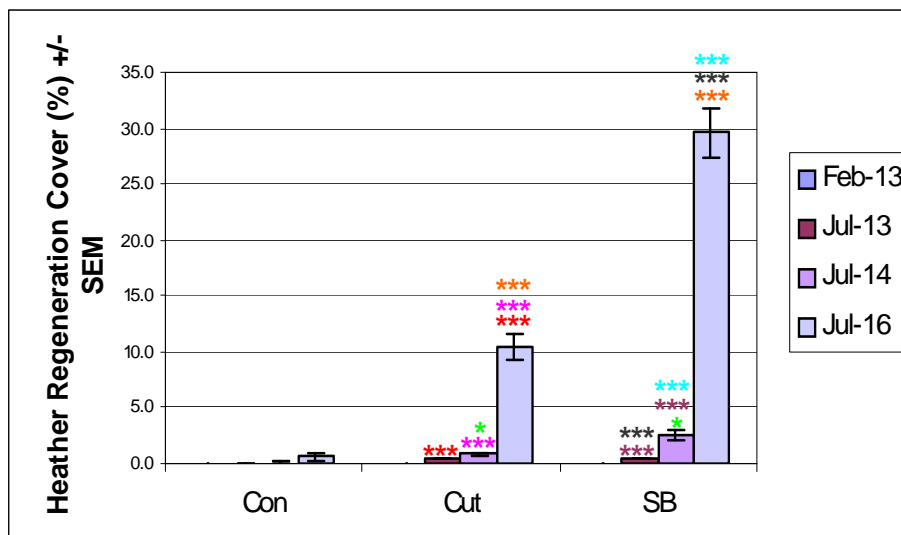
Figure 3 The Cover of Heather in the Plots²



² Treatments on the Crag Estate were as follows: Con = Control plot (no treatment); Cut = All vegetation cut; SB = Spring Burn undertaken in March 2013.

- 3.5 These data showed no statistically significant differences in the heather cover between the three treatment areas prior to the treatment (February 2013) but following treatment there were pairwise significant results ($p < 0.001$, not shown on Figure 3) between the control and the treated in July 2013 and 2014.
- 3.6 The cover of heather in the treated plots did not fall to zero after treatment, indicating that the treatments did not remove all heather cover. Immediately after treatment (July 2013) there was significantly less heather on the burn plot ($p < 0.01$, Figure 3). Burning therefore removed more heather than cutting.
- 3.7 In previous analyses heather re-growth was recorded as 'heather regeneration' to differentiate it from the old heather missed by the treatments. However, from 2017 onwards the separation of 'regenerating heather' and 'old heather' was hard to record accurately in the field and these data have been combined and re-analysed as a 'total heather' class.
- 3.8 Following treatment the heather cover remains low up to 2014, but has increased significantly by 2016 and this is largely maintained into 2018.
- 3.9 In addition, there are significant differences between the treated plots (cut or burn) in 2016, with a more rapid increase in heather cover in the two years after burning, compared to after cutting. However, by 2018 this difference is no longer seen, suggesting that five years after burning or cutting the heather cover has recovered to levels found in the control plot. The heather cover is, however, still significantly lower ($p < 0.001$) than the baseline cover in all cases, including the untreated control which has a decline in heather cover over time.
- 3.10 Recapping the findings on heather regeneration presented in earlier reports, the treatments stimulated heather regeneration and by 2016 the regeneration cover after burning was far greater (c.30%) than that recorded in the cut plot (c.10%) (Figure 4). There was no regenerating heather recorded in any area before treatment and the control showed only minimal regenerating heather (<1% in 2016).

Figure 4 The Cover of Regenerating Heather in the Plots

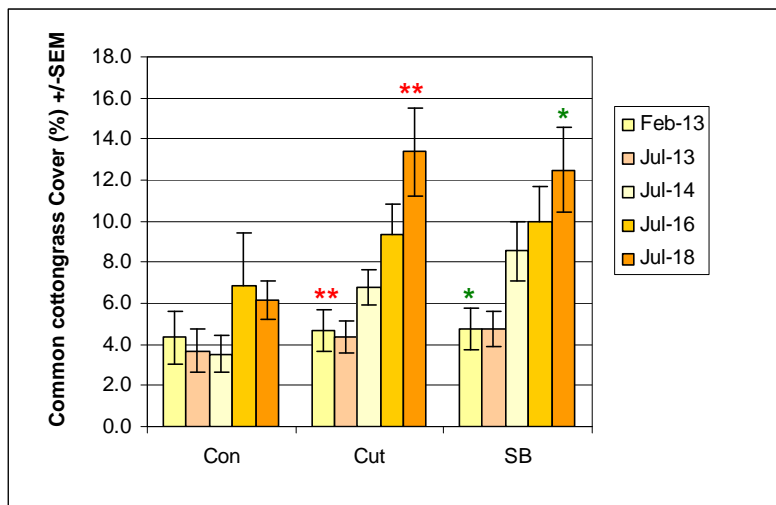


- 3.11 As heather is the main dwarf shrub species, the results and trends for dwarf shrub cover are similar to those of heather cover (Table 4).

Other Vascular Plants

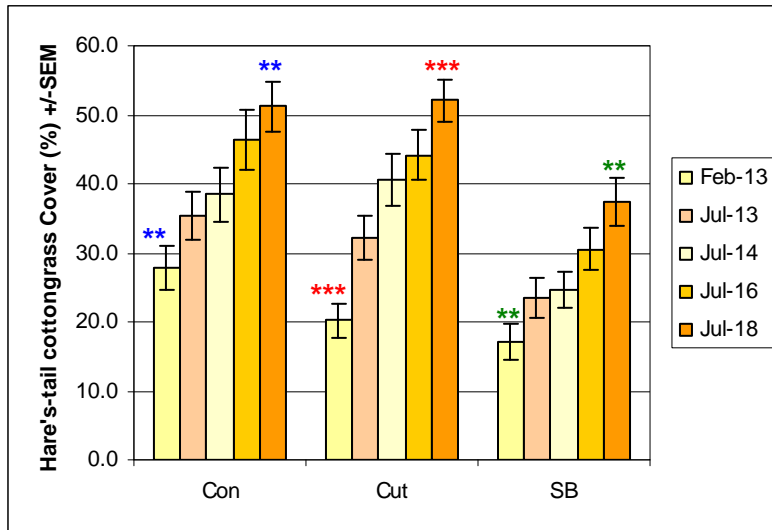
- 3.12 The analysis of common cottongrass (*Eriophorum angustifolium*) returned an overall statistically significant result ($H = 79.76$, d.f. = 14, $p < 0.001$) over time. In previous analysis there was a trend of increasing common cottongrass in both treated plots, up to 2016 (Figure 5). In the 2018 analysis this trend is now statistically significant. It is notable that both treated plots show this increasing trend, while the untreated control does not, and also that treatments themselves appeared to have little effect on cover.

Figure 5 The Cover of Common Cottongrass in the Plots



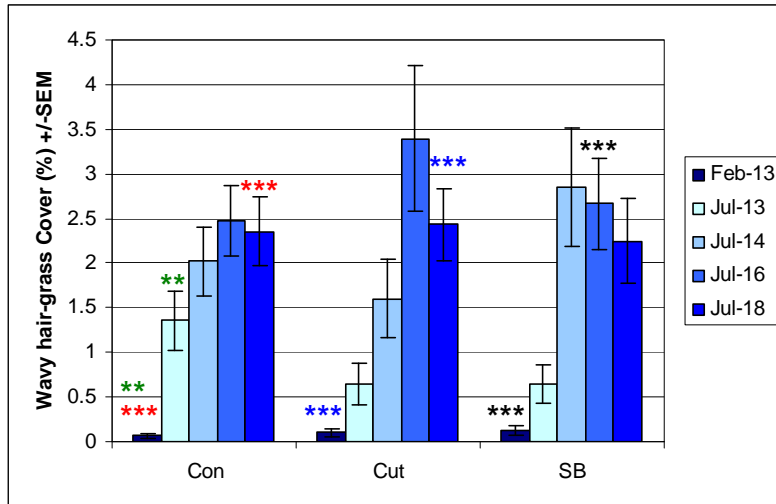
- 3.13 Hare's-tail cottongrass (*Eriophorum vaginatum*) is a much greater component of the vegetation than common cottongrass, with between 37% and 52% cover in July 2018. Again the analysis of cover over time was statistically significant ($H = 108.12$, d.f. = 14, $p < 0.001$). There is, for the first time, a statistically significant increase in the cover of hair's-tail cottongrass over time within all plots (Figure 6). There are no significant differences in any year between any of the plots. The increases over time appear therefore to be independent of treatment and likely the result of other environmental factors.

Figure 6 The Cover of Hare's-tail Cottongrass in the Plots



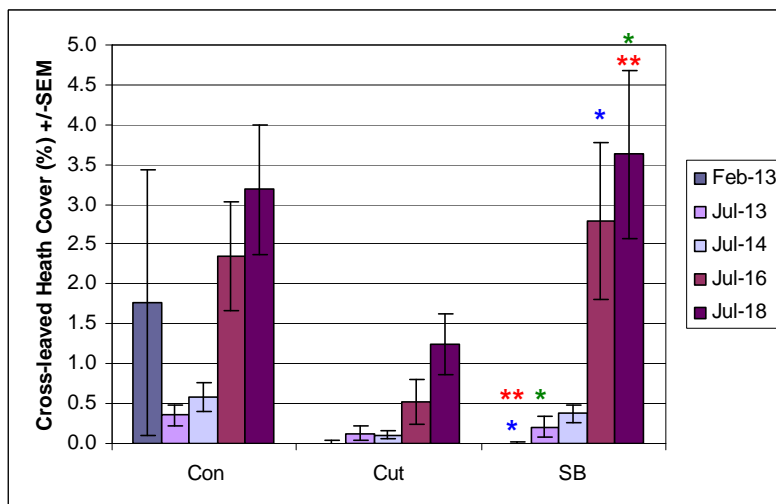
- 3.14 As hare's-tail cottongrass is the main cottongrass species, the total cottongrass category tends to follow the trends described above. In summary, the overall increase in hare's-tail cottongrass cover may reflect a release from competition due to a reduction in cover of heather, either as a result of dieback following the beetle infestation or due to treatment, and before the regenerating heather can shade out the cottongrasses. For common cotton-grass there appears to be a separate effect of treatment (cutting or burning) stimulating growth above and beyond the effect of reduced competition from heather.
- 3.15 The cover of wavy hair-grass (*Deschampsia flexuosa*) has an overall significant result ($H = 155.02$, d.f. = 14, $p < 0.001$) over time with a number of pairwise statistically significant interactions (Figure 7). In the control and cut plots there has been a highly significant increase ($p < 0.001$) in wavy hair-grass from baseline cover (February 2013 to July 2018). In the spring burn plot the overall trend is an increase in cover and this is significant between the baseline and July 2016 ($p < 0.01$) but there is a slight decline in cover in 2018.
- 3.16 The reason for the overall increase is mainly due to the very low cover of wavy hair-grass recorded in the February 2013 baseline monitoring when this species was dormant and hard to record. This means assessing change against the baseline may not reflect genuine changes in this species cover. The mean cover of wavy hair-grass is still under 4% in all plots after five and a half years. With such small values it is difficult to determine any meaningful conclusions from the results.

Figure 7 The Cover of Wavy Hair-grass in the Plots



3.17 Cross-leaved heath (*Erica tetralix*) also has a low cover across the site (<4% in all plots), therefore any results should be interpreted with caution. The analysis gives an overall significant result ($H = 75.282$, d.f. = 14, $p < 0.001$) with three statistically significant pairwise interactions (Figure 8). Cross-leaved heath was largely absent in the treated plots before treatment and the species has colonised these areas since the application of the treatment. The increase is statistically significant in the burn area when the baseline (February 2013) is compared to 2016 and 2018, and also when comparing 2013 to 2018.

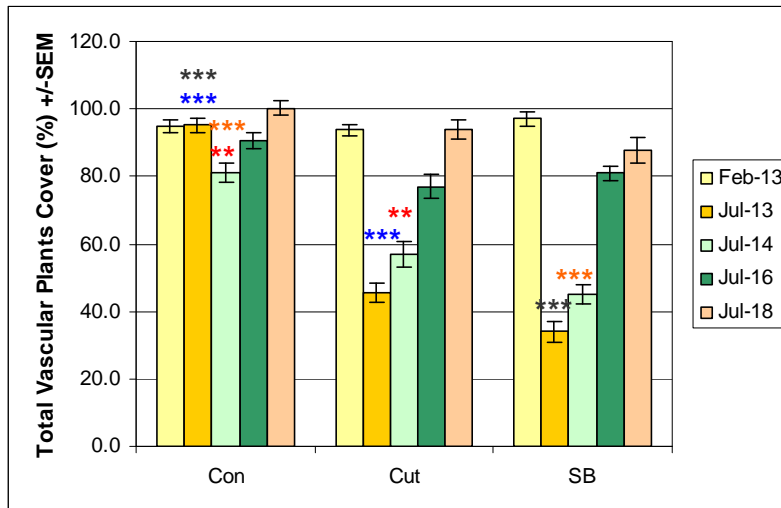
Figure 8 The Cover of Cross-leaved Heath in the Plots



3.18 The analysis for deergrass (*Trichophorum cespitosum*) has returned an overall significant difference ($p = 0.002$) but there are no statistically and ecologically significant pairwise interactions. The cover of deergrass reaches a mean of 6.1% in July 2018 in the control areas, but the standard errors are very high, indicating that the data are very variable.

- 3.19 The analysis for total vascular plants (Figure 9) returned a statistically significant result when the data was assessed over time ($H = 233.45$ d.f. = 14, $p < 0.001$). In general terms, the treatments reduce overall cover for the first two post-treatment monitoring years, but after this vegetation recovers to similar baseline levels. These changes reflect the differences observed in the relative balance of dwarf shrubs to cottongrass cover previously discussed.

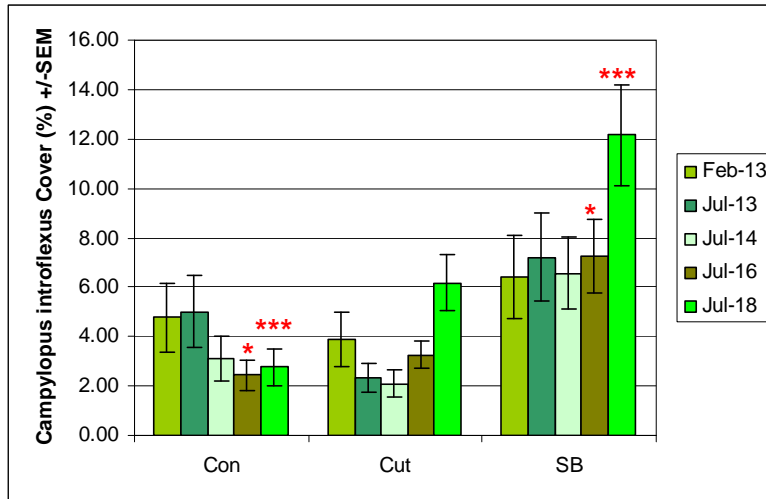
Figure 9 The Total Cover of Vascular Plants in the Plots



Bryophytes

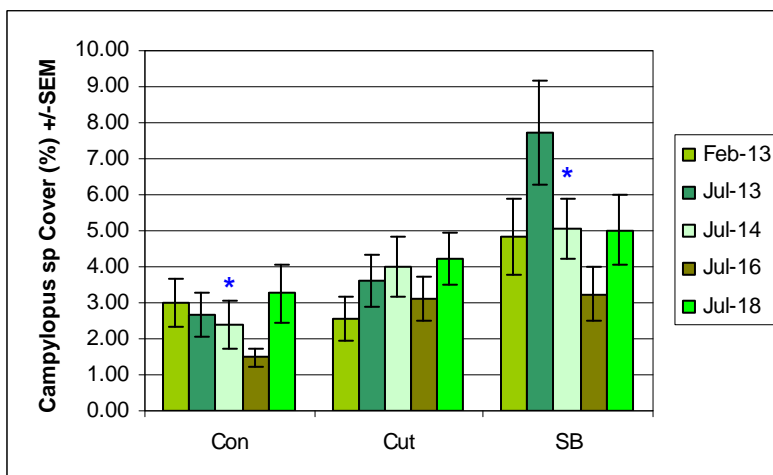
- 3.20 The main mosses on the site are *Hypnum jutlandicum* and *Campylopus* species. There are several species of *Sphagnum* and at least six other moss species recorded at low cover, generally less than 1%.
- 3.21 Overall *Hypnum jutlandicum* cover showed no statistically significant differences over time ($H = 20.859$, d.f. = 14, $p = 0.105$). *Hypnum jutlandicum* is the main moss species in these plots, varying from around 20-35% cover. There are small changes in the cover within each plot over the monitoring period but they are neither consistent nor significant. However, the distribution of this species impacts on the overall bryophyte cover analysis, as it is the major component.
- 3.22 The other key moss is *Campylopus*. The monitoring only separated *Campylopus introflexus* from other species in the group as this is an early coloniser of bare peat and it is the main species on the moor. Statistically significant differences were returned overall for *Campylopus introflexus* ($H = 57.971$, d.f. = 14, $p < 0.001$). There are two ecologically relevant results and these are the declining cover in the control plot and the increasing cover in the spring burn plot which result in significant differences between these two plots (Figure 10).

Figure 10 The Cover of *Campylopus introflexus* in the Plots



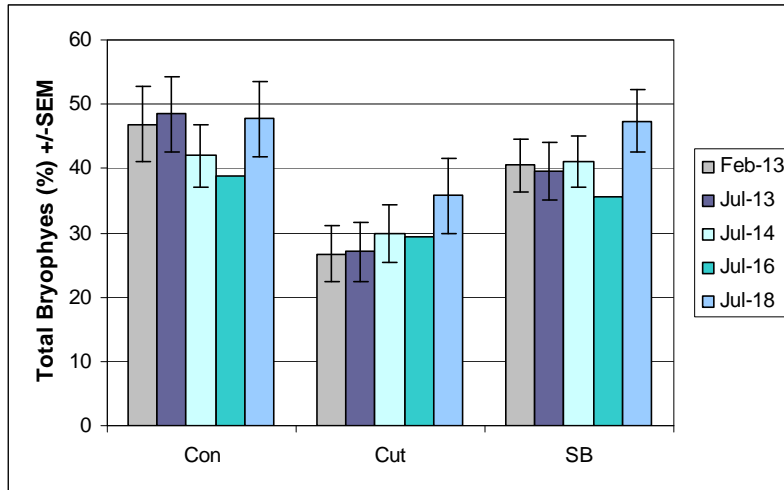
- 3.23 Both treatments show a trend towards increasing cover of *Campylopus introflexus* over time, perhaps typical for an early coloniser of disturbed peatland habitats. The lack of a similar trend in the untreated control indicates that this species has been favoured by the treatments, in particular the burning.
- 3.24 The analysis of the combined class of *Campylopus* species (other than *Campylopus introflexus*) also returned a statistically significant result ($H = 42.094$, d.f. = 14, $p < 0.001$) with only one ecologically relevant pairwise interaction, which is between the control and spring burn plot in July 2014. This result is not easily explained, as the data between these two plots would appear to have been more obviously different in July 2013 but is not significant (Figure 11).

Figure 11 The Cover of All Other *Campylopus* Species in the Plots



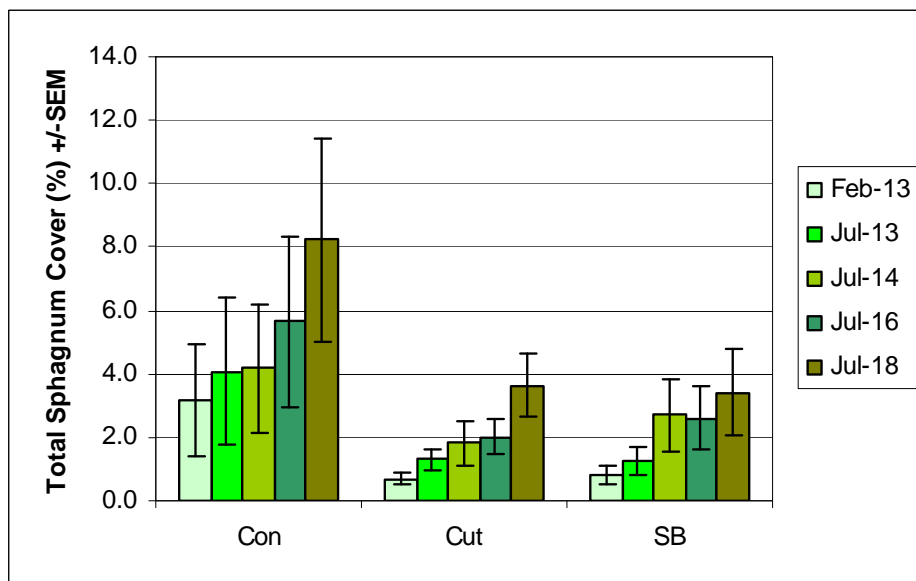
- 3.25 Overall changes in total bryophyte cover are statistically significant over time ($H = 37.00$, d.f. = 14, $p < 0.001$), but there are no pairwise statistically and ecologically significant results and remarkably little change overall considering the treatments applied. The differences between plots appear to be greater than within each plot (Figure 12).

Figure 12 The Total Cover of Bryophytes in the Plots



3.26 *Sphagnum* has been recorded throughout the monitoring but at low levels. The analysis shows no statistically significant differences in the distribution of *Sphagnum* (Figure 13).

Figure 13 The Total Cover of *Sphagnum* in the Plots



3.27 Despite there being no statistically significant results, the graph shows a trend towards increasing *Sphagnum* cover in all plots over time. The control appears to have a considerably higher cover of *Sphagnum*, but this cannot be attributed to lack of disturbance as these differences are seen in the baseline data. The large error bars likely indicate the patchy nature of the *Sphagnum* cover in the plots, however, the overall the trend of increasing cover is of interest.

Bare Ground and Heather Litter Cover

- 3.28 Baseline bare ground cover in the plots was low (less than 2%). Overall, the analysis of bare ground over time has given a highly statistically significant result ($H = 86.365$, d.f. = 14, $p < 0.001$) but ecologically significant pairwise interactions are few.
- 3.29 Following the treatments there was an increase in bare ground in the plots but this was statistically significant in the spring burnt plot only ($p = 0.05$). Bare ground continued to increase significantly each year within the burn plot (Figure 14), with a similar non-significant trend in the cut plot. The mean cover of bare ground in 2018 remains low, the maximum value is just under 6%, and is not of concern as there are no signs of erosion. The overall increase in bare ground is possibly linked to the reduction in heather litter (see Figure 15 below)

Figure 14 The Bare Ground Recorded in the Plots

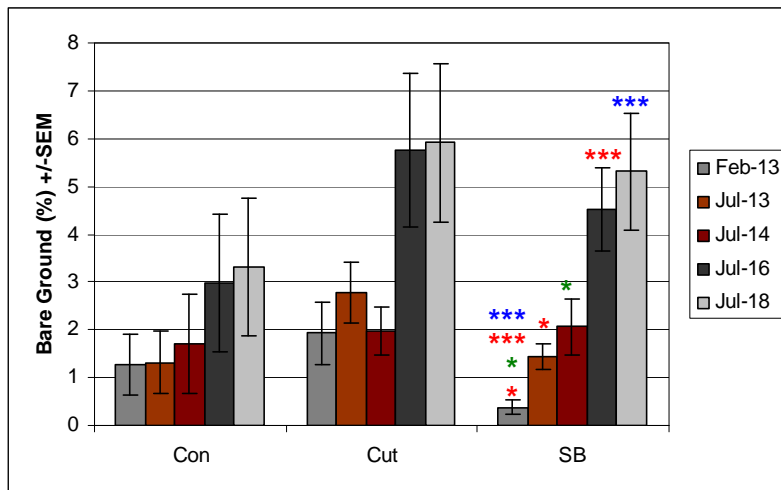
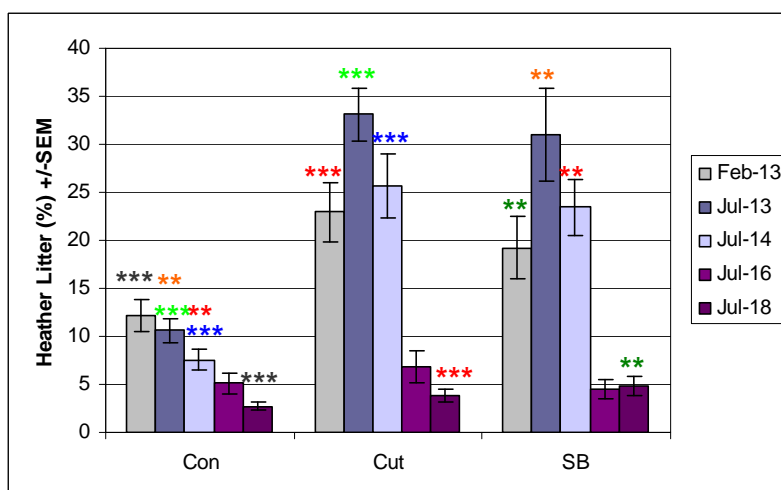


Figure 15 The Heather Litter Recorded in the Plots



- 3.30 Overall, the change in cover of heather litter over time produced a statistically significant result ($H = 192.891$ d.f. = 14, $p < 0.001$). Pre-treatment (February 2013) there were no significant

differences in heather litter cover in the plots, however, following the cutting and burning treatments, the litter cover on both treated plots had increased significantly compared to the control plot, due to brash created by the cutting and an increase in dead and broken stick from the burn.

- 3.31 There is a significant difference in the litter cover between the control and both treated plots in 2014 (Figure 15) but there is no difference between the treatment types. By 2016 litter cover is at very low levels and remains low in 2018 with no statistically significant difference between the treatments and the control plots detected. The increase in heather litter is therefore largely a temporary effect of the treatments.
- 3.32 Within both treatments there is an overall reduction in litter cover from 2014 onwards. Levels of litter were relatively high at the start of the monitoring, partly attributable to the effects of heather beetle, but there were no 'in plot' significant results until 2016 when the overall cover fell dramatically in the treated plots and remained low in 2018 (Figure 15, significances not shown). This decline in heather litter cover was also seen in the control between February 2013 and July 2018.
- 3.33 The trend in the increase in litter in the treated plots immediately after treatment was expected as the litter was left on the site after cutting, and following a cool burn there is a lot of heather 'stick' remaining which will break off with time but remains on site as dead material. The subsequent declining cover is again expected as the litter breaks down further or is removed from the site by the weather. The dramatic decrease in heather litter in 2016 appears to coincide with an increase in bare ground, although the scale of the decline in litter is significantly more than the increase in bare ground.

Conclusions for Crag Estate

- 3.34 The decline in heather cover seen in July 2013 immediately after the treatments has resulted in a low heather cover for the first two years following treatment. Heather cover in the control also declined rapidly in the first two years as the beetle-damaged heather dies and is re-classified as litter if it remains on the site. Heather cover in the control plot has fallen from 59.2% to 25.1% - more than halving in three years. This has not increased significantly in the following two years, in part because of a further infestation of heather beetle.
- 3.35 The cover of regenerating heather increased significantly in the treated plots compared to the control after only four months, and this increase continued in each monitoring period to July 2016 after which regenerating heather was not recorded separately. There are also statistically significant differences between the treatments with more new heather regenerating in the burn plot in July 2014 and July 2016 compared to the cut plot.
- 3.36 Three years after treatment (July 2016) there was an average cover of 10.4% regenerating heather in the cut plot and 29.6% in the burn plot. The results show that on Crag Estate the spring burning of heather damaged by beetle gives a greater cover of heather in the three or four years after treatment, compared to cutting. By 2018 the heather cover no longer shows significant differences between the treatments as the cover has increased slightly in the cut plot and declined in the burnt plot.
- 3.37 Total heather in the treated plots is not significantly different to the control plot five years after treatment, due to the reduced cover of heather in the control plot following repeat beetle infestation. This means that the treating of the beetle-damaged heather (by cutting or burning) on this site has not significantly increased its cover compared to having left the vegetation to develop on its own, where heather beetle continues to be active on the moor.
- 3.38 There has been a trend of increasing common cottongrass in all plots since the start of the monitoring and it is statistically significant over the monitoring period in the treated plots. The treatment and drastic reduction in heather, the dominant species on site, may have stimulated

an increase in common cottongrass expansion due to a lack of competition with the other vegetation. However, as the control plot also exhibits this behaviour, albeit more weakly, there is likely to be some effect from a wider decline in heather cover in the control plot (from 59% in February 2013 to 25-28% in July 2016 – July 2018) due to beetle infestation.

- 3.39 Hare's-tail cottongrass shows an overall statistically significant increase in cover in all plots during the monitoring. However, there are very few pairwise statistically significant results and no ecologically meaningful between plot interactions. The general increase in hare's-tail cottongrass across all plots could be related to the decline in heather cover following the beetle attack (in the control) along with the removal of heather by treatments where these occurred, allowing more space/light for the cottongrass to expand.
- 3.40 Wavy hair-grass has continued to increase in all plots over time with all significant differences occurring within and not between the plots. The initial increase was attributed to the seasonal difference between the monitoring periods (February to July 2013). The later increases (between July 2013 and July 2016) may, as for common cottongrass, be related to the reduced heather cover in all plots enabling this species to expand in cover.
- 3.41 Total vascular plant cover is increasing in the treated plots following the drastic reduction after treatment. The cover is approaching the pre-treatment level and there is no longer a significant difference between pre-treatment levels and 2018 levels in any plots. This indicates a convergence of the vegetation cover to original levels, albeit with slightly different plant species dominant (i.e. less heather and more cottongrass).
- 3.42 There were no statistically significant differences detected in the cover of *Hypnum jutlandicum* across the plots. There are a few statistically significant results in the *Campylopus* categories but they appear to be mainly within, rather than between, plots. Previous suggestions made in earlier analyses and reports that spring burning may reduce the cover of *Hypnum jutlandicum*, or that there is an increasing cover of *Campylopus* species in the plots which received the spring burn treatment, no longer have any statistical basis - any changes were either very short-lived or weak (i.e. not withstanding the addition of an extra dataset).
- 3.43 *Campylopus introflexus* cover has increased in the last two years and is significantly higher in the burnt plot than the control (as it was in 2016), although as this is a long time (five years) after treatment it could be directly related to the burn treatment.
- 3.44 Although there are no statistically significant results to date, there is a trend of increasing *Sphagnum* cover in all plots but values remain low (<8% cover on average).
- 3.45 The cover of bare ground is generally low, with less than 6% cover in July 2018. Neither treatment caused sudden large increases in bare ground which shows care had been taken when applying treatments. In the spring burn there has been an overall significant increase in bare ground during the five years of monitoring, but not high enough to raise concern regarding erosion risk.
- 3.46 The cover of heather litter has followed the expected pattern, with an increase following cutting and burning treatments and a subsequent decline as the material decays or is lost from the site. Heather litter cover in all plots is currently less than 5%.

Combs Moss

- 3.47 There are three very different areas included in the trials on Combs Moss (Area 1, 2 and 4 see Table 2 for more details). The Areas are very different in character and have had different treatments and are described separately below. Each Area had only 1 plot for each treatment with 8 quadrats in each plot. As described in Section 2, the delay in the burning treatment in Areas 1 and 3 means that the plots on Combs Moss are no longer synchronised in terms of monitoring years.

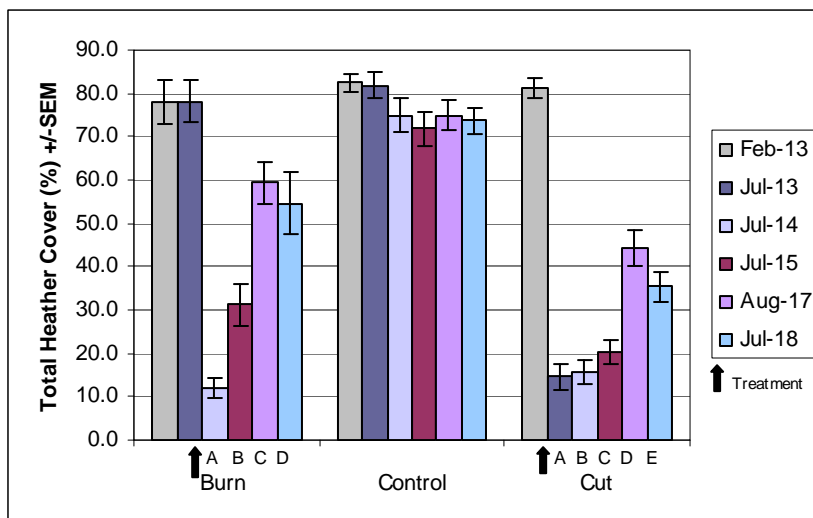
Area 1

- 3.48 Area 1 was initially dominated by mature heather and consists of three plots - one cut (March 2013), one burnt (Dec 2013), and one untreated control. The results of the statistical analysis are presented in Table 5. The two treatments are separated by a growing season and therefore the same monitoring period does not relate to an equal time after treatment. To simplify the results in Area 1 the monitoring periods have been given a code (A-E) to indicate which are equivalent in time after treatment (summarised in Table 3 in Section 2).
- 3.49 This area was subject to a further attack of heather beetle in 2017 and therefore it was decided to re-survey the site in 2018 to see if additional effects on the vegetation could be identified.
- 3.50 In the baseline data analysis, *Hypnum jutlandicum* (a moss) was the only species that was statistically significantly different between the three plots in an ecologically meaningful way. The cover was found to be significantly lower in the plot to be burnt before the treatments were undertaken.

Dwarf Shrubs

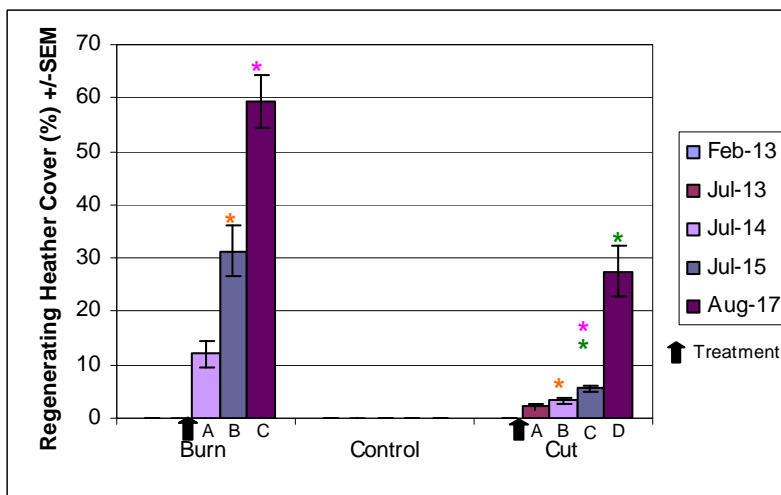
- 3.51 As was the case for the plots on the Crag Estate, the difference between 'old' and 'regenerating' heather was indistinct by 2018, therefore all heather is assessed together. Overall there was a statistically significant difference comparing the cover of heather in the plots over time ($H = 114.577$, d.f. = 17, $p < 0.001$). Heather cover declined sharply following treatment (Figure 16), from around 80% baseline cover. By July immediately after treatment (monitoring period A in both treated plots) the combination of regenerating and uncut heather in the cut plot totalled 14% whilst in the burnt plot heather cover was 12%, all of which was regenerating heather as it had been a clean burn.
- 3.52 There are no statistically significant pairwise comparisons, however, a number of comparisons were close to significant levels. The closest was the reduction in cover of heather immediately after burning ($p = 0.059$). Clear trends can be seen in Figure 16 with a rapid decline in heather cover after both treatments followed by an increase as heather regenerates, particularly after burning. The cover of heather in July 2015 in the burn plot was 31%, well above the 20% level in the cut plot, despite the fact that the cut plot had been treated a year earlier and therefore had more time to recover.

Figure 16 The Cover of Heather in Area 1



- 3.53 Heather regeneration was recorded in the treated plots until 2017, after which the plants became too similar to the existing plants to separate them with confidence. The discussion below is based on the results of the cover of heather regeneration up to 2017.
- 3.54 In the baseline dataset for all plots, there were no heather regeneration/seedlings recorded and for the untreated control plot this remained the case throughout the monitoring period. There were, however, statistically significant differences over time with the overall analysis ($H = 117.436$, d.f. = 14, $p < 0.001$) resulting from the effect of the treatments.
- 3.55 On the cut plot, heather regeneration showed a small but steady increase over time after treatment (Figure 17, July 2013 to July 2015 or monitoring periods A-C). This increase was statistically significant for these years when compared to the February 2013 baseline data ($p < 0.05$).
- 3.56 In August 2017 the heather cover in the cut plot increased significantly ($p < 0.05$) from the July 2015 cover and had reached an average cover of 27.5% five growing seasons after cutting, but with most of this growth occurring between the last two monitoring periods over two growing seasons (2016 and 2017).

Figure 17 The Cover of Heather Regeneration in Area 1



- 3.57 Similarly, after burning, heather regeneration increased significantly compared to the baseline dataset ($p < 0.05$) (significances not shown on Figure 17), reaching an average cover of 59.4% four growing seasons later. Growth appeared fairly even throughout the monitoring period, rather than showing the delayed response as seen after cutting.
- 3.58 The treatments were a growing season apart, with the cutting taking place in March 2013 and the burning in December 2013. This needs to be taken into account when comparing the effects of the two treatment types. Comparing the burn and cut treatments, we find there is no statistically significant difference in the cover of regenerating young heather in the first growing season after treatment (monitoring period A).
- 3.59 However, in the second and third growing seasons after treatments (monitoring periods B and C) there was a statistically significant difference ($p < 0.05$) between treatments, with more regenerating heather being recorded in the burnt plots.
- 3.60 These results show that in both the second and third growing seasons after the treatment there was significantly more heather regeneration in the burnt plots than the cut ones. Put another

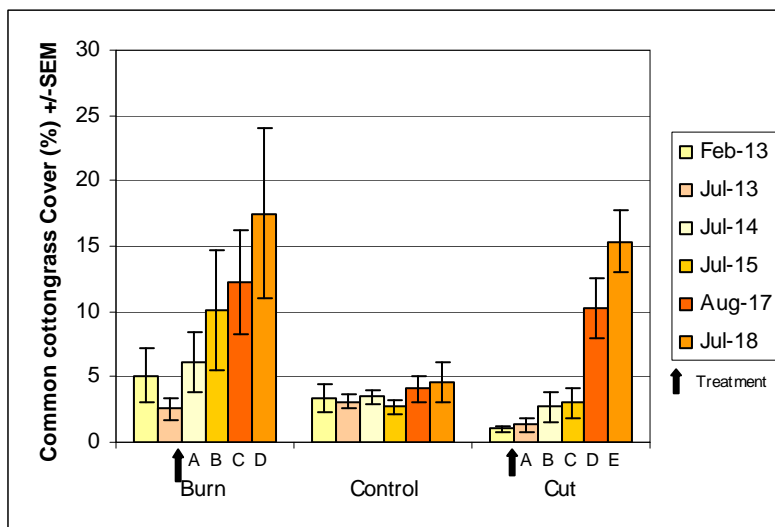
way: after cutting, a plot took four years to reach just under 30% cover, while after burning a plot reached this cover easily within two years.

- 3.61 Heather is the main dwarf-shrub species in Area 1 and trends in total dwarf shrub cover reflect this extremely closely, the figure of distribution of dwarf shrubs is almost identical to that given for total heather cover. There are highly statistically significant differences in total dwarf shrub cover across all plots over time ($H = 113.922$, $d.f. = 17$, $p < 0.001$) but again none of the pairwise comparisons are statistically significant at the $p < 0.05$ level, although the trends were still very evident for total heather cover, as described above.

Other Vascular Plants

- 3.62 Overall, common cottongrass cover showed some statistically significant differences over the monitoring period ($H = 58.648$, $d.f. = 17$, $p < 0.001$), but there are no pairwise significant results. There was, however, the clear trend of increasing cover in the treated plots compared to the control (Figure 18). The increase in common cottongrass appears to be fairly even over time in the burnt plot, whilst there is a delay in the cut plot until monitoring period D, five growing seasons after treatment.

Figure 18 The Cover of Common Cottongrass in Area 1

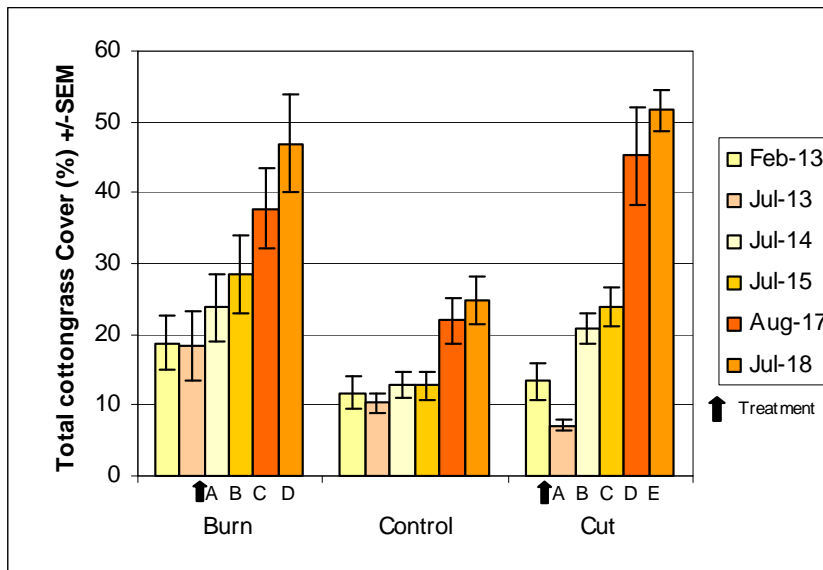


- 3.63 In this area of Combs Moss, hare's-tail cottongrass is the more abundant cottongrass species and the pattern of the hare's-tail cottongrass and total cottongrass results were essentially very similar. The analysis of the cover of hair's-tail cottongrass, while significant overall ($H = 63.497$, $d.f. = 17$, $p < 0.001$), showed no statistically significant pairwise results. There is a trend of increasing cover in the treated plots, with a roughly even incremental increase for the burnt plot, whilst the cut plot is more of a stepwise increase with the first step in monitoring period B (two growing seasons after treatment) and the second in monitoring period D (five growing seasons after treatment).

- 3.64 The total cottongrass category indicated overall significant changes ($H = 88.203$, $d.f. = 17$, $p < 0.001$), again with no significant pairwise interactions but strong trends (Figure 19). There is a trend of increasing cover of all cottongrasses from a low cover immediately after cutting (July 2013). The burnt plot shows no decrease in cover of cottongrasses following the burn, suggesting that the cottongrass retains a good presence, even after burning, and can recover rapidly. The control plot shows a higher and increasing cover of cottongrasses in August 2017

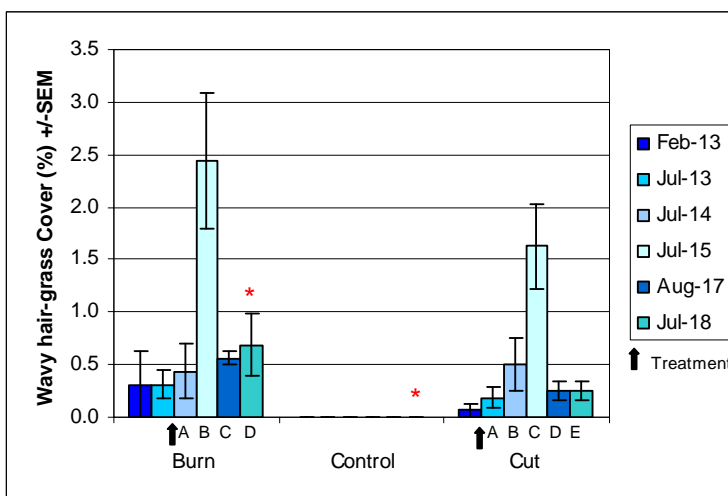
and July 2018, predominantly hare's-tail cottongrass, but there is no treatment stimulus for the increase. It is interesting to note that a similar trend with increasing overall cottongrasses was also seen on the Crag Estate trial site. This is likely to be because the cottongrass is exploiting the space/light available due to the reduction of heather post-treatment, but why the cover has increased in the control is unclear, as there is no substantial decline in heather cover in this control plot.

Figure 19 The Total Cover of Cottongrass in Area 1



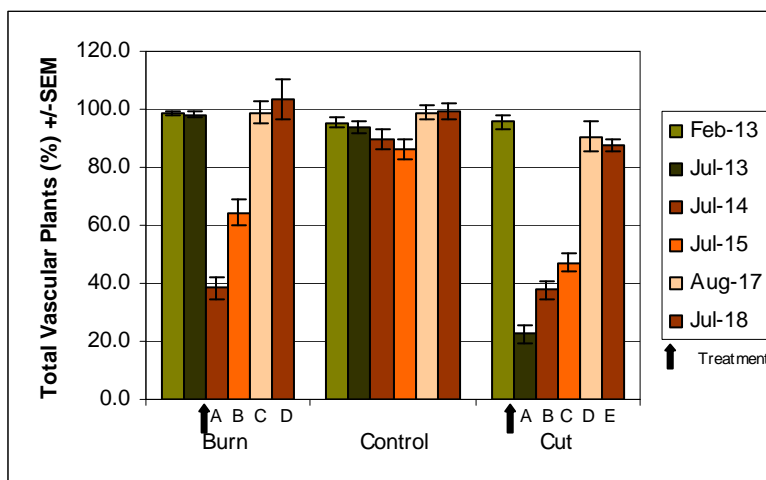
3.65 Overall, wavy hair-grass showed a statistically significant change in cover over time across all plots ($H = 70.404$, $d.f. = 17$, $p < 0.000$), with one statistically significant pairwise interaction which does not appear to have any ecological relevance (Figure 20). Cover was initially very low (typically less than 1%), reaching a maximum average cover of 2.44% in the burn plot in 2015 before again decreasing to $< 1\%$.

Figure 20 The Cover of Wavy Hair-grass in Area 1



- 3.66 Heather and cottongrasses are the main species in the vascular plant category and, therefore, have a large impact on the cover of total vascular plants. Overall, the analysis showed a highly statistically significant difference over time ($H = 101.269$, $d.f. = 17$, $p < 0.000$), but there were no ecologically meaningful pairwise comparisons that were statistically significant.
- 3.67 Following the cutting or burning, all treated plots had a reduced vascular plant cover as expected, but by July 2018 the total cover was very close to the baseline (Figure 21). On this site, after burning, the vascular plant cover had returned to levels similar to the pre-burn situation within four (or less) growing seasons, whilst on the cut site the same has been achieved in five (or less) seasons. As with Crag Estate, the complement of species changed slightly, with cottongrasses becoming more prevalent in the vegetation.

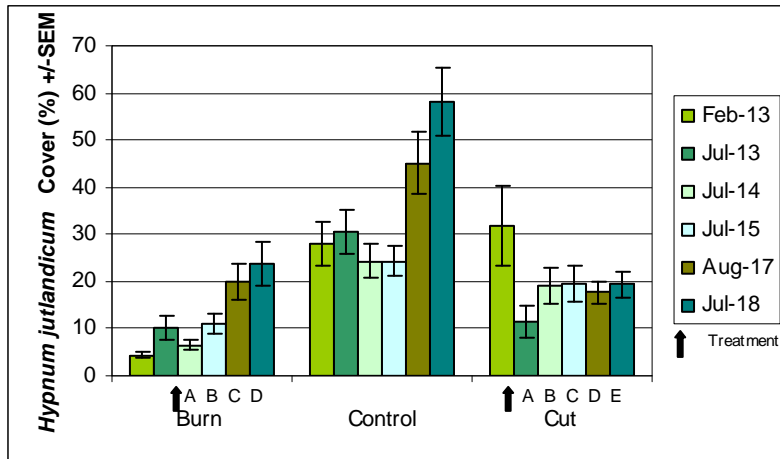
Figure 21 The Total Cover of Vascular Plants in Area 1



Bryophytes

- 3.68 Analysis of the moss species showed a number of statistically significant differences in the cover of different species over time (Table 5). However, for most of these species, the cover was low and the pairwise analyses showed that the differences were unrelated to the treatments undertaken and not ecologically meaningful.
- 3.69 *Hypnum jutlandicum* showed statistically significant differences across all plots over time ($H = 74.587$, $d.f. = 17$, $p < 0.001$) (Figure 22) but there were no significant pairwise comparisons. Some trends were discernable. There appears to be a decline in cover immediately after both treatments with a subsequent trend towards a recovery in the cut plot, and exceeding the original cover levels in the burnt plot. In the last two monitoring periods there also seems to be an increase in *Hypnum* in the control which is not related to any experimental intervention.

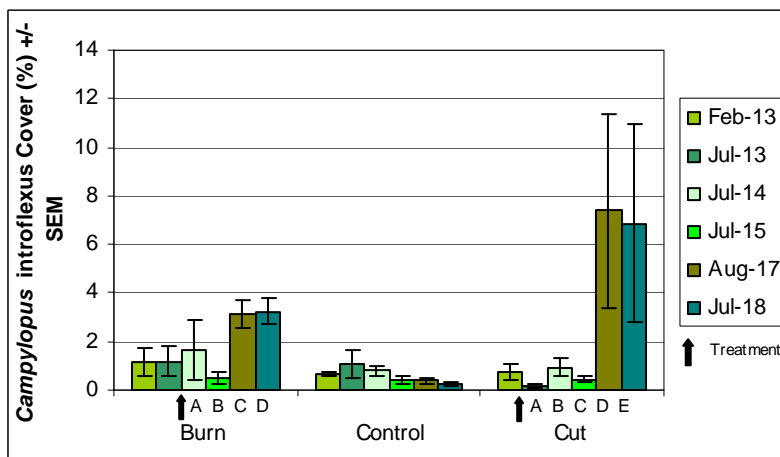
Figure 22 The Cover of *Hypnum jutlandicum* in Area 1



3.70 *Hypnum jutlandicum* is the main bryophyte species and changes in its cover are mirrored by changes in the overall bryophyte category. The changes in cover of the 'total bryophyte' group are statistically significant when assessed across all treatments over time ($H = 80.761$, d.f. = 17, $p < 0.001$) however, again there are no significant pairwise interactions.

3.71 The other main moss species which recorded a statistically significant result was *Campylopus introflexus* ($H = 68.369$, d.f. = 17, $p < 0.001$) but again with no statistically ecologically significant pairwise interactions. This moss is indicative of disturbed areas and is often associated with bare ground and burning. There appears to be an increasing cover in the cut plot in July 2017 and 2018 but the standard errors on these data are very high indicating that the results are variable and conclusions are therefore difficult to draw (Figure 23). A similar trend of increasing *Campylopus introflexus* cover can also be seen in the burn plot in 2017 and 2018.

Figure 23 The Cover of *Campylopus introflexus* in Area 1

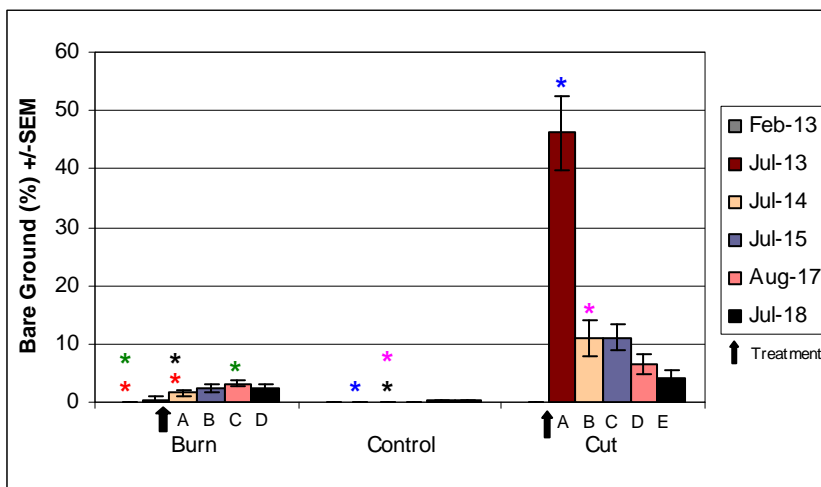


3.72 *Sphagnum* cover is variable in the different plots with no significant results and large errors associated with the mean percentage cover indicating patchy occurrence and cover within the plot. The maximum cover was 7.56% in the control plot in 2018. There are no clear trends in the dataset.

Bare Ground and Heather Litter Cover

- 3.73 Analysis of bare ground cover has resulted in statistically significant differences over time ($H = 121.476$, d.f. = 17, $p < 0.001$) and the changes are shown in Figure 24. There are several ecologically meaningful pairwise statistically significant results.
- 3.74 Statistically significant differences occur between the control plot and cut plot in the first two years following treatment ($p < 0.05$) with the cut plot having higher cover values. There are further differences within the cut plot with the pre-treatment cover being significantly lower than all post-treatment years except for 2018 (significances not shown on Figure 24).

Figure 24 The Cover of Bare Ground in Area 1



- 3.75 Figure 24 shows a gradual but small increase in bare ground on the burn plot over time. Some of these years are statistically higher than the baseline year, but all cover values are low (<5%).
- 3.76 In conclusion, cutting has, in this case, created substantial bare ground (46%) immediately after treatment but this reduced fairly rapidly within a year and to similar levels to the baseline six growing seasons later. In contrast, burning created very little bare ground (maximum 3.35%) on these plots.
- 3.77 Despite these statistically significant results, the situation on the ground is that there are small pockets of bare ground and a general trend of decreasing bare ground in the cut plots. The level of bare ground is not of concern to the integrity of the habitat and could, in some situations, be beneficial to future recruitment of heather seedlings. Alternatively, the bare areas could be exploited by non-desirable species establishing, such as *Campylopus introflexus*. The treatment shows that cutting can cause considerable temporary damage in some instances.
- 3.78 The analysis of heather litter cover returned a statistically significant overall result ($H = 118.840$, d.f. = 17, $p < 0.001$) but there are no pairwise significant results. Heather litter cover was initially quite high (70% in the burn plot) and variable between plots (February 2013) and since then the cover has generally declined in all plots irrespective of treatment.
- 3.79 In all plots the cover of heather litter had fallen to 2% or below by 2017 but then increased, more than doubling, in all plots from 2017 to 2018. This increase in heather litter although not statistically significant is likely due to the effect of the new heather beetle attack killing heather plants over this period.

Conclusions for Combs Moss Area 1

- 3.80 Heather cover declined significantly in the cut and burn plots following treatment. Heather regeneration has been substantial on the burn plot reaching 59.4% in August 2017, but appears to have levelled out or declined slightly after this, possibly as a result of further beetle attacks. The cut plot also supports a recovering heather cover, but at a lower value of 44.4% in 2017 (five seasons after treatment) and also appears to show a slight decline from 2017 to 2018. There are no significant changes in the data in the current analysis.
- 3.81 Burning promoted a higher level of heather regeneration than cutting, over a shorter time period (four growing seasons after burning compared to five growing seasons for cutting).
- 3.82 Total cottongrass cover, and hare's-tail cottongrass specifically, appears to be increasing above the baseline in both treated plots, suggesting both treatments may have facilitated its expansion. In the last two years, however, there is a slight, but not statistically significant, trend towards increased cover in the control too.
- 3.83 Wavy hair-grass cover increased temporarily in July 2015 in both the treated plots, but fell in August 2018 and remains very low. The only statistically significant pairwise interaction is between the burn plot and the control in July 2018, the burn plot having more wavy hair-grass than the control.
- 3.84 The distribution of several mosses has altered significantly over the recording period but none provided statistically ecologically significant pairwise interactions. The changes in *Hypnum jutlandicum* indicate that the inter-plot variation is stronger than any treatment effect. Results from *Campylopus introflexus* and total *Campylopus* species suggest that there is a trend towards this moss expanding in the cut plot in later years, which may be linked to the reduction in bare peat cover.
- 3.85 Bare ground increased significantly to 46% on the cut plot after treatment, although it fell substantially again the following year to 11% and has continued to decline slowly over the following years. Burning did not show the same rapid increase. It is currently at an acceptable low level on both treated plots.
- 3.86 There was a general decline in heather litter on all plots during the monitoring, but this does not seem to be related to the timing of any treatments. The decline, even in the cut plot immediately after cutting, shows that in some situations the build up of litter after cutting may not occur.

Area 3

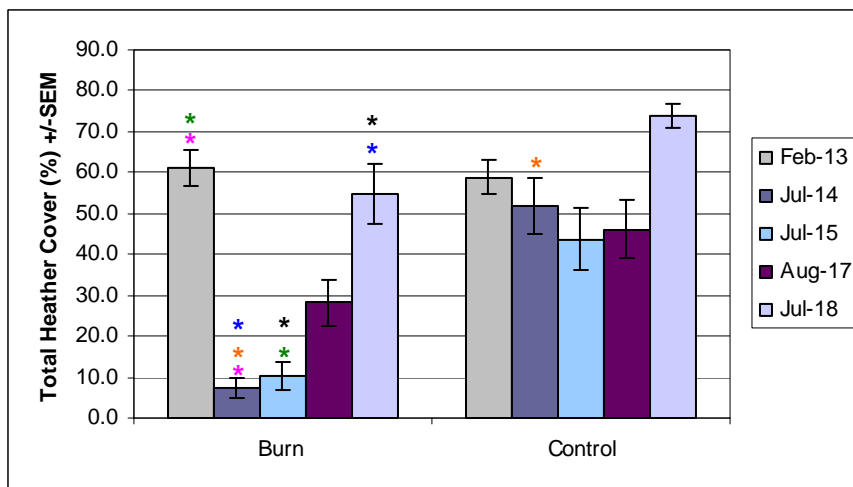
- 3.87 Area 3 is a small area which was, at the start of the experiment, dominated by pioneer/building heather and co-dominant in places with hare's-tail cottongrass. Common cottongrass and bilberry (*Vaccinium myrtillus*) are patchily distributed across the area. The main mosses are *Campylopus* species with *Hypnum jutlandicum* frequent (both species were substantially more predominant pre-treatment in the burn area than the control) and occasional *Sphagnum* species.
- 3.88 The small size of Area 3 meant that there was only space for a control and a burn treatment within this patch of uniformly-aged heather. The heather here had been affected by beetle some years ago, and was burnt and regenerating well before being attacked again by beetle. This damaged heather is much younger (five to six years old at the start of the experiment) than heather which would normally be burnt in typical grouse moor management, and it was uncertain as to whether there would be enough material to burn.
- 3.89 The burn took place in December 2013 with only one baseline dataset (February 2013). The burn was rather patchy leaving a proportion of the existing heather still alive. There are five sets of monitoring data for this area, a baseline in February 2013 and post-treatment monitoring in July 2014, July 2015, August 2017 and July 2018. The results of the statistical analyses are

presented in Table 6. This area was known to have had a heather beetle infestation in 2017 and the resurvey in 2018 was primarily to see if there were changes to the cover of the vegetation attributable to the effects of the beetle.

Dwarf Shrubs

- 3.90 The cover of heather in the baseline was lower (c.60%) in this area than in the mature heather dominated area of Area 1, Combs Moss (c.80%). Heather declined significantly, as expected, following the burn treatment to 7.6% increasing slightly to 10.4% in July 2015 and increasing much more rapidly in the subsequent monitoring periods with statistically significant differences across all plots over time ($H = 48.739$, $d.f. = 9$, $p < 0.001$) (Figure 25).
- 3.91 The statistically significant pairwise interactions were all at the $p < 0.05$ level. They were between the pre-burn baseline year and the first two post-burn years and also between the first two post-burn monitoring results (July 2014 and July 2015) and the final monitoring in July 2018. The significant results are due to the fall in heather cover following treatment, the relatively slow recovery in the second year post treatment (July 2015), and subsequent increases in August 2017 and July 2018 which were not significantly different to the baseline.
- 3.92 There was a slight trend towards a decline in heather cover in the control during the monitoring to 2017, which was reversed in 2018. There was only one significant result in the cover of heather between the treated and control plots, in the year immediately post treatment (July 2014).

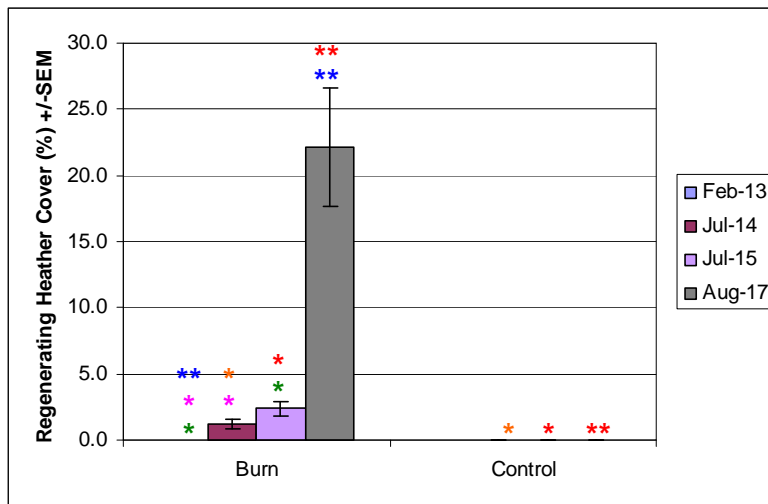
Figure 25 The Cover of Heather in Area 3



- 3.93 By 2018 the differentiation between regenerating heather and total heather was hard to see and the heather categories were amalgamated. However, to recap, no heather regeneration was recorded in the baseline year for either plot, or in the control plot in the subsequent monitoring years. However, on the burn plot, heather regeneration was recorded with a very low overall mean cover of 1.2% seven months after treatment, increasing to 2.4% 19 months on, with a further substantial increase to 22.1% by August 2017 (Figure 26). The analysis showed that there was a statistically significant difference in heather regeneration ($H = 56.649$, $d.f. = 7$, $p < 0.001$), with heather regeneration only occurring on the treated plot.
- 3.94 Although heather regeneration was over 20% four growing seasons after the burn, the rate of regeneration appears to be much slower than in Area 1 (Figure 17), which achieved a cover of around 60% four years after burning. This is likely to be related to the relatively high competition

from other species in Area 3 (the heather cover being considerably lower than in Area 1 when the treatment was applied) and, possibly, the lower seed bank in the younger heather stand in Area 3.

Figure 26 The Cover of Regenerating Heather in Area 3



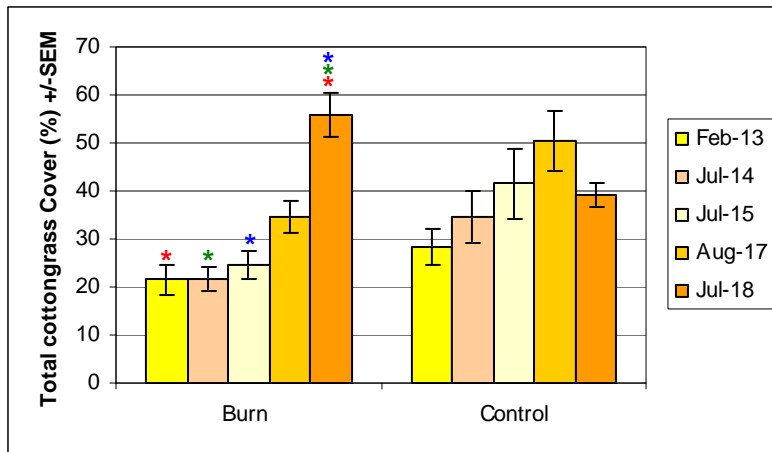
- 3.95 As heather is the main dwarf shrub in this area the total dwarf shrub cover closely reflects the results of the heather analysis and returned statistically significant differences over time ($H = 44.461$, d.f. = 9, $p < 0.001$).
- 3.96 As was the case for total heather, the pairwise comparisons for total dwarf shrub cover pre- and post-burn are significant at the $p < 0.05$ level in July 2014 and July 2015, but there is no significant difference by August 2017 or July 2018. The immediate post treatment cover (July 2014) is significantly different to that recorded in July 2018 whilst the difference between July 2015 and July 2018 is not significant but very close to the threshold ($p = 0.051$).
- 3.97 There is also a significant difference in cover immediately post-burn between the trial plot (July 2014) and the equivalent control in the same period. However, the slight increase in heather cover in the burn plot in July 2015, and the continuing decline of heather in the control, has resulted in no statistically significant difference in the second post-burn monitoring period, which continues in subsequent years as the heather cover increases.

Other Vascular Plants

- 3.98 The results of the analysis for common cottongrass were not statistically significant (Table 6) and cover in the plots is low, less than 8%. As with other areas on Combs Moss, hare's-tail cottongrass is the more abundant cottongrass species here.
- 3.99 Hare's-tail cottongrass, and therefore total cottongrass, show overall statistically significant results (Table 6). Only one pairwise interaction for hare's-tail cottongrass was statistically significant, between the pre-burn cover and the higher cover in July 2018. The total cottongrass analysis returned additional statistically significant results between the post treatment levels in July 2014 and 2015 and the final monitoring results in 2018 (Figure 27). These interactions were close to being significant for hare's-tail cottongrass ($p = 0.057$ and $p = 0.058$ respectively).
- 3.100 There are no significant differences with the control plot in any year indicating that the treatment had no impact on the cover of cottongrass. There is a trend of increasing total cottongrass in both plots (Figure 27). This trend has also been seen in the other trial areas (Crag Estate and

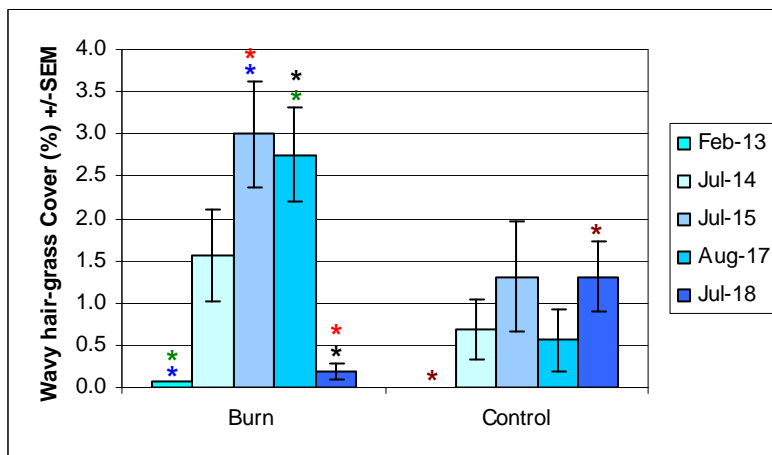
Combs Area 1) supporting the suggestion that there is an environmental factor involved in the increase, not solely the treatment applied.

Figure 27 The Cover of Total Cottongrass in Area 3



3.101 Wavy hair-grass shows an overall statistically significant change in cover ($H = 43.679$, $d.f. = 9$, $p < 0.001$). Cover was very low in the February 2013 monitoring (max 0.1% cover, Figure 28) and increased to 1.6%, 3% and 2.75% in July 2014, July 2015 and August 2017 respectively on the burn plot before falling again in 2018 to 0.2%. The control tends to vary around c.1% over time.

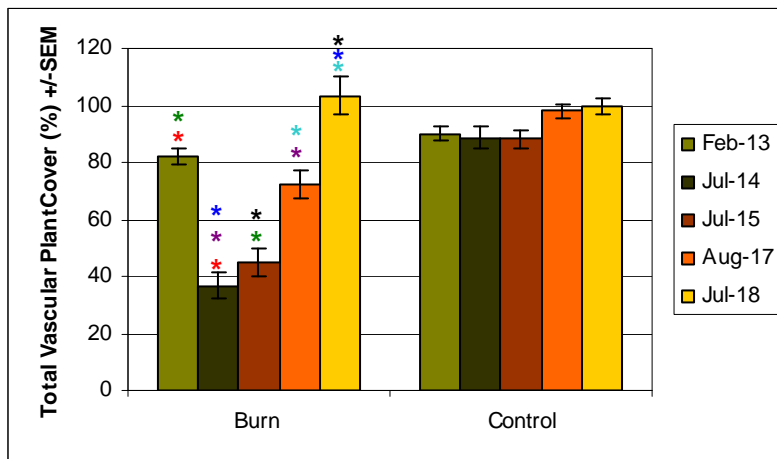
Figure 28 The Cover of Wavy Hair-Grass in Area 3



3.102 It has been suggested earlier in this report that the increase in cover from February 2013 to July 2014 in both plots relates to the alteration of the monitoring period from February to July (thereby reflecting seasonality of plant growth). This hypothesis is strengthened as there was no statistically significant change between the cover in the control and burnt plot immediately after treatment. All statistically significant results relate to changes within a plot rather than between the treated and untreated plots.

- 3.103 Vascular plant cover was found to be significantly reduced in the treated plot compared to the untreated control ($p < 0.05$) in the first two years post-treatment (Figure 29, significances not shown) and close to significant for the third year (August 2017, $p = 0.052$). In 2018 the cover of total vascular vegetation has increased and there is now no significant difference between the treated and untreated plots five growing seasons after treatment. The significant differences in cover after burning in the burn plot also reflect this initial reduction and then re-establishment of vegetation cover.

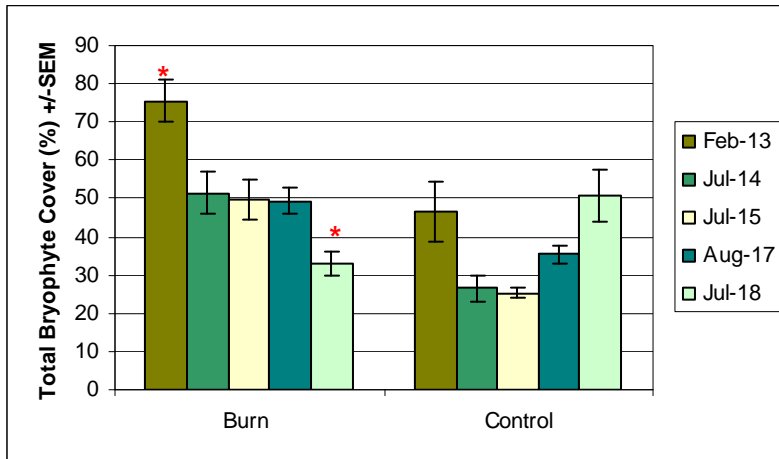
Figure 29 The Total Cover of Vascular Plants in Area 3



Bryophytes

- 3.104 Analysis of the moss species showed statistically ecologically significant differences in the cover of only one moss group, *Campylopus* species. The pairwise analysis showed that the difference was a decline in cover from the baseline (23.9%) to August 2017 (2.25%) and July 2018 (1.56%). A similar trend in declining *Campylopus* species has occurred in the control plot too, indicating there is no significant treatment effect in this case.
- 3.105 Total *Sphagnum* cover is not statistically significant different across this dataset. It reaches a maximum mean cover of 5.2% in the control plot in July 2018 and a maximum mean cover of 5.13% in the burn plot in July 2015. There are no clear trends in changing cover throughout the monitoring period. The high standard errors of the means likely indicate the patchy nature of cover of this group of mosses.
- 3.106 The trend of decreasing cover throughout the monitoring period reported for *Campylopus* species is also seen for *Hypnum jutlandicum*, but only within the burnt plot. The cover of *H. jutlandicum* in the control plot varies very little until a spike in cover occurs in July 2018 (not significant).
- 3.107 As the two main mosses show a trend of declining cover in the burnt plot and a relatively even cover in the control plot, it is unsurprising that this is the pattern of the total bryophyte cover (Figure 30). This analysis returns a statistically significant result ($H = 42.314$, d.f. = 9, $p < 0.001$) but the significant pairwise comparisons relate to the reduction in moss cover over time in the burn plot, rather than differences between the control and treated plot.

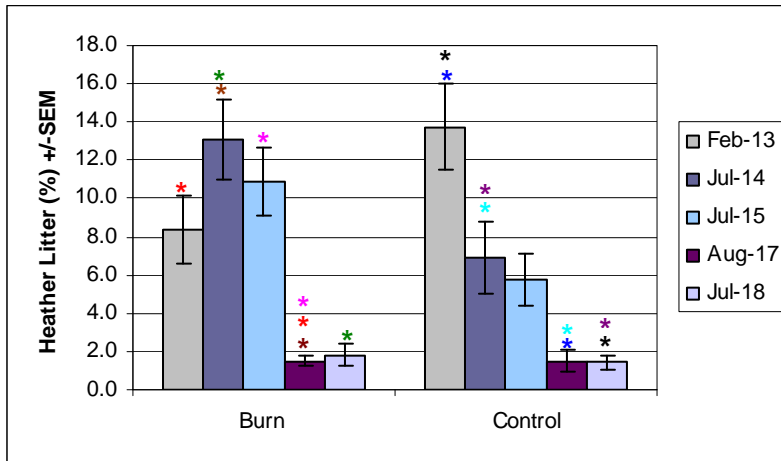
Figure 30 The Total Cover of Bryophytes in Area 3



Bare Ground, Open Water and Heather Litter Cover

- 3.108 Analysis of change in the cover of bare ground has not produced any statistically significant results. However, open water shows an overall statistically significant result (Table 6). The only pairwise statistically significant difference is a reduction in the amount of open water between August 2017 and July 2018 in the control plot. This is likely to be directly related to the wetness of the summer in August 2017 and the drought in July 2018 when no open water was seen on the control site.
- 3.109 Analysis of heather litter returned an overall statistically significant result ($H = 55.516$, $d.f. = 9$, $p < 0.001$). The cover of litter has fallen dramatically since July 2015 in both the burnt and control plots (Figure 31) and all pairwise statistically significant results ($p < 0.05$) relate to this decline in heather litter cover within each plot.
- 3.110 The control plot shows a continuous decline in heather litter, whilst the burn plot showed a temporary and non-significant increase in the litter cover after treatment before a steady decline. No statistically significant differences were detected between plots. The decline in heather litter cover is very similar, although starting from a much lower baseline, to that seen in Combs Moss Area 1.

Figure 31 The Cover Heather Litter in Area 3



Conclusions for Combs Moss Area 3

- 3.111 The heather cover declined significantly in the burn plot following treatment. Heather regeneration was initially very slow but increased dramatically in August 2017 (22%), albeit with less compared to the equivalent time on the burnt plot in Area 1 (59%) despite both burns being undertaken on the same day. This difference may relate to the patchy nature of the burn in Area 3 with lower fuel loads prior to the treatment and/or to the young heather not regenerating as well as the older heather in Area 1 (for example, if the seed bank was more depleted).
- 3.112 The heather in the burn plot has re-established to pre-burn cover and after five growing seasons is within 7% of the baseline. There has been no reduction in total heather cover in 2018 despite the presence of heather beetle in that year.
- 3.113 There is no significant change in the cover of common cottongrass following burning treatment but there were significant results for hare's-tail cottongrass and total cottongrass cover. There is an overall trend of increasing cottongrass cover in the burn treatment with a significant result between the baseline cover and that recorded in 2018. There also appears to be a trend towards increasing cottongrass in the control plot, as was the case in Area 1, but it is not statistically significant.
- 3.114 The distribution of wavy hair-grass has altered significantly over time, with an initial trend towards an increasing cover over the four years following burning and a subsequent decline in 2018. The control plot remains at a fairly stable, low cover.
- 3.115 Total moss cover has declined in the burn plot over the period of the trial ($p < 0.05$) although again, there are no significant results between the treated and control plots suggesting the changes may not be treatment related. A similar initial decline in bryophyte cover in the control plot from February 2013 to July 2013 (not statistically significant) suggests other factors may be influencing this apparent trend, along with a limited impact of the burning.
- 3.116 Overall there was a decline in heather litter on all plots during the monitoring, but no between plot significant results, suggesting that the treatment had no significant effect on the cover of heather litter.
- 3.117 The effect of burning vegetation previously dominated by young building heather appears to have had only limited impact on the different elements of the vegetation cover five growing seasons on. By August 2017 and July 2018 the total cover of dwarf shrubs and total vascular plants are not significantly different to the levels recorded prior to the burn. However, the total

cover of cottongrasses is statistically significantly higher than the baseline, while total cover of bryophytes is significantly lower.

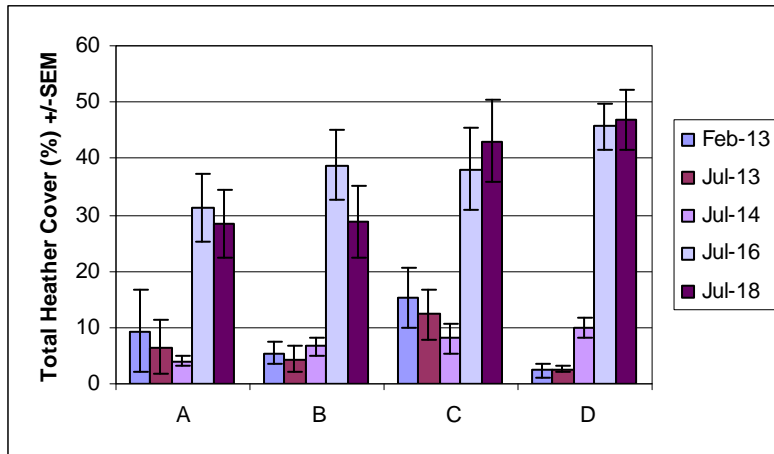
Area 4

- 3.118 Area 4 was dominated by cottongrasses, with very little heather and more than 10% bare ground at the start of the trials. This vegetation had developed from heather-dominated vegetation which was attacked by heather beetle, the damaged heather was then burnt and then the young re-growth was subsequently attacked once again and killed by a further outbreak of heather beetle.
- 3.119 Four plots (A to D) were chosen to act as replicates, although the analysis of the baseline (February 2013) data showed there were some statistically significant differences between the cover of heather, total dwarf shrubs, *Hypnum jutlandicum*, *Sphagnum fimbriatum*, total bryophytes and bare ground between plots at the start of the trials. Therefore the plots are treated separately in the analyses.
- 3.120 The treatment was a heather seed application, undertaken in April 2013, only three months before the second monitoring period. The treatment did not disturb the soils, litter or moss layers and, therefore, the only expected significant results would be within any species categories directly related to heather cover. A control plot with no heather seed added was also included (Plot C).
- 3.121 Area 4 was monitored in February 2013 prior to treatment and then subsequently in July 2013, 2014, 2016 and 2018.

Dwarf Shrubs

- 3.122 The cover of heather in the plots is shown on Figure 32. In previous monitoring the old heather growth and regenerating heather seedlings were recorded separately, with only very low levels (less than 1% cover) of regenerating heather. This was to separate the heather which had established from seed, which may have been a result of the seeding treatment, or stem re-growth from the existing plants. In the current monitoring the heather cover was recorded as one class, as the previous seedlings were by now too well-developed to separate. Heather was therefore recorded as one class in 2018 and compared to the combined heather classes from previous monitoring periods.
- 3.123 When these data were analysed over time a statistically significant result was returned ($H = 104.587$, d.f. = 19, $p < 0.001$), however there were no statistically significant pairwise interactions. Heather cover was relatively low at the start of the monitoring period (c. 2-15%) and in the two subsequent periods, with only Plot D showing an increasing trend over this period. Two growing seasons later, in 2016, the heather cover had increased dramatically to between 31-45% in the four plots and remained at similar values (28-46%) in 2018. There is a clear trend, in all plots, of increasing heather cover over the four growing seasons.

Figure 32 The Cover of Heather in the Four Plots in Area 4

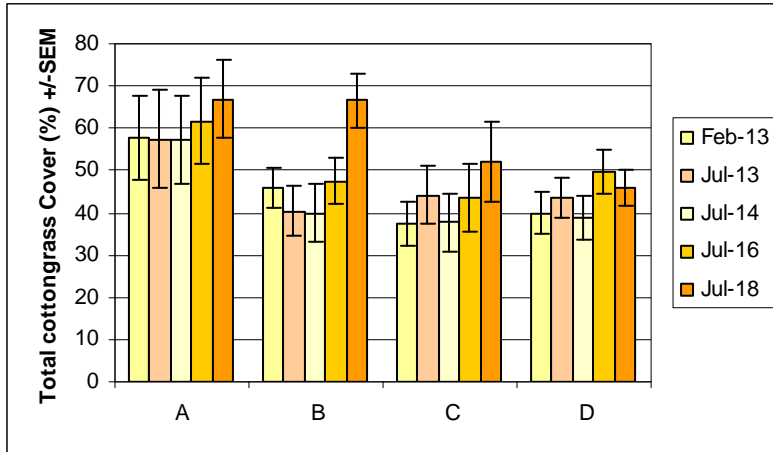


- 3.124 There is no indication that Plot C (the control that had no heather seed added) has a lower cover of heather than the treated plots. It would appear that on this site the addition of heather seed has not increased total heather cover five years/six growing seasons after it was sown.
- 3.125 In a previous report (PAA 2015) data relating to the cover of regenerating heather from seed was reported. In summary, there was an increase in heather from seed in July 2013 in all plots over the baseline levels (zero) but this had disappeared in all plots except Plot A where the cover was less than 1% by July 2014. It might be expected that a year and three months after adding heather seed there would be an increasing cover of regenerating heather from the seed. The lack of heather seedlings suggests that any seedlings which did germinate in summer/autumn 2013 or spring 2014 did not survive to July 2014. This may have been due to a drought in the spring of 2014, as this lack of heather seedlings was observed elsewhere in the area.
- 3.126 The increase in heather cover from July 2014 to July 2016 and sustained higher levels in 2018 is substantial, with all plots supporting over 30% heather cover three years after treatment. Heather seedlings were still regularly seen, but the majority of the heather cover increase is due to stem re-growth from existing plants.
- 3.127 The results for total dwarf shrub cover also follow closely the same pattern as heather (not shown), as heather is the dominant dwarf shrub species. The Kruskal-Wallis results, although overall statistically significant ($H = 103.751$, d.f. = 19, $p < 0.001$), again have no pairwise statistically significant interactions although the trend is similar to that for heather cover.

Other Vascular Plants

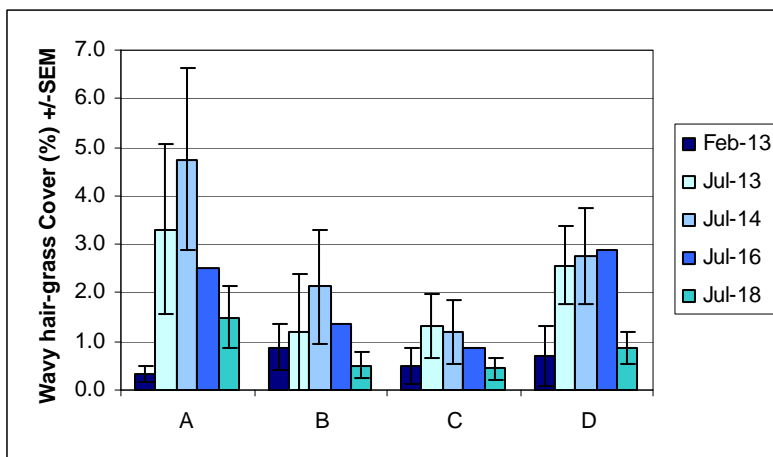
- 3.128 Of the other vascular plants recorded, common cottongrass, wavy hair-grass, cross-leaved heath and ferns (*Dryopteris* spp.) were the only other species to give statistically significant results when assessing differences between plots over time, but there were no pairwise significant results for any of these species.
- 3.129 Cottongrasses are the major vascular component of the vegetation in Area 4, hare's-tail cottongrass being the dominant species. Figure 33 shows the variation in mean cover of total cottongrass in the different plots over the course of the monitoring. In contrast with the other trial areas there is little evidence for a trend of increasing cover of cottongrass with time, although the most recent data, particularly in Plot B, does suggest a slight increase.

Figure 33 The Total Cover of Cottongrass in Area 4



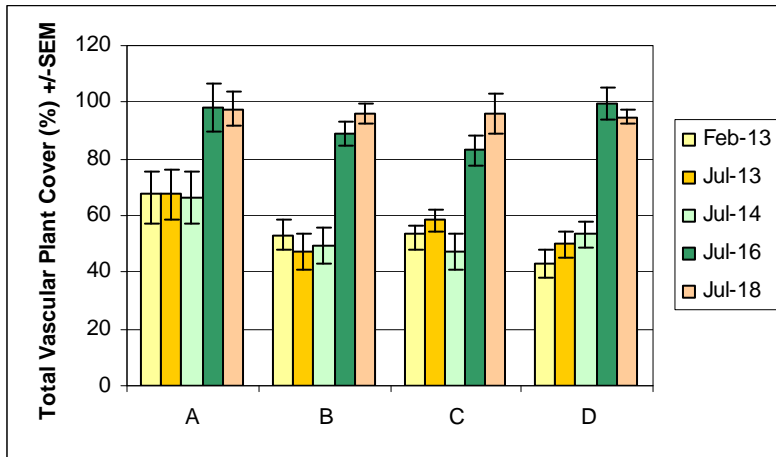
- 3.130 The cover of wavy hair-grass is low in all monitoring periods (reaching a maximum cover of 4.75% in Plot A in July 2014 (Figure 34), and in no period was there any significant difference in cover values between the plots. The trend of increasing grass cover between the baseline February 2013 and July 2013 is (as previously discussed) regarded as a seasonal effect of moving the monitoring to a period of the year when the grass cover is more developed.

Figure 34 The Cover of Wavy Hair-Grass in Area 4



- 3.131 Cross-leaved heath occurred only in Plot A until 2016 when it was also recorded in Plot B. It has increased in cover in Plot A from 0.31% in July 2014, when it was first recorded, to 2.06% in 2016, and has since declined to 0.69% in 2018. Despite the overall statistically significant result ($H = 52.56$, $d.f. = 15$, $p < 0.001$) there are no significant pairwise results.
- 3.132 The 'total vascular plant' group is mainly comprised of heather and cottongrass. The analysis for this group returned a statistically significant result overall ($H = 100.39$, $d.f. = 19$, $p < 0.001$), but despite this there are no significant pairwise interactions (Figure 35). It can be seen that until the July 2016 monitoring, the data looked very similar to that for total cottongrass cover (Figure 33) but in 2016 there is a sharp increase in cover which can be directly attributable to an increase in heather (Figure 32).

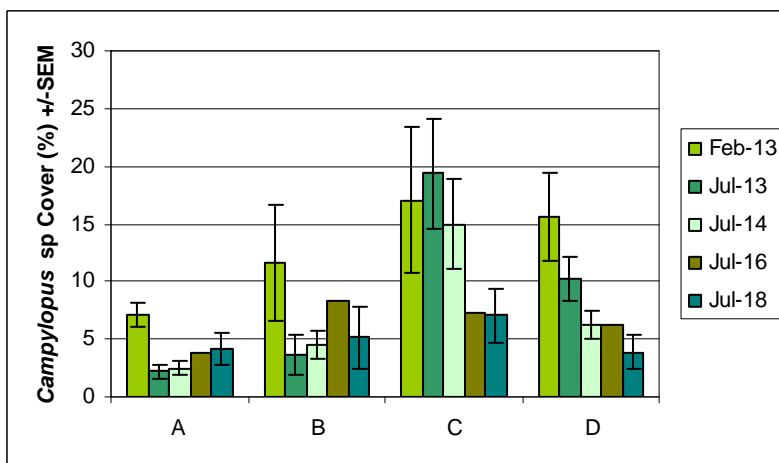
Figure 35 The Total Cover of Vascular Plants in Area 4



Bryophytes

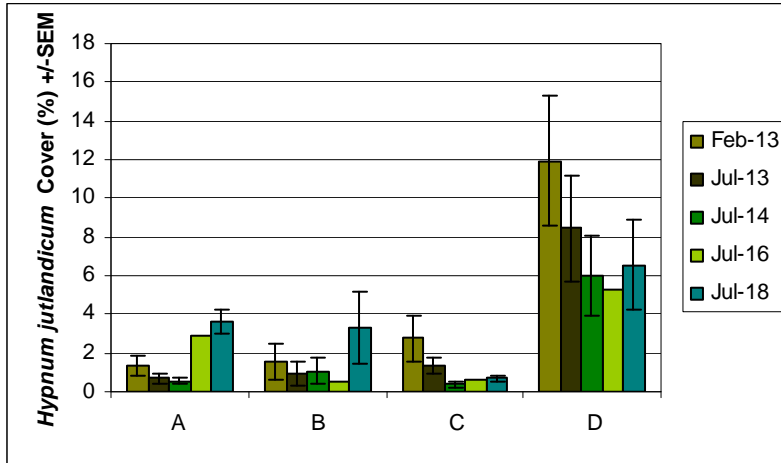
- 3.133 *Campylopus* species and *Hypnum jutlandicum* are again the major mosses occurring in this trial area, and their cover across the plots is shown in Figures 36 and 37. *Campylopus introflexus* is the most abundant *Campylopus* species recorded with cover values of 11-34%, however, the analysis for this species showed no statistically significant differences over time. The *Campylopus* group (i.e. all *Campylopus* species except *C. introflexus*) has a fluctuating cover over the monitoring period across the plots of 2-19%. There is a highly statistically significant difference over time overall in 2018 ($H = 58.37$, d.f. = 19, $p < 0.001$), but no significant pairwise interactions.

Figure 36 The Cover of *Campylopus* Species in Area 4



- 3.134 *Hypnum jutlandicum* cover also varies significantly over time ($H = 71.03$, d.f. = 19, $p < 0.001$), but again there are no significant pairwise interactions. There is a much higher cover of this moss in Plot D but this relates to the high and continued cover of *Hypnum jutlandicum* in the baseline data.

Figure 37 The Cover of *Hypnum jutlandicum* in Area 4

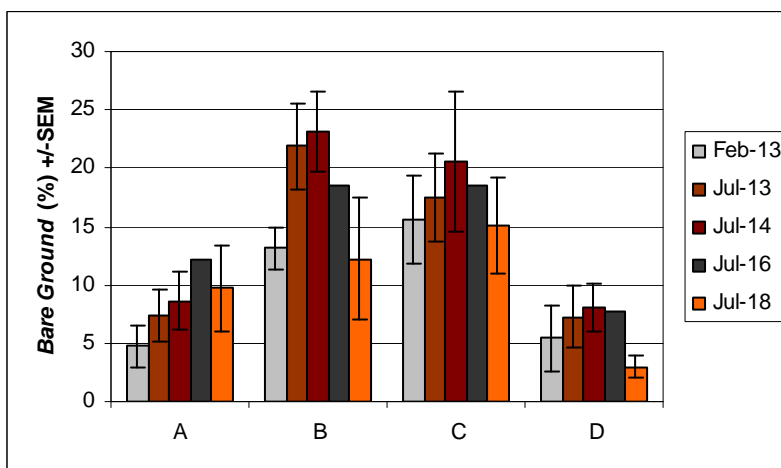


3.135 The liverworts, *Bryum* species, *Polytrichum* species, *Sphagnum* species and total bryophyte group all return statistically significant results (Table 7) but have no significant pairwise results, there is no obvious relation to treatment or with time for any individual plot.

Bare Ground and Heather Litter Cover

3.136 The cover of bare ground is significantly different between the plots over time ($H = 47.80$, d.f. = 19, $p < 0.001$) as it has been in the previous years' analyses, but again there are no pairwise significant results and no obvious trend across the plots although there is a slight indication of an increase and subsequent decrease in cover over time across the plots (Figure 38).

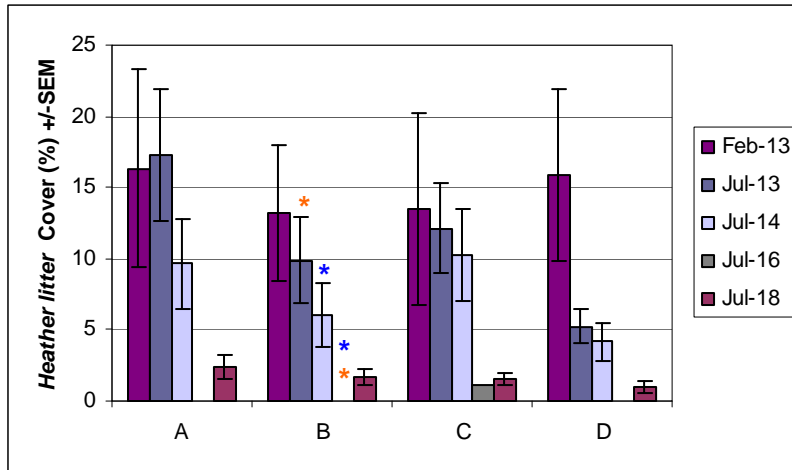
Figure 38 The Cover of Bare Ground in Area 4



3.137 There is a statistically significant difference in the cover of heather litter across all plots over time (Figure 39, Table 7). It is clear from the figure that there has been a sharp decline in the cover of heather litter since the start of the monitoring. This would be expected, given that there was a great deal of dead heather litter on the site initially from previous heather beetle attacks, and this will naturally break down but is not being added to significantly, as the heather is re-

growing and healthy. The significant results are related to the very low levels of heather litter in 2016, particularly in Plot B where none was recorded. The reason for this is not clear.

Figure 39 The Cover of Heather Litter in Area 4



Conclusions for Combs Moss Area 4

- 3.138 There are few statistically significant results within the analysis undertaken between the plots over time. For those which are statistically significant overall (i.e. the Kruskal Wallis statistic is significant at $p = 0.05$ or less) there are rarely any statistically significant pairwise interactions. Many of the significant differences encountered in the plots in Area 4 appear to be related to original differences in vegetation distribution rather than to any effect of the treatment.
- 3.139 The cover of heather litter is the only result that has pairwise significant results, and this should not be affected by the treatment as it was a non-invasive treatment, purely adding seed. The decrease in heather litter cover is a natural decline over time and could be anticipated following the natural decay of dead heather stems after the heather beetle attack.
- 3.140 Heather cover has increased substantially in all four plots from levels of 10% or less in 2014 to between 28-46% in 2018. It is apparent that the majority of this heather is regenerating from the vegetative re-growth of plants previously damaged by heather beetle.
- 3.141 There is no evidence that sowing heather seed on this site at this time has significantly increased heather cover on the plots compared to the untreated control plot (Plot C).

Occurrence of Heather Seedlings

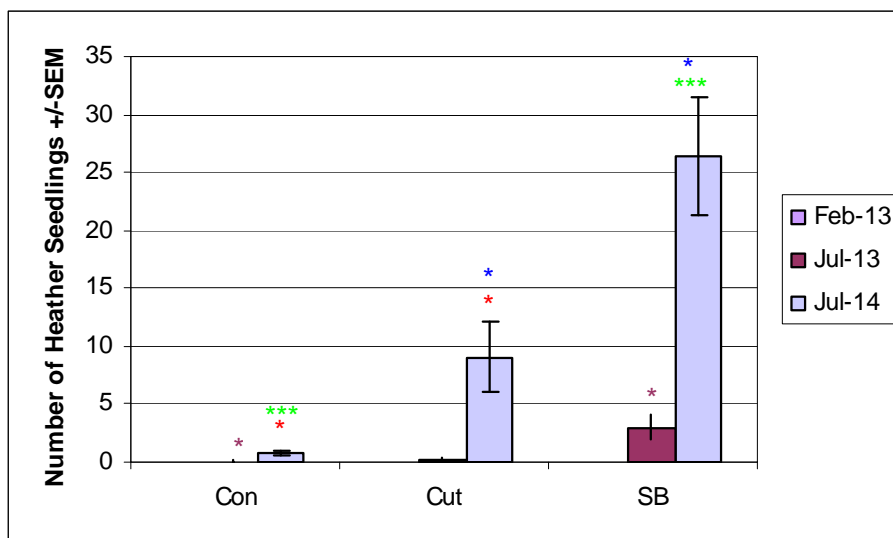
- 3.142 As part of the quadrat recording, at all sites the number of heather seedlings were counted in a 0.1m^2 quadrat located at the north-west corner of the main $2\text{m} \times 2\text{m}$ quadrat. A heather seedling was assessed as a seed which was no more than two years old, i.e. it was a very small, single-stemmed seedling, or having only developed a limited branched structure or typical 'Christmas tree' shape. The paucity of seedlings in February and July 2013 made this an easy decision; in July 2014 it was still relatively easy to determine seedling growth against stem regeneration but by 2016 it was much harder in those treatments and sites where heather cover had increased substantially.

- 3.143 The rationale behind monitoring seedling numbers is to monitor the recovery of heather from a seed source within the plots after the treatment has been applied. The number of heather seedlings within building/mature stands of heather is generally low until a perturbation of the vegetation occurs which enables seed germination.
- 3.144 It would be expected that there would be a significant increase in seedlings following a treatment, i.e. cutting, burning and sowing seed, but that this would, with time, decline as the seedlings develop into established plants. As other plants colonise, the bare ground seedlings are out-competed or may die due to other factors (drought, frost heave, grazing, etc.), and alongside this, levels of light reaching the ground and stimulating germination decline as the vegetation canopy closes over.

Crag Estate

- 3.145 The data analysis indicates there was a significant difference in the number of seedlings counted between the control and spring burn plots in July 2013, four months after the treatment ($p < 0.05$), and again in July 2014 ($p < 0.001$). The highly statistical significant result in July 2014 indicated that seedlings continued to germinate and establish up to 16 months after the treatment was applied (Figure 40).
- 3.146 There was no significant difference between the number of seedlings in the control and the cut plots in July 2013, four months after treatment. However, a year later there was a significant difference ($p < 0.05$) in the number of seedlings recorded in the control and cut plots and between the cut and burnt plots (Figure 40).
- 3.147 The results support the view that burning heather results in a larger number of heather seeds immediately after treatment than cutting heather. This difference is more pronounced 16 months after treatment due to more seedlings being recruited.

Figure 40 The Distribution of Heather Seedlings Within the Plots on Crag Estate

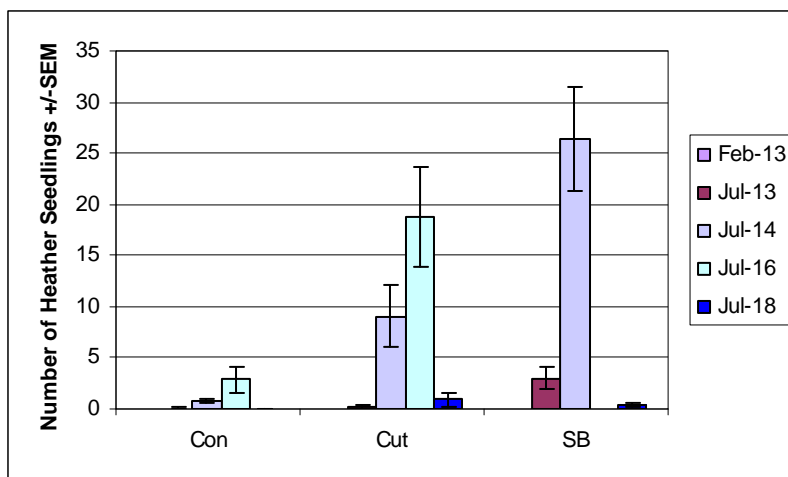


- 3.148 However, in subsequent years the seedlings in the burnt plot had increased significantly in size, so percentage cover rather than number was recorded. In the control and cut plot though, both measures were recorded. Figure 41 shows the number of seedlings in the cut and control plots in 2016 and in all plots in 2018, and there is a clear increase in number of seedlings in the cut

plot by 2016. Statistical analysis was not undertaken as only partial data was recorded but the graph shows that the heather seedlings continue to germinate in the cut area several years after cutting.

- 3.149 By 2018 the number of seedlings, i.e. plants under two years old had fallen dramatically in all plots.

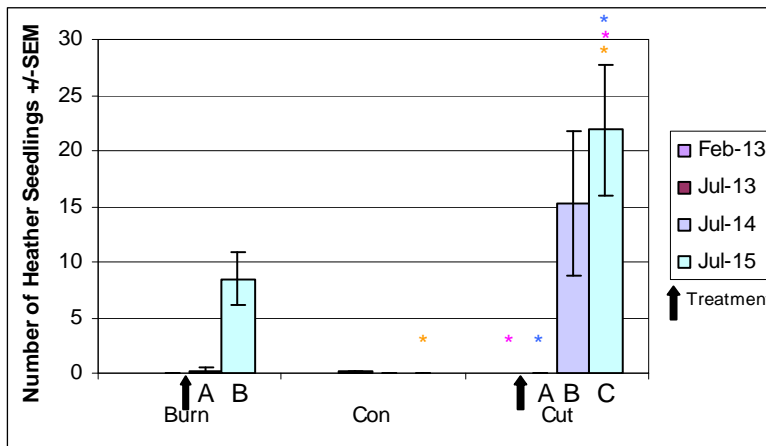
Figure 41 The Distribution of Heather Seedlings Within the Plots on Crag Estate



Combs Moss

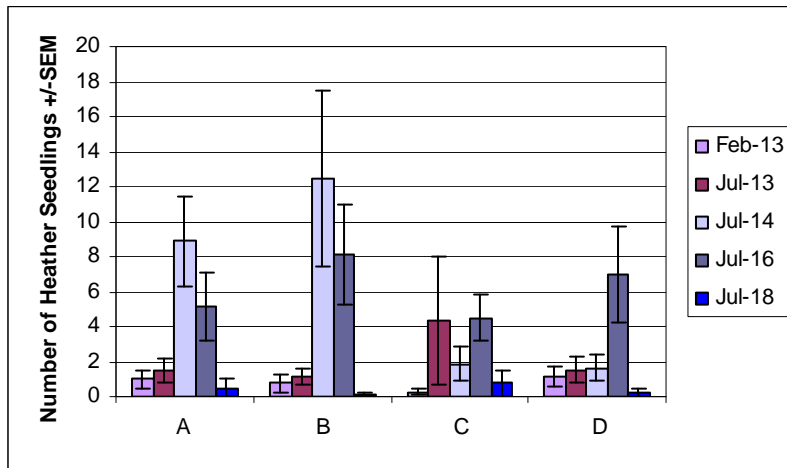
- 3.150 Heather seedlings were recorded in all the treated areas on Combs Moss throughout the monitoring period. However, the delays in the burn treatment in Area 1 and the difficulty in counting seedlings after 2015 in some plots makes these data hard to interpret with certainty.
- 3.151 A previous report (PAA 2016 January) showed that following burning or cutting of mature heather (Area 1) heather seedlings increased very slowly under both treatments in the first year, monitoring period A, (Figure 42).
- 3.152 In the burn plot, the average seedling count the following summer was 0.25, which then increased to 8.5 the following year. In the cut plot there was a season's lag before meaningful numbers of seedlings were seen, as was also observed at Crag Estate.

Figure 42 The Distribution of Heather Seedlings Within Area 1 on Combs Moss



- 3.153 This pattern for post-burn seedling establishment is very different to that recorded the year earlier on mature heather at Crag Estate where the burnt plots showed an immediate, significant increase in seedlings (Figure 41). This difference is likely to be best explained by marked differences in the weather in the two spring periods after burning and prior to monitoring, which has likely affected seedling germination and establishment.
- 3.154 In the younger heather (Area 3) the burnt plots showed a statistically significant increase in seedling numbers from the baseline level (February 2013) but this was not significant compared to increases in the control plots over the same period. It was suggested that the burn was light as there was little fuel with the young age of the heather and therefore many of the seeds did not break their dormancy, as temperatures in the fire were likely to be low and of a short duration. In addition, the burn was not 'clean' with much vegetation remaining on site so light levels were not significantly increased across the site.
- 3.155 The seedling results from Combs Areas 1 and 3 are not robust and no conclusions can really be made from this part of the trials.
- 3.156 In Area 4 on Combs Moss, the only treatment was heather seed addition. The relatively low cover of heather in the plot made the counting of seedlings possible for much longer than in other areas. In all years numbers of seeds were counted and the data is presented in Figure 43 below.
- 3.157 There was an overall statistically significant result when the data were compared for all plots over time ($H = 59.642$ d.f = 19, $p=0.000$). However, there were no statistically significant pairwise interactions.

Figure 43 The Distribution of Heather Seedlings Within Area 4 on Combs Moss



- 3.158 Figure 43 clearly shows a trend of increasing numbers of heather seedlings in Plots A and B to July 2014 with maximum numbers in that year and a subsequent decline. In Plot C the seedling numbers are highly variable whilst seedling numbers showed little change in Plot D until 2016 when the numbers appear to increase. Heather seed was added in April 2013 only three months before the July 2013 monitoring.
- 3.159 There is no consistent trend in heather seedling numbers which relates to the addition of seed on Plots A, B and D. Plots A and B have the greatest similarity, with peak numbers in July 2014 and a decline in 2016, although even here the error bars show a high degree of variability in the data. It is unclear why Area D is atypical of the trends seen in the other two plots where seed was added (Plot A and B).

Conclusions for Heather Seedlings

- 3.160 There are few heather seedlings amongst the building/mature, untreated heather on either Crag Estate or Combs Moss. The spring burning of the plots on Crag Estate resulted in an immediate and significant increase in the occurrence of heather seedlings in July 2013 and this difference continued to summer 2014.
- 3.161 By July 2014 there was also a significant increase in the seedlings recorded in the cut plot when compared to the control. However, this was significantly less than the number of seedlings in the burn plots. This indicates that there was a delay in the seedling establishment following cutting, but that cutting has resulted in more seedlings than no treatment of the heather.
- 3.162 In 2016 seedlings could still be counted in the cut plots and the numbers had continued to increase. The numbers of seedlings could not consistently be recorded in the burn plots due to the high heather cover, so statistical analysis was not possible.
- 3.163 The overseeding treatment (applied in April 2013) at Combs Moss Area 4 has not resulted in any significant or indeed consistent results compared to the control throughout the monitoring period. There was, however, a trend of increasing heather seedling numbers in two of the treated plots in July 2016, two years and three months after sowing.
- 3.164 It would appear that the heather seeding has failed on this site to significantly increase the seedling establishment consistently, but the cause of this is unclear as seeding is a well-

established and frequently successful technique. There may have been a problem with the seed, the hand sowing may have been uneven (the fixed quadrats being missed) or it could be that the weather conditions were unfavourable either immediately after sowing (washing the seed away) or in the following spring (drought).

- 3.165 However, despite the lack of a measurable effect from the seeding treatment in the 0.1m² sub-sample, there is a good cover of heather in the larger 2x2m quadrats (28-46% in 2018). Heather has regenerated from the base of plants and germinated from seed in those areas previously affected by heather beetle.

Heather Beetle Damage

- 3.166 In the first report of this project (PAA March 2013) the rationale and reasoning behind the creation of a 'Heather Damage Index³' was established. The Index (described in detail above in Section 2) is divided into six categories of heather damage. The Index was applied to all the permanent quadrats and an average level of damage determined in each plot in each monitoring period, which has resulted in detailed recording of the damage to heather. All heather damage figures were converted into a percentage of the total heather in each plot.
- 3.167 During the baseline data collection, the heather was broadly similar in structure, age and cover across all plots in all areas. However, after treatment the heather in the treated plots was young regenerating heather, whilst in the control plots it was mature heather.
- 3.168 No statistical analysis has been undertaken on the heather damage categories as this would put more importance on this measure than is warranted as it is an experimental measure. Trends observed in the datasets are, however, discussed.

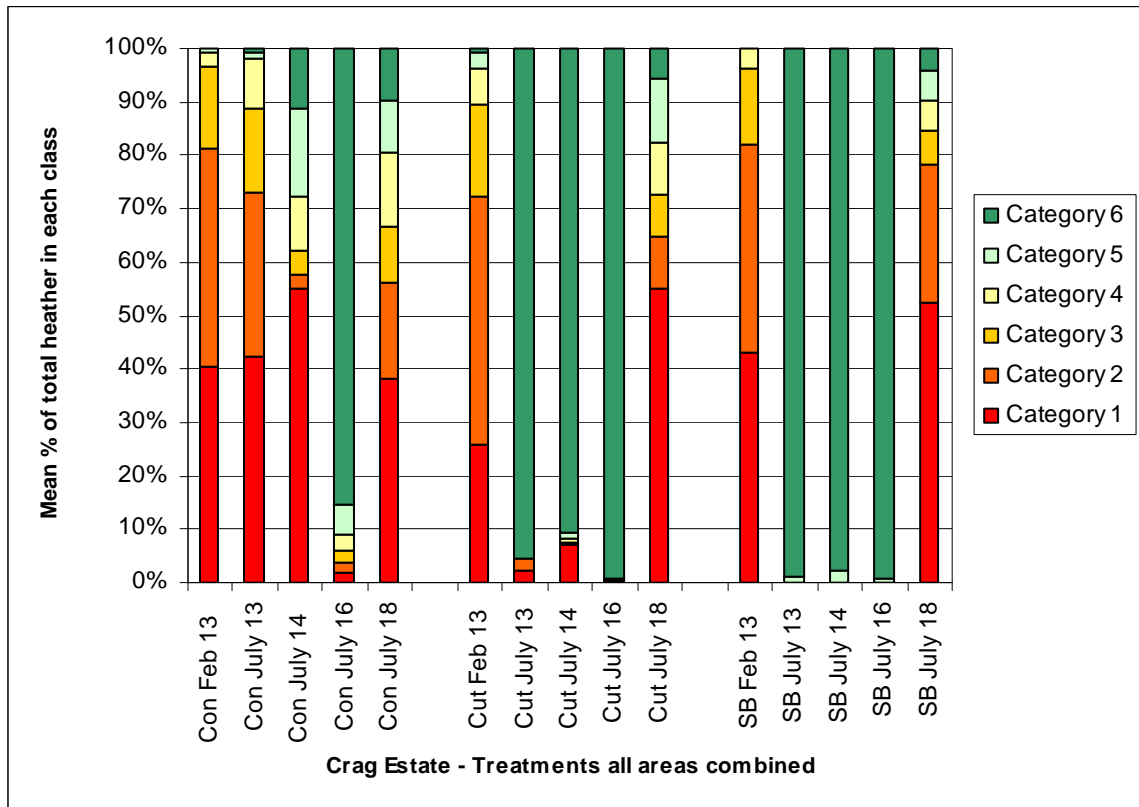
Crag Estate

- 3.169 In this report those data from the three areas at Crag Estate have been amalgamated. The columns show the percentage of total heather in each of the six categories. In Figure 44 those data for the sites at the start of the experiment (February 2013) show that in all cases over 70% of heather was in Categories 1 and 2, i.e. badly damaged (>75% heather dead and grey).

³

Category 1 = >75% heather dead, grey and brittle; Category 2 = >75% heather dead, grey but stem still green; Category 3 = 75-50% heather dead, grey; Category 4 = 50-25% heather dead, grey; Category 5 = <25% heather dead, grey; Category 6 = <5% heather dead, grey.

Figure 44 The Impact of Heather Beetle Damage in the Three Treatments on Crag Estate



- 3.170 In the immediate post-treatment monitoring period the proportion of damaged heather in the burn and cut plots fell substantially, with over 95% being in the lowest damage class (Category 6 = <5% dead and grey). There was very slightly more damage recorded on the heather in the cut plot compared to the burnt plot.
- 3.171 The treatment has effectively removed the bulk of the pre-existing heather and the new regenerating heather is generally in a healthy condition. By the July 2016 monitoring period all heather in the treated plots was in Categories 5 and 6 (i.e. good condition) and the new heather does not appear to have been attacked again by heather beetle. The damaged heather seen in the cut plot in July 2013 and 2014 has either recovered or died completely and the dead material has disintegrated and disappeared by July 2016.
- 3.172 In the control plot, a gradual decline of the proportion of heather in the more highly damaged categories is observed, and by July 2016 less than 10% is in Categories 1-4. The most damaged heather will have died, as described above, and the litter will have broken down, whilst the less damaged heather has put on growth of new healthy shoots.
- 3.173 There was a very low level of red/orange colouration on small patches of heather in July 2016, across all plots, which may have been the result of low levels of beetle damage, drought or other environmental stress.
- 3.174 There is a very clear increase in damaged heather in all plots in July 2018 indicating significant heather beetle attack. The combined proportions of Category 1 and 2 damage (the most severe) reached 56.25% of the heather in the control, whilst in the cut plot the combined cover

was 64.96%, and in the burnt plot even higher at 78.29%. The combined proportion of heather in Categories 1 and 2 in the treated plots are similar to those at the start of the monitoring, whilst the control has a much lower proportion of severe damage.

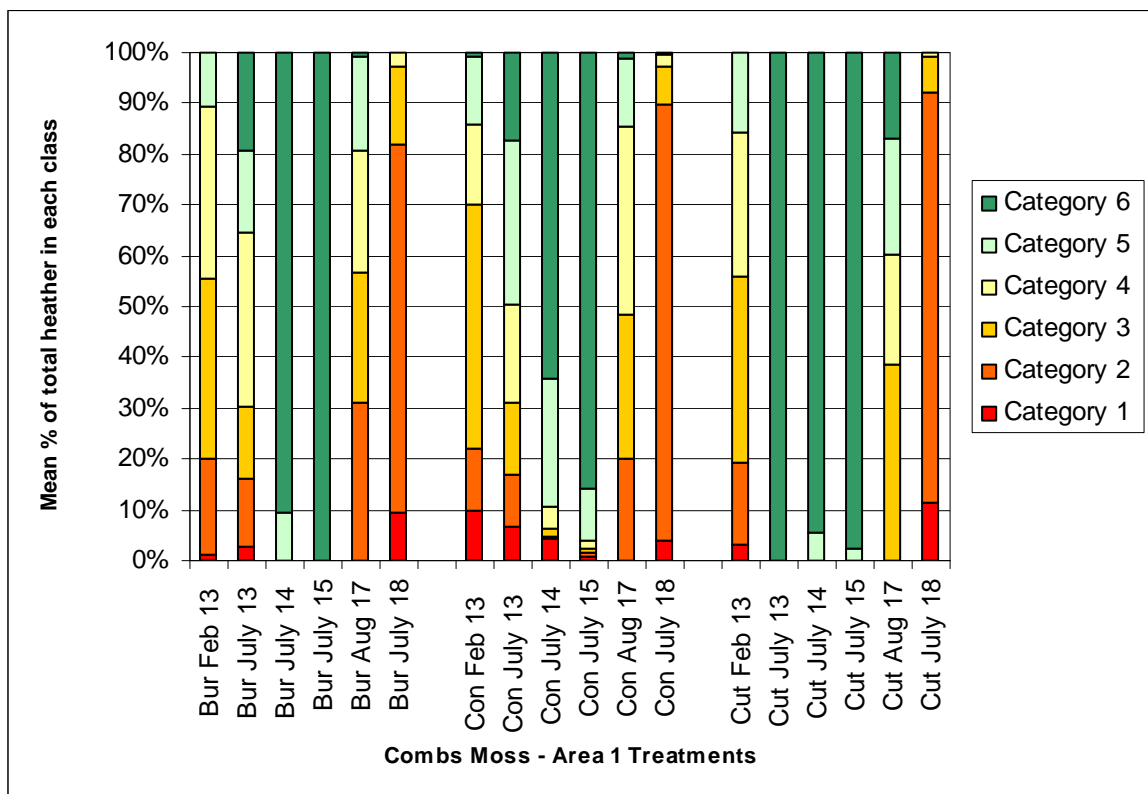
- 3.175 The plots on the Crag Estate are a replicated plot experiment with the plots taken from three areas of the moor and the data are relatively robust. The high level of severe damage on the treated plots in 2018 strongly suggests that the younger heather on these plots, compared to the recovering older heather on the control plots, is more susceptible to heather beetle attack, resulting in a higher level of damage compared to the older heather in the control plots.

Combs Moss

Area 1

- 3.176 The level of heather beetle damage at the start of the monitoring in this area was not as extensive as on the Crag Estate. In all three plots the heather cover in Categories 1 and 2 (greatest damage) reached approximately the 20% levels (Figure 45).

Figure 45 The Impact of Heather Beetle Damage on Area 1 on Combs Moss



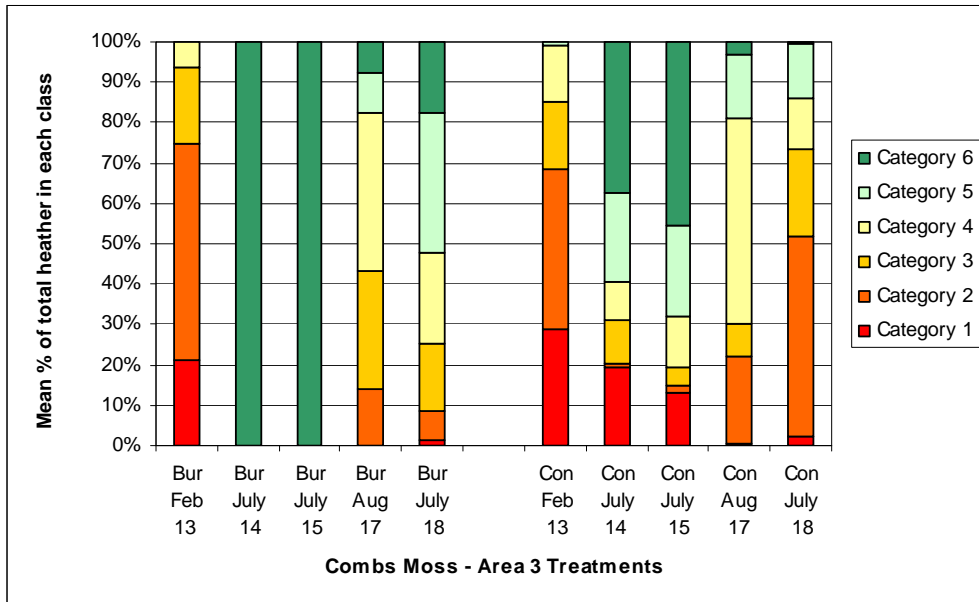
- 3.177 Following the treatment of the heather (cut in March 2013 and burnt in December 2013), the heather cover has fallen and the proportion of heather damage has also reduced dramatically as there was very little damage to the new heather re-growth. There were a few plants in the cut and burnt plots in July 2014 with leaf discolouration, either pink or a slight orange colour (Category 5). This was not extensive and this damage category had reduced to a maximum of 2.4% in the treated plots in July 2015 indicating no substantive damage over the longer-term.

- 3.178 In the control plots there is a slight trend of declining heather cover (Figure 16) of approximately 10% over the monitoring period. Figure 45 shows a continual and substantial decrease in the proportion of heather allocated to the worst-affected categories in the control plots from the baseline to July 2015. As relatively little heather has actually been lost from the plot, the reason for this 'recovery' must be the re-growth of the shoots and leaves on the established heather plants.
- 3.179 However, the monitoring in August 2017 coincided with a heather beetle attack on Combs Moss in the trial areas and there were substantial areas of 'orange' heather indicative of heather beetle damage. The Index was created to record the heather condition post-beetle attack as this was the starting point of the monitoring. Therefore, the allocation of the index categories was not as straightforward, as the heather was not 'grey'. The surveyors in 2017 supplemented the word 'grey' in the category descriptions with 'orange/fox red'. Category 1 was not recoded as the beetle attack was ongoing during the monitoring, with several larvae seen and, therefore, the plants were not brittle and dead as Category 1 describes.
- 3.180 The monitoring in 2018, post attack, (although there were still larvae seen) has shown a large increase in the proportion of heather within the most severe damage Index categories with 9.6%, 11.3% and 4.15 % in Category 1 in the burn, cut and control plots respectively. When Categories 1 and 2 are combined the proportion of damaged plants is 81.8%, 92.1% and 89.6%, respectively.
- 3.181 On Combs Moss, Area 1 there is no clear trend to suggest that the heather re-growth is more vulnerable or more seriously damaged by further beetle attack, all plots on Area 1 of Combs Moss including the control appear to be equally damaged. This is different to the results on the plots at Crag Estate where heather re-growth appeared more seriously affected than the remaining mature heather on the control.

Area 3

- 3.182 Figure 46 shows the changes in the proportion of beetle damage in Area 3. It is important to note that in the baseline year Area 3 had suffered greater damage from beetle attack than Area 1. The pattern of recovery since the beetle attack has however, been similar to Area 1 as discussed below.

Figure 46 The Impact of Heather Beetle Damage on Area 3 on Combs Moss



3.183 Overall, the control plot heather cover decreased over the monitoring period (from 61.3% to 46.1% in August 2017, Figure 25), although this was not statistically significant. In contrast with Area 1 on Combs Moss, there was still a substantial proportion of heather in poor condition in the control plots in July 2015 (c.15%) in Categories 1 and 2. It should be remembered that the heather in the control area was only five to six years old at the start of the trials and the age of the heather when attacked by beetle may influence its susceptibility to attack.

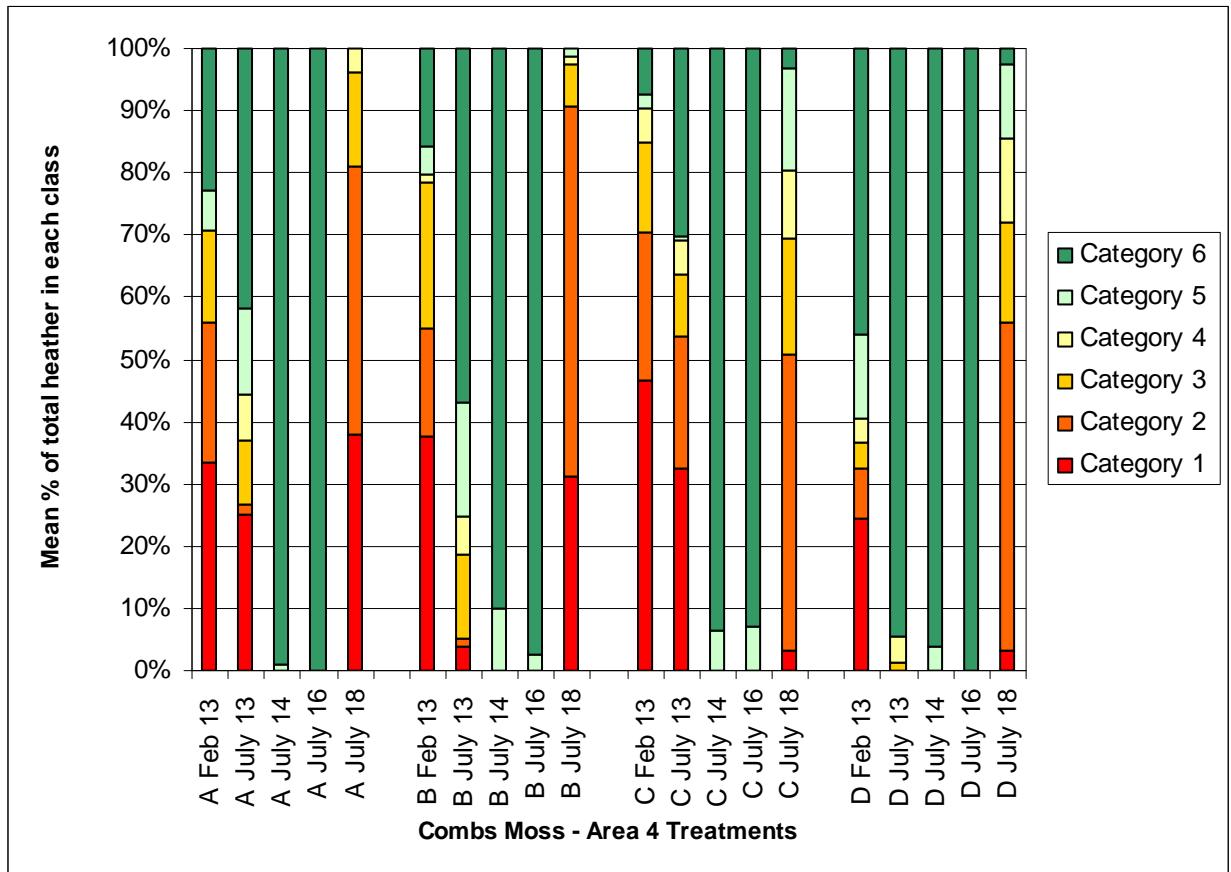
3.184 Area 3 was also attacked by heather beetle in August 2017, again with several larvae seen. The degree of damage in the control and burnt areas appeared broadly similar in 2017 but in 2018 the control appears to have suffered significantly more damage with slightly over 50% in the two categories indicating the most damage, whilst only 10% of the heather in the burnt plot falls into these categories. This appears to be a reversal of the trends seen in the plots on the Crag Estate.

Area 4

3.185 In Area 4 the heather cover at the start of the monitoring was much lower and more variable than other trial areas (3-15%, Figure 32).

3.186 Figure 47 shows the variability of the intensity of the heather damage between the four plots. In the baseline year the most severe damage was recorded in Plot C (the untreated control) with the least severe damage being recorded in Plot D. The proportion of heather in the most damaged categories fell in all plots in July 2013 and by July 2014 there was no heather in any of the plots that was graded as lower than Category 5 (i.e. it was all 'less than 25% dead, grey'). By 2016 both plots A and D had very low proportions of heather damage with all heather in Category 6 (i.e. '<5% heather dead, grey'), Plots B and C had 2.5% and 7% of the heather respectively in Category 5 (<25% heather dead, grey) and the rest in Category 6.

Figure 47 The Impact of Heather Beetle Damage on Area 4 on Combs Moss



3.187 The 2018 results show clearly the impact of the heather beetle with over 80% of the heather in Plots A and B being in Categories 1 and 2 (i.e. the highest degree of damage). Plots C and D have a larger proportion of less severely damaged heather with only 50% in these two categories.

3.188 All plots in Area 4 had the same age of heather and therefore it is difficult to account for the variation in the proportion of damage. The plots are not adjacent to each other as is the case in some of the other trial areas and it may be that the beetle infestation varied across the moor.

Conclusions for Heather Beetle Damage

3.189 Those data collected on the proportion of damage to heather by the heather beetle is semi-quantitative, however, the use of an Index to assess the degree of damage has helped to standardise the records and provide a more systematic way of recording damage.

3.190 In all trial areas there was significant heather damage at the start of the trials due to previous heather beetle attack. During the monitoring period there has, in most control plots been a reduction in heather cover as heather damaged by heather beetle before the start of the trials has died, collapsed and dispersed. This is alongside the reductions in heather due to the burning or cutting on the treated plots.

- 3.191 There has been a second outbreak of heather beetle in all areas in 2017-2018, although this was only recorded when the plots were monitored, not necessarily at the start of the outbreak.
- 3.192 At Crag Estate there is evidence to suggest that the younger heather that has re-grown from the treated areas was more susceptible to the recent beetle attack, with a greater proportion of young heather plants affected and with higher percentages of heather in the more severe damage categories than recorded in the older heather in the control plots. The results from the three different areas on Combs Moss are less clear, this may be due to the small sample size (only eight quadrats in each plot on each area) or due to the variation in the age of the heather at the start of the monitoring (Area 1 is more similar to the heather on Crag Estate, but different to Areas 3 and 4) or it could simply be due to different levels of beetle infestation in the different trial areas. Pinder *et. al.* 2015 stated that 'where there is differential survival of different age classes of heather, it is unknown whether this is due to the initial infestation rate, growth and survival of larvae, or a differential ability of the heather to regenerate vegetatively'.
- 3.193 On the ground, during the monitoring, there was a definite perception that the treated areas with young regenerating heather were more seriously affected by the heather beetle than the older heather within the control plots.
- 3.194 It would be interesting to see if, as in the previous cycle of heather beetle attack, there is considerable improvement in the condition of heather that was previously classified as extensively damaged, or whether the second attack five or six years after the first will be more detrimental to the cover of heather in the long-term.

4. OVERALL DISCUSSION AND CONCLUSIONS

Overall Discussion

- 4.1 The discussions above have focused on the changes in each trial area but it is important to see what can be taken from the overall trials, bearing in mind that every site will be different and therefore are there any conclusions which are consistent throughout the monitoring irrespective of site conditions?
- 4.2 The original questions asked were:
- Is there a difference in the resulting vegetation if the beetle damaged heather is burn, cut or untreated?
 - What effect does burning young (five to six year-old) heather have on the vegetation compared to leaving the damaged young heather alone?
 - Does adding heather seed into a cottongrass-dominated vegetation with a low cover of beetle-damaged young heather increase the cover of heather?
- 4.3 The effect of burning and cutting on heather regeneration was investigated in two trial areas - Crag Estate and Combs Moss, Area 1.

Heather Regeneration and Cover

- 4.4 Heather is the dominant vascular plant species in these areas and its distribution dominates the amalgamated groups of 'dwarf shrubs' and 'total vascular plants'. Where treatments (cutting and burning) were applied, heather cover significantly declined in all plots immediately after treatment and has subsequently increased as expected.
- 4.5 On **Crag Estate** the results show that the spring burning of mature heather damaged by beetle gives a higher cover of heather three years and four months after treatment compared to cutting. By July 2018 the total heather cover in the two treated plots no longer shows significant differences, indicating that after six growing seasons, heather cover is no different if the vegetation was initially cut or burnt.
- 4.6 However, total heather cover in the treated plots is not significantly different to the control plot six growing seasons after treatment. This means that treating beetle affected heather (by cutting or burning) on this site has not significantly increased its cover compared to having left the vegetation to recover on its own. This is because of the decline in heather cover in the control plot likely due to die-back after beetle attack.
- 4.7 Overall, treating heather by cutting or burning after heather beetle attack has not resulted in a greater recovery of heather in terms of percent cover at this site.
- 4.8 The results from **Combs Area 1** support the conclusions from the Crag Estate, with the results again showing that in the second and third growing seasons' burning resulted in significantly more heather regeneration than cutting. However, by 2018 there was no statistically significant difference in the cover of heather between the burn, cut or control plots. The overall trend is for the control to have a greater cover (73.8%) than either the burnt (54.6%) or cut (35.3%) plots.
- 4.9 Overall, heather regeneration is generally greater when the vegetation is burnt rather than cut, but after six growing seasons these differences have disappeared.
- 4.10 At Crag Estate, the highly damaged heather declined in the untreated control and after six seasons is at a very similar cover to the recovering treated plots. At Combs Moss Area 1, the pattern is slightly different. The heather cover remains at a greatest cover in the control plot after a similar time period and does not reduce, becoming equivalent to the recovering heather

cover in the treated plots. On Area 1 the heather was not as badly affected as at Crag Estate and there has been no substantial ongoing loss of heather from the control.

- 4.11 This indicates that if the heather is not too badly damaged by heather beetle (i.e. only around 20% is in Categories 1 and 2 (>75% heather dead and grey), then leaving the heather to recover naturally is likely to achieve a similar heather cover to that observed after any cutting or burning intervention.
- 4.12 At Crag Estate and Combs Moss Area 1 the total cottongrass cover has increased in the treated plots since the start of the trials, significantly so at Crag. However, at Crag this significant increase is also seen in the control and is likely related to the slow decline of heather releasing the cottongrass from competition and enabling its expansion.
- 4.13 It is interesting to note that in the control plot in Area 1 at Combs Moss there is no significant change in the cover of total cottongrasses, only a weak trend, and here the heather cover has hardly changed. This supports the idea that the expansion on Crag is due to an initial stimulus of increased light and/or reduced competition resulting from a reduction in heather cover.
- 4.14 There are no clear trends or meaningful statistically significant results indicating any directional change in the cover of bryophytes or other higher plants between the two treatments or the control.

The Effect of Burning Young Heather Beetle Damaged Heather

- 4.15 On Combs Moss Area 3, an area of young, building, heather was burnt in the trial, there was around 60% heather cover at the start of the experiment in both the area to be treated and the control. Over the course of the monitoring (six growing seasons) the heather cover in the burnt area had reached a level of around 55%. The percentage cover in the control appeared to fall slightly but then increased in 2018 to 73%, however, these were not statistically significant changes.
- 4.16 The results indicate that six growing seasons after treatment the cover of heather is the same, irrespective of burning. The affected heather recovered without any intervention despite its poor appearance at the start of the project.
- 4.17 As identified in Crag and Combs Area 1, the cover of cottongrasses has increased in both the treated and the control plots throughout the monitoring period (although the increase in the control is not significant).
- 4.18 Changes in other species do not show meaningful trends with very few significant results between the control and the treated plots. Most changes are within a plot over time rather than indicating a difference between treated and untreated plots.
- 4.19 The results of this small experiment therefore suggest that leaving building stage heather to recover naturally after a beetle attack is likely to achieve a similar heather cover to that observed after burning intervention after a period of approximately six years.

Addition of Heather Seed to a Cottongrass-dominated Vegetation

- 4.20 Area 4 at Combs Moss was an area which had been heather-dominated but had become cottongrass-dominated due to the effects of previous heather beetle damage, burning of the damaged heather and then subsequent additional beetle damage. The heather in the plots was pioneer heather and had a cover of less than 15% of the total vegetation at the start of the trials.
- 4.21 Unfortunately the trial areas were not as initially similar as anticipated, with statistically significant inter-plot differences at the start of the experiment. The most relevant difference

being that Plot D had significantly less heather and Plot C the most. There were no relevant statistically significant results detected in the 2018 statistical analysis and the discussion below refers to trends in the data.

- 4.22 The heather seed was added in April 2013 and was broadcast across the plots with a similar quantity added to each plot, with an unseeded control included (Plot C). Heather seedling numbers peaked in Plots A and B in 2014, a year and three months after seed addition. By July 2016 seedling numbers had fallen in these plots as expected, as the seed added would have been most likely to have germinated and established as young plants by this time (three years later).
- 4.23 In July 2016 heather cover had increased in all plots to over 30% cover and in Plot D (initially with the lowest heather cover) heather reached 47% cover and was co-dominant with cottongrasses. There was little change in heather cover between 2016 and 2018, with cover increasing in two plots and decreasing in the other two.
- 4.24 There is some evidence to suggest that the heather seedling peak in 2014 in Plots A and B may have originated from the addition of the heather seed, and that the establishment of these seedlings and vegetative re-growth from pre-existing heather plants have combined to result in heather cover of 30-47% in 2016 and 2018. The lack of statistically significant results is surprising, but may be related to the smaller sample size, or the large error bars likely the result of the patchy distribution of heather seedlings.

Conclusions

- 4.25 On both estates there has been a good recovery of the heather plants following the heather beetle attack. There has been some loss of the most damaged heather (particularly on Crag Estate) but there has also been good re-growth and re-sprouting of what were considered to be badly damaged stems in February 2013. The Index used is semi-quantitative and rapid but, despite its limitations, the re-growth of green heather shoots on the affected areas is unequivocal.
- 4.26 In all three experimental situations (cutting or burning heather or adding heather seed) it appears that within five to six growing seasons the cover of heather returns to levels very similar to those seen in the control plot.
- 4.27 The key message is that although the heather looks dead after a heather beetle attack there is no evidence from this study, over the period of these trials (five to six years), that burning or cutting of the heather is necessary to re-establish heather cover after a beetle attack. Heather cover in the control and treated plots is not significantly different five to six years after treatment.
- 4.28 In fact the trials at Crag Estate suggest the approach of managing heather beetle attacks on young heather re-growth by repeatedly burning the damaged heather could result in loss of heather cover over time.
- 4.29 Heather beetle damage may look unsightly but there appears little gain in removing the 'dead' heather, which in many cases will revive in time. Areas of heather beetle damage may be best integrated into the moorland management rotation in the normal manner, rather than targeted for intervention measures immediately after beetle attack.
- 4.30 Re-seeding trials in Plot 4 on Combs Moss indicates that although heather seed addition may increase the cover of vigorous new heather, re-growth from 'dead' plants can be just as effective over a five to six year period, resulting in a similar heather cover.
- 4.31 It would be of benefit to repeat the monitoring at Crag Estate in another two years (July 2020) to establish if the treated areas develop a higher heather cover than the control plots. The changes in the vegetation are still at a relatively early stage after the treatments and further

changes in the vegetation composition, especially following the second beetle outbreak, are likely to occur.

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TABLES

Table 1 Overview of the Treatment Plots on the Crag Estate

Unique Plot Code	Site Name	Area Number	Treatment	Over view of habitat at the start of the trials
CE 1 Con	Crag Estate (CE)	Area 1	None - control (Con)	Heather mostly 8-9 years old and 20-25cm tall with small areas 11-12 years old (30-35cm). Heather-dominant over area with abundant hare's-tail cottongrass and frequent common cottongrass. <i>Hypnum jutlandicum</i> and Sphagnum species frequent to locally abundant with <i>Campylopus</i> occasional. Occasional bilberry and deergrass and locally abundant patches of bog asphodel and locally frequent purple moor-grass both associated with small water channels. These were generally avoided when placing quadrats.
CE 1 Cut			Cut (Cut) March 2013	
CE 1 AB			Autumn Burn (AB)	
CE 1 SB			Spring Burn (SB) March 2013	
CE 2 Con	Crag Estate (CE)	Area 2	None - control (Con)	The heather is mostly 8-10 years old and 25-30cm tall with some small areas a little older and taller max 12 years old (40cm). Heather dominant with abundant hare's-tail cottongrass and locally frequent common cottongrass. <i>Hypnum jutlandicum</i> abundant with patchy <i>Sphagnum</i> species and locally occasional <i>Campylopus</i> species. Occasional bilberry at low levels and patchy deergrass. Wavy hair-grass very occasional and rarely cross-leaved heath. Several small water channels within the plots again these were avoided when placing quadrats.
CE 2 Cut			Cut (Cut) March 2013	
CE 2 AB			Autumn Burn (AB)	
CE 2 SB			Spring Burn (SB) March 2013	
CE 3 Con	Crag Estate (CE)	Area 3	None - control (Con)	The heather is generally 10-12 years old and 20-25cm tall with some small areas a little older or younger but only by 1-2yrs. Heather is again dominant with abundant hare's-tail cottongrass and locally frequent common cottongrass. <i>Hypnum jutlandicum</i> is again abundant with patchy <i>Sphagnum</i> species and locally occasional <i>Campylopus</i> species. Bilberry, deergrass and wavy hair-grass are all occasional and at low levels. Cross-leaved heath and crowberry are locally rare. As with the other areas there are several small water channels within the plots again these were avoided when placing quadrats, purple moor-grass is locally frequent in some of these channels.
CE 3 Cut			Cut (Cut) March 2013	
CE 3 AB			Autumn Burn (AB)	
CE 3 SB			Spring Burn (SB) March 2013	

Table 2 Overview of the Treatment Plots on Combs Moss

Unique Plot Code	Site Name	Area Number	Plot	Treatment	Overview of Habitat in Each Area*
CM 1 D Con CM 1 D Cut CM 1 D Bur	Combs Moss (CM)	Area 1	Mature heather. Drier site (D)	None - control (Con) Cut (Cut) March 2013 Burn (Bur) December 2013	Relatively dry site with dominant building/mature phase heather. Varies from 8-12 years old across the plots. Approx. 20-30cm tall. Hare's-tail cottongrass and <i>Hypnum</i> moss abundant. Scattered patchy common cottongrass and occasional <i>Sphagnum</i> patches. Low constant occurrence of bilberry and little bare ground.
CM 3 Y Con CM 3 Y Bur	Combs Moss (CM)	Area 3	Young heather (Y)	None - control (Con) Burn (Bur) December 2013	Young building heather 5-6 years old and 15-20cm tall. Heather is slightly more abundant than hare's-tail cottongrass although this is an abundant species and, in sections, co-dominant. Common cottongrass is occasional and patchy whilst bilberry is insignificant. <i>Campylopus</i> is the most abundant moss with <i>Hypnum</i> frequent to locally abundant; <i>Sphagnum</i> is occasional.
CM 4 OS A CM 4 OS B CM 4 OS C CM 4 OS D	Combs Moss (CM)	Area 4	Cottongrass area to be overseeded (OS)	Overseeded with heather (A) April 2013 Overseeded with heather (B) April 2013 None - control (C) Overseeded with heather (D) April 2013	Areas of cottongrass dominance. There is more variability within this area than in the others. Heather is a small component of the vegetation, generally under 10% cover, 2-4 years old and under 10cm tall. Hare's-tail cottongrass is dominant (average 35%) and there is a substantial amount of bare ground scattered in the area between the cottongrass tussocks (10%). <i>Campylopus</i> species are the dominant mosses (45%) with little <i>Hypnum</i> or <i>Sphagnum</i> .

Table 4 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots at Crag Estate

Species and Species Group		Kruskal Wallis Statistic (H)	Significant Pairwise Interactions	p-value	
VASCULAR PLANTS					
Common Name	Scientific Name				
Total heather	<i>Calluna vulgaris</i>	251.24	Yes	0.000	***
Bilberry	<i>Vaccinium myrtillus</i>	37.00	3, not ecologically significant	0.001	***
Crowberry	<i>Empetrum nigrum</i>	16.01	-	0.313	ns
Bell heather	<i>Erica cinerea</i>	18.74	-	0.175	ns
Cross-leaved heath	<i>Erica tetralix</i>	75.28	Yes	0.000	***
Cranberry	<i>Vaccinium oxycoccos</i>	20.35	-	0.120	ns
Common cottongrass	<i>Eriophorum angustifolium</i>	79.76	Yes	0.000	***
Hare's-tail cottongrass	<i>Eriophorum vaginatum</i>	108.12	Yes	0.000	***
Total cottongrass	<i>Eriophorum</i> sp.	119.32	Yes	0.000	***
Deergrass	<i>Trichophorum cespitosum</i>	34.59	1, not ecologically significant	0.002	**
Purple moor-grass	<i>Molinia caerulea</i>	28.60	None	0.012	*
Wavy hair-grass	<i>Deschampsia flexuosa</i>	155.02	Yes	0.000	***
Tormentil	<i>Potentilla erecta</i>	9.13	-	0.823	ns
Common sedge	<i>Carex nigra</i>	13.04	-	0.524	ns
Heath wood-rush	<i>Luzula multiflora</i>	14.00	-	0.450	ns
Bog asphodel	<i>Narthecium ossifragum</i>	27.93	None	0.015	*
Total Dwarf Shrubs		252.32	Yes	0.000	***
Total Vascular Plants		233.45	Yes	0.000	***
BRYOPHYTES					
<i>Brachythecium rutabulum</i>		39.55	None	0.000	***
<i>Campylopus introflexus</i>		57.97	Yes	0.000	***
<i>Campylopus</i> sp.		42.09	Yes	0.000	***
Total <i>Campylopus</i> sp.		52.99	6, not ecologically significant	0.000	***
<i>Dicranum scoparium</i>		31.01	None	0.006	**
<i>Kindbergia praelongum</i>		13.04	-	0.524	ns
<i>Hypnum jutlandicum</i>		20.86	-	0.105	ns
Lichen		9.13	-	0.823	ns
Liverwort		21.99	-	0.079	ns
<i>Plagiothecium undulatum</i>		13.04	-	0.524	ns
<i>Polytrichum</i> sp.		40.50	3, not ecologically significant	0.000	***
<i>Rhytidiadelphus squarrosus</i>		29.41	None	0.009	**
<i>Sphagnum capillifolium</i>		11.09	-	0.679	ns
<i>Sphagnum fallax</i>		9.63	-	0.788	ns
<i>Sphagnum fimbriatum</i>		5.94	-	0.968	ns
<i>Sphagnum palustre</i>		20.55	-	0.114	ns
<i>Sphagnum papillosum</i>		14.82	-	0.390	ns
<i>Sphagnum subnitens</i>		11.79	-	0.623	ns
<i>Sphagnum</i> sp.		10.11	-	0.754	ns
Total Sphagnum		11.26	-	0.665	ns
Total Bryophytes		37.00	1, not ecologically significant	0.001	***
OTHER DATA					
Bare ground		86.37	Yes	0.000	***
Open water		26.45	None	0.023	*
Heather litter cover		192.89	Yes	0.000	***

Table 5 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots in Area 1 at Combs Moss

Species and Species Group		Kruskal Wallis Statistic (H)	Significant pairwise interactions	p-value	
VASCULAR PLANTS					
Common Name	Scientific Name				
Total heather	<i>Calluna vulgaris</i>	114.58	None	0.000	***
Bilberry	<i>Vaccinium myrtillus</i>	27.98	None	0.045	*
Crowberry	<i>Empetrum nigrum</i>	14.30	-	0.646	ns
Cross-leaved heath	<i>Erica tetralix</i>	22.03	-	0.184	ns
Common cottongrass	<i>Eriophorum angustifolium</i>	58.65	None	0.000	***
Hare's-tail cottongrass	<i>Eriophorum vaginatum</i>	63.50	None	0.000	***
Total cottongrass	<i>Eriophorum</i> sp.	88.20	None	0.000	***
Holly	<i>Ilex aquifolium</i>	17.00	-	0.454	ns
Wavy hair-grass	<i>Deschampsia flexuosa</i>	70.40	Yes	0.000	***
Total Dwarf Shrubs		113.92	None	0.000	***
Total Vascular Plants		101.27	None	0.000	***
BRYOPHYTES					
<i>Aulacomnium palustre</i>		27.38	-	0.053	ns
<i>Brachythecium rutabulum</i>		43.11	None	0.000	***
<i>Campylopus introflexus</i>		68.37	None	0.000	***
<i>Campylopus</i> sp.		43.87	2, not ecologically significant	0.000	***
Total <i>Campylopus</i> sp.		78.27	None	0.000	***
<i>Ceratodon purpureus</i>		17.00	-	0.454	ns
<i>Dicranum scoparium</i>		30.13	None	0.025	*
<i>Kindbergia praelongum</i>		32.69	None	0.012	*
<i>Hypnum jutlandicum</i>		74.59	None	0.000	***
Lichen		20.05	-	0.272	ns
Liverwort		20.29	-	0.260	ns
<i>Plagiomnium undulatum</i>		16.11	-	0.516	ns
<i>Polytrichum</i> sp.		53.99	1, not ecologically significant	0.000	***
<i>Rhytidiadelphus squarrosus</i>		19.98	-	0.275	ns
<i>Scleropodium purum</i>		17.00	-	0.454	ns
<i>Sphagnum fallax</i>		22.08	-	0.182	ns
<i>Sphagnum fimbriatum</i>		18.13	-	0.381	ns
<i>Sphagnum palustre</i>		15.21	-	0.580	ns
<i>Sphagnum papillosum</i>		13.38	-	0.711	ns
<i>Sphagnum subnitens</i>		25.26	-	0.089	ns
<i>Sphagnum</i> sp.		59.87	None	0.000	***
Total Sphagnum		20.77	-	0.237	ns
Total Bryophytes		80.76	None	0.000	***
OTHER DATA					
Bare ground		121.48	Yes	0.000	***
Open water		91.38	None	0.000	***
Heather litter cover		118.84	None	0.000	***

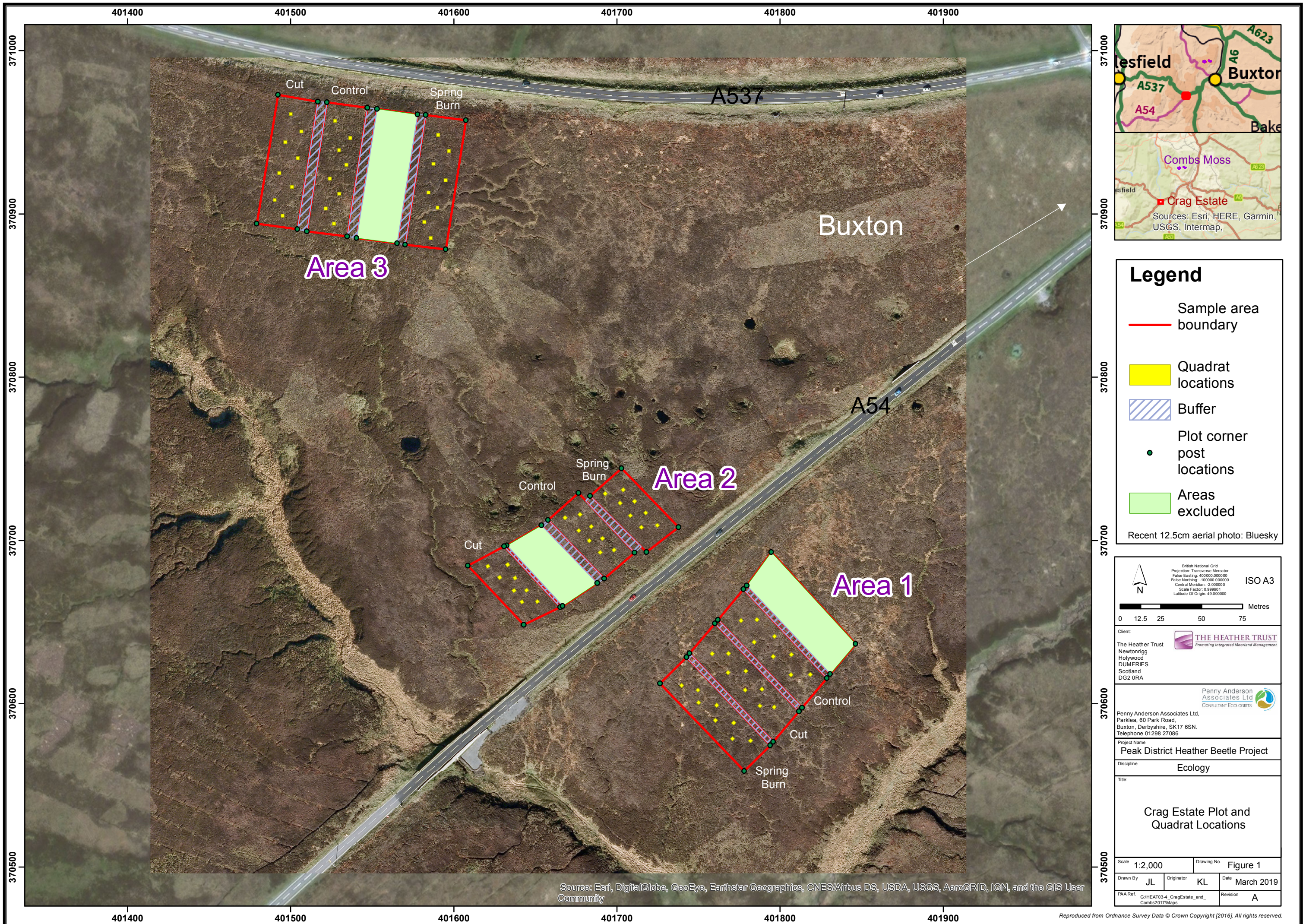
Table 6 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots in Area 3 at Combs Moss

Species and Species Group		Kruskal Wallis Statistic (H)	Significant Pairwise Interactions	p-value	
VASCULAR PLANTS					
Common Name	Scientific Name				
Total heather	<i>Calluna vulgaris</i>	114.58	None	0.000	***
Bilberry	<i>Vaccinium myrtillus</i>	29.69	None	0.000	***
Crowberry	<i>Empetrum nigrum</i>	11.09	-	0.270	ns
Cross-leaved heath	<i>Erica tetralix</i>	6.18	-	0.722	ns
Common cottongrass	<i>Eriophorum angustifolium</i>	14.89	-	0.094	ns
Hare's-tail cottongrass	<i>Eriophorum vaginatum</i>	28.63	Yes	0.001	***
Total cottongrass	<i>Eriophorum</i> sp.	39.83	Yes	0.000	***
Wavy hair-grass	<i>Deschampsia flexuosa</i>	43.68	Yes	0.000	***
Total Dwarf Shrubs		113.92	None	0.000	***
Total Vascular Plants		101.27	None	0.000	***
BRYOPHYTES					
<i>Aulacomnium palustre</i>		9.00	-	0.437	ns
<i>Campylopus introflexus</i>		14.26	-	0.114	ns
<i>Campylopus</i> sp.		33.56	Yes	0.000	***
Total <i>Campylopus</i> sp.		23.47	None	0.005	**
<i>Dicranum scoparium</i>		8.34	-	0.501	ns
<i>Hypnum jutlandicum</i>		20.08	None	0.017	*
Lichen		36.57	None	0.000	***
Liverwort		21.45	None	0.011	*
<i>Polytrichum</i> sp.		17.18	None	0.046	*
<i>Rhytidiadelphus squarrosus</i>		8.10	-	0.524	ns
<i>Scleropodium purum</i>		9.00	-	0.437	ns
<i>Sphagnum fallax</i>		8.10	-	0.524	ns
<i>Sphagnum fimbriatum</i>		7.55	-	0.580	ns
<i>Sphagnum subnitens</i>		6.81	-	0.657	ns
Total Sphagnum		4.87	-	0.846	ns
Total Bryophytes		42.31	Yes	0.000	***
OTHER DATA					
Bare ground		16.71	-	0.053	ns
Open water		32.99	Yes	0.000	***
Heather litter cover		55.52	Yes	0.000	***

Table 7 Summary of the Statistical Results for Kruskal-Wallis Tests on the Plots in Area 4 at Combs Moss

Species and Species Group		Kruskal Wallis Statistic (H)	Significant pairwise interactions	p-value	
VASCULAR PLANTS					
Common Name	Scientific Name				
Total heather	<i>Calluna vulgaris</i>	104.59	None	0.000	***
Bilberry	<i>Vaccinium myrtillus</i>	13.90	-	0.789	ns
Broad buckler-fern	<i>Dryopteris dilatata</i>	18.11	-	0.515	ns
Cranberry	<i>Vaccinium oxycoccos</i>	18.11	-	0.515	ns
Crowberry	<i>Empetrum nigrum</i>	14.64	-	0.745	ns
Cross-leaved heath	<i>Erica tetralix</i>	52.56	None	0.000	***
Common cottongrass	<i>Eriophorum angustifolium</i>	39.72	None	0.004	**
Hare's-tail cottongrass	<i>Eriophorum vaginatum</i>	18.16	-	0.512	ns
Total cottongrass	<i>Eriophorum</i> sp.	24.39	-	0.182	ns
Fern species	<i>Dryopteris</i> sp.	30.72	None	0.043	*
Royal fern	<i>Osmunda regalis</i>	19.00	-	0.457	ns
Wavy hair-grass	<i>Deschampsia flexuosa</i>	33.64	None	0.020	*
Total Dwarf Shrubs		103.75	None	0.000	***
Total Vascular Plants		100.39	None	0.000	***
BRYOPHYTES					
<i>Campylopus introflexus</i>		21.32	-	0.319	ns
<i>Campylopus</i> sp.		58.37	None	0.000	***
Total <i>Campylopus</i> sp.		35.20	None	0.013	*
<i>Bryum</i> sp.		30.80	None	0.042	*
<i>Dicranum scoparium</i>		11.59	-	0.902	ns
<i>Hypnum jutlandicum</i>		71.03	None	0.000	***
<i>Hypnum</i> sp.		19.00	-	0.457	ns
Lichen		20.98	-	0.338	ns
Liverwort		34.26	None	0.017	*
<i>Polytrichum</i> sp.		45.12	None	0.001	***
<i>Sphagnum fimbriatum</i>		26.50	-	0.117	ns
<i>Sphagnum palustre</i>		18.11	-	0.515	ns
<i>Sphagnum papillosum</i>		17.22	-	0.575	ns
<i>Sphagnum subnitens</i>		27.76	-	0.088	ns
<i>Sphagnum</i> sp.		30.55	None	0.045	*
Total Sphagnum		24.28	-	0.185	ns
Total Bryophytes		52.74	None	0.000	***
OTHER DATA					
Bare ground		47.80	None	0.000	***
Open water		23.49	-	0.216	ns
Heather litter cover		85.32	Yes	0.000	***

FIGURES



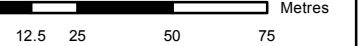
Legend

- Sample area boundary
- Quadrat locations
- Buffer
- Plot corner post locations
- Areas excluded

Recent 12.5cm aerial photo: Bluesky

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 False Northing: -100000.000000
 Central Meridian: -2.000000
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ISO A3



Client:
THE HEATHER TRUST
 Newtonrigg
 Holywood
 DUMFRIES
 Scotland
 DG2 0RA

Penny Anderson Associates Ltd
 CONSULTANT ECOSYSTEMS

Penny Anderson Associates Ltd,
 Parklea, 60 Park Road,
 Buxton, Derbyshire, SK17 6SN.
 Telephone 01298 27086

Project Name
Peak District Heather Beetle Project

Discipline
 Ecology

Title:
**Crag Estate Plot and
 Quadrat Locations**

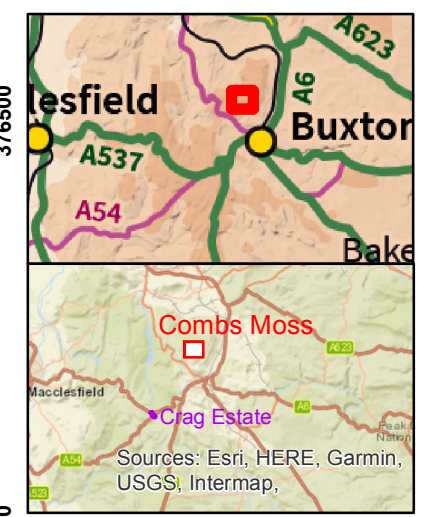
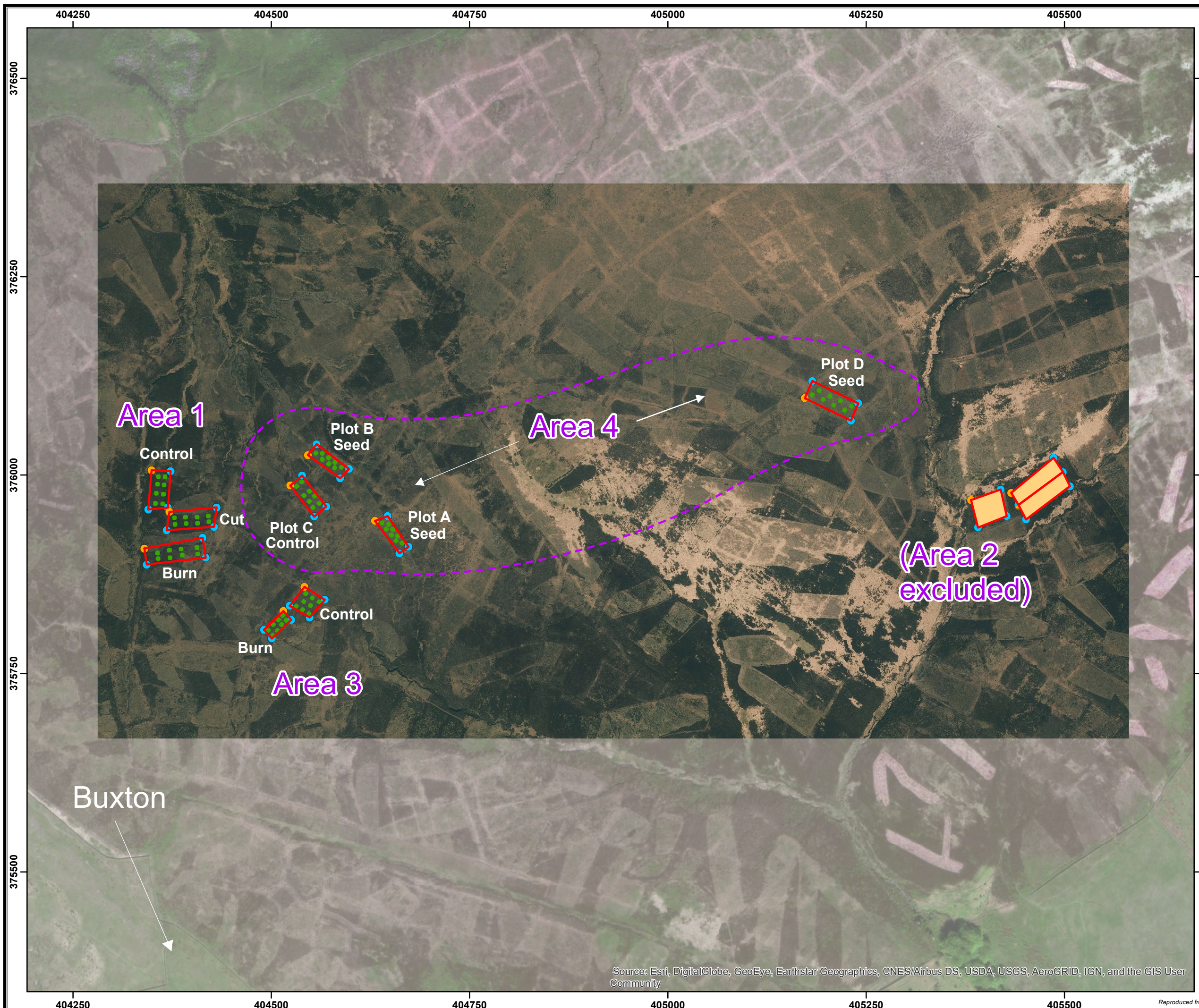
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Drawn By: JL Originator: KL Date: **March 2019**

PAA Ref: G:\HEAT03_4_CragEstate_and_Combs2017\Maps Revision: **A**

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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Legend

- Sample area boundary
- Areas excluded
- Area 4
- Quadrat locations
- Plot corner post locations
- NW corners

Aerial photo: Bluesky 2010

British National Grid
 Projection: Transverse Mercator
 False Easting: 400000.000000
 False Northing: -100000.000000
 Central Meridian: -2.000000
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 Latitude Of Origin: 49.000000

ISO A3

0 25 50 100 150 Metres

Client:
THE HEATHER TRUST
 Newtonrigg
 Holywood
 DUMFRIES
 Scotland
 DG2 0RA

Penny Anderson Associates Ltd
 CONSULTANT ECOSYSTEMS

Penny Anderson Associates Ltd,
 Parklea, 60 Park Road,
 Buxton, Derbyshire, SK17 6SN.
 Telephone 01298 27086

Project Name
Peak District Heather Beetle Project

Discipline
 Ecology

Title:
Combs Moss Plot and Quadrat Location

Scale: 1:4,500 Drawing No: **Figure 2**

Drawn By: **DR/JL** Originator: **KL** Date: **26/03/2019**

PAA Ref: G:\HEAT03_CragEstate_and_CombsMoss\HEAT03-2_2015 Revision: **A**

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

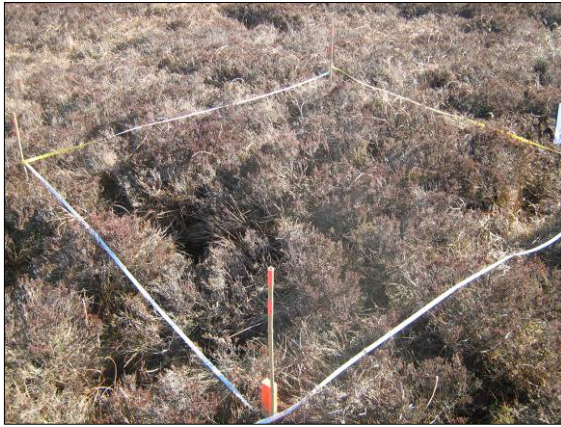
APPENDIX

APPENDIX 1

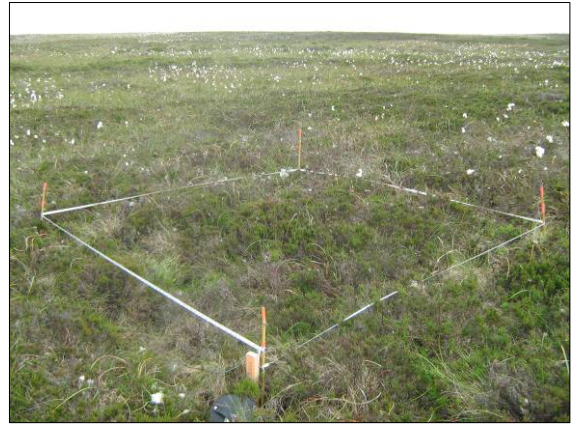
Fixed Point Photographs for Both Sites

Combs Moss, Area 1

Burn Plot Q4



*February 2013
Pre-treatment*



*July 2013
Pre-treatment*



*July 2014
Post-treatment*



*July 2015
Post-treatment*



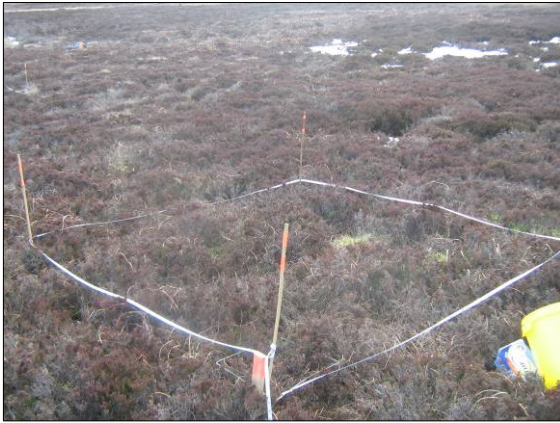
*August 2017
Post-treatment*



*July 2018
Post-treatment*

Combs Moss, Area 1

Control Plot Q1



February 2013



July 2013



July 2014



July 2015



August 2017



July 2018

Combs Moss, Area 1

Cut Plot Q4



*February 2013
Pre-treatment*



*July 2013
Post-treatment*



*July 2014
Post-treatment*



*July 2015
Post-treatment*



*August 2017
Post-treatment*



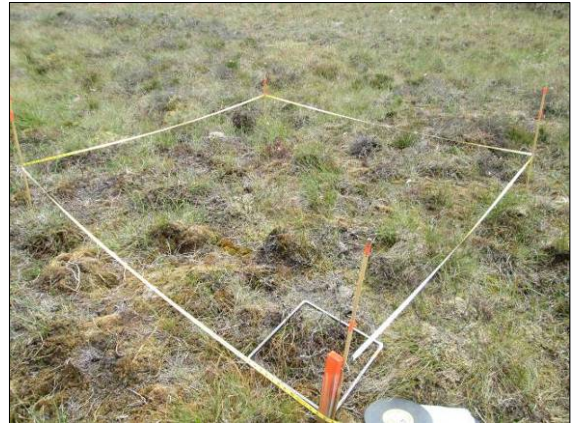
*July 2018
Post-treatment*

Combs Moss, Area 3

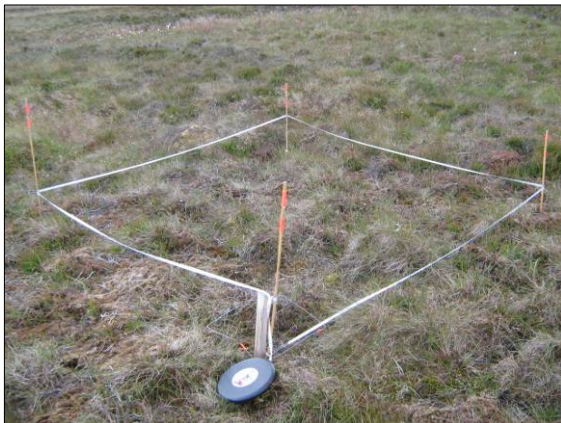
Burnt Plot Q4



*February 2013
Pre-treatment*



*July 2014
Post-treatment*



*July 2015
Post-treatment*



*August 2017
Post-treatment*



*July 2018
Post-treatment*

Combs Moss, Area 3

Control Plot Q8



February 2013



July 2014



July 2015



August 2017



July 2018

Combs Moss, Area 4

Plot A Q4



February 2013



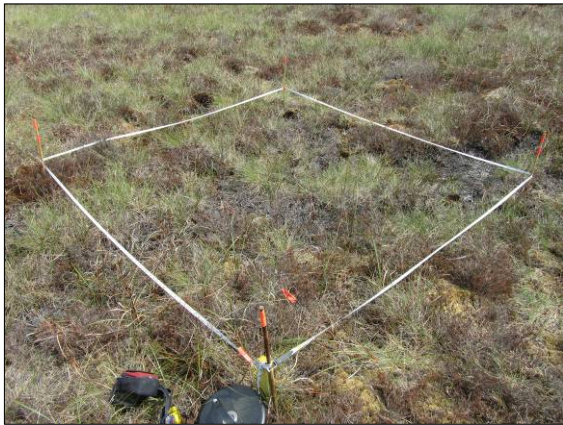
July 2013



July 2014



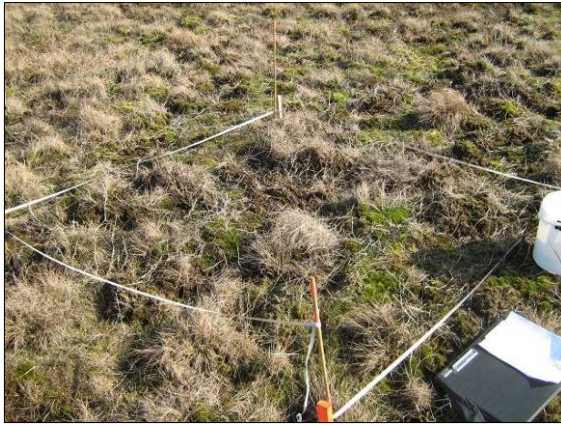
July 2016



July 2018

Combs Moss, Area 4

Plot B Q4



February 2013



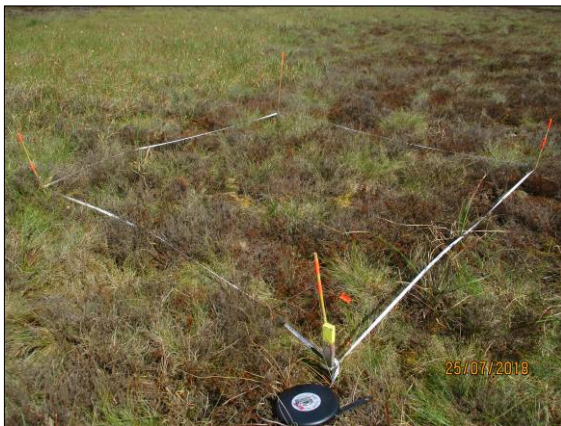
July 2013



July 2014



July 2016



July 2018

Combs Moss, Area 4

Plot C Q1



February 2013



July 2013



July 2014



July 2016



July 2018

Combs Moss, Area 4

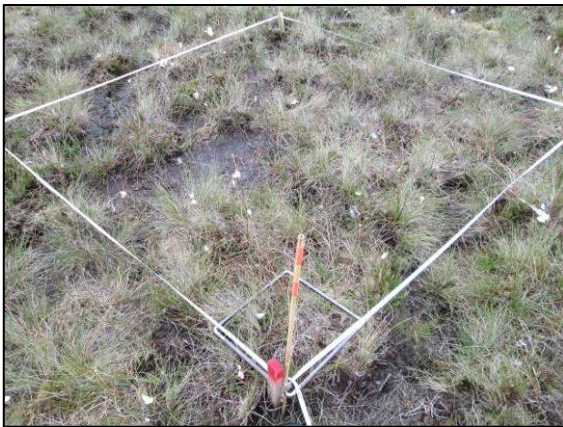
Plot D Q8



February 2013



July 2013



July 2014



July 2016



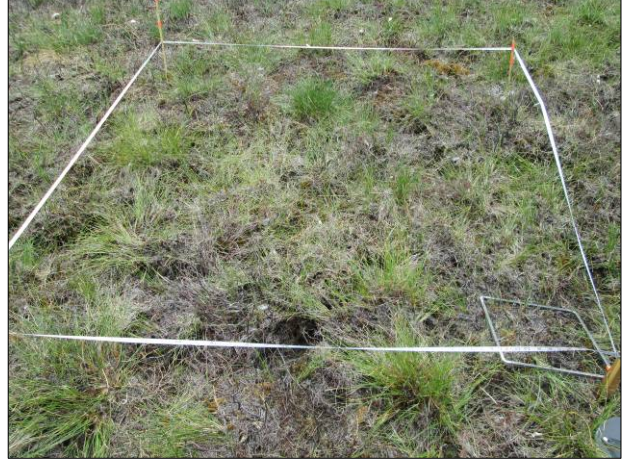
July 2018

Crag Estate, Area 1

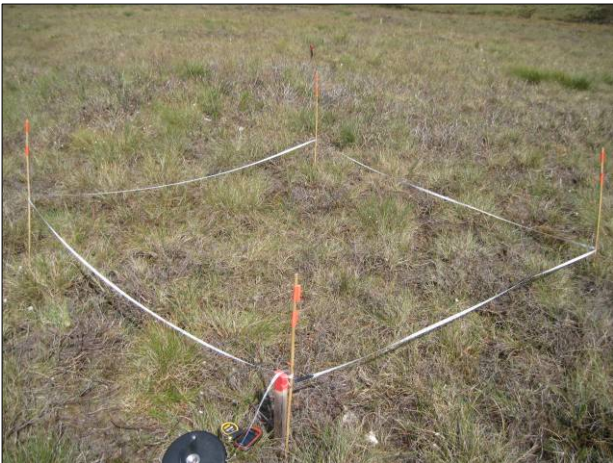
Burn Plot Q4



Winter 2013



Summer 2013



Summer 2014



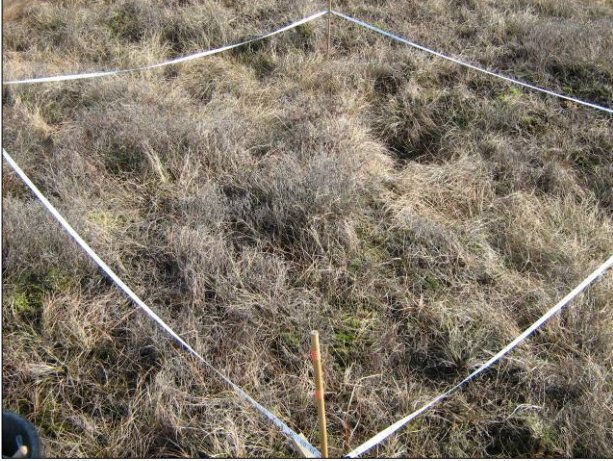
Summer 2016



Summer 2018

Crag Estate, Area 1

Control Plot Q1



Winter 2013



Summer 2013



Summer 2014



Summer 2016



Summer 2018

Crag Estate, Area 1

Cut Plot Q4



Winter 2013



Summer 2013



Summer 2014



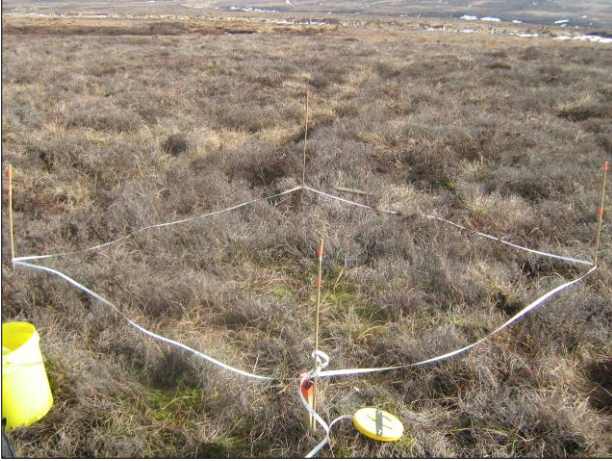
Summer 2016



Summer 2018

Crag Estate, Area 2

Burn Plot Q8



Winter 2013



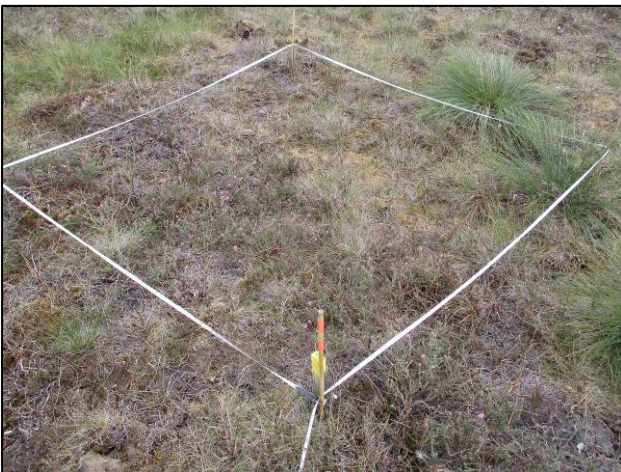
Summer 2013



Summer 2014



Summer 2016



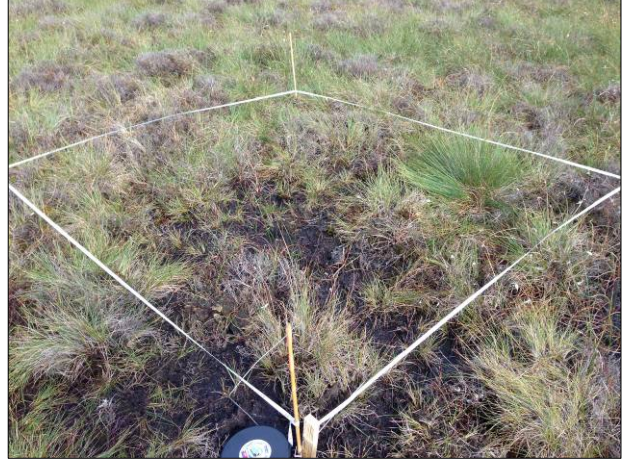
Summer 2018

Crag Estate, Area 2

Control Plot Q1



Winter 2013



Summer 2013



Summer 2014



Summer 2016



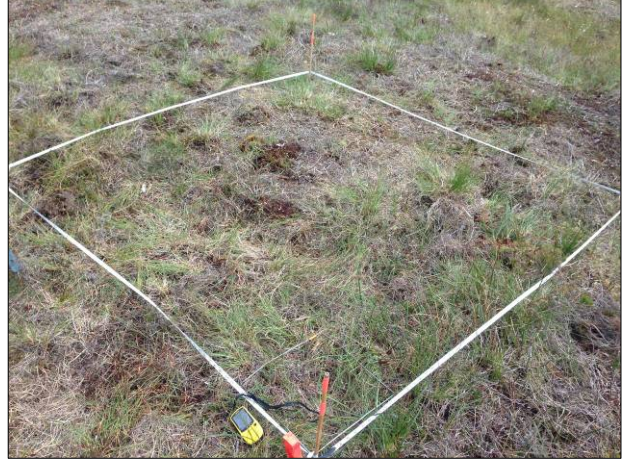
Summer 2018

Crag Estate, Area 2

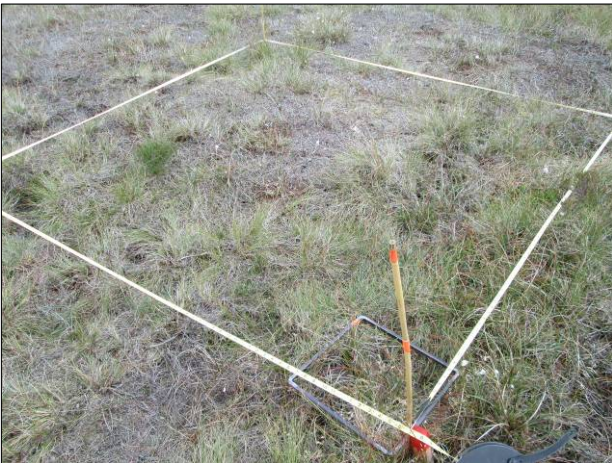
Cut Plot Q1



Winter 2013



Summer 2013



Summer 2014



Summer 2016



Summer 2018

Crag Estate, Area 3

Burn Plot Q1



Winter 2013



Summer 2013



Summer 2014



Summer 2016



Summer 2018

Crag Estate, Area 3

Control Plot Q4



Winter 2013



Summer 2013



Summer 2014



Summer 2016



Summer 2018

Crag Estate, Area 3

Cut Plot Q4



Winter 2013



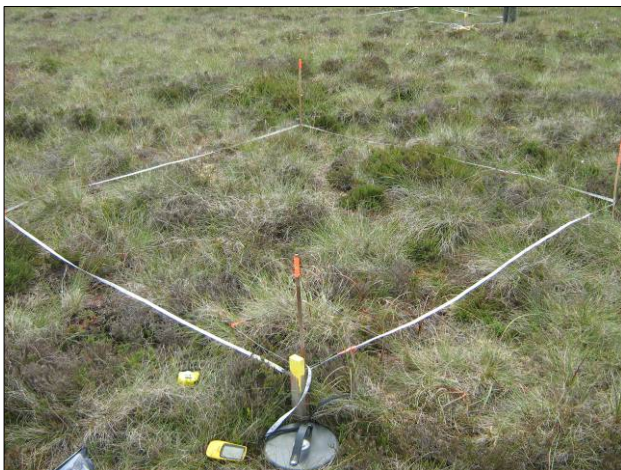
Summer 2013



Summer 2014

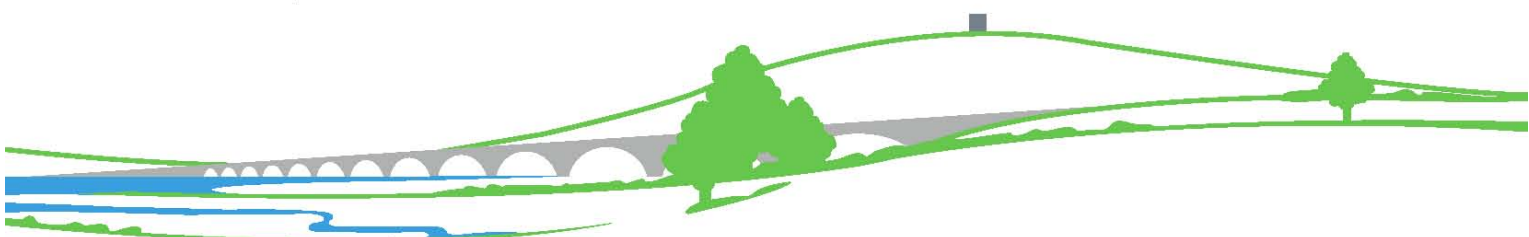


Summer 2016



Summer 2018

Penny Anderson
Associates Ltd
CONSULTANT ECOLOGISTS



Park Lea, 60 Park Road, Buxton, Derbyshire SK17 6SN